Premier Reference Source

Improving K-12 STEM Education Outcomes through Technological Integration

IGI GLOBAL
DISSEMINATOR OF KNOWLEDGE

Michael J. Urban and David A. Falvo

Improving K-12 STEM Education Outcomes through Technological Integration

Michael J. Urban
Bemidji State University, USA

David A. Falvo
Walden University, USA

A volume in the Advances in Early Childhood and
K-12 Education (AECKE) Book Series

Information Science
REFERENCE
An Imprint of IGI Global

Published in the United States of America by
Information Science Reference (an imprint of IGI Global)
701 E. Chocolate Avenue
Hershey PA, USA 17033
Tel: 717-533-8845
Fax: 717-533-8661
E-mail: cust@igi-global.com
Web site: http://www.igi-global.com

Library of Congress Cataloging-in-Publication Data

Names: Urban, Michael J., 1977- editor of compilation. | Falvo, David A., 1960- editor of compilation.
Title: Improving K-12 STEM education outcomes through technological integration / Michael J. Urban and David A. Falvo, editors.
Description: Hershey, PA : Information Science Reference, [2016] | Includes bibliographical references and index.
Identifiers: LCCN 2015037582| ISBN 9781466696167 (hardcover) | ISBN 9781466696174 (ebook)
Subjects: LCSH: Science--Study and teaching--Technological innovations. | Educational technology.
Classification: LCC LB1585 .I47 2016 | DDC 372.35/044--dc23 LC record available at http://lccn.loc.gov/2015037582

This book is published in the IGI Global book series Advances in Early Childhood and K-12 Education (AECKE) (ISSN: 2329-5929; eISSN: 2329-5937)

British Cataloguing in Publication Data
A Cataloguing in Publication record for this book is available from the British Library.

Advances in Early Childhood and K-12 Education (AECKE) Book Series

Jared Keengwe
University of North Dakota, USA

ISSN: 2329-5929
EISSN: 2329-5937

Mission

Early childhood and K-12 education is always evolving as new methods and tools are developed through which to shape the minds of today's youth. Globally, educational approaches vary allowing for new discussions on the best methods to not only educate, but also measure and analyze the learning process as well as an individual's intellectual development. New research in these fields is necessary to improve the current state of education and ensure that future generations are presented with quality learning opportunities.

The Advances in Early Childhood and K-12 Education (AECKE) series aims to present the latest research on trends, pedagogies, tools, and methodologies regarding all facets of early childhood and K-12 education.

Coverage

- Bullying in the Classroom
- Performance Assessment
- Special Education
- Poverty and Education
- STEM Education
- Pedagogy
- K-12 Education
- Diverse Learners
- Individualized Education
- Urban K-12 Education

IGI Global is currently accepting manuscripts for publication within this series. To submit a proposal for a volume in this series, please contact our Acquisition Editors at Acquisitions@igi-global.com or visit: http://www.igi-global.com/publish/.

The Advances in Early Childhood and K-12 Education (AECKE) Book Series (ISSN 2329-5929) is published by IGI Global, 701 E. Chocolate Avenue, Hershey, PA 17033-1240, USA, www.igi-global.com. This series is composed of titles available for purchase individually; each title is edited to be contextually exclusive from any other title within the series. For pricing and ordering information please visit http://www.igi-global.com/book-series/advances-early-childhood-education/76699. Postmaster: Send all address changes to above address.

Titles in this Series

For a list of additional titles in this series, please visit: www.igi-global.com

Challenges Surrounding the Education of Children with Chronic Diseases
Maria Gordon (Voyageur Memorial Elementary School, Canada)
Information Science Reference • copyright 2016 • 329pp • H/C (ISBN: 9781466694521) • US $185.00 (our price)

Medical and Educational Perspectives on Nonverbal Learning Disability in Children and Young Adults
Barbara Rissman (Queensland University of Technology, Australia)
Information Science Reference • copyright 2016 • 380pp • H/C (ISBN: 9781466695399) • US $200.00 (our price)

Examining Response to Intervention (RTI) Models in Secondary Education
Pam Epler (Grand Canyon University, USA)
Information Science Reference • copyright 2015 • 301pp • H/C (ISBN: 9781466685161) • US $185.00 (our price)

Revolutionizing Arts Education in K-12 Classrooms through Technological Integration
Narelle Lemon (La Trobe University, Australia)
Information Science Reference • copyright 2015 • 364pp • H/C (ISBN: 9781466682719) • US $175.00 (our price)

Models for Effective Service Delivery in Special Education Programs
Pam Epler (Grand Canyon University, USA) and Rorie Ross (Grand Canyon University, USA)
Information Science Reference • copyright 2015 • 299pp • H/C (ISBN: 9781466673977) • US $185.00 (our price)

Cases on Instructional Technology in Gifted and Talented Education
Lesia Lennex (Morehead State University, USA) and Kimberely Fletcher Nettleton (Morehead State University, USA)
Information Science Reference • copyright 2015 • 585pp • H/C (ISBN: 9781466664890) • US $185.00 (our price)

Exploring the Effectiveness of Online Education in K-12 Environments
Tina L. Heafner (University of North Carolina at Charlotte, USA) Richard Hartshorne (University of Central Florida, USA) and Teresa Petty (University of North Carolina at Charlotte, USA)
Information Science Reference • copyright 2015 • 481pp • H/C (ISBN: 9781466663831) • US $185.00 (our price)

Critical Practice in P-12 Education Transformative Teaching and Learning
Salika A. Lawrence (William Paterson University, USA)
Information Science Reference • copyright 2014 • 317pp • H/C (ISBN: 9781466650596) • US $175.00 (our price)

IGI GLOBAL
DISSEMINATOR OF KNOWLEDGE
www.igi-global.com

701 E. Chocolate Ave., Hershey, PA 17033
Order online at www.igi-global.com or call 717-533-8845 x100
To place a standing order for titles released in this series, contact: cust@igi-global.com
Mon-Fri 8:00 am - 5:00 pm (est) or fax 24 hours a day 717-533-8661

Editorial Advisory Board

Porter Coggins, *Bemidji State University, USA*
Amy Eguchi, *Bloomfield College, USA*
Thomas Garvin, *Murrieta Mesa High School, USA*
Kimberly Gomez, *University of California – Los Angeles, USA*
Leman Gul, *University of Sydney, Australia*
Linda Hirsch, *New Jersey Institute of Technology, USA*
Peiyi Lin, *Columbia University*, *USA*
Richie Moalosi, *University of Botswana, Botswana*
Roxanne Pickle, *Bemidji State University, USA*
Alfredo Pina, *Universidad Pública de Navarra, Spain*
Elizabeth Pourciau, *Martha Vinyard Elementary School*, *USA*
Jerry Suits, *University of Northern Colorado, USA*
Marrion Usselman, *Georgia Institute of Technology, USA*
Jacek Uziak, *University of Botswana, Botswana*

List of Reviewers

Sevil Akaygun, *Bogasici University, Turkey*
Danielle Boyd-Harlow, *University of California – Santa Barbara, USA*
Gayle Buck, *Indiana University, USA*
Isha DeCoito, *Western University, Canada*
Anne Gatling, *Merrimack College, USA*
Clement Gomes, *Columbia University, USA*
Tracey Goodson-Espy, *Appalachian State University, USA*
Resa Kelly, *San Jose State University, USA*
Meghan Marrero, *Mercy College, USA*
Mahnaz Moallem, *University of North Carolina – Wilmington, USA*
Bethenay Reichen, *University at Albany, USA*
Loraine Snead, *YSC Academy, USA*
Niwat Srisawasdi, *Khon Kaen University, Thailand*
Karen Woodruff, *U.S. Satellite Laboratory, USA*

Table of Contents

Section 1
Teaching and Learning in STEM

Section 2
Real-World Contexts for STEM

Section 3
Educational Technologies for Use in STEM

Detailed Table of Contents

Section 1
Teaching and Learning in STEM

This chapter explores the potential of a digital game, The History of Biology (HoB) as a learning environment in which today's learners find technology engaging and practical to advance their learning and interact with STEM content. The authors report on a study which assumed an explicit-reflective teaching approach from the perspective that the HoB game was developed in the context of the history, philosophy, and sociology of science and technology. The study addressed the following question: What effect, if any, does HoB have on students' a) learning 21st century skills, and b) engagement with integrated STEM content? The authors hypothesize that by providing opportunities for exploring integrated STEM content via a digital online game, pre-service science students may enhance their own numeracy, and scientific and technological literacy, and also develop positive attitudes toward teaching STEM content through digital technologies in the classroom.

One of today's equity challenges is the need to increase media literacy among all students, especially traditionally marginalized students. Media literacy is defined by the way that particular student groups are limited in their engagement with digital resources that promote critical thinking and problem solving. This chapter provides implementation models for seven different types of media projects focused on climate change science that have been successfully piloted with 78 secondary students primarily from impoverished backgrounds. Results show that students' experiences while participating in these projects were transformational. Both the digital and STEM divides were bridged by including science-focus media projects.

With the current focus to have all students reach scientific literacy in the U.S, there exists a need to support marginalized students, such as those with Learning Disabilities/Differences (LD), to reach the same educational goals as their mainstream counterparts. This chapter examines the benefits of using audio assistive technology on the iPad to support LD students to achieve comprehension of science vocabulary and semantics. This research is composed of quantified data supported by qualitative information. Significant statistical evidence from pretest and posttest ANCOVA analysis reveals that audio technology is beneficial for seventh grade LD students when learning unfamiliar science content. Analysis of observations and student interviews support the quantified findings. This chapter provides useful information for the rising number of identified LD students and their parents and teachers by providing the benefits of using audio assistive technology to learn science. Audio assistive technology can be the tool to bridge the gap for LD students to achieve scientific literacy.

This chapter uses the theoretical perspective of dialogism to examine how two suburban secondary math teachers use technology in the classroom to enhance language and content knowledge development for English learner students. Data for this study includes teacher lesson plans, transcripts of recorded lessons, and teacher reflections and is analyzed using a collective case approach. Results indicate that communicative acts in the classroom fall along a communication spectrum, and uses of specific technologies to increase dialogic interaction among students and between students and teachers are discussed. Thoughtful use of certain technologies may enhance opportunities for English learner students to claim a voice in the classroom and improve their language skills.

Technological tools such as interfaces, sensors and probeware are increasingly prevalent in science classrooms. With increased prevalence comes a need to improve the research base on how to use technology in ways that maximize student learning. These resources potentially support inquiry-based learning approaches through the collection and transformation of data. Furthermore, by making data trends evident, these technologies have the potential to support construction of scientific explanations and complex reasoning. The purpose of this study was to analyze the levels of reasoning displayed by African American girls engaged in technology-enhanced inquiry so as to better understand the extent to which technology can support scientific literacy. Our results indicated modest gains in the girls' ability to display data and connect data trends to scientific phenomenon. We believe that studying the experiences and learning of students from historically underrepresented backgrounds in STEM is critical for ensuring equitable educational experiences and access to STEM-related professions.

This chapter presents research about a combination of physical experimentation (PE) and virtual experimentation (VE) in computer-based inquiry learning as an instructional value to students' affective domain. For this study, the author has developed a science lesson for promoting interactive inquiry learning, and the researcher investigated whether orchestrating PE and VE in sequential learning affect students' learning perception and science motivation. To evaluate the lesson, questionnaires were used to examine how students perceived the lesson and their perceptions about how the lesson promotes science motivation. The results indicated students' positive perceptions that experiencing the lesson supported cognitive performance, emotional practice, and the social inquiry process. In addition, exposure to the lesson improved students' science motivation for both females and males. This highlights that the combination is an effective way to enhance the effectiveness of high school science learning.

Using Squeak Etoys to Infuse Information Technology (USeIT) was designed to offer expanded information technology experiences to 155 middle and high school students over a three-year period by exploiting the Squeak Etoys media authoring tool as a simulation and modeling environment. Through problem-solving activities and development of Squeak Etoys modeling projects, USeIT investigated the impact of Problem-Based Learning (PBL) and utilization of Squeak Etoys on student understanding of scientific and mathematical concepts. A design-based research method was used to collect data. The results revealed that when simulation and modeling are used under specific learning conditions, a deeper level of understanding of key science and mathematics concepts is observed. In addition, problem-based simulation tasks cognitively engaged students, particularly those who otherwise did not see the relevancy of STEM content in their lives. Less motivated students developed interests in STEM content and showed confidence in their abilities to learn mathematics and science.

Learning chemistry involves understanding chemical phenomena at macroscopic, symbolic and submicroscopic levels. Even though chemistry instructors integrate these levels in their lessons, it cannot be assumed that students relate them properly. Therefore, it is important to identify students' mental models that will reveal how they visualize and conceptualize chemistry. Mental models can be represented in various forms including static drawing and animations. Considering the dynamic nature of chemistry, animations prepared by students can be more informative conveying students' understandings. This study aimed to investigate how high school students visualize condensation and to compare their dynamic and static mental. The analysis of the results suggested that static and dynamic mental models were found to be significantly different ($p<0.05$). Static mental models were found to be more focusing on structure whereas dynamic ones included more macroscopic features and interactions. Finally, students revised their mental models towards more accurate models after preparing animations.

Section 2
Real-World Contexts for STEM

In an attempt to foster inquiry-oriented learning in middle grades (grades 6 – 8), a technology mediated pedagogy integrating science and mathematics was promoted through Project SMILE (Science and Mathematics Integration for Literacy Enhancement). It involved in-service teachers in professional learning and classroom implementation over a period of two academic years, with the explicit goal of enhancing teachers' ability to foster more authentic inquiry in their classes. This chapter describes the design of Project SMILE in the context of recent reform efforts in science and mathematics education, along with the theoretical underpinnings for the design. Project activities, followed by the research methodology employed to investigate the impact on both teachers and students are described next. Finally, research results and their implications are discussed with an eye toward the usefulness of integrating science and mathematics and involving specific technological tools to foster greater inquiry-oriented learning in school science and mathematics.

Chapter 10

A Qualitative Study of Teachers' Understanding of Sustainability: Education for Sustainable Development (ESD), Dimensions of Sustainability, Environmental Protection................................ 206

Hsiaowei Cristina Chang, San Jose State University, USA
Resa Marie Kelly, San Jose State University, USA
Ellen P. Metzger, San Jose State University, USA

This qualitative study was focused on exploring how in-service teachers' who were attending a three-day "Educating for Sustainability" workshop made sense of sustainability. Another goal of this study was to examine teachers' perceptions of the portrayal of the three dimensions of sustainability (environment, economy and social equity) in short movies that served as "real world" exemplars of sustainability that were freely available online through YouTube or other websites. Data was collected largely through individual semi-structured interviews, but also through questionnaires and written and drawn documentation. The findings, obtained through the constant-comparative method of coding, indicated that teachers' spontaneous descriptions of sustainability emphasized the environmental and economic dimensions of sustainability, but overlooked the equity dimension of sustainability. The videos helped teachers incorporate the 3E's into their sustainability discussions when all three dimensions were addressed, but when the social equity dimension was missing, then it tended to go unnoticed.

Chapter 11

Coupling Geospatial and Computer Modeling Technologies to Engage High School Students in Learning Urban Ecology.. 235

Dennis J. DeBay, University of Colorado – Denver, USA
Amie Patchen, Boston College, USA
Anne C. Vera Cruz, Boston College, USA
Paul E. Madden, Boston College, USA
Yang Xu, Boston College, USA
Meredith Houle, San Diego State University, USA
Michael Barnett, Boston College, USA

This chapter is a description of the Urban Tree Project where high school students were engaged in the use of Geographic Information System (GIS) technologies to determine the economic and ecological value of trees in their neighborhood. Students collected data on tree locations and conditions and then used CITYgreen to evaluate the economic and ecological value of their trees. Urban high school youth had the opportunity to explore urban ecology in their neighborhoods. Pre–post interview and written assessments were conducted across a wide sample of school contexts. The goal of these assessments was to explore the students' beliefs and understanding regarding the ecosystem services that trees and greenspace provide to a city. The results were mixed as students' understanding measured by the written assessments increased significantly. However, upon further probing, students often showed difficulty in drawing coherent concepts and ideas that depicted a robust understanding of urban ecological principles regarding green space and the services that trees provide.

A critical consumer is able to ask questions and discern information about data—its collection and analysis, and is able to judge whether conclusions are warranted (GAISE, 2007; Best, 2001). Promoting statistical knowledge by exploring social issues that create disparities helps individuals foster initiative for positive change and engage in equitable practices (Moses & Cobb, 2001; Gutstein, 2006). This chapter explains investigations suitable for use with pre-service/in-service teachers and middle school or high school students. Investigations were structured to help participants: 1) Engage in statistical problem solving using real data; 2) Focus on the process of statistical investigation (Rossman & Chance, 2012); and 3) Consider statistics as a means of promoting social change. A description of investigations and sample artifacts are included.

Our planet is under intense observation—by satellites, seismometers, buoys, radar, and more. These instruments generate authentic data sets that are freely accessible online, and thus available for K-12 students and teachers to use in STEM classrooms. This chapter examines how teachers engaged in the NASA Endeavor program, a STEM teacher professional development initiative, use authentic online data in their classrooms and the effects of these activities on teaching and learning. Endeavor teachers use data in many ways, including through curriculum programs developed to scaffold earth data sets for use by students. Through qualitative analysis of teacher interviews, teacher course work, student work, and other relevant data, the researchers discovered that employing authentic online data in Endeavor teachers' classrooms helped students to construct explanations based on evidence and make real world connections to science content.

Section 3
Educational Technologies for Use in STEM

It is becoming increasingly important to incorporate engaging and relevant interactive technologies into the physics and general study curricula of K-12 students. Theoretical principles of kinematics can be brought to life by including complementary technologies and activities that require manipulation and construction of textbook knowledge. This chapter explores the use of Adidas Smart Ball technology, the Physics Education Technology (PhET) online simulation, and Apex Digital Learning in grades nine through twelve enrolled in a small private college preparatory academy. The chapter is centered on the development of a kinematics unit that encourages higher-order cognitive skills in the classroom by focusing on how a combination of technologies and non-technology modalities demonstrate Bloom's cognitive skills: remembering, understanding, applying, analyzing, evaluating, and creating. Furthermore, it is shown that the combination of all three technologies, rather than independent use of a singular technology, can achieve higher-order thinking in science. This was demonstrated through the culmination of the project with student-designed and -driven physics experiments. This chapter further supports the widely held belief that teachers should employ the interests and passions of students in the context of teaching STEM subjects.

Chapter 15

Computing has impacted almost all aspects of life, making it increasingly important for the next generation to understand how to develop and use software. Yet, a lack of research on how children learn computer science and an already impacted elementary school schedule has meant that very few children have the opportunity to learn computer science prior to high school. This chapter introduces literature on teaching computer programming to elementary and middle school, highlights three studies that span elementary and middle school, and discusses how programming can be integrated into other content areas and address national standards.

Chapter 16

This chapter describes a teacher preparation model incorporating a STEM focused, technology enhanced course and field experiences for preservice teachers. This field-based science method course supports and engages preservice teachers in creating and implementing lessons for early childhood and elementary students enrolled in an afterschool STEM Enrichment Program offered in a diverse urban elementary school. Technology is woven throughout the model, supporting preservice teachers as they build their content knowledge, and research effective practices to teach and assess their students. This model also helps to address the need to enhance STEM instruction in schools and inspire preservice teachers to engage their students in the STEM learning process. Findings from the model's implementation indicates a positive impact on the preservice teachers' understanding of science content and standards, on their pedagogical practices to design STEM lessons based on the revealed understandings of students' knowledge, and on the development of their professional identities.

Chapter 17
Technology-Assisted Formative Assessment 380
Karen E. Irving, The Ohio State University, USA

Reliable just-in-time assessments are the foundation of informed teaching and learning. Modern electronic technologies assist in the formative assessment process by supporting classroom environments that allow students and teachers to assess learning and providing mechanisms to present information about student learning during instructional sequences. To implement formative assessment practices, students and teachers benefit from rich educational tasks that invite students to share information about their understanding of the lesson while the lesson is occurring in order to nurture productive learning by both teacher and student. Formative feedback is facilitated by technologies such as connected classrooms, videography, online formative quizzes, and manuscript multi-draft editing. Technology-assisted formative assessment represents a powerful option to promote improved classroom communications that support formative assessment practices for teachers in twenty-first century classrooms.

Chapter 18
Using Reason Racer to Support Argumentation in Middle School Science Instruction 399
Marilyn Ault, University of Kansas, USA
Jana Craig-Hare, University of Kansas, USA
James D. Ellis, University of Kansas, USA
Janis Bulgren, University of Kansas, USA
Isa Kretschmer, Independent Researcher, USA
Bruce B. Frey, University of Kansas, USA

With secondary students reporting that they are not attracted to science, technology, engineering, or mathematics (STEM) disciplines, educators are turning to games as one strategy to engage students. The goal of integrating games into science learning is to create an excitement difficult to achieve with typical instruction. This chapter reviews games in education, particularly in STEM. Recognizing that teachers often lack the time to integrate role-playing games, the use of casual games is suggested. Casual games are easy to learn and simple to play, and incorporate game features designed to compel students to repeated play. The Reason Racer game addresses the difficult skill of scientific argumentation in a casual, competitive game. Evaluated with more than 700 students, those who played the game at least 10 times during science instruction over 6-weeks improved in every aspect of argumentation, and reported an increase in confidence and motivation to engage in science, compared to those who did not play the game. Readers are walked through the game and the resources in the Teacher Portal.

Foreword

Teachers in every age have sought the most useful and powerful tools to enhance their teaching. Teachers today are no different, but the tools available to them have never been so powerful or so complex. Consequently, every teacher today is faced with more decisions—and more difficult decisions—than any teachers in history. This situation is particularly trying for science, technology, engineering, and mathematics (STEM) teachers, for the professors who prepare them for the classroom, and for educational researchers. Reliable sources of solid information about the use of technology in STEM classrooms are not common, nor are they readily accessible. For example, a study on inquiry learning conducted in Thailand or an application of classroom visualization techniques carried out in Turkey might be very relevant for a science teacher in the United States, but it is not likely that the teacher would know about the project. On the other hand, another difficulty facing teachers, parents, school administrators, and education professors is the plethora of readily available information on the Internet that is neither sorted nor evaluated.

This book was developed to meet those needs. The editors have brought together reports of a wide variety of important research findings and examples of successful technology integration that work. As a result the book represents an authoritative and valuable aid for teachers, administrators, and professors involved in teacher education or educational research. Reading this book is like attending a conference in which you meet people with similar interests who have done pioneering work on the uses of technology in teaching and have reliable information and methods to share.

One thing that is very apparent when reading this book is the importance of multidisciplinary collaborations in technology integration. The authors of the chapters come from widely divergent fields, such as computer science, mathematics, geology, chemistry, education, and video game development. This book has the potential to be a stimulus for the development of additional collaborations among researchers and developers and between STEM teachers, professors, administrators, and parents. It represents a new beginning for many in the field, as it provides the guidance needed to approach technology integration with confidence.

Loretta Jones
University of Northern Colorado, USA

Preface

What we consider the *technology of today* has revolutionized the way societies function in nearly every respect: commerce, communication, information access and distribution, entertainment, marketing, and social interaction. Nearly everywhere you turn, and at any moment, you can observe someone doing something with technology -- from talking on a cell phone to listening to music on an iPod, checking email to playing a game on a hand-held device, updating Facebook status to reading the newspaper online, and much, much more. Given its propensity for making our lives easier, it only makes sense that we would strive to integrate technology into all aspects of our lives: work, home, and entertainment. To be considered fully participative and productive members of the global society today, all of its citizens have a responsibility to intentionally seek and attain a certain level of technological literacy, embracing all technology has to offer in terms of productive enterprise.

Today's K-12 schools are not exempt from this expectation; teachers, administrators, and students alike should all be literate in the use and application of technology. Progressive preschools, elementary schools, middle schools, and high schools (along with post-secondary institutions and other formal, and informal, educational entities) all infuse multiple facets of technology into their curricula and day-to-day operations. These schools apply technology in a variety of ways: some have initiated a 1:1 student-to-technology program, where each child in every classroom is assigned an iPad, tablet, laptop computer, or other device, providing almost endless opportunities for purposeful interaction with technology; some implement a "bring your own device" (BYOD) strategy, allowing students to select whatever electronic tool they already have and use it for class; some require every teacher to enter grades and attendance in a database via computer; others encourage teachers to reach out to the parents of struggling students by email, in addition to phone; still others provide the means for parents to access their child's grades, school calendars, and homework details by visiting an online portal. Many schools utilize several or all of the preceding and more. The capacity for schools to advance their charge, namely to produce an informed, responsible, critical-thinking, problem-solving, decision-making, and employable future citizenry, can be greatly aided and enhanced through the intentional exposure to, and explicit instruction of, skills specifically related to technology. Clearly, the integration of technology for a variety of purposes should be an inherent and overt goal of all schools.

SCIENCE, TECHNOLOGY, ENGINEERING, AND MATHEMATICS (STEM)

In addition to the general societal revolution heralded by the explosion of technology, another specific revolution has led to a reformation in curriculum and methods of instruction for teaching and learning in science-related classrooms. Science, technology, engineering and mathematics (STEM) as a term, initially emerged from initiatives at the *National Science Foundation (*NSF), but has evolved to describe curriculum and employment areas that emphasize engineering, physical sciences, math and computer sciences, life sciences, and technology integration. Much research has been conducted about using technology to enhance the effectiveness of STEM education. This body of knowledge has been crucial in supporting the appropriate use of integrated technology for effective and efficient STEM teaching and learning. Even so, much more research is needed to further enhance our ability to address the need for improved skills and understandings of STEM for our future workforce. In addition to these workforce issues, the general public will benefit from a collective of citizens who will have these skills and understandings and may use them to make quality life and personal decisions.

Although this book is designed to reach out *internationally*, and includes chapters from authors in several different regions of the globe, some of the specific discussion will relate to STEM education as it looks in the United States of America. And, even though one would hope that at least some overall *integration* of science, technology, engineering, and mathematics occurs in classrooms around the globe, portions of the discussion will need to focus on the individual disciplines separately.

Advances in science, technology, engineering, and math (STEM) are critical to determining a nation's prosperity and success in procuring and utilizing natural resources, establishing and maintaining national security, and stretching the boundaries of innovation – all of which have been in place in the United States since the days following *Sputnik* and the "space race" (circa 1960). We are all understandably concerned about global environmental sustainability, national security, and how we will fare in this age of technological revolution, especially when we consider how our current students are performing in the STEM disciplines within a market of International competition. We ask ourselves, who will be responsible for envisioning the next technological innovations? The answer could have important ramifications for the world.

According to international tests, students in the United States are falling behind a number of global competitors when it comes to STEM. Our own *Nation's Report Card* identifies similar weaknesses in science and mathematics. Individual state tests show clear and present problems in the way science is being taught in our elementary, middle, and high school classrooms today. Nevertheless, the STEM workforce is expanding and educators in America must address this growing need for STEM workers by motivating students to consider and enter STEM fields, and adequately preparing them to work in these disciplines. Scientists use technology to aid in the collection and analysis of data, representation and modeling, and the communication of information, so it is critical that technology be infused into the STEM curriculum where practical and appropriate.

Technology used to be explicitly linked to science, as in "science and technology," relegated to a subsidiary status and potentially dependent association; however, technology is no longer considered subordinate to science, and instead may well be elevated in standing relative to it. Clearly, technology as a general description, is a far-reaching and diverse term, encompassing much more than science today. It permeates essentially every component of a school's formal curriculum and has wide applications. As a tool, and set of related skills, technology forms a natural and applicable union with each of the other disciplines in STEM. Connections to science and engineering are perhaps more obvious than to mathematics, but computers, calculators, and software -- to name just a few -- are clearly important resources for both theoretical and applied mathematics. Both the *National Council of Teachers of Mathematics* and the *Next Generation Science Standards* advocate active use of technology in the teaching of mathematics and science. And, the *International Society for Technology in Education* has created sets of technology standards for teachers and students. Integrating and infusing technology into the science, engineering, and mathematics curricula may almost happen automatically, even without consciously addressing state or national standards. But this is *only* true for those curriculum developers and teachers who are knowledgeable about and comfortable with "technology." And, alas, that is not everyone.

Engineering, while certainly a free-standing discipline of its own accord, has typically been covered under the auspices of "science," at least within K-12 state and national standards. Although, in the past few years, the *National Academy of Engineering* has explored the possibility of generating content standards for K-12, there are none as of yet. Engineering relies on the fundamental principles of scientific and technological knowledge, facilitating and furthering our capacity to design, build, and evolve societal infrastructure. And, as anyone who has formally studied the mechanics of engineering knows well, complex mathematics underlies much of the technical and practical nuances of both statics and dynamics.

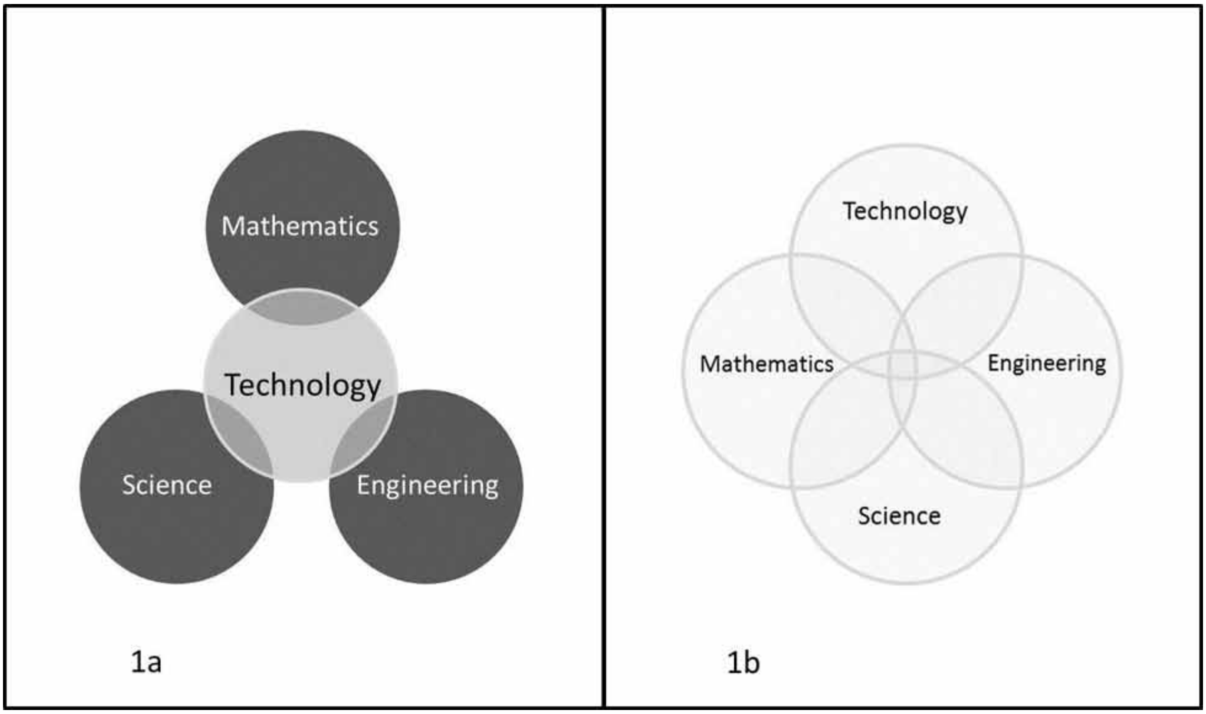
Science and mathematics, as disciplines themselves, embody separate but related collections of specific content knowledge and skills. Each can be applied in certain instances, with specific intent, yet each is equally difficult to remove fully from a greater context, or *Gestalt*, in which the other factors to a varying degree on a spectrum of interconnectedness. For example, science can serve as a venue for the application of mathematics, whereas the progression of mathematical theory can foster the advancement of science into new areas previously limited by an incomplete mathematical expression. The *Principles and Standards for School Mathematics* (2000) and the *Next Generation Science Standards* (2013) identify several specific standards that should be covered by schools in relevant math and science classes respectively.

There is precious little room to debate the ubiquity and applicability of technology, or the interdisciplinarity of the STEM fields: K-12 teachers should be actively using and teaching technology, and actively using it for, and within, the teaching of STEM. Teachers should not only consider the application of technology to each STEM discipline separately, but must consider technology within an interdisciplinary and holistic framework of STEM. To illustrate this point, compare and contrast Figure 1a to Figure 1b. The realization of a truly interdisciplinary approach to STEM learning will require, for some, a conscious and deliberate change in thinking.

TECHNOLOGY AS A DOORWAY TO THE FUTURE

Today's technologies have opened doors many of us had only dreamed possible just a few years ago, and because of the recency and originality of technological diversity today, many of us have been left behind with regard to technological prowess—especially in comparison to the youngest generations. Individually, none of us should despair at any perceived personal deficiencies or discomfort using technology, because for most of us, there simply are not enough hours in a day, week, or year, to learn every new high-tech gadget or interactive program out there now. However, we should concede that with a little motivation, practice, and perhaps assistance, essentially all of us can achieve some level of technological proficiency. Those who consider themselves tech-savvy or technologically elite may find that they are not in need of suggestions or encouragement to dive into new technologies, but that is not the case for everyone. Enough teachers, and laypeople, face challenges that it warrants mentioning. And, while it is essential to incorporate technology in the curriculum, it is critical to understand the potential for its abuse. Along with the numerous advantages, a few potential disadvantages must be recognized and actively addressed related to the use of technology in schools, including: curricularly unrelated, off-task,

Figure 1. Illustration of the difference between integrating technology in science, engineering, and mathematics (1a) versus integrating all STEM disciplines together (1b)



and non-instructional instances of texting, instant messaging, Facebooking, and other "multitasking" activities *during* instructional time.

Most concerning of all, there is the unfortunate, and significant, fact that too many teachers—at all levels—are technology phobic, poorly adept, or simply out-of-touch with the pervasiveness and essentiality of technology to the classroom environment. At the end of the day, technology is here to stay, albeit maybe not in all of its present incarnations, but certainly as a means to foster efficiency and further the daily capabilities of the 21st century workplace. If schools are truly designed to create a literate and skilled citizenry, then they must embrace the changing face of instruction in light of technological advances. Consequently, teachers themselves must embrace the use of technology; not just paying lip service to the importance of it, but really working to grasp the power and potential technology provides for teaching and learning. Much easier said than done, to be sure. And, to be fair, teachers are already oftentimes overloaded with larger class sizes, standards-based assessments, additional non-teaching duties, and reading- and math-related professional development initiatives; so how can more time be found to learn the plethora of new technologies seemingly popping up endlessly day after day? For some of those tech-savvy "digital natives" who seem to delight in all things technological, there is simply not enough class time to explore each and every gizmo, gadget, and app that *just has to be shared* with their students. For other *digital natives* and many "digital immigrants," either the time or appeal, or both, of technology may be elusive or end up free-falling to the bottom of the mounting stack of responsibilities in an average school day. A solution to the problem of insufficient time is not necessarily easy to discover, but there are options and incremental steps that each and every teacher can utilize to learn new classroom technologies and become increasingly more *comfortable* and *confident* with technology.

WHAT IS TECHNOLOGY?

The term *technology* encompasses a variety of resources and takes on a number of different meanings depending on the situation or setting. Consequently, it is important to establish what is meant by *technology* as a component of STEM, and how this differs from *technology integration*, if indeed it does. For purposes of this book, we will define technology very loosely as a collection of electronic tools and skills that can be used to accomplish a specific task, reserving technology integration specifically for the action of *applying* the tools and skills of technology to the teaching and learning of STEM, especially to the solving of authentic problems. The *technology of today* comes in a variety of forms: hardware, software, animations, simulations, games, probes, social media (e.g., Facebook), and more.

Most would agree that new technologies have been transforming our lives and world. As is the case in our educational institutions at all levels, students and teachers are using more technologies more often than perhaps they were even just a few years ago. There is no doubt about the potential of integrated technology for effective and efficient teaching and learning, but continued research related to integrated educational technologies will continue to help us better understand how technologies are best used, and sometimes misused, in our classrooms. In addition, systematic formative and summative assessments provide practitioners data to ascertain if indeed the technologies and curriculum are providing desired learning outcomes. In some instances non-technological strategies may be effective and should be maintained if they help students learn. This book highlights many examples where integrated education technologies have improved STEM learning.

Almost one hundred years ago sound recordings and radio broadcasts were finding their way into teaching and learning environments. It is generally accepted that the term technology represents tools, systems, or mechanisms developed based upon applied science, and in most cases equipment often used by skilled laborers to solve complex tasks. Technology is often viewed as the delivery mechanism, and the success of implementation depends upon the overall instructional design and the quality of the curriculum. A combination of good teaching and integrated technology is commonly understood as a road-map for success. In addition to the notion of technology as instructional delivery, technology serves as a tool for classroom discovery. Consider students, in a multi-disciplinary lesson, using data sets, and software such as Google Earth to explore and better understand the complex issues related to carbon dioxide emissions in terms of how they impact weather, public health, and people in various geographical and social situations. Such a problems-based inquiry learning activity exemplifies students using a variety of tools including online (and real) data sets, software applications, and documentary about real and current issues. Again, the success of this scenario in terms of learning is contingent upon quality instructional design combined with good teaching.

CHALLENGES

A growing number of challenges plague both teachers and schools as they strive to incorporate technology and train students in its use. A few of them include:

1. Technology is unavailable at the school for enough, or all, students to use.
2. The available technology is well behind what is considered "cutting-edge" or relevant for today.
3. Schools may have technology, but the staff is ill-equipped to train faculty in its use and application in instruction.
4. Teachers are afraid of using technology (tech-phobic) or do not have the skills to use it.
5. Teachers do not know what technology resources and applications are available to them or how to evaluate and use them for instruction.

The editors of this book have worked with college students, practicing teachers, university colleagues, and K-12 students who all display a variety of interest, skill, and proficiency in the use of technology. One thing we hear and parrot often is the phrase "just start using it." The first step is to be proactive, rather than reactive, and start slowly, engaging or interacting with some new forms of technology. In only this way can people actively begin to construct a knowledge base, and establish a toolbox of applicable skills, for the utilization of the various forms of technology. With even more new and creative technologies popping up every day, we must consciously select which individual representatives we wish to devote our time and explore. These days time is more precious than gold, and wasted time translates into lost money, inefficiency, and discouragement. Just as with individuals, there is the potential for schools to experience myriad challenges as they seek to acquire and implement technology. Some of these problems have specific formulas for solving, others do not.

POTENTIAL SOLUTIONS

While there are a number of possible solutions to the aforementioned challenges, they can probably be grouped into a couple of basic categories: 1) those that require funding (e.g., professional development, trainers, purchase of materials) and 2) those that do not require funding (e.g., interest, motivation, time). This book is designed to focus on providing data and recommendations in relation to the last two challenges mentioned earlier:

1. Teachers are afraid of using technology (tech-phobic) or do not have the skills to use it.
2. Teachers do not know what technology resources and applications are available to them or how to evaluate and use them for instruction.

It is much easier to provide advice and relay experiences, than it is to give money, and that is what this book is written to do. To obtain funding, schools and teachers may consider writing grants to obtain technology in the form of hardware and software, access expert professional development opportunities, hire trainers, and overhaul systems (e.g., web pages, interactive databases, etc.). Districts, administrators, professional learning communities, and teachers all work at their respective levels to facilitate change and usher in new eras of technology use as they are able, but sometimes additional resources are necessary.

IMPETUS FOR THE BOOK

The driving force behind this book is the desire to provide a resource with examples of technology and technological applications that have been used, or are being used, in schools and classrooms around the globe. Because best practice is defined through rigorous empirical research, many of the chapters in this book are based upon research findings that support effective integration. Unfortunately, the book cannot serve as a "how-to" manual for incorporating technology in classroom settings; however, it can and does serve as a model for what could be done with technology in the classroom by sharing descriptions of research studies conducted in relevant and applicable settings (mostly K-12), discussed in terms of implementation strategies, recommendations, and lessons learned. The primary aim of the book is to provide practicing in-service teachers, and teachers-in-training (i.e., pre-service teachers), a compendium of evidence-based technological applications they can consider using in their classes. The readers and users of the book are encouraged not only to look into the various animations, simulations, software applications, integration models, and the variety of tools and resources discussed in the book, but to *try them out* in their own classrooms. Since it can be challenging to know which of the myriad technologies one should try in the classroom, descriptions of what has been done, with what, who, and where, can be very useful. Therefore, a secondary aim of the book is to illustrate learning gains, achievement, and perceptions of learners using the herein described resources, and in so doing, suggest how, when, or if using them can be beneficial to the learning process. Of the many technological devices and applications out there today, only a select few have actual data supporting their use or value in instructional environments. The research-based recommendations provided in this book lend further credence to a few of the established applications, and new evidence for a few others.

ORGANIZATION OF THE BOOK

Data and findings from a variety of studies involving K-12 students, college students, and pre-service teachers are reported with emphasis on applicability to the K-12 environment. The book has been divided into three distinct sections with 18 total chapters. The first section, comprised of eight chapters, covers a variety of research-based studies that address important STEM teaching and learning issues. This first section provides important findings and recommendations to enhance the use of integrated instructional technologies for higher-order thinking and active learning of STEM content. The second section of the book consists of five chapters all pertaining to real-world environmental and social issues in STEM. This section contains various studies that explored inquiry and problem-based teaching methods to help educators better understand the advantages of and skills for science awareness instruction related to critical trends and issues that impact humans and the natural world. The final five chapters in the third section provide excellent examples of educational technologies for efficient and effective teaching and learning in STEM classrooms. The intention for this final section is to give practitioners some detailed illustrations of technological STEM classrooms, perhaps to serve as models for what might serve the needs and desires of those wanting to enhance their teaching through integrated technologies for STEM learning. Certainly, the individual chapter topics transcend any imposed boundaries, but the compartmentalization was an attempt to group chapters into a coherent scheme for purposes of device or discipline similarity, curricular application in a science or STEM methods-type college course, and to provide the reader with some content continuity.

Section 1: Teaching and Learning in STEM

Chapter 1 introduces gaming as a learning strategy in STEM. Authors DeCoito and Richardson consider the potential for acquiring 21st century skills and the effects on student engagement of a specific biology game used to explore integrated STEM content. Consequently, their work with pre-service teaching candidates sets a solid stage for examining other strategies for teaching and learning STEM. *Chapter 2*, by Smith, Rooney-Varga, Gold, Oonk, and Morrison, examines media literacy challenges within a context of climate change science. Their findings have implications for using digital resources with secondary students in STEM. In *Chapter 3*, Gomes and Mensah discuss using assistive technologies to improve scientific literacy for students with learning disabilities. Reichen, Oliveira, Oliver, and Florencio-Wain, explore through a case study analysis in *Chapter 4*, the use of technology in mathematics for helping English Language Learners improve their language skills and content knowledge. *Chapter 5* investigates STEM learning with historically underrepresented groups. Specifically, Buck, Beeman-Cadwallader, and Trauth-Nare analyze African American girls' reasoning through technology-enhanced inquiry. In *Chapter 6*, Niwat describes findings related to the combined use of physical and virtual experimentation on student perception and motivation in high school chemistry. Mahnaz, Morge, Narayan, and Tagliarni describe technology use in Problem-Based Learning for understanding middle and high school science and mathematics concepts within *Chapter 7*. The section concludes with *Chapter 8*, in which Akaygun analyzes visualization technologies for modeling concepts in macroscopic and microscopic chemistry as a way to increase comprehension in high school.

Section 2: Real-World Contexts for STEM

Chapter 9, authored by Dass and Spagnolo, describes how teachers can develop skills for using inquiry learning with middle school students through technology combined with the integration of mathematics and science. The study documents findings from a two-year period of classroom implementation with in-service teachers. In *Chapter 10*, Chang, Kelly, and Metzger, discuss qualitative findings from semi-structured interviews, and other instruments, with in-service teachers participating in a three-day sustainability workshop. Videos related to real-world sustainability were used to elicit teachers' perceptions about the components of sustainability in one aspect of the study. Authors DeBay, Patchen, Vera Cruz, Madden, Xu, Vaughn, and Barnett explore urban ecology with high school students who collected tree data and analyzed it using Geographic Information System technologies in *Chapter 11*. Pre- and post-assessments and interviews were used to examine how the students perceived and understood the value of city greenspace. In *Chapter 12*, Poling, Naresh, and Goodson-Espy describe the importance of statistical problem solving and analysis skills for drawing conclusions about data. The investigations included may be equally suitable for middle or high school students and pre-service teachers. With *Chapter 13*, the section concludes with Marrero, Gunning, and Woodruff's examination of freely available authentic datasets online and their classroom use by in-service teachers. A variety of qualitative data is analyzed to illustrate the value of these online resources for helping student to make real-world science connections.

Section 3: Educational Technologies for Use in STEM

Chapter 14, by Snead and Simms, discusses the combined use of several technologies for understanding the physics of kinematics and achieving higher-order thinking in middle and high school science. In *Chapter 15*, Boyd Harlow, Dwyer, Hansen, Hill, Iveland, Leak, and Franklin describe the incorporation of computer programming into the curriculum of elementary and middle school classes, stressing the importance of acquiring computer science knowledge and skill prior to entering high school. Gatling illustrates, in *Chapter 16*, a model for a field-based science methods course in which pre-service teachers practice using and applying technology to lessons in an elementary afterschool STEM-enrichment program. The model emphasizes technology integration, science standards, pedagogical practices, and content knowledge. Technology-assisted formative assessment through the use of videography, online quizzes, and more, is the focus of Irving's *Chapter 17*. The final chapter in the section and book is *Chapter 18*, by Ault, Craig-Hare, Ellis, Bulgren, Kretschmer, and Frey, and in it the authors describe the use of gaming to foster high school students' interest in STEM.

It is our hope that the research, descriptions, and strategies provided in the eighteen chapters of this book suggest both reasons and ways for practicing and pre-service K-12 teachers to enhance their classroom integration of technology in STEM.

Michael J. Urban
Bemidji State University, USA

David A. Falvo
Walden University, USA

Acknowledgment

The editors would like to acknowledge the assistance of all people involved in this project and wish to thank the authors and reviewers who took part in the review process.

Michael J. Urban
Bemidji State University, USA

David A. Falvo
Walden University, USA

Section 1

Teaching and Learning in STEM

Chapter 1

Using Technology to Enhance Science Literacy, Mathematics Literacy, or Technology Literacy:

Focusing on Integrated STEM Concepts in a Digital Game

Isha DeCoito
Western University, Canada

Tasha Richardson
University of Toronto, Canada

ABSTRACT

This chapter explores the potential of a digital game, The History of Biology (HoB) as a learning environment in which today's learners find technology engaging and practical to advance their learning and interact with STEM content. The authors report on a study which assumed an explicit-reflective teaching approach from the perspective that the HoB game was developed in the context of the history, philosophy, and sociology of science and technology. The study addressed the following question: What effect, if any, does HoB have on students' a) learning 21st century skills, and b) engagement with integrated STEM content? The authors hypothesize that by providing opportunities for exploring integrated STEM content via a digital online game, pre-service science students may enhance their own numeracy, and scientific and technological literacy, and also develop positive attitudes toward teaching STEM content through digital technologies in the classroom.

INTRODUCTION

There is a worldwide call for schools to improve students' numeracy, scientific and technological literacy, as well as their understanding of science and technology content, socio-scientific issues, the nature of

DOI: 10.4018/978-1-4666-9616-7.ch001

science, and scientific and technological problem-solving (Millar, 2006). The shift in our society's growing reliance on technology demands that our students' education emphasize technological literacy, thus benefitting students who may or may not pursue technology based careers, such as engineering and architecture. Furthermore, there is a need for students to experience opportunities in formal and informal settings that will result in enhancing 21st century learning skills such as (a) creativity and innovation; (b) critical thinking and problem solving; (c) communication; (d) collaboration; (e) information literacy; (f) media literacy; (g) information and communications technology (ICT) literacy; (h) flexibility and adaptability; (i) initiative and self-direction; (j) social and cross-cultural skills; (k) productivity and accountability; and (l) leadership and responsibility, as detailed in NSTA's 21st Century Skills Map (NRC, 2011; Partnership for 21st Century Skills, 2009). The all-encompassing nature of this list targets the growth and development of global citizens who are effective at problem-solving and decision-making (Silva, 2009). While educators and others have listed and described 21st century skills, teachers continue to search for strategies to effectively address the development of these skills in the preferred learning styles of today's students.

The serious games movement (Annetta et al., 2006; Lester et al., 2014; Spires, 2008) is responding to the need to unite content and game play as a way to promote 21st century skills. One avenue for enhancing literacy – scientific, engineering, technological, and numeracy – and developing 21st century skills is through the implementation of digital games with integrated science, technology, engineering, and mathematics (STEM) education. Learning environments can be transformed to be more effective and powerful using serious games (Wrzesien & Raya, 2010). However, despite today's students' emerging learning styles and the educational value of computer-based games, few educators use digital games in any substantive way in teaching and learning. The authors report on the exploration of *History of Biology* (*HoB*) as a learning environment in which today's learners find technology engaging and practical to advance their learning and interaction with STEM content. *HoB* is an innovative educational game that uses a combination of strategies such as story, interactive puzzles, mini-games, and online scavenger hunts. Thus, the *objectives* of this study are to explore if and how *HoB* impacts students' a) 21st century learning skills, and b) engagement with integrated STEM content.

BACKGROUND

Digital Games and Pedagogical Orientations

Studies of student's learning styles have shown that recent advances in ICT are reshaping the ways in which students of the "Net Generation" (Annetta, 2008; Trotter, 2005) learn and prefer to learn. For example, Dede (2005) reported that today's students' emerging learning styles include: fluency in multiple media and simulation-based virtual settings; communal learning; experiential learning; guided mentoring and collective reflection; and co-designing learning experiences that are personalized to individual needs and preferences. To better support today's students, it is necessary for teachers to reflect upon their own practices and adapt similar teaching styles (Foster & Mishra, 2009).

A primary challenge for education is to transform student's learning processes in and out of school and to engage student interest in gaining 21st century skills and knowledge. Lemke (2004) reported a link between 21st century skills and academic achievement, making the case for incorporating teaching activities that adhere to 21st century skills. Furthermore, the report by the Federation of American

Scientists (2005) argues that digital games can potentially help students learn what they need in order to succeed in a globalized world. The placement of learning experiences in context by using educational digital games can allow learners to develop characteristics such as understanding, skills, and innovativeness while engaging in complex activities (Fabricatore, 2000) – characteristics crucial for success in the 21st century (Shaffer & Gee, 2005).

Using games as part of the educational environment fits into the philosophy of active learning and constructivism. Kohn (1997) suggested that in order to promote a deeper understanding of curricular content, students ought to be engaged in their learning. Applefield, Huber, and Moallem (2000) reported on the benefits of adopting a more constructivist, student-centered model of teaching and learning. Similarly, McKeachie (1994) claimed that involving students as active participants results in a positive learning experience. More specifically, McKeachie explains that learning is enhanced if students make decisions (with teacher guidance), and then assess and evaluate the consequence(s) of each decision. Based on the increased possibilities for learning in and from these environments, it is not surprising that a great deal of attention is being focused on the role of digital games in education. For example, results of studies on the use of digital games in mathematics (Conati & Zhao, 2004), language arts and reading (Yip & Kwan, 2006), physics (Ravenscroft & Matheson, 2002), natural science (Pillay, 2002), and engineering (Foss & Eikaas, 2006) show enhanced learner experiences; development of positive experiences toward subject area; increased student motivation; enhanced learning; improved cognitive outcomes from basic recall to higher level thinking; and improved performance on problem solving tasks (Ke, 2009).

Part of the benefit for both students and teachers is that video games provide both constant assessment and evaluation of the gamer's progress, through what Beatty (2013) describes as "continual, contextualized, meaningful, nonthreatening and informative" (p. 72). Consider in a traditional classroom that the teacher sets the agenda of how and when assessments and evaluations will occur. The student needs to adhere to the pace dictated by the teacher, which overall is prescribed by an over packed curriculum. The student submits to evaluations with the final consequence of a final mark assigned to their degree of mastery at that moment in time. This mark is irreversible, remaining with the student throughout their academic career. In a videogame, long gone is the three lives scenario and loss. Video games such as *Lara Croft: Tomb Raider*, allow you to continue in your game from your most recent save, and often there are spaces in the game where a player can review and practice skills (such as the workout room in *Tomb Raider*). In video games the assessments and evaluations are therefore nonthreatening for the player's overall progress through the game (Beatty, 2013). Within game, users can keep trying rather than being impacted negatively with the assignment of a mark (Sheldon, Clare, & Rufo-Tepper, 2014). The unsuccessful completion of a challenge in the game informs the individual that certain skills need to be developed before proceeding, not that they are inept at the game in its entirety.

In education, digital video games are slowly being introduced into the classrooms as educational video game designers, such as Spongelab Interactive, are developing games that are aligned with the school curriculum and more easily integrated into instruction. The road into the classroom though is fraught with challenges some of which are shared by computer simulations, but others are unique to digital video games. So, what is the difference?

Use of Technology

Educational institutions are investing vast amounts of resources to integrate technology into the classroom in various forms, ranging from presentation platforms (e.g., digital slides, interactive boards, etc.)

to virtual classrooms and classroom supports (e.g., teacher websites) to data capturing and analysis equipment and software for classroom experiments (iLab and FAR Labs), to simulations, and now most recently, digital video games. A computer simulation is a virtual experience that allows a concept or phenomenon to occur without consequences to real animals or environments. It is generally in isolation from any context not specifically connected to the concept or phenomenon that is under exploration. For example, Winsberg (2010) has traced the use of computer simulations in industry to just after World War II in the areas of meteorology and nuclear physics. In science education, the greatest impact so far seems to be in the use of computer simulations to supplement instruction and to perform science experimentation (Rutten, van Joolingen, & van der Veen, 2012). Benefits of conducting an experiment virtually include pre-lab training or providing a space for more exploratory rather than recipe experiments without incurring the costs of a "failed" experiment (Hennessy et al., 2007). Further justifications for the inclusion of computer simulations are found in an international study (Aklilu, Tilahun, & Mesfin, 2011) which concluded that computer simulation assisted instruction were more effective than traditional instructional methods in enhancing the achievement of both physics and chemistry majoring students. For example, the *Real Time Relativity* simulation developed at the Australian National University by Lachlan McCalman, Antony Searle, Craig Savage and Michael Williamson, enable students to witness relativistic effects when they travel at speeds that approach the speed of light. With control over their ship, the student is able to manipulate the parameters and so identify and address their misunderstandings of relativistic effects in ways that sitting in a classroom looking at pictures in a book cannot hope to address (Wegener, McIntyre, Savage & Williamson, 2012). This use of simulation is in line with the recommendations of Lee, Guo, and Ho (2008) that encourage the use of simulations when they are "appropriate to learning needs of students and encourage reflection" (p. 462). In science education, simulations are used in abundance, with few educators using digital video games. In the next section we explore the current literature of how digital games are used and how they do (not) contribute to STEM learning and the development of 21st century skills.

DIGITAL GAMES

It is evident that today's students play video games in large numbers, enjoy playing video games, and they learn from playing video games (Granic, Lobel, & Engels, 2013; Hays, 2005). There have been numerous studies conducted to ascertain the percent of the population that is playing video games. The results range from 59% in Canadian households playing a few times a week (Entertainment Software Association of Canada (ESAC), 2011) to 67% of American households (Ching, 2012). ESAC reported that of those Canadian households, 90% of children aged 6-12 and 80% of children 13-17 are playing video games. More recently, Granic, Lobel, and Engels (2013) reported that over 90% of teenage girls and close to 100% of teenage boys play video games.

Digital games have greater opportunities to address STEM content and 21st century learning skills than simulations. Recently, researchers have found that computer-based games have significant educational value (Dostál, 2009; Van Eck, 2006) and may help students learn the principles, laws, and theories of science, problem-solving in science, and the nature of science (NOS) (Clark, Nelson, Sengupta, & D'Angelo, 2009; DeCoito, 2009; Lederman, 1992; Tuzin, 2007). Of course, not all digital video games are created equally. If videogames are any game that can be played on a computer (including mobile and handheld devices), then one quickly sees that there are many different kinds, and research indicates that different types of games also emphasize the development of different skills such as spatial awareness, historical understanding, leadership abilities, or scientific reasoning skills (Muehrer, Jenson, Friedberg, & Husain, 2012), and can even lend themselves to emotional benefits such as "mood improvement, reduced anxiety and a sense of relaxation" (Granic, Lobel, & Engels, 2013, p. 71).

Digital video games are not the same as simulations. While simulations provide the opportunity to work with a single discrete idea isolated from a larger context, video games use multiple ideas in order to achieve a larger goal – for the user, the goal shifts from a single idea to the bigger picture or game objective. Consider the work of Prensky (2001) who developed what he describes as a *Doom-style* game to teach engineers how to program using 3D CAD software. Learning to program in the language became embedded in the overarching goal to infiltrate the villain's headquarters. In a digital video game the overarching goal of the game drives the desire to learn each component, rather than being driven to learn each component for its own sake.

In order for a game to be what Gee (2013) refers to as "good learning" it needs to include specific characteristics, and the more it has the more effective it is. These characteristics fall into three major categories: empower learners (co-design, customize, identity, manipulation and distributed knowledge), involve problem solving (well-ordered problems, pleasantly frustrating, cycles of expertise, information "on demand" and "just in time", fish tanks, sandboxes, skills as strategies), and develop understanding (system thinking, meaning as action image) (pp. 23-36). Consider the computer game *Tetris* programmed by Alexey Pajitnov in the 1980s. This tile-matching game has very clear goals as to what the gamer is expected to accomplish, and the gamer is unable to move outside of those goals. While arguably an addictive game involving characteristics of problem solving (well-ordered problems, pleasantly frustrating, and cycles of expertise), it does not empower learners nor does it develop understanding. As a comparison, the app *The Numbers Game* by Hungry Eyes involves incorporating the mastery of number skills in order to complete an overriding quest. While the goal is clear, the player is able to make decisions about their identity, and it also has connections to social media. This type of game empower learners by allowing them to customize, create an identity, problem solve, and develop understanding to a degree. Based on Gee's criteria, *The Numbers Game* is a better learning game, but even within this type of game the goal continues to be generated by the programmer rather than the user.

Of computer games that are available, Gee separates them into three major categories, those that are "drill and practice" (breaking a whole into parts and requires mastery of each bit), those that are "problem-and-goals-centered" but "mindless progressive theory" (goals are fully determined by the user), and finally those that are "problem-and-goals-centered" but "situated embodied learning" (Gee, Hayes, & Jenkins, 2013, p. 2). It is the third type that Gee et al. (2013) connects to the best learning for users. They describe "situated embodied learning" as

> *Learning by participation in well-designed and well-mentored experiences with clear goals; lots of formative feedback; performance before competence; language and texts "just in time" and "on demand"; and lots of talk and interaction around strategies, critique, planning, and production within a "passionate affinity space" (a type of interest-driven group) built to sustain and extend the game or other curriculum. (p. 2)*

While Gee at al. (2013) recognizes that digital games are not exclusive to this aspect of learning (there are other ways to have situated embodied learning), they point out that there are some digital video games that incorporate this goal quite effectively.

Linear and Sandbox Games

In linear games, there is a specified sequence of challenges that the user faces within a gaming context. There are numerous games that fit this category such as *Return to Castle Wolfenstein* by Activision. In this first person shooter game, the user navigates a series of increasingly complex challenges in order to ultimately disrupt the plans of the Nazis. To a degree, this game empowers the user, develops problem-solving abilities and understanding to a degree, but the user is still ultimately guided through a sequence of events.

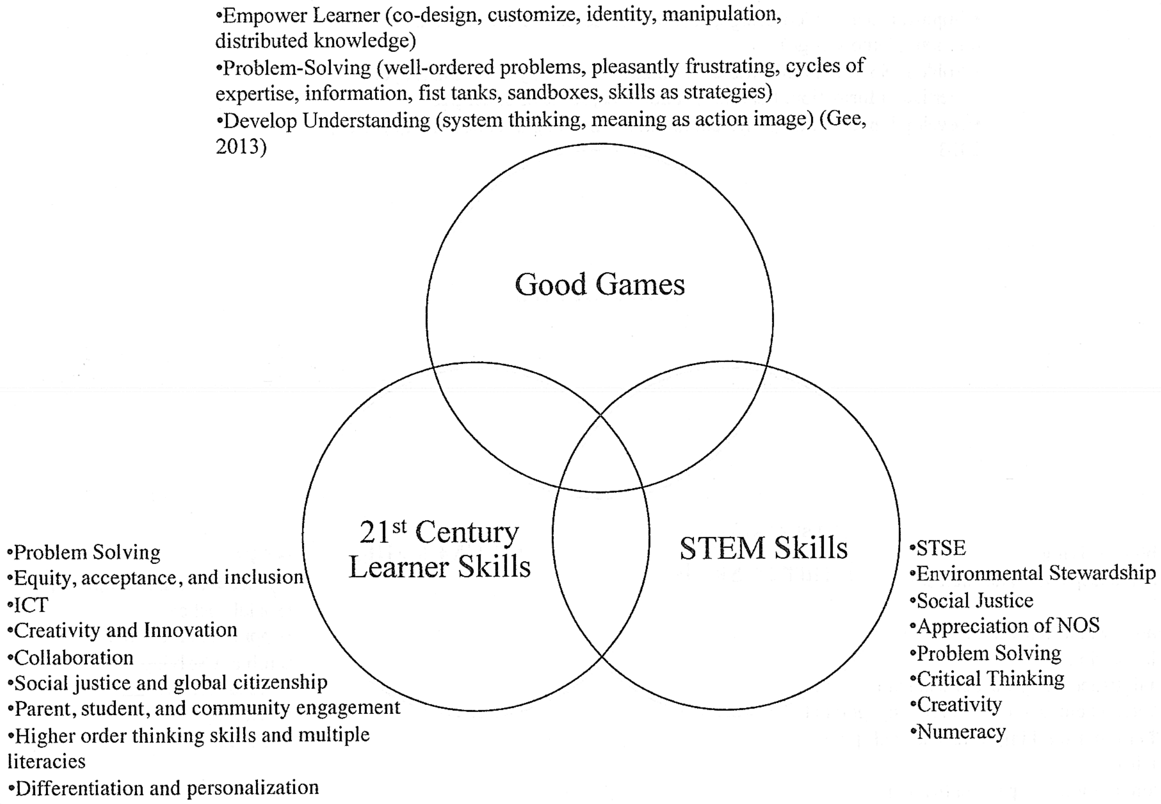
Sandbox games are those games that embed the learning experience in a story that is generated by the user. All of the learning is contextualized, and the user experiences the story through challenges that they encounter and constantly improve their skills. The users learn both the skills necessary to play the game, but also the curriculum of the game. These types of games, such as *Sim City, The Sims,* and *Spore*, permit the user to use the tools that are within the game but are not limited to what the programmers want the users to do. That is, sandbox game designers put in basic controls and environments, but in these games the users set their own goals (Ching, 2012). Consider *Spore* designed by Will Wright. Users are able to have their organisms evolve, and once they reach a certain point may depart and explore other worlds. What is left to the user is how the organisms evolve (part of why the game is so successful is the creature editor that allows users to create their new creature) and how they will interact with other worlds: experiment, conquer, form alliances, study. It is completely user directed. In *Spore*, the user can change the atmosphere composition of carbon dioxide and watch what would happen from both geological and biological perspectives (Wright, 2007). Comparing this kind of problem-and-goals game with the criteria outlined by Gee (2013), the game does well by empowering the learner, and involving problem-solving. However, without a clear idea of the overall context, the understanding that is developed may not be the learning that is desired.

In this chapter, the authors focus on an interactive digital game, *History of Biology*, which is a linear "problem-and-goals" centred game in that the user works through a predetermined series of challenges in order to solve an overarching mystery. The game falls short of situated embodied learning as defined by Gee, as there is little outside the box opportunities to develop competence, and gain necessary feedback. The skills developed do not necessarily build on each other, and the user is expected to have a certain level of proficiency prior to play, without which the clues are standard and do not provide additional or personalized assistance when required. This leads to an unbalanced experience for users. The greatest strength of the game are the opportunities to develop problem solving skills, collaboration, and to a lesser extent, systems thinking in that there is a continuous thread throughout the game that teaches the user about the role society plays in both scientific discoveries and who is credited for those discoveries.

How do Digital Games Support the Development of 21st Century Learning Skills?

Gee considers many of the skills inherent in good games that lend themselves to good learning, and are similar to STEM and 21st century skills (Figure 1). Comparing each, we find a large overlap between elements of good games and STEM and 21st century skills, including: technological literacy (games that allow co-design, manipulation and distribution of knowledge; communication), problem-solving (leading to critical thinking), and developing understanding.

Figure 1. Skills fostered in 21st Century learning, STEM integration and good games



Video games emphasize the inquiry process (Steinkuehler & Duncan, 2008). While in schools students need to problem solve for extrinsic rewards and within a predetermined period of time, within a video game, users are able to develop problem solving skills more deeply as there are unlimited opportunities to use trial and error (Granic, Lobel, & Engels, 2013). For example, *Super Mario Bros* is used in part in a cross curricular manner to integrate physics, mathematics, and technology (Nordine, 2011). In Steinkuehler and Duncan's 2008 study of the *World of Warcraft,* they found that the majority of online chatter about the game could be considered "social knowledge construction" (p. 534). Knowledge is constructed collaboratively in online communities composed of game players. In *History of Biology*, opportunities to develop 21st century skills are present throughout the game in the form of tasks that incorporate problem solving, inquiry, critical thinking, research, content knowledge and skills, as well as technological application, to name a few.

What games offer are more intrinsic motivations to learn which are not generally found in the classroom (Sheldon, Clare, & Rufo-Tepper, 2014). They provide opportunities for science and mathematics (and other subjects) to be placed into the virtual world, and by extension into a real world context, something that is lacking in many K-12 studies of math and science (Archer et al., 2010; Tella, 2007). With declining interest in STEM related courses (Blickenstaff, 2005; DeCoito 2014; Orpwood, Schmidt, & Jun, 2012), the use of digital games could also fill part of the gap in interest that students in non-game based learning experience as compared to their game based learning counterparts who enjoy their classes more. In a gaming environment, failure is expected as part of the journey towards success (Ching, 2012).

In addition to studies reporting actual and potential benefits of digital games in the classroom, some have identified various drawbacks of using digital games in teaching and learning. Some studies have shown that while some digital games may enhance learning, they are not superior to other nongaming approaches to learning (Serrano & Anderson, 2004). While two meta-analyses completed by Liao and Chen (2007) and Lee (1999) favour the use of computer simulations over traditional instruction methods, a meta-analysis by Dekkers & Donatti (1981) of ninety-three empirical studies indicates a lack of evidence supporting the superiority of computer simulation instruction over traditional lecture-based methods. Dekkers and Donatti did, however, show that, in general, digital games result in enhanced student attitudes toward learning; while others have shown that digital games impair learning, especially if instructors are not provided with resources that help them understand gaming theory and gaming technology, and help them integrate gaming in their instructional programs (Rowe, 2001).

THE STUDY

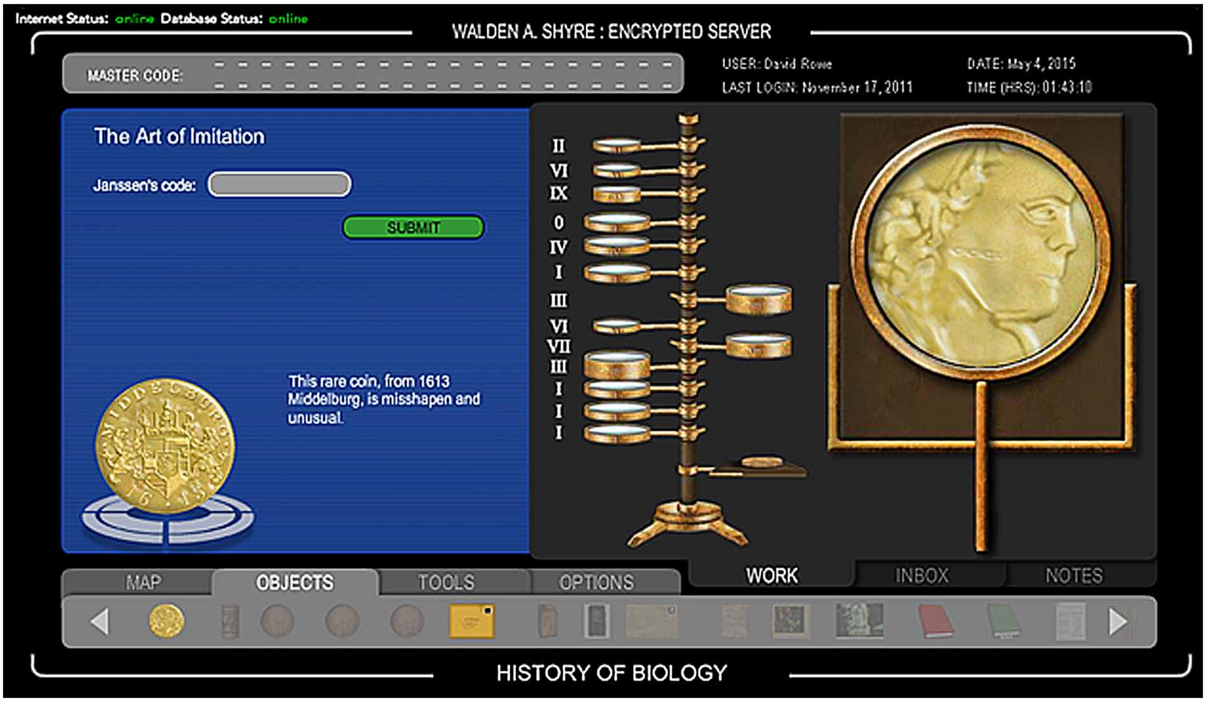
The Game

History of Biology is an interactive, online digital game designed to guide grades 7-12 science students through concepts about the history of biology, including the lives of scientists, their discoveries, and the impact of their discoveries on our culture, society, politics, economics, and ethics. Starting in the 17th century, with the invention of microscopes (Figures 2 & 3), and the first descriptions of microscopic life, users complete missions and solve puzzles by researching the lives and scientific discoveries of over 20 scientists. Users progress through 14 stages of a rich, story-line driven game that parallels the scientific timeline of discovery. Topics include cell theory, microscopes, classification, evolution, heredity, the central dogma of genetics, and genomics. Missions are designed to expand players' knowledge of science and foster various 21st century skills including critical thinking, communication, problem solving, collaboration, creativity, adaptability, initiative, self-direction, information literacy, media literacy, information communication technology (ICT) literacy, and knowledge and skills in core subjects, including English, Arts, Mathematics, and Science. Even as *HoB* creatively has the user access a variety of sites (such as Basic Local Alignment Search Tool (BLAST) that allows a user to input a nucleotide sequence to determine the significant similarities of segments) that they otherwise would not have been aware of on the Internet, the user is required to successfully fulfill tasks in order to move through the programmers' predetermined path. When a mission is not completed the user is not able to move forward to attempt the next mission. Based on the style of game, *HoB* is both a linear game and has elements of situated embodied learning.

Methodology

An understanding of game play and its relationship to the cognitive processes involved is essential for answering the question of how games succeed or fail, and it plays a critical part in untangling the complex relationships between the learning processes and learning outcomes (Wideman, Owston, Brown, Kushniruk, Ho, & Pitts, 2007). Hence, developing effective approaches to studying the integration of digital

Figure 2. An early microscope (Spongelab, 2010)


Internet Status: online Database Status: online

WALDEN A. SHYRE : ENCRYPTED SERVER

USER: David Rowe

LAST LOGIN: November 17, 2011

DATE: May 4, 2015

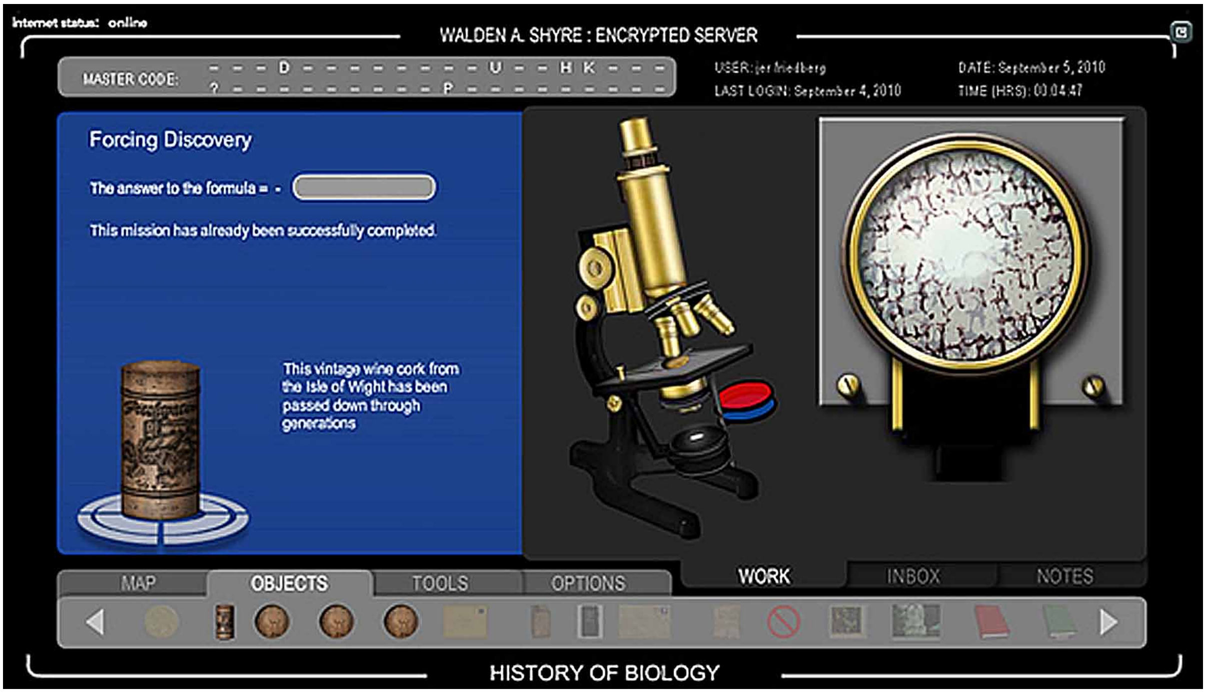
TIME (HRS): 01:43:10

The Art of Imitation

Janssen's code:

This rare coin, from 1613 Middelburg, is misshapen and unusual.

Figure 3. A modern microscope (Spongelab, 2010)


Internet status: online

WALDEN A. SHYRE : ENCRYPTED SERVER

MASTER CODE: - - - D - - - - - - - - - U - - H K - - -
? - - - - - - - - - P - - - - - - - - - -

USER: jer friedberg

LAST LOGIN: September 4, 2010

DATE: September 5, 2010

TIME (HRS): 00:04:47

Forcing Discovery

The answer to the formula = -

This mission has already been successfully completed.

This vintage wine cork from the Isle of Wight has been passed down through generations gaming in teaching and learning has proved to be a challenging task for a number of reasons. For this study, a mixed methods research design (Mills, Durepos, & Wiebe, 2010) was utilized over two years. Participants included 39 teacher candidates (TCs) in an Intermediate/Senior Biology Methods course in a Faculty of Education at a Canadian university. As part of the methods course, one of the topics focused on digital technologies for teaching and learning science. This topic was introduced and facilitated via a workshop by the games developer, Jeremy Friedberg. The goal of the workshop was to introduce digital games as a pedagogical tool. It should be noted that when this study was conducted, digital games were not used throughout the course. The digital games, however, were visibly incorporated in curriculum resources developed by TCs. The workshop introduced TCs to *Genomics Digital Lab* (an integrated, hands-on approach to help learners understand the big picture of cell biology and its importance in our lives), *Transcription Hero* (students assume the role of RNA Polymerase as they travel down the rails of a DNA sequence, trying to transcribe the gene without causing too many mutations), and *History of Biology*. During the workshop, TCs registered as members of SpongeLab Interactive (free of charge) and were provided opportunities to interact with the games and explore various digital games with a focus on curricular alignment and effective implementation in the classroom environment.

TCs expressed interest in *HoB*, and after the workshop, there was consensus to pursue playing *HoB*. Participants volunteered to play *HoB* game over a four month period. The game was not part of course work and was pursued by TCs out of the classroom on a voluntary basis. Data sources included pre-post (Likert scale) NOS questionnaires (DeCoito, 2009), completed at the beginning of the course and at the end of the study; TCs' notes related to learning science, learning about science, and doing science (Hodson, 1998) that were compiled as they completed the 14 levels in the game; reflections on their understanding and experiences with digital games, and level of engagement and motivation; and semi-structured interviews conducted after they completed playing the game. The interviews explored TCs' experiences with digital games in learning and/or teaching, and their experiences with the *HoB* game. In this chapter, the authors highlight data emanating from TCs' notes as they played the game, interviews, and reflections.

Analysis of data obtained from student notes, reflections and interviews constituted an interpretational analysis framework, executed through the process of thematic coding and a constant comparative method (Stake, 2000). By comparing and contrasting the data collected across the set of participants, common patterns and themes emerged pertaining to the effectiveness of *HoB* in terms of its potential to a) enhance 21st century learning skills; and b) engage participants with integrated STEM content.

FINDINGS

Digital Games as a Pedagogical Tool

None of the teacher candidates had experienced digital online games in teaching and learning science in the past, however, two participants had experiences with virtual dissections and animations. Nevertheless, there was overwhelming agreement for including digital online games in science teaching. After the teacher candidates experienced playing *HoB*, they were asked whether they would use digital video games in their future practices. The teacher candidates unanimously agreed that science teachers should use digital online games in their science teaching for engagement, relevance, reinforcement of content areas, and promoting 21st century skills:

Engagement: They make learning more interesting as gaming is exciting for students… It definitely makes learning a little bit more exciting using digital games.

Relevance: The youth culture right now, gaming is very popular, so if we want to connect to the kids where they are, then we definitely need to get into their culture and use it to our advantage.

Reinforcement of content: I think that it will be a good way to engage the student in the lesson, but we have to be careful when choosing the game. I think that it will support and reinforce the material.

Promoting 21st Century learning skills: This is the way the world is going… we are online; we are digital and need to teach those skills … it is another medium which would be a step out of conventional teaching. Digital games promote creativity and problem-solving. They can be used as a collaboration tool or team-building tool among the students.

As evidenced in the above accounts, TCs highlight the use of games that go beyond the curricular subject matter (some subjects mentioned include: chemical bonding, genetics, ecosystems, probability, cellular metabolism), in order to develop necessary 21st century learning skills and engagement with STEM skills and content.

Findings indicate that TCs felt the games would be motivating and engaging; that they could be used for student assessment; and that video games could assist them to teach or review content by providing differentiated instruction for different learning styles.

I think it is important to remember that we all learn differently and some students may benefit from game-learning more than others (who need to learn through direct instruction, through visual or audio methods, etc.). That being said, I believe it is our duty as teachers to use various methods or tools in order to differentiate our teaching so that no one is left behind or suffering because of our teaching strategies.

The concerns voiced by TCs surrounding using digital video games in the classroom are vast. A recurring concern is that students would become too invested in successfully playing the game rather than learning the science. One TC writes: “I think that it would be very easy for students to lose sight of the task/goals of the digital game and become lost in the game itself.” In addition,

TCs identified that digital video games may not have the same benefit for some learners as for others (as the case for students who are visually-impaired), but a recurrent theme was the concern of access to compatible computers and the Internet, making the issue of equity a broader concern. They also raised concerns over students’ level of expertise in gaming, that is, gamers would excel and perform better than non-gamers. Other concerns around dis-engagement (quality and design of the game), other distractions (social media), and cheating were all raised. For games to be successfully implemented in the classroom, the TCs consider that specific “rules for conduct” needs to be established by the teacher to ensure students are not “wasting time” when they are allotted time in class to play the game.

Using Gee’s (2013) list of good gaming for good learning, we find that TCs’ reflections of using digital video games rather telling. They mention video games as a tool to a) reinforce content, b) motivate and engage learners, and c) develop 21st century learning skills. They highlight the need for games to be aesthetically pleasing to students. However, the teacher candidates were more focused on using digital video games to improve content comprehension, and problem-solving skills, rather than looking at games to be used for a broader purpose, such as empowering learners or promoting understanding.

Reflecting on *History of Biology*

TCs described *HoB* as a mystery, complete with challenges and levels that are used to collectively unlock an overall master code. The challenges are questions that need to be answered, and the answers are found by solving equations and unveiling clues. According to a TC,

History of Biology Game is sort of like your high end mystery game. Each of the levels you have a different challenge which is somehow related to a different aspect all the way to how the PCR was developed and you go through these series of different levels, and when you finally complete each challenge, it unlocks this master code. And you have this choice about what to do with the information, which I thought was interesting.

Five of the candidates found the game frustrating to the point that some needed help from others (classmates and the developer) and two players reported that they abandoned playing the game altogether. The organization of the game, the instructions, and the required precision of entering the answers are elements that the players found contributed to frustration. One TC commented, "I feel like I was learning more about what to do rather than learning science" and "I don't really think I learned science, I just learned how to play the game." Not all teacher candidates found the frustration a complete negative. Once they encountered difficulty in navigating through the various levels of *HoB*, the TCs consulted each other thus establishing a collaborative network. One TC stated:

I guess one success, not necessarily just in the game, but in terms of us as a group working together, we learned to interact with each other and help each other and be able to ask other people for help instead of just doing everything on our own. So that was definitely a success, bringing students together.

While these insights point to the structure of the game, TCs recognized that the game is deeper than simply game play, but rather it teaches about what one TC refers to as "scientific perspective" and what another described as "how different discoveries were done in the past".

When the results are compared with Gee's (2013) list of what makes good games good learning, we find that *HoB* ranks somewhere in the middle. The next section considers Gee's three major categories of empowering learners, encompassing problem solving, and developing understanding separately.

Empowering Learners

HOB is not compelling in terms of empowering its players. The TCs' reflections do not include any elements of co-designing their learning environment, or of being agents of their own learning. There is also no evidence of customizing the learning. While *HoB* does include various types of information, the player must partake in each style to gather discrete pieces of information, some from the Internet, some from manipulating the "tools" in the game, some from interpreting clues in email messages. Within *HoB*, the player assumes the identity of the research student who searches for a missing famous scientist, Walden Shyre. This identity is predetermined by the programmer and not altered by the user. One TC described the student's identity in the following description:

You play a student who has been hired by a mysterious scientist to, you assume at the beginning, to do some menial tasks, I suppose, then you find out that he has specifically chosen you and there's a very important discovery about to be made, but it's very secretive. You don't really get the full story. And he communicates to you through e-mail, and each e-mail is like a separate challenge you have to figure out.

None of the TCs described evolution of their identity or provided evidence that decision making in the game impacted their identity. What *HoB* does effectively is allow the player to manipulate and distribute knowledge through a variety of activities. A TC summarizes these activities in the following excerpt:

You have to go to the Internet. Wikipedia is a huge thing. I think they have specifically designed it around Wikipedia pages, most of them. And then there are a few other pages they've manufactured to go with it. Like there's the Art Gallery, and there's an online auction which is pretty cool that you had to go and check and see what he's been up to. So, you're sleuthing around after this elusive scientist who is missing until the very end. And of course along the way you learn about all the major breakthroughs in biology. So it starts out with microscopy, of seeing a microorganism for the first time and who the scientist was and what they were they trying to do.

In addition to the actions the TC identified, the player is able to interact with virtual objects and tools within the game to find clues to help move forward in the game.

Encompassing Problem Solving

HoB involves problem solving characteristics throughout the game. Players found the problems to vary in difficulty. A TC summed it up in the following manner:

I found that it was hard for me at the beginning just because, I don't know, maybe I was tired, but I spent a lot more time trying to figure out what they were asking me to do rather than doing it, and sometimes I would do it and I didn't know what I was doing. But I feel, for me, the later levels were easier.

Similar to Gee (2013) the earlier levels did provide some strategies for play later on, which may have led to the feeling that the later levels became easier as strategies to complete the levels became increasingly established. This may not have been the case for the five players that found the game frustrating, and the two who abandoned the game altogether. For example, one TC indicated that it was necessary to email the developer to gain some insight into why she was not able to proceed, which turned out to be a technical issue with her computer rather than an error in interpreting the game.

There was no evidence in the TCs' reflections that *HoB* utilized cycles of expertise. The skills the player developed often ended up being used only in the game (accessing a specific website or using one of the virtual tools), however, that the user must search or use virtual tools becomes more automatic each time that skill is required. The information that was provided "on demand" and "just in time" was provided in written form from the emails from your virtual mentor. As Gee (2013) describes, written information needs to be provided in context of its usefulness, and *HoB* accomplishes this aspect quite successfully. Unfortunately, the information is static, meaning that the user cannot get any additional information when they may need it.

There is no fish tank for *HoB*. The player is thrown into the mystery and the first challenges are sufficiently complex to make the game frustrating as evidenced by the two players who abandoned the game. *HoB* also does not provide a sandbox or safe place for the player to make mistakes. Right from the beginning the player is given a specific number of clues and must answer them correctly or not move forward. A TC recounted her experience playing *HoB,*

For me, it just seemed like I had to overcome all of these obstacles of just trying to figure out how to do something. And the group of us, we were sort of caught up with the "how to" as opposed to what we are actually learning. I found that there was very little instruction in telling you what you needed to do.

This was a recurring theme – players had little instruction from within the game and needed to seek assistance from outside sources.

HoB does make good use of skills and strategies. Although the players do not reflect on this specifically, the game skills of looking for codes on envelopes is reused in multiple levels, as is the need to search the Internet or manipulate numbers that the player encounters.

Developing Understanding

The TCs did not provide evidence that they learned what did or did not work within the game environment.

Some of the levels were extremely easy and I think that what made some of the levels difficult were just sort of organizational things. For example, for mission 10, you have to go to this bidder.com website that they create and you have to figure out the order … I can't remember exactly what … they required you to add or multiply the big numbers by something. It requires you to do it in order of the bids, but the way that they are visually organized on that "bidder" website is not the same order that they were in on the actual challenged screen so it was really frustrating because I didn't realize that the orders were not the same.

By level 10, a TC described that she was still not able to figure out the organizational aspects of the game. This was echoed by another TC:

The most challenging thing for me was just the precision required in order to get an answer right. The numbers you had to add up had to be exact and you're researching through quite a lot of information.

Despite some TCs experiencing frustration with this aspect, the majority felt that navigating through these levels required critical thinking and problem solving to attain the goal of completing the game.

The final characteristic included by Gee (2013) is meaning as action image. Within *HoB*, players are asked to accept that there may be some kind of conspiracy that has led to the disappearance of Walden Shyre. Throughout the game the players are bombarded with evidence about the social influences in the progression of science and NOS, which heightens the feeling that Walden Shyre's disappearance may have more sinister underpinnings. This thread is mentioned in the majority of TCs' reflections. They accept that there is a motivation for engaging in the game to solve the overarching mystery.

Table 1. Teacher candidates' account of science learning through the game

Level	STEM Content	STEM & 21st Century Skills
1	Manipulating an early microscope.	Problem solving for clues.
2, 3, 4	Hooke's Law; Leeuwenhoek's discoveries; learning/naming tools and organisms; terminology.	Problem solving; following clues to Internet research. Researching biological terminologies.
5	Introduction to Linnaean taxonomy.	Applying knowledge to problem solving.
6	Geography of Galapagos Islands; longitude and latitude; GPS coordinates; variation in finch species and the basics of natural selection.	Finding GPS coordinates on a map; problem solving to determine a course of action, navigation, and coordinates; using online resources not provided to determine the islands and their areas.
7	Darwin and Wallaces' work.	Conducting research through scientific correspondences between Darwin and Wallace.
8	Mendel's ratios.	Using BLAST (finds regions of local similarity between sequences) to find genus and species name; applying BLAST to Mendel's discoveries.
9	Introduction to nucleic acids	Problem solving to determine nucleic acid as the answer to a poem; researching on the Internet.
10, 11	The nature of DNA	Problem solving in an online auction house to piece the discoveries together; researching the scientists and experiments on the Internet. Interpreting an autoradiograph.
12	The stages and formula of amplification of polymerase chain reaction (PCR)	Calculating amount of DNA after PCR; researching PCR and Mullis on the Internet.
13	Introduction to gene expression	Researching in BOLD database; interpreting a gene expression array.
14	More about gene expression	Problem solving using bacterial growth.
The End		Choosing a course of action with important, albeit hypothetical, consequences

STEM Content and 21st Century Skills

Teacher candidates' notes, recorded while playing the game, are summarized and depicted in Table 1. It is evident that *HoB* is a valuable learning environment for a) learning science and b) doing science. TCs' account of these aspects clearly suggest that the game has the potential for *learning science* in terms of providing a context for teaching science, and acquiring and developing conceptual and theoretical knowledge in science. For example, throughout the 14 levels in the game, participants learned science content, including Hooke's Law, Leeuwenhoek's discoveries, biological terminology, the geography of the Galapagos Islands, Linnaean taxonomy, scientists such as Wallace and Mendel, as well as the discoveries of DNA and gene expression, to name a few. Participants felt the game was valuable for engaging students and teaching science:

Overall, the game was challenging, fun to play, highly interactive, and engaging as you learn about fascinating people in history while learning about the actual science as well.

The game addressed *learning about science* in terms of developing an understanding of the nature and methods of science, an appreciation of its history and development, and an awareness of the complex interactions among science, technology, society, and the environment. There was unanimous agreement that the game is also effective for teaching and learning about NOS:

The humanness of scientists is definitely there. Not in every case, because the information comes from online sources too, but in a lot of cases, you learn things you wouldn't have thought about these people, and you find out that they are just people … in that sense the nature of the enterprise, it's not this rigid objective thing. It does talk about the context of a lot of those discoveries and it talks about the ramifications of them too.

HoB provided participants with opportunities to *do science* as they searched for clues, became engaged in and developed expertise in scientific inquiry and problem solving. Participants immersed themselves in the tools of biology, including historic single lens microscopes and compound microscopes, problem solving, deductive reasoning, the scientific method, locating GPS coordinates, interpreting autoradiographs, and using genetic databases such as BOLD and BLAST. Hence, the game promotes several 21st century learning skills and opportunities for learning integrated STEM content throughout the various levels. The importance of developing expertise in scientific inquiry and problem solving is highlighted by a TC:

All the stages [of the game] did a good job of having students "do science" in that it required a lot of problem solving and research. I liked that almost everything required students to surf the Internet. It is such a valuable tool that students need to learn how to navigate and this game provided many opportunities to do so. Additionally, information "sticks" with the students much better when they themselves are finding the information, struggling with their learnings, and piecing together to create knowledge to develop a larger picture in order to solve the challenges.

Overall, the majority of TCs completed the game. Some of the challenges included ambiguous instructions and technical aspects associated with navigating through the various levels of the game. Successes included collaboration amongst TCs; conducting research to find clues; engagement; incorporating everyday components such as Google Maps; and the fact that tasks (quizzes, etc.) were directly related to various components of the game, thus enhancing learning. *HoB* effectively contextualizes learning: creates engaging, relevant, and personalized learning experiences, as outlined by a TC:

I thought the game did an excellent job of having students get to know the names behind the science. It was great to personify the science (e.g., researching the person who invented PCR technique or who first saw tiny creatures in water using a microscope). I think when students put a face to the science it makes it much more human, more personal to them, and more relevant.

According to TCs, advantages of using the game to teach science included developing problem solving skills, engaging learners, catering to a variety of learners' needs, improving content knowledge, and learning about NOS. The participants all agreed that they would incorporate digital online games in their future classroom practices as a mode of engaging students and teaching science and NOS, provided that there was access to computers. Finally, teacher candidates' motives for participating in playing the game included seeking ways to incorporate new technologies in the classroom, exploring various strategies to engage students, evaluating the game as a teaching and learning tool, and experiencing *HoB* and its potential for teaching and learning in and about science.

CONCLUSION

The research study conducted with teacher candidates reveal that by large, *HoB* is a valuable environment for promoting 21st century skills including critical thinking, communication, problem solving, collaboration, initiative, self-direction, information literacy, information communication technology (ICT) literacy (NRC, 2011; Partnership for 21st Century Skills, 2009), and learning integrated STEM knowledge and skills in core subjects, including mathematics, technology and science.

Few TCs felt that they did not learn content, but more so how to play the game. This finding is in keeping with claims of opponents of using digital video games, in that rather than students learning the desired curriculum, they may be learning more about how to play the game than the content (Yeo, Loss, Zadnik, Harrison, & Treagust, 2004). While the TCs listed this as a disadvantage, the literature considers that this may be a benefit of playing games when the goal is to enhance 21st century skills. Chmiel (2012) reported that students playing *Coaster Creator* released by the JASON Project, rather than creating a roller coaster that would maximize scores, that they found a way to take advantage of a Flash Player memory problem to manipulate the game to achieve scores programmers had not thought possible. The students also disseminated that information to other players through an online group. While students deviated from the "curriculum" of the game, and how they extended this beyond the game, this is evidence of developing skills required for STEM related careers, including exploration, questioning, and curiosity.

Concerns mentioned by TCs included technical difficulties leading to two TCs abandoning the game due to frustration. Findings of Mucherer, Jenson, Friedberg, and Husain (2012) found that when students experienced technical difficulties they tended to readily disengage with the game. However, the majority of TCs interacted and collaborated with their peers as they sought out advice and assistance to move through the levels. This observation parallel findings of Granic, Lobel, and Engels (2013) who found that with the development of games that can be played online, it is found that more than 70% of gamers support others which lead to prosocial rather than anti-social behaviours. TCs' concern about the successful completion of the game being linked to expertise in gaming is echoed in Mucherer et al's. (2012) study which also examined expertise in gaming and found no significant difference between gaming and non-gaming groups and their performance on digital games.

The findings are encouraging and shed light on the implementation of digital games in science education. This study was instrumental as teaching in ways that inspire all students and deepen their understanding of integrated STEM content and practices is a demanding enterprise. *HoB* exposed the participants to content knowledge, as well as tested skills like problem-solving and scientific inquiry. An integrated STEM approach provides the context for teaching content and skills and establishing connections to real-life application and is positioned within situation cognition theory (Lave, 1988) and grounded in social learning theory (Bandura, 1977). There is evidence demonstrating that the game is a viable tool for teaching and learning integrated STEM content, and fostering 21st century skills. In addition to fostering 21st century skills, the game has the potential to improve scientific literacy in terms of Hodson's (1998) three major elements: *learning science, learning about science,* and *doing science.* TCs' documentation of how the game addressed Hodson's three elements clearly show the potential of this game to teach about NOS (Lederman, 1992) and thus improve their scientific literacy (Millar, 2006). Finally, *HoB* game was credited with creating engaging, relevant, and personalized learning experiences as it provided a context for students to situate their learning.

These research findings have the potential to make significant contributions to our understanding of how educational digital games may assist teachers in helping students develop 21st century skills, enhance teachers' and students' numeracy, and scientific and technological literacy, and improve attitudes toward teaching and learning integrated STEM content through digital technologies in the classroom.

NEXT STEPS

The results of this study also raise many issues and questions. Some areas of concern include the fact that, currently, online educational games are not typically aimed at high school students (Qian, 2009), nor are they generally aligned with government-mandated curricula. Future studies on digital games like *HoB* should assess the potential of games to advance a broad set of science learning goals, including motivation, conceptual understanding, science process skills, understanding of the nature of science, scientific discourse, and identification with STEM and STEM learning. These issues warrant further research in terms of how we envision teaching and learning integrated STEM and NOS, implications for enhancing scientific and technological literacy and numeracy, as well as equipping students with 21st century skills. One of the next steps identified by TCs is a need to collaborate on the development of digital games. Partnerships between teachers and game developers could incorporate the principles outlined by Gee (2013) and would assist teachers to move towards more engaging classes that are not only looking at curricular content, but also developing 21st century skills and STEM skills deemed essential for STEM related careers. Such research is needed to more clearly illuminate the full range of competencies that can be supported with digital games.

REFERENCES

Aklilu, T., Tilahun, T., & Mesfin, T. (2011). Effectiveness of Computer Simulations in the Teaching/Learning of Physics. In *Proceedings of the 2011 Annual Meeting of the National Association for Research in Science Teaching (NARST)*. Orlando, FL: Academic Press.

Annetta, L. A. (2008). Video games in education: Why they should be used and how they are being used. *Theory into Practice*, *47*(3), 229–239. doi:10.1080/00405840802153940

Annetta, L. A., Murray, M., Gull-Laird, S., Bohr, S., & Park, J. C. (2006). Serious games: Incorporating video games in the classroom. *EDUCAUSE Quarterly*, *29*(3), 16–22.

Applefield, J. M., Huber, R. L., & Moallem, M. (2000). Constructivism in theory and practice: Toward a better understanding. *High School Journal*, *84*(2), 35–46.

Archer, L., DeWitt, J., Osborne, J., Dillon, J., Willis, B., & Wong, B. (2010). "Doing" science versus "Being" a scientist: Examining 10/11-year-old schoolchildren's constructions of science through the lens of identity. *Science Education*, *94*(4), 617–639. doi:10.1002/sce.20399

Bandura, A. (1977). *Social learning theory*. Englewood Cliffs, NJ: Prentice Hall.

Beatty, I. D. (2013). *Improving physics instruction by analyzing video games. 2012 Physics Education Research Conference* (pp. 70–73). Philadelphia: AIP Publishing.

Blickenstaff, J. C. (2005). Women and science careers: Leaky pipeline or gender filter. *Gender and Education*, *17*(4), 369–386. doi:10.1080/09540250500145072

Ching, D. (2012). Passion play: Will Wright and games for science learning. *Cultural Studies of Science Education*, *7*(4), 767–782. doi:10.1007/s11422-012-9456-5

Chmiel, M. (2012). Learning about the game: Designing science games for a generation of gamers. *Cultural Studies of Science Education*, *7*(4), 807–812. doi:10.1007/s11422-012-9428-9

Clark, D., Nelson, B., Sengupta, P., & D'Angelo, C. (2009). *Rethinking science learning through digital games and simulations: Genres, examples, and evidence*. Washington, DC: National Research Council.

Conati, C., & Zhao, X. (2004). Building and Evaluating an Intelligent Pedagogical Agent to Improve the Effectiveness of an Educational Game. In *Proceedings of IUI '04, International Conference on Intelligent User Interfaces*. doi:10.1145/964442.964446

DeCoito, I. (2009). *Improving Teachers' and Students' Nature of Science Conceptions- Using Reading and Writing Activities to Reflect on the Nature of Science*. Lambert Academic Publishers.

DeCoito, I. (2014). Focusing on Science, Technology, Engineering, and Mathematics (STEM) in the 21st Century. *Ontario Professional Surveyor*, *57*(1), 34–36.

Dede, C. (2005). Planning for "neomillennial" learning styles: Implications for investments in technology and faculty. In J. Oblinger & D. Oblinger (Eds.), *Educating the net generation* (pp. 226–247). Boulder, CO: EDUCAUSE Publishers.

Dekkers, J., & Donatti, S. (1981). The Integration of Research Studies on the Use of Simulation as an Instructional Strategy. *The Journal of Educational Research*, *74*(6), 424–427. doi:10.1080/00220671.1981.10885343

Dostál, J. (2009). Educational software and computer games - tools of modern education. *Journal of Technology and Information Education*, *1*(1), 24–28.

Entertainment Software Association of Canada (ESAC). (2011). *Canada's Entertainment Software Industry in 2011*. NDP Group.

Fabricatore, C. (2000, September 26). *Learning and videogames: An unexploited synergy.* Retrieved August 2, 2013, from http://www.learndev.org/FabricatoreAECT2000.pdf

Federation of American Scientists. (2005). *National Summit on Educational Games: Fact Sheet*. Washington, DC: Author.

Foss, B. A., & Eikaas, T. I. (2006). Game play in engineering education - Concept and experimental results. *International Journal of Engineering Education*, *22*(5), 1043–1052.

Foster, A., & Mishra, P. (2009). Games, Claims, Genres, and Learning. In R. E. Ferdig (Ed.), *Effective Electronic Gaming in Education* (Vol. 1, pp. 33–50). New York: Information Science Reference. doi:10.4018/978-1-59904-808-6.ch002

Gee, J., Hayes, E., & Jenkins, P. (2013). Games and learning: an overview. In J. P. Gee (Ed.), *Good Video Games + Good Learning* (pp. 1–13). New York: Peter Lang Publishing, Inc.

Gee, J. P. (2013). *Good video games + good learning*. New York: Peter Lang Publishing, Inc.

Granic, I., Lobel, A., & Engels, R. C. (2013). The Benefits of Playing Video Games. *The American Psychologist*, *69*(1), 66–78. doi:10.1037/a0034857 PMID:24295515

Hays, R. T. (2005). *The effectiveness of instructional games: Literature review*. Alexandria, VA: U.S. Army Research Institute for the Behavioural and Social Sciences.

Hennessy, S., Wishart, J., Whitelock, D., Deaney, R., Brawn, R., Velle, L., & Winterbottom, M. et al. (2007). Pedagogical approaches for technology-integrated science teaching. *Computers & Education*, *48*(1), 137–152. doi:10.1016/j.compedu.2006.02.004

Hodson, D. (1998). *Teaching and Learning Science: Towards a Personalized Approach*. Buckingham: Open University Press.

Ke, F. (2009). A qualitative meta-analysis of computer games as learning tools. In R. E. Ferdig (Ed.), *Effective Electronic Gaming in Education* (Vol. 1, pp. 1–32). New York: Information Science Reference. doi:10.4018/978-1-59904-808-6.ch001

Kohn, A. (1997). Students don't 'work' – They learn. *Education Week*, (Sept): 3.

Lave, J. (1988). *Cognition in practice: Mind, mathematics, and culture in everyday life*. Cambridge, UK: Cambridge University Press. doi:10.1017/CBO9780511609268

Lederman, N. G. (1992). Students' and teachers' conceptions about the nature of science: A review of the research. *Journal of Research in Science Teaching*, *29*(4), 331–359. doi:10.1002/tea.3660290404

Lee, Y. F., Guo, Y., & Ho, H. j. (2008). Explore Effective Use of Computer Simulations for Physics Education. *Journal of Computers in Mathematics and Science Teaching*, *27*(4), 443–466.

Lemke, J. (2004). *Why study digital game worlds? Notes toward a basic research agenda for learning technologies.* Retrieved December 11, 2013, from http://www-personal.umich. edu/~jaylemke/games.htm

Lester, J. C., Spires, H. A., Nietfeld, J. L., Minogue, J., Mott, B. W., & Lobene, E. V. (2014). Designing games-based learning environments for elementary science education: A narrative-centred learning perspective. *Journal of Information Science*, *264*, 4–18. doi:10.1016/j.ins.2013.09.005

Liao, Y. K., & Chen, Y. W. (2007). The Effect of Computer Simulation Instruction on Student Learning: A Meta-analysis of Studies in Taiwan. *Journal of Information Technology and Applications, 2*(2), 69-79.

McKeachie, W. (1994). *Teaching tips: Strategies, research, and theory for college and university teachers*. Lexington, MA: D.C. Heath and Company.

Millar, R. (2006). Twenty First Century Science: Insights from the design and implementation of a scientific literacy approach in school science. *International Journal of Science Education*, *28*(13), 1499–1521. doi:10.1080/09500690600718344

Mills, J. M., Durepos, G., & Wiebe, E. (2010). *Encyclopedia of Case Study Research*. Thousand Oaks: Sage Publications Inc. doi:10.4135/9781412957397

Muehrer, R., Jenson, J., Friedberg, J., & Husain, N. (2012). Challenges and opportunities: Using a science-based video game in secondary school settings. *Cultural Studies of Science Education*, *7*(4), 783–805. doi:10.1007/s11422-012-9409-z

National Research Council (NRC). (2011). *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*. Washington, D.C.: The National Academies Press.

Nordine, J. C. (2011). Motivating Calculus-Based Kinematics Instruction with Super Mario Bros. *The Physics Teacher*, *49*(380), 380–382. doi:10.1119/1.3628271

Orpwood, G., Schmidt, B., & Jun, H. (2012). *Competing in the 21st Century Skills Race*. Ottawa: Canadian Council of Chief Executives.

Partnership for 21st Century Skills. (2009). *21st Century Skills Map.* National Science Teachers Association.

Pillay, H. (2002). An investigation of cognitive processes engaged in by recreational computer game players: Implications for skills for the future. *Journal of Research on Technology in Education*, *34*(3), 336–350. doi:10.1080/15391523.2002.10782354

Prensky, D. (2001). *Digital game-based learning*. New York: McGraw-Hill.

Qian, Y. (2009). An Investigation of Current Online Educational Games. In R. E. Ferdig (Ed.), *Effective Electronic Gaming in Education* (Vol. 1, pp. 67–82). New York: Information Science Reference. doi:10.4018/978-1-59904-808-6.ch004

Ravenscroft, A., & Matheson, M. P. (2002). Developing and evaluating dialogue games for collaborative e-learning interaction. *Journal of Computer Assisted Learning*, *18*(1), 93–102. doi:10.1046/j.0266-4909.2001.00215.x

Rowe, J. (2001). An experiment in the use of games in the teaching of mental arithmetic. *Philosophy of Mathematics Education, 14*.

Rutten, N., Joolingen, W. R., & Veen, J. T. (2012). The learning effects of computer simulations in science education. *Computers & Education*, *58*(1), 136–153. doi:10.1016/j.compedu.2011.07.017

Serrano, A. B., & Anderson, A. Q. (2004). The evaluation of food pyramid games, a bilingual computer nutrition education program for Latino youth [Electronic version]. *Journal of Family and Consumer Sciences Education*, *22*(1), 1–16.

Shaffer, D. W., & Gee, J. P. (2005). *Before every child is left behind: How epistemic games can solve the coming crisis in education.* (WCER Working Paper No. 2005-7). University of Wisconsin-Madison, Wisconsin Center for Education Research. Retrieved from http://www.wcer.wisc.edu/

Sheldon, L., Clare, A., & Rufo-Tepper, R. (2014). Gamification: Creating new education tools by applying games to classroom learning. *The Current.* (A. M. Tremonti, Interviewer) CBC.

Silva, E. (2009). Measuring Skills for 21st Century Learning. *Phi Delta Kappan*, *90*(9), 630–634. doi:10.1177/003172170909000905

Spires, H. (2008). 21st century skills and serious games: Preparing the N generation. In L. A. Annetta (Ed.), *Serious Educational Games* (pp. 13–23). Rotterdam, The Netherlands: Sense Publishers.

Stake, R. (2000). Case Studies. In N. K. Denzin & Y. S. Lincoln (Eds.), *Handbook of Qualitative research* (pp. 435–454). Thousand Oaks, CA: Sage.

Steinkuehler, C., & Duncan, S. (2008). Scientific Habits of Mind in Virtual Worlds. *Journal of Science Education and Technology*, *17*(6), 530–543. doi:10.1007/s10956-008-9120-8

Tella, A. (2007). The Impact of Motivation on Student's Academic and Learning Outcomes in Mathematics among Secondary School Students in Nigeria. *Eurasia Journal of Mathematics, Science, & Technology (Elmsford, N.Y.)*, *3*(2), 149–156.

Trotter, A. (2005). Despite allure, using digital games for learning seen as no easy task. *Education Week*, *25*, 1–19.

Tuzin, H. (2007). Blending video games with learning: Issues and challenges with classroom implementations in the Turkish context. *British Journal of Educational Technology*, *38*(3), 465–477. doi:10.1111/j.1467-8535.2007.00710.x

Van Eck, R. (2006). The effect of contextual pedagogical advisement and competition on middle school students' attitude toward mathematics and mathematics instruction using a computer based simulation game. *Journal of Computers in Mathematics and Science Teaching*, *25*(2), 165–195.

Wegener, M., Mcintyre, T. J., McGrath, D., Savage, C. M., & Williamson, M. (2012). Developing a virtual physics world. *Australasian Journal of Educational Technology*, *28*(3), 504–521.

Wideman, H. H., Owston, R. D., Brown, C., Kushniruk, A., Ho, F., & Pitts, K. C. (2007). Unpacking the potential of educational gaming: A new tool for gaming research. *Simulation & Gaming*, *38*(1), 1–21. doi:10.1177/1046878106297650

Winsberg, E. (2010). *Science in the age of computer simulation*. The University of Chicago Press. doi:10.7208/chicago/9780226902050.001.0001

Wright, W. (2007). Spore, birth of a game. *TED2007.* Retrieved from http://www.ted.com/talks/will_wright_makes_toys_that_make_worlds?language=en

Wrzesien, M., & Raya, M. A. (2010). Learning in serious virtual worlds: Evaluation of learning effectiveness and appeal to students in the E-Junior project. *Computers & Education*, *55*(1), 178–187. doi:10.1016/j.compedu.2010.01.003

Yeo, S., Loss, R., Zadnik, M., Harrison, A., & Treagust, D. (2004). What do students really learn from interactive multimedia? A physics case study. *American Journal of Physics*, *72*(10), 1351–1358. doi:10.1119/1.1748074

Yip, F., & Kwan, A. (2006). Online vocabulary games as a tool for teaching and learning English vocabulary. *Educational Media International*, *43*(3), 233–249. doi:10.1080/09523980600641445

Chapter 2

Media Literacy as a Pathway to Bridge the Digital and STEM Divides:

Interest Driven Media Projects for Teachers in the Trenches

Lesley K. Smith
University of Colorado, USA

Anne U. Gold
University of Colorado, USA

Juliette N. Rooney-Varga
University of Massachusetts, USA

David J. Oonk
University of Colorado, USA

Deb Morrison
Broomfield Heights Middle School, USA

ABSTRACT

One of today's equity challenges is the need to increase media literacy among all students, especially traditionally marginalized students. Media literacy is defined by the way that particular student groups are limited in their engagement with digital resources that promote critical thinking and problem solving. This chapter provides implementation models for seven different types of media projects focused on climate change science that have been successfully piloted with 78 secondary students primarily from impoverished backgrounds. Results show that students' experiences while participating in these projects were transformational. Both the digital and STEM divides were bridged by including science-focus media projects.

INTRODUCTION

The student population in the U.S. is increasingly more racially, ethnically, and linguistically diverse. Nationally, the white student population was 60% in 2001, while in 2011 it was 52% (NCES, 2015). This shift is mostly a result of an increasing Latino population, which, during the same period of time, increased from 17% to 24%, while African American, Asian/Pacific Islander, and Native American/ Alaskan Native populations all stayed relatively stable. With the increase in the Latino population, the

DOI: 10.4018/978-1-4666-9616-7.ch002

number of students in English Language Learning status has also increased from 8.7% to 9.1% between 2002 and 2011. These trends have been occurring for decades now and are predicted to continue into the future, making American schools much more racially and linguistically diverse.

Students in U.S. schools also are on average getting poorer (NCES, 2015). In the 2000-2001 school year, the national participation in school-based free and reduced lunch programs (FRL), a measure of family wealth, was 38%. By the 2010-2011 school year, 48% of students in U.S. public schools were enrolled in FRL programs. This change is significant as students in poverty may be less likely to have access to the same types of physical and cultural resources as more affluent students. For example, in terms of physical resources, impoverished students are less likely to have current computer technology, software, and stable Internet connections (Eamon, 2004). Additionally, in terms of cultural resources, economically disadvantaged students have challenges in fully accessing science-based forms of communication in the classroom that can often influence the way in which they see themselves as participants in these activities (Brown, 2006; see also Chapter 11 of NGSS Framework, NRC, 2012). To bridge these differences and address these challenges, schools can provide structural supports for students to help bridge language discourses (Gutierrez, Baquedano-Lopez, & Tejeda, 1999) and provide access to the latest technological resources (Vickery, 2014).

A digital divide developed in the 1990s between those with access to computers and the Internet and those without; however, that divide has shifted in more recent years. Initially, African American and Latino students had little access to digital resources, but with the increase in access to inexpensive mobile devices and mobile Internet, Latino and African American youth had increasing access to these forms of digital resources and were viewed as early adopters and mobile trendsetters (Horrigan 2009). However, the use of mobile devices by these populations may be limited to gaming, watching videos, and listening to music, and they may have limited participation in other forms of more creative digital literacy, resulting in another form of digital divide (Hargittai, E., 2011; Hargittai, E. & Walejko, G., 2008; Vickery, 2014).

While there are many ways to describe the digital divide, the term media literacy is used in this chapter to define the way that particular student groups are limited in their full participation of engaging with digital resources that promote critical thinking and problem solving (see Potter (2010) for a full range of definitions for media literacy and the skills associated with media literacy). This definition stems from work by Watkins (2012) on design literacy in which he describes this learning as the "capacity to engage in critical thinking, inquiry and discovery, and real world problem solving" (p. 9). Further, Hobbs (2010) describes five steps towards digital and media literacy: 1) Access, 2) Analyze and Evaluate, 3) Create, 4) Reflect, and 5) Act. The differential digital resource access found in different student populations impacts particular students' abilities to engage in rich and deep ways with technology. For example, Miles (2007) discusses network literacy, the sharing of work through networks, which can be impacted by limited Internet or through lack of access to particular forms of technology. Resnick et al. (2009) add to this discussion with the term digital fluency, the need for students' technology work to "include designing and creating, not just browsing and interacting." To empower youth to produce and create digital media and build digital literacy, students need access to up-to-date computers, software, and technology, as well as training in media tools. Schools can play a critical role in providing access to technology and educational opportunities in order to level the playing field for all students to become literate in all aspects of digital media.

Another pathway for students to become media literate is through informal venues. Studies in informal learning environments centered on digital literacy have found that students value interest driven learning and value the choices they have to participate collaboratively with peers in media projects (Vickery, 2014). In contrast to formal educational settings, informal environments foster experimentation and allow failure without implications, because they are free from high-stakes assessments. The idea of *play* in digital learning, and of *learning from each other*, as highlighted in *Hanging Out, Messing Around and Geeking Out* (Ito et al. 2010), stands in contrast to traditional formal K-12 experiences of students (Stone & Gutierrez, 2007). While informal settings provide opportunities for students to experiment, play, and fail in ways productive to learning, these venues reach relatively few students. Formal K-12 settings have the greatest reach to students and, therefore, can broadly help breach the digital divide.

Recent shifts in Science, Technology, Engineering, and Math (STEM) educational policy have increased the need for schools to build towards digital literacy within formal K-12 settings. The Next Generation Science Standards (NGSS) highlight the practice of communication about scientific thinking (NGSS Lead States, 2013). In addition, the NGSS Framework (the policy document governing NGSS) specifies that youth's everyday discourses should be bridged to a scientific discourse in explicit and culturally relevant ways (NRC, 2012). Digital media provide one avenue for connecting youth culture to scientific discourses through the communication of interest driven projects relevant and engaging to today's students.

In this chapter, several types of student-interest driven media projects that can be implemented in the formal classroom setting or in informal settings are described. Specifically, the focus will be on two projects: the Lens on Climate Change (LOCC) program and the Climate Education in an Age of Media (CAM) Project. These projects promoted the engagement of students primarily from impoverished communities with the intention of breaking down the barriers of the digital and STEM divides.

CLIMATE CHANGE SCIENCE AS A VEHICLE FOR MEDIA LITERACY

The CAM and LOCC projects engaged students in media projects that were focused on climate change science partly because of this topic's strong potential to engage students with diverse interests and socioeconomic backgrounds in learning (Gold et al., 2015; Rooney-Varga, Brisk, Adams, Shuldman, & Rath, 2014). Climate change impacts virtually all aspects of human life, from agricultural productivity to the integrity of the built environment, human health, water supplies, national security, and economy (IPCC, 2014). Thus, unlike many other topics in STEM areas of inquiry, the relevance of climate change to the everyday lives of students is readily apparent, providing a natural means to motivate engagement in the topic (Forest & Feder, 2011). Its cross-disciplinary nature also makes it relevant to students interested in almost any career path, as demonstrated by the rapidly growing body of work across STEM fields, as well as in the social sciences (e.g., economics, political science, and sociology) and humanities (e.g., ethics, philosophy, and arts) that consider human impacts from and responses to climate change (there is an extensive body of literature; a few examples are Holm et al., 2013; Palsson et al., 2013; Rose et al., 2012; Van Langenhove, 2012).

Understanding and addressing climate challenges require a STEM lens, as scientific observations and concepts—from analyses of globally distributed temperature anomalies to measurements of atmospheric levels of greenhouse gases and projections of future climate trends—are beyond the observational capabilities of unaided human senses (Weber, 2010). Furthermore, the embedded equity, justice, and ethics issues in climate problems (Eakin & Luers, 2006) make the societal importance and relevance of these issues, especially to vulnerable populations, clearly evident. As such, the climate challenges provide an opportunity to make STEM-rich content relevant to students with diverse disciplinary interests and may also have strong potential to engage under-represented groups with STEM content.

The participants in each of the two projects described here became smart consumers of digital media, as well as contributors to digital media, thus decreasing the digital divide. The focus of the CAM Project was primarily on designing and developing a suite of resources that integrate media literacy and climate change science education through student-produced media projects (Rooney-Varga et al., 2014). These resources have been piloted in a range of educational settings, from middle school to graduate level courses, as well as in informal after-school programs with high schoolers (the latter will be the focus of this chapter). The LOCC program focused on student-driven media projects that engaged secondary students in digital literacy through the production of short 3-5 minute documentary videos on a locally relevant climate change topic (Gold et al., 2015)[1].

THE CAM AND LOCC PROJECTS

In order to engage students who may not have the means to actively participate in the full spectrum of media literacy, both projects targeted schools with a student body above the state average in FRL or which were located in rural areas (Table 1). The two high-poverty, urban schools—Whittier ECE-8 School located in Denver Public Schools and Cambridge Rindge and Latin School, a high school located in Cambridge Public Schools—will be highlighted at the end of this chapter.

The media projects produced by students participating in both of these programs were implemented in a variety of ways, which demonstrates the flexibility that these projects offer to educators. The CAM Project summer programs were informal and had 14 high school student participants; three undergraduate students served as mentors. In the second summer, different types of media projects were paired with different content learning outcomes, and curriculum materials were designed around each project type, engaging the high school teachers (who also participated in three weeks of the program) in the design of those materials. The LOCC Project team worked with the teacher sponsors to implement the program in a way that fit best into existing structures at their schools. As a consequence, the media projects were incorporated into the regular science classes, were combined with science and technology classes, or were offered outside the formal school day during the collaboration period of late-start days, during the lunch period, or after school.

Several elements were common to both of the programs. First, both provided mentors for the students to help them with their media projects. Each LOCC student group was paired with a graduate student in the sciences at the University of Colorado (CU) to help guide them on the science content of their video, as well as an expert in videography to help them with the technical aspects of their work. Similarly, in each of the CAM Project summer programs, three University of Massachusetts (UMass) Lowell undergraduates served as mentors for high school students. Second, both programs exposed the secondary students to college life with the intention of sparking interest in pursuing a college degree. The LOCC students spent a day on the CU campus. They toured the campus with their mentors, learned about the different types of programs and majors available, how to apply to CU, and how to find out about scholarships, and they ate lunch in the bustling student cafeteria, where they got a glimpse of the college experience. The culmination of the day and the program was the screening of their videos in the historic Old Main

Table 1. Summary of the socioeconomic and ethnic diversity of schools participating in the two programs (2013-2014 school year). Values that are above the respective state average are marked with an asterisk. Nederland and Estes Park are rural mountain schools. Data for the Colorado schools (above the row with the Colorado state average) are published by Colorado Department of Education (CDE 2013a, 2013b). The data for Cambridge Rindge and Latin High School are published by the Massachusetts Department of Education (MDE 2014).

Participating School, Type of School, School District	Total Students	Free and Reduced Lunch	American Indian or Alaskan Native	Asian	Black or African American	Hispanic or Latino	Other or Mixed Ethnicity	White
Alamosa High School, Alamosa RE-11J School District	507	57.6% *	0.7%	0.7%	0.4%	62.5% *	0.2%	35.3%
Arapahoe Campus, CTE Program, Boulder Valley School District	137	59.9% *	1.5% *	0.7%	1.5%	62.8% *	2.9%	30.6%
Estes Park Middle School, Estes Park R-3 School District	231	39.0%	0.9%	1.3%	0.4%	24.2%	1.2%	71.4% *
Greeley Central High School, Greeley – Evans School District 6	1,518	65.7% *	0.3%	1.0%	2.7%	63.6% *	1.8%	30.5%
Manhattan Middle School, Boulder Valley School District	547	29.4%	0.9%	6.0% *	0.9%	23.6%	2.9%	66.0% *
Nederland Middle/High School, Boulder Valley School District	308	23.1%	0.6%	2.3%	0%	8.1%	5.5% *	83.4% *
Poudre High School, Poudre R-1 School District	1,779	35.0%	0.8%	3.3% *	1.1%	23.0%	2.6%	68.7% *
Whittier ECE-8, Denver Public Schools	274	93.8% *	0.9%	0.9%	44.0% *	40.6% *	4.7% *	8.5%
Colorado State Average	876,999	42.2%	1%	3%	5%	33%	3%	55%
Cambridge Rindge & Latin School, Cambridge Public Schools	1,684	44.8%[1] *	0.6%	11.7% *	33.2% *	14.0%	3.0% *	36.9%
Massachusetts State Average	954,739	38.3%[1]	<1%	6.1%	8.7%	17.0%	2.9%	66.0%

[1] Referred to as Low Income rather than FRL.

Building with an audience of more than 150 people. The Cambridge Rindge and Latin School students came to UMass Lowell and presented their videos at a meet-the-filmmaker event that was part of the annual Climate Change Teach-In, with an audience of more than 400 university students, high school students, and faculty members.

IMPLEMENTATION STAGES OF MEDIA PROJECTS

Using the video production process employed by the LOCC program as an example (Table 2), the general flow of a typical student media project is described in this section. The media production process generally has four phases: *pre-production, production, post-production,* and *dissemination*. While the focus generally is on the final product, be it a documentary video, animation, or other media product, learning occurs throughout the production process (Lumpe & Stayer, 1995; Johnson & Johnson, 1999), and students engage in many of the scientific practices outlined in the NGSS along the way (Table 2). Rooney-Varga et al. (2015) liken the process to an iceberg with the small exposed tip akin to the media piece and the massive underwater portion comprising all the unseen learning that occurs.

The first step of any media project is to *engage* students by showing them a series of media related to the project they will produce that employ a range of styles and techniques, such as wide shot, close-up, white board use, and animation. Students discuss with each other what the focus of each example is, how the media engages the students in the topic, what techniques they find interesting, and what they like and dislike about it. The responses are recorded for review later, when students begin scripting their projects.

Building on this foundation, students *explore* relevant topics for their own project. Depending on the age/grade level, the educator can provide a selection of topics to the students, or students can brainstorm among themselves topics of interest that fit within the parameters of the class. To assure relevance to the students, the topics ideally have a local impact, could be centered on a relatively recent event (e.g., a recent storm), and should be easily accessible in order to make filming easy. There are a number of excellent reviewed resources on climate change that can pique student interest (Table 2). With a short list of topics in hand, students discuss the topics and select the one that incites the most discussion and enthusiasm. After the topic has been chosen, students brainstorm media ideas related to the topic and develop a concept map or storyboard to draft their media piece. Such a graphical guide will give educators an initial inventory of the student's knowledge, their misconceptions, and their general interests (e.g., more interest in local impacts versus the environment at large).

Using the concept map or storyboard as a guide, students continue to *explore* their topic through their own research and build their knowledge base of the topic and its impact on their community or local environment. This is another point where students can view more media to help them gain foundational knowledge, as well as to show them examples that they can emulate in their own production.

After students have moved through the *explore* and *engage* steps that are common to all media projects, they are ready to move into the *pre-production* stage. Armed with knowledge of their topic and their guide (concept map or storyboard), students develop their scripts. A common template to employ in writing a script is the traditional three-act structure used in most movies, books, and plays (Table 2). Students should answer the following questions and decide where they can plug their answers into the three-act structure. What is the purpose of your video (e.g., inform the audience, inspire change)? What story do you want to tell? Who is the audience for this video? How do you want to tell your story (e.g., straight documentary, animation, narrative)? It is helpful for students to write a three-paragraph story about their topic, matching the three-act structure. These short stories can be used as the inspiration for their project.

Regardless of the creative way students choose to tell their story, they may want to interview experts or the average person on the street for their project. Experts can be scientists, local government officials, emergency responders, or stakeholders to name a few. Students need to draft a list of questions for the interviews, including a mix of personal, professional, and topic-specific questions.

Table 2. General components for the production of a media project, based on the short documentary video process used by the Lens on Climate Change program. Assessments that educators can use with their students are indicated by asterisks under Notes. The selected Scientific Practices satisfied by each activity in terms of the Next Generation Science Standards (NGSS, 2012) are included: 1. Asking questions and defining problems, 2. Developing and using models, 3. Planning and carrying out investigations, 4. Analyzing and interpreting data, 6. Constructing explanations and designing solutions, 7. Engaging in argument from evidence, 8. Obtaining, evaluating, and communicating information.

Components	Notes	Resources	NGSS
Engage & Explore			
Engage **(30 min)**	Expose students to video shorts	MinuteEarth YouTube (tinyurl.com/mej9gxx); MinutePhysics YouTube (tinyurl.com/laj289r); LOCC Videos (tinyurl.com/mhvwzl9); CAM Project (tinyurl.com/ner99aq)	1
Explore topics **(30-90 min)**	Choose topic; Concept map or storyboard*	Stanford University Storyboarding tutorial (tinyurl.com/pj6dueb); storyboard template (tinyurl.com/qfahjm9)	1, 2, 3
Topic research **(1-3 hr)**		CLEAN Collection (https://cleanet.org); Climate.gov (http://climate.gov/teaching); Learn More About Climate (http://learnmoreaboutclimate.colorado.edu)	1, 2, 3, 4, 6, 8
Pre-Production			
Write script **(1-3 hr)**	Write 3-paragraph story in 3-act structure*	Elements of Cinema.com (tinyurl.com/pkrrtsq)	3, 4, 6, 7, 8
Write interview questions **(30 min)**	Identify experts; Write questions*		1, 2, 3, 8
Identify shot list **(30-60 min)**			3, 6, 8
Production			
Technical workshop **(1 hr)**	Learn about equipment & techniques	Rule of Thirds (http://digital-photography-school.com/rule-of-thirds/)	3, 8
Filming day 1 **(1-2 hr)**	Shoot interviews		1, 3, 4, 8
Filming day 2 **(2-4 hr)**	Shoot B-roll		8
Post-Production			
Footage inventory **(1-2 hr)**	Review footage; identify gaps		2, 3, 4, 5, 7, 8
Fill in gaps **(1-2 hr)**	Shoot missing footage	freeimages, a free image library (tinyurl.com/qxxe8qc); freesound, a free sound effect library (tinyurl.com/6847ht); AudioMicro, royalty-free music (tinyurl.com/2b5kphl)	2, 3, 4, 8
Edit video **(2-6 hr)**	First cut of media product		3, 4, 6, 7, 8
Final edits **(2 wks before screening)**	Teacher reviews media product*		8
Public Screening and Dissemination			
Decide where media will be screened	Classroom, school assembly, etc.		8
Disseminate media	Internet	YouTube channel; Vimeo	8

The final part of the *pre-production* phase is the shot list. A shot list is a spreadsheet where students list all the footage they need for their project. In addition to the shot list, they should develop a list of footage or images they will need to intercut between the interviews (this is called B-roll). For example, many of the LOCC student groups made videos about the great flood of 2013 in Colorado. Their B-roll contained shots of collapsed roads, cars toppled in streams, or still images from news sources.

For the *production* stage, students need to learn basic videography and photography skills, including aesthetic and technical aspects. Skills they learn in this phase include the use of their camera (still, video, or cell phone), setting up a tripod, framing the interviewees (using the rule of thirds, Table 2), and interview skills. Students can practice these skills by interviewing fellow students while filming them. Students often are scared to interview the experts, but they usually enjoy meeting and interacting with them. They also learn important professional skills, such as requesting an interview, proper demeanor when conducting an interview, and writing a follow-up thank you note.

To prepare for the filming days, each student should be assigned a "job" before filming on location. Jobs include cameraman, interviewer, and note-taker (who writes down detailed notes of the interviewee's answers). Duplicate jobs can be assigned to accommodate additional students; we suggest having students switch jobs during the filming. On the first filming day, students film the interviews with the experts. On a subsequent filming day, students collect the remaining footage on their shot list. This could be on-location B-roll or set filming with student actors. After the interviews, all footage files should be downloaded to a computer.

The *post-production* phase is the most time-intensive step of producing a documentary video. First, students watch the footage they have, identify how each section of footage fits into the video script, and take notes on where the footage goes and why. This step is key to understanding where gaps are in their video and to determine if they need to film additional footage, find photos, or record narration.

Next, students begin editing the video. Students use their scripts, along with their notes from the interview, filming day, and footage inventory stages, and they start assembling their video using video editing software (e.g., free software products such as iMovie and Windows Movie Maker). There should be one or two editors who are in charge of placing the footage in its proper place and assembling the video. Assigning different roles during this stage is important to keep all students busy, since only a few students can edit at once. Other roles can be selecting copyright-free music on a separate computer, studying their documentation, and directing the editors on what should come next in the video. The video will go through several "rough cuts" which are reviewed by peers, the educator, and/or a combination of the two. The final video should be reviewed two weeks before the final screening to facilitate any changes that are necessary, such as leveling the audio across the different segments or other technical details.

The final and important step in the video production process is the *public screening*. Public recognition of the students' work is a great motivator and boosts confidence because students have a product they can share, that can be celebrated, and that they can be proud of. Videos can be screened as part of school assemblies, in a festive setting where parents and friends are invited, or simply as part of a class. An additional incentive for the screening event is a ranking of the videos by a jury (the audience or external jury) using different criteria. The LOCC project used the following four categories and a scoring rubric to rank the videos (Table 3): "Most Creative," "Most Entertaining," "Best Scientific Content," and the overall "People's Choice Award."

Table 3. Rubric used by jury to rate the student-produced films

	Beginner	Novice	Intermediate	Expert
Most Creative	Little evidence of creative planning	Some creative planning	Use of creative storytelling of topic	Very creative. I wish I could be as creative!
Most Entertaining	Little entertainment value	Some entertainment value	Fun and entertaining	Very entertaining. I didn't want it to stop!
Best Scientific Content	Little scientific information	Some scientific information with 2-3 facts and few citations of sources	Essential scientific information and sources properly cited	Covers topic completely and in depth. I learned a lot!

Dissemination of the media products is an important part of media literacy. Students may want to share their videos on social media with their families and peers. To facilitate this sharing we suggest setting up a program website (see LOCC and CAM webpages as examples, Table 2). Local media channels such as newspapers, local TV stations, or radio stations also might be interested in reporting on the projects.

EXAMPLES OF DIFFERENT TYPES OF INTEREST DRIVEN MEDIA PROJECTS

Media projects can be readily adapted to suit diverse educational settings and goals, ranging from a short, single-class-period activity or homework assignment to a semester-long capstone event, and can be done in a formal or an informal setting. Here, examples of media projects that can be used to achieve different learning goals in a variety of settings are described. These projects can be completed in shorter time frames or expanded, depending on time and resources available. Most of the projects share a similar production sequence as that described above. A brief overview of all the different types of media projects is shown in Table 4.

Media Projects When Time and Resources are Limited: Visual Storytelling and Video Mash-Ups

Both visual storytelling and video mash-ups are effective projects when in-class time and/or media technology resources are limited. In their simplest form, *visual storytelling* projects consist of a series of still shots, edited together with or without text or other graphic overlays, to convey a scientific concept. These projects can be executed with technology as common as a phone camera, although they can also be used as a means to introduce more sophisticated equipment and technology, from tablets with a camera and an editing app to sophisticated cameras and video editing software. Visual storytelling projects can be completed as a homework assignment or as an in-class activity, requiring as little time as one class period. Despite their simplicity, the projects provide an effective means to expose and correct misconceptions and to learn key media literacy skills, including creating a storyboard and shot list, using a camera and framing shots, video editing, and digital dissemination. For example, through the CAM Project, students were asked to use visual storytelling to identify key sinks and sources of atmospheric

Table 4. Overview of each type of student interest driven media project

Project Type	Minimum Time Needed	Minimum Media Tech Resources Needed	Key Science Learning Outcomes	Key Media Literacy Outcomes
Visual Storytelling[1]	3 hours	Still camera	Expose misconceptions Understand and explain key concepts	Framing Creating a shot list (Storyboarding) Script writing
Video Mash-Up[1]	1-2 weeks	Computer Microphone Video editing software	Research, understand, and synthesize content Create compelling and concise piece that communicates key content Find and manipulate digital audio and visual assets that accurately depict content	Storyboarding Recording and editing audio assets Video editing Digital dissemination
Animation[1]	~4 hours	Still camera Microphone Computer Video editing software	Systems thinking skills Understanding and depicting complex, dynamic processes with abstract components	Script writing Storyboarding Paper-mation, whiteboard Animation, and/or animation software Stop-motion photography Video editing Digital dissemination
POS and Mock Game Show[1]	1-2 weeks	Video camera Microphone Computer Video editing software	Research and understand content Devise relevant questions and research answers Identify misconceptions and correct them	Interviewing skills Script writing Storyboarding Filming Video editing Digital dissemination
PSA[1]	1-2 weeks	Video camera Microphone Computer Video editing software	Understand and synthesize concepts Identify societal relevance in scientific topics Understand how societal awareness, attitudes, and behavior connect back to science-informed problem Distill clear, concise, message that makes science and society connections clear	Script writing Storyboarding Filming Video editing Digital dissemination
Short Documentary	1 semester/ 1 hr 1-2/week	Video camera Microphone Computer Video editing software	Expose misconceptions Research, understand, and synthesize content Devise relevant questions Identify societal relevance in scientific topics Create compelling and concise piece that communicates key content	Script writing Concept map/storyboarding Interviewing skills Filming Video editing Digital dissemination

[1] How-to guides, learning goals and curriculum associated with these media projects can be accessed on the CAM website (http://cleanet.org/cced_media/index.html).

carbon dioxide in their everyday environment. In order to complete the project, students first needed to consider what defined a carbon dioxide source or sink, and then consider what objects or living things would fall under those definitions. They collaborated in small groups to research the question, brainstorm answers, plan a shot list, and consider a sequence and types of shots to create an interesting visual story that addressed the questions (e.g., an extreme close-up of a bird's beak may convey respiration effectively, while a long shot of a forest might be used to convey net ecosystem productivity). An interesting outcome of this assignment was that students' misconceptions about carbon sinks and sources were quite literally exposed during the production process. For example, many students wrongly assumed that because they associated an object with nature, it served as a carbon dioxide sink. Thus, their rough-cut included images of birds as carbon sinks and stimulated an in-class discussion of the scientific concepts and processes underlying carbon dioxide sinks and sources.

Although more involved, *video mash-up* projects can also be completed with little in-class time and media equipment. In these projects, students synthesize scientific concepts in an original script, but, rather than creating their own footage, draw on visual assets found online, bypassing the filming phase of production and therefore requiring less equipment and in-class time.

These video projects are well-suited to learning goals that include in-depth student research about a complex STEM topic. As with other media projects, the pre-production phase (i.e., student research, written scripts, and storyboards) can be expanded or contracted to meet educational goals. For example, at a middle or high school level, students might be given an accessible text about the content area and asked to synthesize key concepts in a script, while more advanced students conduct independent research. Unlike conventional research papers, video mash-ups challenge students to find and match visual assets to the concepts they wish to convey and to condense complex material in a compelling manner. The editing process provides an opportunity for iterative learning, discussion, and reflection on the content area, with students often commenting that they have a better understanding and longer term retention of science concepts as a result (Rooney-Varga et al., 2014). Last, unlike a written paper, these projects lend themselves to being shared online or face-to-face. Here, too, students have commented that when family and friends asked them what they learned in a class, they responded by sharing their video mash-up piece and effectively using it as a means to stimulate a discussion, revisiting the material once again by sharing it with others.

Animation to Bring Systems Thinking into STEM Learning

Educational goals that include understanding complex dynamic systems and abstract concepts can be met through *animation* projects (Rooney-Varga et al., 2015). Animation is inherently dynamic and not constrained to real-world objects, making it a natural fit for learning systems thinking skills, which are also increasingly seen as critical twenty first century skills (Trilling & Fadel, 2009) and are a core cross-cutting theme in the NGSS (NGSS Lead States, 2013). Systems thinking approaches take a holistic, long-term perspective that focuses on relationships between interacting parts, and how those relationships generate behavior over time (Sterman, 2006).

Animation projects can be executed using stop-motion photography and technology as simple as paper cutouts or whiteboards and still cameras, or as complex as sophisticated software packages like After Effects or VideoScribe. A growing number of apps for phones, tablets, and computers fall somewhere in between, such as Explain Everything, which enables users to create animations by capturing drawing, writing, and manipulation of images on an iPad. Animation lends itself naturally to depicting abstract complex processes that, like the medium itself, are inherently dynamic. Like other media projects, animation projects can be adapted to meet different educational goals and instructional settings by adjusting the pre-production content learning phase. In the CAM Project resources, animation projects are included which provide students with short, accessible explanations of feedback loops in the climate and energy systems. Students then use causal loop diagrams (CLDs; (Kirkwood, 2013) to visually depict the interrelationships between system components and predict how key components may change over time. From their CLDs, students develop a storyboard and paper-mation or whiteboard animation, resulting in a project that can be completed in a few hours. As with other video projects, more advanced students may be asked to independently research content areas and identify causal relationships with less scaffolding.

Learning through Questioning: Person-on-the-Street Interviews and Mock Game Shows

Directly exposing and addressing misconceptions has been shown to be an effective pedagogical approach in STEM education (Engelmann & Huntoon, 2011). Two types of media projects that directly use this approach are *person-on-the-street (POS) interviews* and *mock game shows.* In both projects, students formulate questions relevant to the content area and explore and correct misconceptions as the questions are answered. In POS projects, students compare the beliefs of laypeople with those of experts, who may be scientists (if they are accessible), instructors, or the students themselves, after they have become informed through researching their content area.

In many ways, mock game shows dramatize learning that might otherwise occur through exams—with some important distinctions, such as students collaborating to generate the questions, as well as both incorrect and correct answers. Mock game shows also lend themselves to injecting humor and a bit of drama into learning and creating a vehicle to engage an audience. The CAM Project found that mock game shows produced by high school students had strong appeal to younger students, who found the humor and creativity of their older counterparts appealing.

Winning Hearts and Minds: PSAs to Engage Affective and Analytic Processing

Public service announcements (PSAs) are intended to be short, engaging pieces that deliver a message to raise awareness or influence attitudes and behavior that is in the public's interest. In these projects, students are challenged to bring metaphor, humor or emotion, and creative storytelling into science communication. Unlike technical science communication, PSAs intentionally engage the affective system, which plays an important role in evaluating uncertainty and risk (such as potential climate change impacts or mitigation), and is the primary motivator for action (Weber, 2006) and sustained commitment to difficult problems (Pidgeon & Fischhoff, 2011). While the affective system enables rapid responses, analytic reasoning requires us to learn algorithms for decision-making and apply them through conscious awareness and control. Importantly, these two processing systems work together: analytic reasoning is not effective unless guided by emotion and affect and, if the responses of the two systems are in conflict, the affective system almost always prevails (Damasio, 1994). Thus, emotion is integral to our thinking, perceptions, and behavior (Pidgeon & Fischhoff, 2011).

PSA projects in STEM education are described in more detail by Rooney-Varga et al. (2014). PSA projects are particularly effective for STEM topics with immediate societal relevance and provide an opportunity for students to foster science-informed decision-making among their peers, in their communities, and beyond. They can be used to generate high levels of intrinsic motivation and engagement among student producers, as well as critical thinking, social learning, and instilling students with a sense of empowerment and agency (Rooney-Varga et al. (2014).

Short Documentary Videos to Engage Students Deeply in a Long-Term Project

Student-interest driven *documentary video* production is an active learning technique that has been used successfully in both formal (Gold et al., 2015; Harrison-Pitaniello, 2013; Rouda, 1973) and informal (Levin, 2011; Vickery, 2014) settings. Thus, video production engages students in authentic learning (Herrington & Oliver, 2000) in which they collaboratively work towards a product—the video. This active learning process leads to strong student engagement and a sense of ownership of the product (Kearney & Schuck 2005, 2006; Hofer & Swan, 2008) and thus, indirectly, to a student-centered learning process (Vickery 2014; Dando & Chadwick, 2014). Through the video production process, student learning reaches the highest cognitive level in the Bloom pyramid of learning—creating (Bloom, Engelhart, Furst, Hill & Krathwohl, 1956; Anderson & Krathwohl, 2001)—and has even been described as transformational (Watkins, 2012; Kearney, 2011). Engaging students in video production may improve their ability to critically view videos produced by others, an additional aspect of media literacy.

The process of producing a short documentary video has been described in detail in the previous section. Students engaged in this type of long-term project learn the full suite of media literacy skills from consuming to producing and sharing their product, as well as practicing many key science learning outcomes (Table 4). In addition, during the production process, students can employ a variety of the techniques as described previously in the shorter media project examples. For example, the Nederland Middle and High School group's documentary focused on the shrinking Arapahoe Glacier, which is located near their homes and is one source of drinking water for the city of Boulder. They melded together both the POS and expert interview techniques to highlight the importance of the glacier through interviewing the watershed manager, and they exposed the lack of knowledge that students and teachers had about the glacier through the POS interviews. Another student group in the LOCC project used an animation to step through the history of the glacier and to show how much of its mass has been lost over the past century. It was not only the production groups who learned more about this critical water resource close to home; the whole school learned about it when the films were screened at a school-wide assembly.

FOCUS ON TWO HIGH-POVERTY SCHOOLS

Evaluation of the LOCC and CAM programs indicated that they were effective in many aspects (Gold et al., 2015; Rooney-Varga et al., 2014). First, students developed in-depth knowledge about a climate change science topic of their choice. Second, they practiced many other skills like teamwork and self-directed, goal-oriented work that straddled technology, artistic, and professional interaction. The programs were particularly impactful at two high-poverty urban schools with traditionally marginalized student populations. For example, after their successful completion of the LOCC program, students from Whittier ECE-8 School were asked to reflect on their experience throughout the LOCC Program[2]. The students highlighted the positive aspects of teamwork and collaboration (67% of respondents), as well as the perseverance (67%) required in sticking with the project and bringing it to a successful end. Fifty-six percent listed the campus tour as one of the highlights of their participating in the program.

Having been recognized with an award during the final screening event (Most Entertaining Film), 44% of the students mentioned this accomplishment in their reflection statement. Other program aspects that students described in the reflection statements were the video skill training (33%), building of confidence (22%), and practicing communication skills (22%). The reflection of one 6th grade student captures these sentiments well:

The most beneficial thing that I got from making the video was . . . to be confident. Because when we first started making the video I was kind of thinking to drop out of the group and not do it. Then my teacher had a conversation with me that once you start something and you finish it you will feel good about it and it will help me in life. That really helped me because when we got the video done I was really glad that I made something and finished it. It helped me to be confident with myself because I am the kind of person who doesn't have confidence in doing something and finishing it.

Insights from the sponsor teacher during the program and a follow-up interview corroborated what the Whittier students revealed in their reflection pieces. He mentioned that his students from impoverished backgrounds lacked role models who completed a task, and they lacked confidence in their ability to finish projects:

Building confidence is most likely my number one goal. And, boy howdy, they told me afterwards that they understand what I meant about confidence. I am going to try and build on this "get the job done" experience and help move more of my students forward.

I have several students who now want to participate in the NREL [National Renewable Energy Laboratory] solar and electric spring this May.

In addition, he said having contact with graduate student mentors and visiting CU had a noticeable influence on several of his students:

Those who think they will be going to college are beginning to see that it takes work and discipline.

We have noticed that 3 students have really picked up their efforts and have openly talked about going to college. What an amazing contribution that you have all made for our students!!

Like the Whittier students, several of the students from Cambridge Rindge and Latin School (CRLS) commented in their student focus groups about how they had not considered going to college before, and now they felt they would. At least one student applied to the University of Massachusetts at Lowell after the CAM summer program.

Participating students in the summer CAM Project consistently reported that the process of creating the media projects had substantially improved their understanding of climate change science[3]. Although not mentioned in the student reflection pieces, the teacher from Whittier also mentioned that his students increased their content knowledge on climate change topics, saying "The kids absolutely didn't know anything about global climate change. They know more now."

As part of their focus group comments, the CRLS students said they enjoyed the process of making the videos and they learned a lot from the experience. They also spoke about the skills they had gained in the process, of which they were very proud. A few examples of students' comments demonstrate these outcomes:

The best part of the experience was taking the week of learning science from the instructors and putting it into media. It's really fun being able to learn something that relates to you, be able to use expensive camera equipment and programs.

Media can be put to a lot of important uses. It is one of the most compelling ways to get a message out to a large audience, and should be taken advantage of no matter what you are trying to show people.

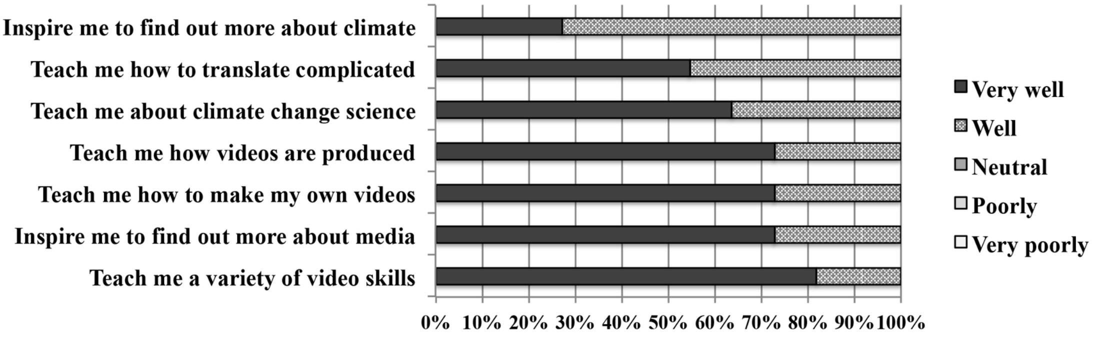
A good way to teach the public about climate change is through media.

Survey results corroborate these reflections and indicate substantial learning gains in both the areas of video production and climate change science by the CRLS students (Figure 1).

The effect of interest driven media projects on their sense of empowerment was evident for the CRLS students. In the first summer, they were given free rein to create any type of media project they could realistically complete within the five-week program, enabling them to be key innovators for the CAM Project as they created and piloted their media projects. By the end of the summer, the students themselves named the program, "YEP!" for "Youth Educating the Public!" which conveys the sense of empowerment they gained from their experience.

Teacher observations emphasized how these programs were empowering experiences for students who are often marginalized. One CAM Project teacher noted that using media projects was a particularly effective means of getting students who might not otherwise be interested in the topic of climate change to become engaged in learning the material; she was particularly impressed by the amount of knowledge that the students had retained in order to complete their projects. Furthermore, teachers from both schools commented that both artistic and more academically minded students could contribute their skills to the media projects. For example, the Whittier group had several artists who drew the animations that were filmed, and they felt validated by the recognition of the skills they brought to the production. These students typically were not interested in school, but the video production engaged them, and they were able to "get the job done."

Figure 1. Pre- and post-survey results of high school students who partipated in the summer CAM Project (n = 11). See Rooney-Varga et al. (2014) for the evaluation methodology.



CONCLUSION

One of today's equity challenges is the need to increase media literacy among all students, especially traditionally marginalized students. Watkins (2012) challenges educators when he states, "Tools literacy is foundational; design literacy is tranformational" (p. 9). In this chapter, implementation models for seven different types of media projects that have been successfully piloted with 78 secondary students primarily from impoverished backgrounds are provided (Gold et al., 2015; Rooney-Varga et al., 2014). Results from the evaluations show that students' experiences while participating in these projects were transformational. The students felt a strong sense of accomplishment and pride, which translated to increased confidence and sometimes even an interest in attending college as reported by their teachers. Students who were typically not interested in science topics took an interest in their own projects, stepped up their participation, and worked hard to "get the job done." Students with a broad array of interests—from artistic to more academically inclined—found a way in which they could contribute to the projects; thus, the projects provided an inclusive space.

While working on their media projects, participating students gained experience in the full spectrum of media skills—from the simplest form of consuming media in order to find inspiration from different genres to learning about their subject matter and acquiring higher order media skills, including the planning, executing, and sharing of media projects. Not only did students learn a variety of media skills, they also learned soft skills like the development of interview protocols, communication with professionals, interview techniques, and how to be a good listener. Students were required to organize their ideas and provide feedback internally to their team; in addition, each student needed to find their role in the process. Team members worked together and developed the ability to collaborate. All of these are important life skills.

Through their research, students learned about the challenges of climate change and how climate change will affect their local communities. The process of developing the concept map or storyboard and writing a script exposes misconceptions. It also forces students to make connections and to take the fragmented pieces (such as interviews, animations, and B-roll) and meld them together to create a cohesive and compelling story. As the students stepped through the components of their media projects, they also practiced the Scientific Practices described in the NGSS. These media projects allowed for a seamless integration of the practices in the classroom.

Although not explicitly an objective of the two projects, the work with teachers and students exposed the power of partnerships. For example, although it is generally believed that the majority of schools have bridged the "tools" divide, the LOCC program ran into this roadblock at a high-poverty school. The Whittier ECE-8 School did not have powerful enough computers to download large video files and allow editing of the footage. LOCC created a partnership with CU, which was able to provide the equipment necessary to carry out and complete the video project. (Of course, a lack of computing power and high speed Internet does not need to be a barrier to media projects; some of the media projects highlighted in this chapter require only a cell phone or an iPad to complete.)

More importantly, the partnership between the mentors and students provided the students with role models who were not much older than themselves; the mentors offered the students personal insights into academic careers. They also got to know these young scientists as "real" people who were not bespectacled, gray-haired, white men—the stereotypical image of a scientist. Bringing the students to campus was valuable and extended the experience of the media projects. It allowed students a glimpse into college life, and some of the students could see themselves as college students in the future. A possible way to develop such a partnership is to contact a nearby two- or four-year post-secondary institution to inquire about partnering and whether college students would be interested in mentoring. Most universities have an outreach program or department, which would be the first place to inquire about such a partnership.

Taking on a media project might be daunting to an educator. Shorter-duration media projects, such as visual storytelling or animation, can provide a means to gain first-hand experience in the field. Developing partnerships within the school and collaborating with a technology teacher or a technology class for the implementation of such a media project might provide another avenue to increase the available media expertise that students can access.

As the projects discussed here have shown, media literacy can be transformational for students. The guidelines described in this chapter will support schools as they incorporate media projects into their classrooms or informal program offerings, thus narrowing the media literacy divide.

REFERENCES

Anderson, L. W., & Krathwohl, D. R. (2001). *A taxonomy for learning, teaching, and assessing: A revision of Bloom's taxonomy of educational objectives*. New York, NY: Longman.

Bloom, B. S., Engelhart, M. D., Furst, E. J., Hill, W. H., & Krathwohl, D. R. (1956). *Taxonomy of educational objectives: The classification of educational goals. Handbook I: Cognitive domain*. New York, NY: David McKay Company, Inc.

Brown, B. A. (2006). "It isn't no slang that can be said about this stuff": Language, identity, and appropriating science discourse. *Journal of Research in Science Teaching*, *43*(1), 96–126. doi:10.1002/tea.20096

CDE (Colorado Department of Education). (2013a). *Fall 2013 PK-12 free and reduced lunch eligibility by school* [Excel file]. Retrieved from http://www.cde.state.co.us/cdereval/fall2013pk12frleligibilitybydistrictandschoolxls

CDE (Colorado Department of Education). (2013b). *2013 PK-12 pupil enrollment by school, grade, race/ethnicity and gender* [Excel file]. Retrieved from http://www.cde.state.co.us/cdereval/fall2013pupilmembershipbyschethnicitygendergradexls

Damasio, A. R. (1994). *Descartes' error: Emotion, reason, and the human brain*. New York: Avon Books.

Dando, C. E., & Chadwick, J. J. (2014). Enhancing Geographic Learning and Literacy through Filmmaking. *The Journal of Geography*, *113*(2), 78–84. doi:10.1080/00221341.2013.846394

Eakin, H., & Luers, A. L. (2006). Assessing the vulnerability of social-environmental systems. *Annual Review of Environment and Resources*, *31*(1), 365–394. doi:10.1146/annurev.energy.30.050504.144352

Eamon, M. K. (2004). Digital divide in computer access and use between poor and non-poor youth. *Journal of Sociology and Social Welfare*, *31*(2), 91–112. Retrieved from http://imet.csus.edu/imet8/leu/251/articles/Article_Eamon_PoorYouth.pdf

Engelmann, C. A., & Huntoon, J. E. (2011). Improving student learning by addressing misconceptions. *Eos*, *92*(50), 465–466. doi:10.1029/2011EO500001

Forest, S., & Feder, M. (2011). *Climate change education: Goals, audiences, and strategies: A workshop summary*. Washington, DC: The National Academies Press.

Gold, A. U., Oonk, D. J., Smith, L. K., Boykoff, M., Osnes, B., & Sullivan, S. B. (2015). Lens on climate change: Student-produced videos as an effective learning approach. *The Journal of Geography*, *0*, 1–12. doi:10.1080/00221341.2015.1013974

Gutiérrez, K. D., Baquedano-López, P., & Tejeda, C. (1999). Rethinking diversity: Hybridity and hybrid language practices in the third space. *Mind, Culture, and Activity*, *6*(4), 286–303. doi:10.1080/10749039909524733

Hargittai, E. (2011). Minding the digital gap: Why understanding digital inequality matters. In S. Papathanassopoulos (Ed.), *Media perspectives for the 21st century* (pp. 231–240). New York, NY: Routledge.

Hargittai, E., & Walejko, G. (2008). The participation divide: Content creation and sharing in the digital age. *Information Communication and Society*, *11*(2), 239–256. doi:10.1080/13691180801946150

Harrison-Pitaniello, M. (2013). Using Student-Produced Time-Lapse Plant Movies to Communicate Concepts in Plant Biology. *Journal of Microbiology & Biology Education*, *14*(1), 101–102. doi:10.1128/jmbe.v14i1.436 PMID:23858359

Herrington, J., & Oliver, R. (2000). An instructional design framework for authentic learning environments. *Educational Technology Research and Development*, *48*(3), 23–48. doi:10.1007/BF02319856

Hobbs, R. (2010). Digital and Media Literacy: A Plan of Action. A White Paper on the Digital and Media Literacy Recommendations of the Knight Commission on the Information Needs of Communities in a Democracy. Washington, DC: The Aspen Institute. Retrieved from http://www.academia.edu/2866630/Digital_and_media_literacy_A_plan_of_action

Hofer, M., & Swan, K. O. (2008). Technological Pedagogical Content Knowledge in Action: A Case Study of a Middle School Digital Documentary Project. *Journal of Research on Technology in Education*, *41*(2), 179–200. doi:10.1080/15391523.2008.10782528

Holm, P., Goodsite, M. E., Cloetingh, S., Agnoletti, M., Moldan, B., Lang, D. J., & Pohl, W. et al. (2013). Collaboration between the natural, social, and human sciences in Global Change Research. *Environmental Science & Policy*, *28*, 25–35. doi:10.1016/j.envsci.2012.11.010

Horrigan, J. (2009). *Wireless internet use*. Retrieved from Pew Internet and American Life Project: http://www.pewinternet.org/files/old-media//Files/Reports/2009/Wireless-Internet-Use-With-Topline.pdf

IPCC. (2014). Summary for policymakers. In C. B. Field, V. R. Barros, D. J. Dokken, K. J. Mach, M. D. Mastrandrea, T. E. Bilir, M. Chatterjee, K. L. Ebi, Y. O. Estrada, R. C. Genova, B. Girma, E. S. Kissel, A. N. Levy, S. MacCracken, P. R. Mastrandrea & L. L. White (Eds.), Climate change 2014: Impacts, adaptation, and vulnerability. Part A: Global and sectoral aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (pp. 1-32). Cambridge, UK: Cambridge University Press.

Ito, M., Baumer, S., Bittani, M., boyd, d., Cody, R., Herr-Stephenson, B., . . . Tripp, L. (2010). Hanging out, messing around and geeking out: Kids living and learning with new media. Cambridge, MA: The MIT Press.

Johnson, D. W., & Johnson, R. T. (1999). Making cooperative learning work. *Theory into Practice*, *38*(2), 67–73. doi:10.1080/00405849909543834

Kearney, M. (2011). A learning design for student-generated digital storytelling. *Learning, Media and Technology*, *36*(2), 169–188. doi:10.1080/17439884.2011.553623

Kearney, M., & Schuck, S. (2005). Students in the director's seat: Teaching and learning with student-generated video. In P. Kommers & G. Richards (Eds.), Proceedings of Ed-Media 2005—World Conference on Educational Multimedia, Hypermedia, & Telecommunications. Norfolk, VA: Association for the Advancement of Computing in Education. Retrieved from http://www.editlib.org/p/20518/

Kearney, M., & Schuck, S. (2006). Spotlight on authentic learning: student developed digital video projects. *Australasian Journal of Educational Technology, 22*(2), 189-208. Retrieved from http://www.ascilite.org.au/ajet/ajet22/kearney1.html

Kirkwood, C. W. (2013). *System dynamics methods: A quick introduction*. Retrieved from http://www.public.asu.edu/~kirkwood/sysdyn/SDIntro/SDIntro.htm

Levin, H. (2011). Authentic doing: Student-produced web-based digital video oral histories. *The Oral History Review*, *38*(1), 6–33. doi:10.1093/ohr/ohr046

Lumpe, A. T., & Staver, J. R. (1995). Peer collaboration and concept development: Learning about photosynthesis. *Journal of Research in Science Teaching*, *32*(1), 71–98. doi:10.1002/tea.3660320108

MDE (Massachusetts Department of Education). (2013). *2014 Report card - Cambridge Rindge and Latin* [data tables]. Retrieved from http://profiles.doe.mass.edu/reportcard/rc.aspx?linkid=37&orgcode=00490506&fycode=2014&orgtypecode=6

Miles, A. (2007). Network literacy: The new path to knowledge. *Screen Education, 45*, 24-30. Retrieved from http://vogmae.net.au/research/thinking/Network-Literacy-The-New-Path-To-Knowledge/

NCES. (2015). *Digest of education statistics* [data files]. Retrieved from http://nces.ed.gov/programs/digest/current_tables.asp

NGSS Lead States. (2013). *Next generation science standards: For states, by states*. Washington, DC: The National Academies Press.

NRC (National Research Council, Committee on a Conceptual Framework for New K-12 Science Education Standards Board on Science Education, Division of Behavioral and Social Sciences and Education). (2012). A framework for K-12 science education: Practices, crosscutting concepts, and core ideas. Washington, DC: The National Academies Press.

Palsson, G., Szerszynski, B., Sörlin, S., Marks, J., Avril, B., Crumley, C., & Weehuizen, R. et al. (2013). Reconceptualizing the 'Anthropos' in the Anthropocene: Integrating the social sciences and humanities in global environmental change research. *Environmental Science & Policy*, *28*, 3–13. doi:10.1016/j.envsci.2012.11.004

Patton, M. Q. (2001). *Qualitative research & evaluation methods*. Thousand Oaks, CA: Sage Publications.

Pidgeon, N., & Fischhoff, B. (2011). The role of social and decision sciences in communicating uncertain climate risks. *Nature Climate Change*, *1*(1), 35–41. doi:10.1038/nclimate1080

Potter, J. (2010). The state of media literacy. *Journal of Broadcasting & Electronic Media*, *54*(4), 675–696. doi:10.1080/08838151.2011.521462

Resnick, M., Maloney, J., Monroy-Hernández, A., Rusk, N., Eastmond, E., Brennan, K., & Kafai, Y. et al. (2009). Scratch: Programming for all. *Communications of the ACM*, *52*(11), 60–67. doi:10.1145/1592761.1592779

Rooney-Varga, J. N., Brisk, A. A., Adams, E., Shuldman, M., & Rath, K. (2014). Student media production to meet challenges in climate change science education. *Journal of Geoscience Education*, *62*(4), 598–608. doi:10.5408/13-050.1

Rooney-Varga, J. N., Brisk, A. A., Shuldman, M., & Rath, K. (2015). The CAM Project: Tools for bringing student media production into climate change education. *In the Trenches, 5*(1), 4-7. Retrieved from http://nagt.org/nagt/publications/trenches/articles/v5n1-2.html

Rose, D. B., van Dooren, T., Chrulew, M., Cooke, S., Kearnes, M., & O'Gorman, E. (2012). Thinking through the environment, unsettling the humanities. *Environmental Humanities, 1*(1), 1-5. Retrieved from http://environmentalhumanities.org/arch/vol1/EH1.1.pdf

Rouda, R. H. (1973). Student-produced videotapes in a physical chemistry laboratory course. *Journal of Chemical Education*, *50*(2), 126. doi:10.1021/ed050p126

Sterman, J. D. (2006). Learning from evidence in a complex world. *American Journal of Public Health*, *96*(3), 505–514. doi:10.2105/AJPH.2005.066043 PMID:16449579

Stone, L. D., & Gutierrez, K. D. (2007). Problem articulation and the process of assistance: An activity theoretic view of mediation in game play. *International Journal of Educational Research*, *46*(1-2), 43–56. doi:10.1016/j.ijer.2007.07.005

Tierney, J. P., & Grossman, J. B. (2000). *Making a difference: An impact study of Big Brothers Big Sisters*. Philadelphia, PA: Public/Private Ventures.

Trilling, B., & Fadel, C. (2009). *21st century skills: Learning for life in our times*. San Francisco, CA: Jossey-Bass.

Van Langenhove, L. (2012). Global issues: Make social sciences relevant. *Nature*, *484*(7395), 442. doi:10.1038/484442a PMID:22538586

Vickery, J. R. (2014). The role of after-school digital media clubs in closing participation gaps and expanding social networks. *Equity & Excellence in Education*, *47*(1), 78–95. doi:10.1080/10665684.2013.866870

Watkins, S. C. (2012). Digital divide: Navigating the digital edge. *International Journal of Learning and Media*, *3*(2), 1–12. doi:10.1162/ijlm_a_00072

Weber, E. U. (2006). Experience-based and description-based perceptions of long-term risk: Why global warming does not scare us (yet). *Climatic Change*, *77*(1), 103–120. doi:10.1007/s10584-006-9060-3

Weber, E. U. (2010). What shapes perceptions of climate change? *Wiley Interdisciplinary Reviews: Climate Change*, *1*(3), 332–342. doi:10.1002/wcc.41

ENDNOTES

[1] Student videos may be viewed at http://cires.colorado.edu/education/outreach/LOCC/.

[2] In order to ascertain from the students what skills they felt they gained during the LOCC project, they were given a writing assignment in their literacy class to describe what they had learned from their experience. They were not given any prompts to guide their writing, and they wrote short essays of about five to eight sentences. The written responses were analyzed using quantitative methods (Patton 2001). Each of their essays was coded, with one coder developing a code book. Each essay was coded by two different coders, and they reached 85% intercoder reliability. The codes were then consensus-coded for each code that reached less than 80% reliability.

[3] External evaluation of the CAM Project included focus groups with students and pre- and post-surveys of students' knowledge and attitudes about climate change science and media literacy. Details of the evaluation are in Rooney-Vega et al. (2014). The evaluators also interviewed participating teachers during the second summer.

Chapter 3

Sounding Out Science:
Using Assistive Technology for Students with Learning Differences in Middle School Science Classes

Clement Vashkar Gomes
Teachers College, Columbia University, USA

Felicia Moore Mensah
Teachers College, Columbia University, USA

ABSTRACT

With the current focus to have all students reach scientific literacy in the U.S, there exists a need to support marginalized students, such as those with Learning Disabilities/Differences (LD), to reach the same educational goals as their mainstream counterparts. This chapter examines the benefits of using audio assistive technology on the iPad to support LD students to achieve comprehension of science vocabulary and semantics. This research is composed of quantified data supported by qualitative information. Significant statistical evidence from pretest and posttest ANCOVA analysis reveals that audio technology is beneficial for seventh grade LD students when learning unfamiliar science content. Analysis of observations and student interviews support the quantified findings. This chapter provides useful information for the rising number of identified LD students and their parents and teachers by providing the benefits of using audio assistive technology to learn science. Audio assistive technology can be the tool to bridge the gap for LD students to achieve scientific literacy.

INTRODUCTION AND PURPOSE

In-tro-duc-tion. That is how most children are taught to break down the word and sound it out. But what if you did not know, could not remember, or were not sure of what sound “in” or “tro” makes or maybe you were not sure how “duc” would sound? How can you figure out the meaning of the word if you struggle with what sound it makes when you read it? This is the common challenge with many students

DOI: 10.4018/978-1-4666-9616-7.ch003

who struggle when learning through reading and writing (Lovett, Borden, DeLuca, Lacerenza, Benson, & Brackstone, 1994).

Phonemes, small units of sound, correspond to graphemes, printed characters, allowing us to transform the letters we see on the page into the spoken words we hear (Richardson, Thomson, Scott, & Goswami, 2004). Auditory and visual processing are two key components to assess for the presence of language-based learning disabilities (Shaywitz, 1998). Hearing the word "introduction" may cause a student with dyslexia or another Language Learning Impairment (LLI) to struggle to break down and spell the word, especially if the individual is unaware of, unfamiliar with, or has difficulty remembering the phonemes. When asked to write down a word such as "introduction," the student will turn to simpler, familiar sight words to compose larger and more complex words, for example, by transliterating the spelling of "introduction" into a form that "sounds" the way they hear it, namely "*introduckshin.*" The difficulty in formulating the connection between sounds and written words can make learning and retaining new vocabulary very arduous for a person with dyslexia (Lovett et al., 1994).

With the growing diversity of students in American classrooms, it is important for educators to understand and modify their teaching to accommodate individual needs. Each student walks into a classroom with different life experiences and modes of thinking and learning. Whether it is due to ethnicity, culture, family, lifestyle, gender, medical history, or personality, particularly in a country as heterogeneous as the United States, we are all very different beings. This adds to the beauty of the diverse and unique world we live in. With these differences comes the struggle of teaching young minds new disciplinary knowledge when there are so many approaches and methods necessary for each individual (Faggella-Luby, Graner, Deshler, & Drew 2012).

Students with Learning Disabilities (LD) are a marginalized group that has often been overlooked. LDs are more appropriately termed "Learning Differences" and can affect the way students learn, retain, and understand written and spoken language. LDs can affect reading and comprehension as well as writing and speech, even though the students are of average intelligence and cognitive ability (Shaywitz, 1998, 2003). The most common language-based LD is dyslexia. In recent years, more focus has been placed on students who have dyslexia and how to better assist them (Turnbull, Huerta, & Stowe, 2006).

In the past, many LD students were placed in classrooms that were not supportive of their needs, which is a disservice to their learning. These students should be provided an appropriate and modified educational setting that will allow for learning (Salvia, Ysseldyke, & Bolt, 2010). As the neurologic, linguistic, and educational communities continue to learn and understand LDs, new and innovative supports are being developed to assist this marginalized group of individuals.

One of the advances that has had great positive impact on students with LDs is technology. Technology has been assisting individuals with disabilities for many decades now. With innovations such as hearing aids, wheelchairs, and even elevators, technology has allowed individuals who are different from the mainstream population to perform activities and tasks independently that would not have been possible without the assistance of others (Turnbull, Huerta, & Stowe, 2006). Technology has also greatly facilitated individuals with LDs. For example, students with fine and gross motor control issues can use computers to type. Dyslexic students can use voice recognition and text reading software to hear and type responses. Pictographic apps on the iPad are allowing non-verbal autistic students to communicate with others. There are increasing numbers of new programs and technology tools to assist individuals with special needs (Raskind, 2000). Language-based LDs such as dyslexia can affect learning the unfamiliar language and vocabulary of science, because they affect reading, processing, and retaining new information (Carlisle, Fleming, & Gudbrandsen, 2000).

PURPOSE OF THE STUDY

The purpose of this research is to understand the challenges students with LDs have when learning science language and vocabulary and how to support them using technology. This study examines the use of audio technology to determine if there are positive benefits to incorporating it into science curricula for LD students. More particularly, this study addresses how the use of assistive technology can enable LD students to effectively learn science language, vocabulary, and content independently. Specifically, the research questions are: (1) What are the challenges that students with LDs have when learning science language and vocabulary, and (2) How will the use of audio technology affect LD students' understanding and comprehension when reading science text? This chapter answers these questions by presenting qualitative data using narrative descriptions based on observation, interviews, and artifacts, as well as quantitative pretest and posttest analysis.

THEORETICAL FRAMEWORK

Our current state of reform in science education has led to a multitude of changes due to concerns for the educational level of science understanding for many American students (American Association for the Advancement of Science [AAAS], 1998). Some concerns that need to be addressed are standardized testing, teacher quality and preparation, national learning goals, and equity/equality issues. Focusing on the latter topic, this study addresses the concerns for the marginalized population of LD students and what supports can be provided to assist them in attaining the learning goals of their mainstream cohort. LD students struggle with language-based learning, but with an appropriate and modified educational environment, these students are capable of reaching the same understanding as those without an LD (Turnbull et al., 2006).

Disabilities Theory

This research encompasses a postmodern interpretive perspective on disabilities theory and research, supports the phonological deficit hypothesis (Swan & Goswami, 1997), and offers technological alternatives to having a scribe or reader to assist LD students in their learning (Raskind, 2000). In the past, it was believed that visual issues developed LDs, but based on further research, the phonological deficit hypothesis proposes that auditory processing is another major component of having a language-based LD (Shaywitz, 2003; Swanson, 1999).

The disability rights movement began in the early 1960s to promote ideas that consider individuals with disabilities as active members of the community that should be provided equal accessibility and rights (Goldsmith, 1963). Based on disability theory, which regards disability as a form of human difference and not a defect (Creswell, 2007), people with disabilities should be treated with respect and equality. This movement led to great changes for accessibility in the physical and ergonomic space of public places (CAST, 1999).

One of the major forefronts of change for people with disabilities came with the development of Universal Design. This term refers to the broad ideas considered when developing public infrastructures and spaces as well as products that are accessible to people with or without disabilities (Goldsmith, 1963). The Center for Universal Design (CUD) at North Carolina State University includes but is not limited to the following considerations when creating new universally designed spaces: equitability, flexibility, simple/intuitive nature, perceptible information, tolerance for error, and appropriate ergonomics (CUD, 2008). With these efforts and ideas greatly focused on individuals with physical differences, the concept of Universal Design has been applied to learning in educational reform.

Universal Design for Learning (UDL) was developed in 1984 by the Center for Applied Special Technology (CAST) to create an approach to education that includes diverse learners of different levels and abilities. The proposed learning principles were based on the CUD considerations for universally designed spaces as mentioned above (CAST, 1999). The three primary principles include:

1. **Multiple Means of Representation:** to give diverse learners options for acquiring information and knowledge
2. **Multiple Means of Action and Expression:** to provide learners options for demonstrating what they know
3. **Multiple Means of Engagement:** to tap into learners' interests, offer appropriate challenges, and increase motivation

The educational researchers of CAST focused on new technologies as the means to provide students with disabilities greater opportunities to learn.

Over the years, many approaches to teaching students of all abilities have been developed further due to the importance of technology in the classroom (CAST, 1999). Technology in every classroom has become a major focus of education with the current Science, Technology, Engineering, and Mathematics (STEM) reform movement (National Research Council, 2012). The importance of understanding and involving technology in teaching has had unprecedented impact on education as a whole. The disability framework addresses that individuals of any ability should be provided equal access to all opportunities and experiences that life has to offer, and technology can be a means of achieving this.

Phonological Deficit Hypothesis

Advancements in medicine and research have led to a better understanding of the causes of LDs and the many forms of support that can be used to assist individuals with learning difficulties. Over the past decade, research has shown that the auditory component of language has a large impact on impairments that involve reading and comprehending written information (Swan & Goswami, 1997; Tallal, Merzenich, Miller, & Jenkins, 1998). The proposed explanation involving auditory processing as the cause and/or development of LDs is called the phonological deficit hypothesis. The two major components of reading are decoding and comprehension. To decode or identify words, the reader must be able to compose a clear auditory translation of the textual information (Shaywitz, 1998, 2003). Students with hearing impairments can be found to develop language and literacy difficulties (Richardson, Thomson, Scott, & Goswami, 2004). The individual needs to be able to connect the grapho-phonemic relationship of words in order to match sounds to the letters they represent (Swanson, 1999). Students with dyslexia and other LLIs struggle with making this connection between the phonology, or sounds, of the word and the graphemes, or written text, the word is composed of. This disconnect can lead to difficulty with comprehension of the written content (Shaywitz, 1998, 2003; Swanson, 1999). Individuals with dyslexia have difficulty with decoding, which impacts comprehension of written information. In the past, this difference was believed to be due to cognitive level, but when the content was presented using alternate methods such as reading aloud, visual representations, and other multisensory techniques, the individual was able to grasp and understand the content with greater ease (Ramus, 2003). Understanding the phonological component of LDs leads to the use of audio technology to assist these students when they are learning science through reading and writing. Based on the phonological deficit hypothesis, audio assistive technology provides the additional auditory support for LD students to reach comprehension when learning science content (Raskind, 2000).

Assistive Technology Use in Education

The addition of technology to any classroom can improve learning for all students, especially those with LDs. The Individuals with Disabilities Act (IDEA) includes assistive technology as one of the many possible supports a student with disabilities may require (Turnbull et al., 2006). A variety of assistive technologies may be provided to students, ranging from simple tools such as voice recorders to more complex devices such as iPads with speech-to-text software (Thompson, Bakken, Fulk, & Peterson-Karlan, 2004). Students with dyslexia benefit from these and other forms of audio presentation of information.

One major educational assistive technology that has been used to support LD students is books in audio format. Narrative books can be found quite easily and used in classes involving literature and reading. This has been shown to greatly benefit LD students when learning new words and vocabulary (Raskind, 2000). A deficit with this technology is the lack of audio books for other subject areas, such as science. With science textbooks composed of expository information requiring the reader to retrieve detailed content, it would be ideal and highly beneficial for LD students to have audio versions of these publications. Another factor to consider is the unique and often complex language of science (Fang, 2005). Being able to hear the unfamiliar vocabulary of science would also assist LD students to learn and understand the words. A way around this issue would be the utilization of audio technologies to support learning.

Recent advances in text-to-speech and voice recognition technologies, such as Siri on Apple products, have provided a way to work around this difference in learning ability. Technology has also reduced the issue of timing, allowing a faster pace to learn more information. These technologies help expedite the process of learning and are useful for students with slower speeds of processing and other LDs to accomplish educational goals and reduce the stress of time (Shaywitz, 1998). These new technological tools can be used to read the text aloud for the students.

Literacy Learning and Scientific Literacy

For LD students, literacy and fluency are challenges that are constantly at the forefront of their learning. Literacy refers to the ability to read information to gain meaning and create writing or text to express ideas. Fluency is the ability to accomplish these tasks easily and readily (Fang, 2005). Having a LD delays the process of reading and writing, which directly affects these two required skills for comprehension. This fundamental level of literacy presents a hurdle when learning content in any subject area (Wellington & Osborne, 2001).

Recent science reform focuses on the push for students to reach a level of scientific literacy to be educated members of society (DeBoer, 2000; Hurd, 1998). The current definition of scientific literacy focuses on the comprehension component and often overlooks the student's independent literacy skills and the importance of reading ability (Glynn & Muth, 1994). Science can be taught and understood through means beyond independent reading and writing, but these traditional methods of educating are most prevalent in classrooms throughout the world and can be very effective to reach scientific literacy if embedded in an inquiry-based, student-centered, multimodal curriculum (Glynn & Muth, 1994; Pearson et al., 2010). Independent reading and writing are not the only means to achieving scientific literacy but are often the major emphasis in learning for students in traditional classrooms (Fang, 2005). These fundamental literacy skills become increasingly demanding as students progress from primary school to the university level. It is commonly assumed by most teachers that middle or high school level students are literate and fluent (Norris & Phillips, 2003; Shanahan & Shanahan, 2008). This holds the key difference when trying to achieve scientific literacy with LD students. To achieve comprehension, these students have the challenge of overcoming their fundamental literacy and language difficulties (Wellington & Osborne, 2001).

To achieve scientific literacy, students go through a series of levels of fundamental literacy in the discipline to reach understanding of the content through reading and writing (DeBoer, 2000; Glynn & Muth, 1994; Shanahan & Shanahan, 2008; Swan & Goswami, 1997). Students need to grasp fundamental literacy, focusing on independent reading and writing skills, to be able to retrieve and convey information via text (Faggella-Luby et al., 2012; Fang 2005). Once students are able to independently read and write, the next level would be to apply these skills to the discipline, which is usually done in the classroom (Shanahan & Shanahan, 2008).

Being able to read expository scientific text and writing in the unique linguistic language of science can be the gateway to understanding science content and expressing scientific thought. If these fundamental skills are not strong, as with most LD students, they can struggle to achieve scientific literacy through reading and conveying their understanding in written form (Fang, 2005). Once the students have achieved this understanding, they will have the ability to express and understand science using the language, reading, and writing of the scientific discipline to make knowledgeable decisions as active, thoughtful members of the community (Faggella-Luby et al., 2012; Hurd, 1998).

A method to resolve this issue for LD students and assist them to achieve this scientific literacy and comprehension utilizes the support of assistive technology (Raskind, 2000). The goal for the current reform to achieve scientific literacy for all individuals, including LD students, can be made possible by utilizing audio technology to assist in learning. The purpose of this study is to assess the effectiveness of audio technology in curriculum to support students with LDs through the lenses of disability theory, technology use in education, and scientific literacy for all.

RESEARCH DESIGN

This study is grounded in a qualitative case study research design and supported by quantitative data to add weight and rigor (Creswell, 2007). A qualitative approach is used because each individual student is unique and the data collected are specific to that person. Adding the elements of rich narration and quantified statistics allows for transferability so the information and methods can be beneficial to other similar cases (Merriam, 2009). The design is very similar to a mixed methods study but will have greater emphasis within the qualitative component (Hoy, 2010). The numerical data analysis is used to explain and add to the qualitative information. Member checks, peer debriefing, and triangulation of research were also done to add rigor to the study (Stake, 2005).

The importance of utilizing both approaches in research is to fully capture the dynamic nature of educational research and the classroom environment. Using only one method leaves the research with unanswered questions pertaining to the depth of information collected for the study. A purely qualitative study leaves the reader wondering how the research presented would affect quantified tests often associated with and implemented in education. Using only quantified data leaves the reader with questions of the numerical results, especially when dealing with LD students, since their scores often inaccurately represent their cognitive ability and level. When both methods are used, the quantitative research is able to complement the qualitative methods and allow for thorough analysis (Creswell, 2007). This holistic approach is ideal when collecting data and research involving social sciences, such as education. More detail will be provided in the Data Collection Methods section later in this chapter.

Field Setting

The field setting was an independent K-12 school for students with a variety of language based LDs, including attention, memory, auditory/visual processing, and reading/writing difficulties. The school is located in a large urban city and has a diverse student body. All the students have an Individualized Education Program (IEP) and are taught using methods appropriate for their unique learning needs. The students at this school are held to the same educational expectations and standards as their non-LD counterparts but with special accommodations (Turnbull et al., 2006). The method of purposeful sampling was used to acquire the students as participants for this study. Choosing LD students with dyslexia and other LLIs provided specific and information-rich cases based on the data collected (Stake, 2005). No proper names were used in this study in order to ensure participant anonymity. All actual names were replaced by pseudonyms and/or coded with numbers.

Participants

Students with LD

The participants were thirty-six seventh grade students between the ages of 11 and 13 years. The students were both male and female and represented a diversity of races and ethnicities. The study had no attrition because the field school has a set LD program, which requires the students to stay the full year if accepted. On occasion, during the pretest and posttest portion of the study, some students were absent but completed the task upon their return to school and continued with the curriculum.

Since it was a purposeful sample, all the students have some form of language LD, which affects their progress at a mainstream school. The students have a range of LDs that require different techniques to support their learning needs. With LDs being such a broad category, many of the students exhibit one or more differences and range in skill and ability (Shaywitz, 1998). The major LD is Dyslexia, but students may also exhibit other LDs, such as Dysgraphia, Attention Deficit Hyperactive Disorder (ADHD), delayed auditory and visual processing, and executive functioning struggles. All the students are labeled in their IEP as LD and the specific type of LD is not identified or available to the researchers.

All grades are split into three classes of twelve students that are heterogeneously mixed by race, gender, and ability. Hence, each grade consists of thirty-six students, so for the quantified data, N=36. For the qualitative interviews and reading assessment, ten students were randomly selected for short interviews.

Classroom Teacher

The teacher, Ms. M, is an experienced fifth year middle school science teacher and has her M.A. in Science Education from an accredited university. She is also New York State (NYS) certified in secondary science education with an extension in special education. Her teaching experience has predominantly been at the field school, but Ms. M has done observations and taught at other schools and educational settings. She has been trained in teaching the curriculum using the iBook program on the iPad as well as many other apps, software, and educational technology. Since the pretests and posttests were a part of the units within the curricula, Ms. M administered this portion of the study. She guided the specific units that were part of the study and gave the instructions on how to use the audio iBooks.

The Researchers

The first author for this study has been working in the middle school science department at the field school for over eleven years. During the first eight years, the he has taught sixth grade chemistry, seventh grade life science, and eighth grade physical science. He is currently the Department Coordinator of Middle School Science at the school and works closely with the middle school staff to develop curriculum, teach, and observe. For this study, only the designated teacher, Ms. M, did all the classroom teaching and instruction. The role of the first author in the classroom was to record observations when the students were utilizing the audio technology. He also conducted all the interviews with the specific students, parents, and teachers involved in the study. The second author served as a debriefer throughout the study, from design to analysis to writing (Spillett, 2003).

Assistive Technology Materials and Research Procedures

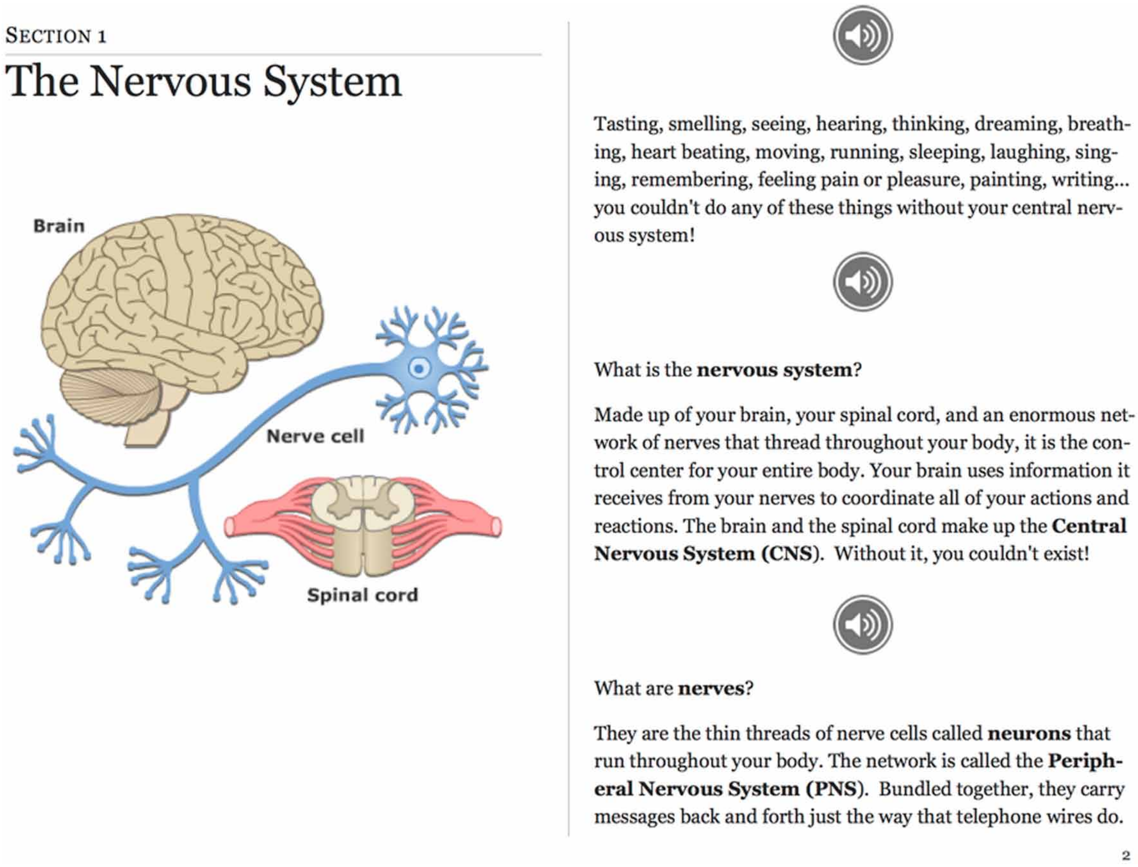
The technology for this study involved using audio iBooks on the iPad. The iBooks were embedded into the current seventh grade Biology curriculum that had been taught for over five years at the school. The audio technology modifications of the readings were provided to all the seventh grade students. Three passages were chosen that were of similar level and science topic area from the same book series. The science passages were on three different body systems: the Nervous, Cardiovascular, and Respiratory Systems. The passages were retyped, edited, and modified to create an iBook for each body system using Apple's iBook Author software. After the books were created, audio recording were done for each of passages using the GarageBand software, the internal microphone on the MacBook Pro, Harman/Kardon portable computer speakers, and a pair of Apple earphones.

Two sets of recordings were done of the passages for each unit. One set of audio was of natural voice recordings done while the reader read each passage aloud. The other set comprised automated recordings of the computer voice reading the same passages. These passages were done at the same volume, arrangement, pace, and voice, and used the same equipment every time to keep each audio recording as consistent as possible. The audio files were then edited and clipped by paragraph and embedded into the specific iBook body systems readings. Two teachers and one peer researcher reviewed the iBooks for errors, consistency, and flow.

The students were all given the same model Sony MDR-222KD headphones when listening to the audio on the iBook. Volume was not controlled, as it would be too difficult to monitor, and everyone has a difference preference in loudness. As long as the track was audible, differences in volume should not have affected the results. All the students involved were part of a one-to-one iPad program that began at the beginning of the school year. By the time the students began using the iBooks developed for this study a few months later, they were adept with the features of the iPad. This reduced the learning curve and extra time needed for the students to understand how to use the technology when utilizing the audio iBooks for the research. The iBook was simple to use in which the students opened the app by clicking the icon on their iPad screen followed by clicking the iBook icon for that unit. Once the iBook was open a circular symbol of a speaker with sound waves can be found above each paragraph. When the students tapped on the symbol the audio would read aloud the paragraph. The control iBooks without audio looked the same but lacked this speaker symbol above each paragraph. Figure 1 is a sample of an iBook page from the nervous system unit.

Students were also provided a blank fillable T chart in PDF format to allow them to take notes on the reading. A sample of the T chart can be found in Appendix 1. They used the Notability app on their iPad to write or type notes into the T chart on each of the body system readings. This allowed them to document their learning and to add support to the study with written reflections of their understanding when utilizing the audio iBook technology. The pretests and posttests were typed on the computer, printed, and photocopied. The students were given hard copies on paper to complete and submit to the teacher. Modifications were offered to the students for reading and scribing.

Figure 1. Sample iBook from nervous system unit



SECTION 1

The Nervous System

Tasting, smelling, seeing, hearing, thinking, dreaming, breathing, heart beating, moving, running, sleeping, laughing, singing, remembering, feeling pain or pleasure, painting, writing... you couldn't do any of these things without your central nervous system!

What is the **nervous system**?

Made up of your brain, your spinal cord, and an enormous network of nerves that thread throughout your body, it is the control center for your entire body. Your brain uses information it receives from your nerves to coordinate all of your actions and reactions. The brain and the spinal cord make up the **Central Nervous System (CNS)**. Without it, you couldn't exist!

What are **nerves**?

They are the thin threads of nerve cells called **neurons** that run throughout your body. The network is called the **Peripheral Nervous System (PNS)**. Bundled together, they carry messages back and forth just the way that telephone wires do.

2

Table 1. Randomization of audio technology by class

2 Week Topics	Class 1	Class 2	Class 3
Nervous System	No Audio	Automated Voice Audio	Natural Voice Audio
Circulatory System	Natural Voice Audio	No Audio	Automated Voice Audio
Respiratory System	Automated Voice Audio	Natural Voice Audio	No Audio

The heterogeneous student groupings for each of the three classes that were decided by the faculty prior to the study were not reorganized. Since the audio technology was embedded into the curriculum all the students had to learn the content from each of the units. Also, since it was a paired study all the students had to experience the iBook lacking audio (control) and the iBooks with the automated and natural voice audio technology. The goal was to create the least amount of disturbance to the students' schedules, class groups, and curriculum other than the addition of the audio technology. Table 1 shows the randomization of the audio technology by class to ensure all this was possible.

DATA COLLECTION METHODS

Qualitative Design

The methods of data collection for the qualitative case study component of the research consisted of interviews with ten students, formal and informal observations/ field notes, and analysis of written artifacts. Semi-structured interviews were done with ten randomly selected students from the group to learn more about the challenges they have in science and literacy. The interviews were done to gain further insight on the students' unique styles of learning in order to assist them. The interview questions can be found in Appendix 2. Follow-up interviews were conducted to learn about the students' views after using the audio technology (Appendix 3). Each interview lasted approximately 15 to 20 minutes. The interviews were audio-recorded, transcribed, stored as digital files, and reviewed thoroughly. The same questions were used as a guide for each interviewed student.

Formal and informal observations/field notes of the students were done, and field notes were taken during regular class periods to find a base line. Observations were also done of the classes while the students were using each form of iBook. Each observation was approximately 40 minutes long for each class period and done over a three-month period. The observations and field notes were recorded in writing and stored in digital format.

Artifacts such as pretests and posttests and T chart graphic organizer note sheets were reviewed to observe written and comprehension difficulties and any other struggles the students had. The students whose artifacts were reviewed were the same ten students that were interviewed.

Quantitative Design

The quantitative portion of the research is a quasi-experimental designed paired study based on data from pretests and posttests before and after the seventh grade students used each form of audio technology. A total score of ten points was possible as questions one through six were valued at one point each and questions seven and eight were two points. An analysis of covariance (ANCOVA) adjustment of the posttest scores using the pretest sores as predictors was done, thus controlling statistically for any differences in the pretest scores between the control and experimental groups.

There were a total of thirty-six students involved in the quantitative component of the study; these were all students in the three seventh grade classes. The technology for this phase of the study was the addition of the different types of audio technology for the students to listen and read about three different body system units on the iBook: Nervous, Circulatory, and Respiratory. The technology was embedded into the yearly curriculum so all students took part in the study. Since this is a paired study, all the students were included in all three sets of pretests and posttests: no audio, automated voice, and natural voice (Hoy, 2010). The three body system units were relatively the same length, reading level, content focus, and presentation style. The students took an untimed eight-question pretest that took them approximately ten minutes to complete. After using the iBook technology, the students took the same eight-question pretest as the posttest. This procedure was repeated for each iBook unit for the study. The three classes had the treatments given at different times to randomize the tests, unit order, and students as shown on Table 1.

DATA ANALYSIS

Both qualitative and quantitative data analyses were done for this study. First, an analysis was conducted of the qualitative interviews and observations of the students using the iBook program with and without the audio. This information helped to gain a holistic view on the technology by adding depth to the numerical data collected. All the interviews and observations done while the students completed the reading tasks on their iBooks. All interview were coded and analyzed in search of emergent themes (Hoy, 2010). Coding of interviews was done by first reading the transcribed information three times. During the fourth review, notes and highlighting were entered directly on the digitally transcribed interviews. Coding was done using colors to identify different key components for each interview and observation, and annotations were written. Blue highlighting identified ideas/suggestions, red highlighting identified key words/content, and green highlighting identified feelings/emotions. Once the color-coding was done, the information was compiled into a chart with responses for key emerging themes (Creswell, 2007). This process required recording the key responses under each emerging theme. As each interview was reviewed, if new responses led to new themes, they were added to the chart. This organized chart led to further understanding of the students' challenges with learning and their views on technology for learning through analysis.

Second, once each set of quantified data was collected, several mathematical calculations were done to analyze the data for statistical significance. The gain scores were calculated from the raw data of each set of pretests and posttests of the non-audio, automated, and natural voice iBook results to measure the students' learning gains. The nominal data were then analyzed further using ANCOVA to compare the non-audio and automated voice audio test scores (Hoy, 2010; Mendenhall, Beaver, & Beaver, 2006). Following parametric statistical methods leads to more accurate and precise estimates of the information collected (Mendenhall et al., 2006).

RESULTS

Quantitative Findings

The results of the pre- and posttests of this study show informative statistical results when using ANCOVA to compare the non-audio to the automated voice audio. ANCOVA has more statistical power because it decreases within group error (Field, 2012), and in this research more particularly provided a means of controlling for any differences in the pre-test scores between treatment and control groups. This is more applicable in educational research and makes for a more rigorous study. Table 2 presents the pretest means, posttests means, and ANCOVA adjusted posttest means for the non-audio and automated audio voice for the three iBook units.

The *p* value used of the study was less than or equal to 0.05 (95% confidence interval) with a total n = 24. Since it was a paired study, the 12 students in each class completed both the pretest and posttest for each unit. Table 3 presents the ANCOVA data for the non-audio and automated voice audio pretest and posttest results.

Based on the statistical analyses, it is apparent that the audio technology did not have a statistically significant effect on student learning compared to the control for either the respiratory system or circulatory system (F = 1.25, df = 1, $p = 0.28$; F = 2.21, df = 1, $p = 0.15$, respectively). The audio technology used for the nervous system, on the other hand, did have a statistically significant effect (F = 5.34, df = 1, $p = 0.03$).

An analysis of the mean scores of the non-audio and automated voice for each unit shows that the respiratory system and circulatory system pretest mean scores were high, so the students were already fairly knowledgeable in the content prior to using the audio iBooks. The average of the non-audio and

Table 2. Pretest means, posttest means, and ANCOVA adjusted posttest means for the non-audio and automated voice audio for each iBook unit

iBook Unit	Pretest Means	Posttest Means	ANCOVA Adjusted Posttest Means
Respiratory System Non-Audio	48.64	59.55	59.25
Automated Voice	47.73	66.82	67.12
Circulatory System Non-Audio	34.17	61.25	59.79
Automated Voice	28.75	49.17	50.62
Nervous System Non-Audio	19.09	45.00	46.47
Automated Voice	29.55	63.18	61.71

Table 3. ANCOVA results comparing between non-audio and automated voice audio pretest and posttest

iBook Unit	SS & MS	df	F	P
Respiratory System	340.49	1	1.25	0.28
Circulatory System	496.43	1	2.21	0.15
Nervous System	1108.97	1	5.34	0.03

automated voice pretest mean scores from Table 2 for the respiratory system and circulatory system were 48.19 and 31.46, respectively. Examining individual data shows that the scores were substantial initially for the circulatory and respiratory topics, which indicates that the control was not particularly less able. This affected the gain scores for these two units. The students were familiar with the content; hence their initial means were higher.

The average of the non-audio and automated voice from Table 2 for the nervous system control group was 24.32. Comparing the average pretest means scores of the three units, we can see the students were initially less familiar with the content in the nervous system unit. The data from the pretest score show that the students possessed less initial knowledge, and, moreover, the nervous system may have had more difficult content to learn. This could have led to a greater statistical significance between the pretest and posttest results for the audio technology treatment, especially if it provided affordances to support LD student learning. It is also possible that, beyond the language and vocabulary of each unit, the students have greater familiarity with the overall concept of the circulatory and respiratory system as opposed to the nervous system. This prior understanding could have also impacted the high pretest scores for those two units.

Table 4 provides a sample of some of the vocabulary words from each of the three body system units. The vocabulary words found in the nervous system unit are less commonly used in everyday language, whereas the vocabulary in the circulatory and respiratory system units is more prevalent in colloquial conversation (Fang, 2005). This provides the students with familiarity and a stronger understanding of the words from those two units, leading to higher pretest scores and smaller learning gains when compared to the nervous system unit. Some of the nervous system words also do not follow the phonetic rules, such as peripheral and hypothalamus. This can increase the difficulty for LD student to decode, pronounce, and remember the words (Swanson, 1999).

The statistical results from this study show that using audio technology can lead to higher learning gains for LD students, especially when the content is less familiar and/or more demanding. It is possible that the experimental group was more capable but this was a paired study and the ANCOVA partially adjusted for this possibility based on the pre-test predictor variable (Field, 2012).

Qualitative Findings

The results obtained below relate to the participant information collected from the interviews and observations. To fully explore the possible complexities of learning the more challenging nervous system

Table 4. Sampling of vocabulary words found in each body system unit, exhibiting the comparative variations in word difficulty among the three systems

Respiratory System	Circulatory System	Nervous System
Lungs	Heart	Myelin
Diaphragm	Blood	Neurons
Trachea	Arteries	Hypothalamus
Bronchi	Veins	Peripheral
Oxygen	Capillaries	Axons
Alveoli	Plasma	Dendrites

content, interview data were obtained to gain insight into the students' observations about the learning experiences.

Challenges with Science Words

Initially, to understand LDs from personal and individual perspectives, students were asked what areas of learning science they struggled with. Some of the challenges expressed by the LD students on learning science focused on the words rather than the content. This was an overarching theme among all the students that were interviewed. The issues they brought up included pronunciation, reading and decoding, unfamiliar and multisyllabic science terminology, and spelling.

When asked about challenges with school and learning, Jenny described that "learning all of the new vocabulary words and trying to remember them in the amount of time" can be difficult for her. Tom, Max, and Matthew brought up difficulties with reading. Max stated, "I struggle in English…. Just reading specifically." The students' main hurdle before tackling the concepts and ideas in science was the fundamental ability to read material independently at an age-appropriate level (Shanahan & Shanahan, 2008; Wellington & Osborne, 2001). With their language-based LDs, and additionally the unfamiliar and complex language of science, the students faced a large obstacle to overcome before they could grasp the concepts and processes when reading independently to learn science content (Fang, 2005; Rivard, 2004). Oftentimes, these same students also struggled with time management, task organization, and attention. When the students struggled with reading and understanding words, it slowed the pace of their learning, which in turn affected their stamina and desire to learn about the topic (Gomes & Mensah, 2013). The students' attention drifted and caused them to become further removed from the learning process. Max described that "if the class is really long and kind of going a slow pace, it's like you're not really engaged in it and you're kind of zoning out sometimes. That's sometimes hard to stay focused." Consequently, the students' language struggles can lead to a dislike of science due to the uncommon and complex language of the content.

When the students were asked how they felt about science, it seemed that Ms. M had been utilizing her skills to ensure that the students' LDs and associated challenges did not negatively influence their views on science. She provided supports to enhance learning of science without students feeling burdened by the lexically unique language (Faggella-Luby et al., 2012). Kerry described science in comparison to other school subjects, stating, "It teaches you about the world and it teaches you a lot of things that I think are useful. It feels like it's open, not like as restrictive as English or math, it's open, and ... that's why I really like it."

But the language component of science can be grueling for LD students (Fang, 2005). When asked about understanding new science vocabulary, the students' responses expressed difficulty, as may be expected due to their language-based LDs. "A lot of the words are very tongue-twisty and hard to say, and you have to go over it and over it again", Kerry stated. Jenny expressed that "you might not understand exactly what the words mean. If you can't really pronounce them, it can be a struggle." The students were describing the unfamiliarity and difficulty of the terminology, which can cause delays when learning science (Fang, 2005; Norris & Phillips, 2003). However, the audio technology provided certain supports not available in other formats. For example, with a simple click, the students were able to define the words within the iBook audio program or use the Internet to search lexical and semantic information (Ramus, 2003). When taking the posttests after completing the readings, Trevor asked, "Does spelling count?" to which Ms. M said, "No, just sound it out." Then in a low voice Trevor responded, "But I forgot how to pronounce it." Trevor may be at a disadvantage on the posttest because he cannot pronounce the word. Among other contributory factors, he may either get the incorrect answer or get frustrated and leave it blank. Alas, if he had the audio for the test, he would be able to hear and pronounce the words to respond with the correct answer.

The students expressed that it did not have to do with the difficulty of the concepts but their struggle with the language and pronunciation of the words (Wellington, & Osborne, 2001). Tucker stated, "I don't think the concept is difficult. I find learning the pronunciation difficult." The difficulty of the language leads to a breakdown in understanding. The time it takes for the students to learn the words leads them to even forget the meaning or concept. Factors such as time constraints, short-term memory issues, and conscious awareness can also play into the struggle with understanding the information presented (Ramus & Szenkovits, 2008). Matthew described, "Some of them, they are really big words and I really don't know how to pronounce them and I forget the meanings sometimes." The focus of their mental energy is spent on reading rather than understanding the concepts (Ramus & Szenkovits, 2008; Richardson et al., 2004). The students' focus on the pronunciation of the words ties back to the phonological deficit hypothesis for dyslexia and other LDs (Shaywitz, 1998, 2003; Swanson, 1999). For LD students, there is a strong need to hear the pronunciation of the words to help them read and understand the vocabulary. These LD students expressed their auditory needs to better understand the meaning and content of the science words they are learning.

Techniques for Learning Science Words

When asked what the students do to help them learn and remember new words, they described some techniques, such as repetition, reading aloud, and rewriting. Most of the students said that when they are having difficulty with a word, they read it again audibly to themselves. Max said, "Yes, not super loud, a little. I could hear myself," and Jenny also described, "A really difficult paragraph I read it to myself." Kerry stated, "When I'm reading subtext, for example, and I don't understand a chapter, I have to read it out loud." To get a thorough understanding, Kerry and her fellow LD classmates reread words aloud to hear and understand the information. Max described, "Once you keep looking at them and read them, it just becomes easy and comes back into your memory." Mark said that when he is taught new science vocabulary, it is helpful for him to "write them down on a piece of notepaper." Similarly Tom stated, "It helps me to write them out maybe even more than once, and then to read over them." This research focuses on the students' need for reading aloud and hearing the pronunciation of words to better understand and reach scientific literacy in the broadest sense. Tom described his challenge with reading, stating, "I find reading difficult, which has been hard for me for a while now, and my time management has been also hard for me."

The addition of the audio technology for use with expository science text can bridge the gap that exists for these students to attain and enjoy science without struggling through their language LDs. The addition of the audio technology gave the students the support needed to learn the words without feeling dependent on others to read for them (Gomes & Mensah, 2013). The audio technology ameliorated the major challenges the students identified, such as pronunciation, repetition, and even finding the meaning of the words. The technology allowed the students to hear the properly articulated auditory version of the science vocabulary they were attempting to learn. It also allowed them to repeat the words as many times as they felt necessary to grasp the phonology.

Connecting quantitative data with the aforementioned qualitative results, it is apparent that there is a clear correlation between the students' science content learning outcomes in the treatment and the analysis of interview data. The significant outcome of the ANCOVA for the nervous system ($F = 5.34$, $df = 1$, $p = 0.03$) provides support for the hypothesis that audio technology can be beneficial for LD students in learning new science vocabulary and concepts, especially when the language of science is more demanding (Fang, 2005). Some of the following qualitative findings lend credence to this interpretation. The learning outcomes for topics on the cardiovascular ($F = 2.21$, $df = 1$, $p = 0.15$) and respiratory ($F = 1.25$, $df = 1$, $p = 0.28$) systems, on the other hand, did not show a statistically significant effect. Students were able to use the mediating role of semantics to link the linguistically unique vocabulary of science to gain an understanding of the content (Fang, 2005). By being able to hear the words and connect them with their meanings, the LD students were able to gain stronger disciplinary understanding of the language of science to further develop the linkages and associations necessary to lead to learning that goes beyond just that of content knowledge (Shanahan & Shanahan, 2012).

The use of the T chart allowed the students to engage, reflect, and document their process of learning while using the audio technology. The interviews and classroom observations revealed that the students expressed some distinct differences and preferences in their use of audio technology. Discussions of the content after using each type of iBook showed strong student support of the need for audio technology.

When Ms. M asked questions about the content, the students' responses were also recorded and analyzed as a means of enriching the interpretation of the interview and observational data. It was apparent from the observations of the students and the pretest scores they were not as familiar initially with the nervous system content, and the students' responses helped to clarify these findings. When reviewing the information after reading, it was apparent the students struggled most with the pronunciation of the nervous system unit vocabulary. Abby explained, "Part of the central nervous, and how do you say per… if…." She tried to enunciate, and Ms. M helped her by slowly pronouncing out the word "peripheral." When told to highlight the key information from the nervous system text, Amber stated, "For this one [reading] I am going to end up highlighting the entire reading." In another class, while asked about the peripheral nervous system, Judy said it's "something with P-H." As soon as she said that, Aaron used the audio feature on the iPad to make it say "peripheral" aloud, and the class started laughing. This observation in itself showed the benefit of the audio. Judy knew the correct answer, though she struggled to articulate and pronounce the word, but she was assisted by the audio technology. This identifies the challenge for these students is not with the concepts but the vocabulary of science.

DISCUSSION OF FINDINGS

Using a qualitative approach supported with quantified data, this study presents the benefits of using audio technology for students with language-based LDs and is supported with recent and relevant research. Research on the phonological deficit hypothesis presented by Swanson (1999), Swan and Goswami (1997), and Shaywitz (1998, 2003) is addressed and amplified in this study by supplementing reading material presented to the students with audio support. This research provides additional evidence to support the phonological deficit hypothesis and shows the importance of auditory presentation of text information for LD students (Shaywitz, 1998, 2003; Swan & Goswami, 1997; Swanson, 1999). The results from the study support the use of audio technology to ensure LD students are provided the same opportunities to learn and understand science as the mainstream cohort. Providing audio iBooks on the iPad emphasizes the importance of utilizing technology as a learning and assistive tool for all students, including those with an LD (Songer, 2007).

The benefits of audio technology the students described during their interviews and based on observations include the ability to hear the words as they are perceived in the text so that the students can properly parse the text and learn the proper pronunciation, thus leading to more proficient comprehension and recall. The students struggle with word recognition (parsing the words) and not comprehension during reading. By having the words read aloud, they can learn the proper pronunciation and meaning of science vocabulary. In addition to hearing the words, students are able to click on the word for definitions, leading to quicker provision of the information to support their understanding. They also have access to the Internet to allow them to search additional background information, such as examples and images, to add to their learning. All of this additional information can be read aloud to them using the audio technology on their iPads (Ramus, 2003). Having the students actively listening to audio and engaging with the iPad, reflecting what they learned by completing the digital T charts, concluding the information during the whole class discussion guided by Ms. M, and finally planning the next steps by repeating use of the audio assistive technology with future readings, a learning cycle is developed to help them learn using more than just the common method of rote independent reading (Mumford, 1997).

The findings reveal the nervous system had the greatest significant learning gains when analyzed using ANCOVA, showing that LD students can learn more vocabulary when using audio technology for unfamiliar and complex science language. Several factors have to be considered when reviewing these results. One major component is that the students were less familiar with the content and vocabulary of the nervous system, yielding a lower pretest mean score as opposed to the respiratory and circulatory system units. This information does not mean students cannot benefit from using audio technology for less challenging written science content. Their initial familiarity with the content of the unit from prior learning and everyday knowledge rendered the students with higher pretest scores, decreasing the opportunity to make larger strides, which reduced the learning gains to provide insignificant results. When the data are revisited on Table 2, it is apparent that learning was occurring for all three units, as there was an increase in mean posttest scores, but just not to the degree for the ANCOVA to identify the respiratory and circulatory data as significant. Further research should be done with students who have very little to no exposure to respiratory and circulatory system vocabulary and content to see if audio technology is beneficial for less difficult science topics.

One of the bigger challenges for LD students is sufficient time to process information (Ramus & Szenkovits, 2008; Shaywitz, 2003; Swanson 1999). Using audio technology eases the burden of time to allow for faster auditory information processing and makes the effort of reading more efficient and effective. It also makes the learner more independent and allows her/him to feel capable when accomplishing reading tasks without requiring support from others, such as having someone else read to them. For example, watching Tom read was an eye-opening experience. The amount of patience and endurance it took him to read a sentence showed his true motivation to learn. While others would give up, Tom was patient and remained focused while he slowly articulated each word and reread the sentences until he fully understood what was being presented. The support from audio technology drastically improves the learning process for hard-working and motivated LD students like Tom.

IMPLICATIONS AND CONCLUSION

This study focused on evaluating audio supports and technology tools to assist LD students with learning science. It provides evidence to support the benefits of using audio technology to help LD students read science text. Through quantitative data, supported by qualitative evidence, including the students' perceptions of their learning challenges, evidence was obtained to demonstrate the merits of using audio technology for LD students. This holistic approach provides novel classroom-based evidence to augment prior reported findings that audio technology may aid text-based learning by LD students. In addition, this approach adds weight to the arguments and promotes the importance of developing more audio technology for expository science education to support learning by LD students.

Based on the interview findings, in general the students described their struggles with pronouncing, reading, processing, and decoding words, especially multisyllabic and unfamiliar science terminology. They explained that reading the words out loud or having someone else read to them was a more effective way to learn the content. Moreover, based on the quantitative portion of this study, it appears that audio-enhanced reading of text material was particularly effective when the content was more demanding, as evidenced by the significant gains with the neuroscience content. After using the audio iBooks on the iPad, the students described the many ways they found the technology helpful. They expressed that their struggle is not with understanding the content but reading it, and the audio technology allows them to overcome that struggle. By listening to the science text, LD students are able to pronounce the words, which can lead to greater comprehension. Another major factor is the time it takes to read. The audio technology allows them to accomplish this task with more efficiency while also giving them the benefit to repeat the information with a simple tap. They also described the additional benefits of technology with the ease to access information by looking up the definitions on apps or the Internet.

REFERENCES

American Association for the Advancement of Science (AAAS). (1998). *Blueprints for reform science, mathematics, and technology education.* New York, NY: Oxford University Press.

Carlisle, J. F., Fleming, J. E., & Gudbrandsen, B. (2000). Incidental word learning in science classes. *Contemporary Educational Psychology*, *25*(2), 184–211. doi:10.1006/ceps.1998.1001 PMID:10753546

Center for Applied Special Technology. (1999). *Universal design for learning.* Retrieved from http://www.cast.org/udl/

Center for Universal Design. (2008). *The principles of universal design.* Retrieved from http://www.ncsu.edu/ncsu/design/cud/

Creswell, J. W. (2007). *Qualitative inquiry and research design: Choosing among five approaches.* Thousand Oaks, CA: Sage.

DeBoer, G. E. (2000). Scientific literacy: Another look at its historical and contemporary meanings and its relationship to science education reform. *Journal of Research in Science Teaching*, *37*(6), 582–601. doi:10.1002/1098-2736(200008)37:6<582::AID-TEA5>3.0.CO;2-L

Faggella-Luby, M. N., Graner, P. S., Deshler, D. D., & Drew, S. V. (2012). Building a house on sand: Why disciplinary literacy is not sufficient to replace general strategies for adolescent learners who struggle. *Topics in Language Disorders*, *32*(1), 69–84. doi:10.1097/TLD.0b013e318245618e

Fang, Z. (2005). Scientific literacy: A systemic functional linguistics perspective. *Science Education*, *89*(2), 335–347. doi:10.1002/sce.20050

Field, A. (2012). *Discovering statistics using SPSS*. New York, NY: Sage.

Glynn, S. M., & Muth, K. D. (1994). Reading and writing to learn science: Achieving scientific literacy. *Journal of Research in Science Teaching*, *31*(9), 1057–1073. doi:10.1002/tea.3660310915

Goldsmith, S. (1963). *Designing for the disabled.* Newcastle upon Tyne, UK: RIBA Publications.

Gomes, C. V., & Mensah, F. M. (2013). The impact of technology on students with disabilities achieving scientific literacy. *EDULEARN13 Proceedings, 5,* 4817-4826.

Hoy, W. K. (2010). *Quantitative research in education: A primer*. Thousand Oaks, CA: Sage.

Hurd, P. D. (1998). Scientific literacy: New minds for a changing world. *Science Education*, *82*(3), 407–416. doi:10.1002/(SICI)1098-237X(199806)82:3<407::AID-SCE6>3.0.CO;2-G

Lovett, M. W., Borden, S. L., DeLuca, T., Lacerenza, L., Benson, N. J., & Brackstone, D. (1994). Treating the core deficits of developmental dyslexia: Evidence of transfer of learning after phonologically and strategy-based reading training programs. *Developmental Psychology*, *30*(6), 805–822. doi:10.1037/0012-1649.30.6.805

Mendenhall, W., Beaver, R., & Beaver, B. (2006). *Introduction to probability and statistics* (12th ed.). Belmont, CA: Thompson Brooks/Cole.

Merriam, S. B. (2009). *Qualitative research and case study applications in education* (3rd ed.). San Francisco, CA: Jossey-Bass.

Mumford, A. (Ed.). (1997). *Action learning at work*. Farnham, UK: Gower.

National Research Council. (2012). *Next generation science standards.* Retrieved from http://www.nextgenscience.org

Norris, S. P., & Phillips, L. M. (2003). How literacy in its fundamental sense is central to scientific literacy. *Science Education*, *87*(2), 224–240. doi:10.1002/sce.10066

Pearson, P. D., Moje, E., & Greenleaf, C. (2010). Literacy and science: Each in the service of the other. *Science*, *328*(5977), 459–463. doi:10.1126/science.1182595 PMID:20413491

Ramus, F. (2003). Developmental dyslexia: Specific phonological deficit or general sensorimotor dysfunction? *Current Opinion in Neurobiology*, *13*(2), 212–218. doi:10.1016/S0959-4388(03)00035-7 PMID:12744976

Ramus, F., & Szenkovits, G. (2008). What phonological deficit? *Quarterly Journal of Experimental Psychology*, *61*(1), 129–141. doi:10.1080/17470210701508822 PMID:18038344

Raskind, M. (2000). *Bridges to reading*. San Mateo, CA: Schwab Foundation for Learning.

Richardson, U., Thomson, J. M., Scott, S. K., & Goswami, U. (2004). Auditory processing skills and phonological representation in dyslexic children. *Dyslexia (Chichester, England)*, *10*(3), 215–233. doi:10.1002/dys.276 PMID:15341199

Rivard, L. P. (2004). Are language-based activities in science effective for all students, including low achievers. *Science Education*, *88*(3), 420–442. doi:10.1002/sce.10114

Salvia, J., Ysseldyke, J. E., & Bolt, S. (2010). *Assessment in special and inclusion education* (11th ed.). Belmont, CA: Wadsworth, Cengage Learning.

Shanahan, T., & Shanahan, C. (2008). Teaching disciplinary literacy to adolescents: Rethinking content-area literacy. *Harvard Educational Review*, *78*(1), 40–59. doi:10.17763/haer.78.1.v62444321p602101

Shanahan, T., & Shanahan, C. (2012). What is disciplinary literacy and why does it matter? *Topics in Language Disorders*, *32*(1), 7–18. doi:10.1097/TLD.0b013e318244557a

Shaywitz, S. (1998). Dyslexia. *The New England Journal of Medicine*, *338*(5), 307–312. doi:10.1056/NEJM199801293380507 PMID:9445412

Shaywitz, S. (2003). *Overcoming dyslexia*. New York, NY: Random House.

Songer, N. (2007). Digital resources versus cognitive tools: A discussion of learning science with technology. In S. Abell & N. Lederman (Eds.), *Handbook of Research in Science Education* (pp. 471–492). Mahwah, NJ: Erlbaum.

Spillett, M. A. (2003). Peer debriefing: Who, what, when, why, how. *Academic Exchange Quarterly*, *7*(3), 36–41.

Stake, R. (2005). Qualitative case studies. In N. K. Denzin & Y. S. Lincoln (Eds.), *The Sage handbook of qualitative research* (pp. 443–466). Thousand Oaks, CA: Sage.

Swan, D., & Goswami, U. (1997). Phonological awareness deficits in developmental dyslexia and the phonological representations hypothesis. *Journal of Experimental Child Psychology*, *66*(1), 18–41. doi:10.1006/jecp.1997.2375 PMID:9226932

Swanson, H. L. (1999). Reading comprehension and working memory in learning-disabled readers: Is the phonological loop more important than the executive system? *Journal of Experimental Child Psychology*, *72*(1), 1–31. doi:10.1006/jecp.1998.2477 PMID:9888984

Tallal, P., Merzenich, M. M., Miller, S., & Jenkins, W. (1998). Language learning impairments: Integrating basic science, technology, and remediation. *Experimental Brain Research*, *123*(1-2), 210–219. doi:10.1007/s002210050563 PMID:9835411

Thompson, J. R., Bakken, J. P., Fulk, B. M., & Peterson-Karlan, G. (2004). *Using technology to improve the literacy skills of students with disabilities.* Retrieved from North Central Regional Educational Laboratory: http://www.learningpt. org/pdfs/literacy/disability.pdf

Turnbull, R., Huerta, N., & Stowe, M. (2006). *The Individuals with Disabilities Education Act as amended in 2004*. Upper Saddle River, NJ: Pearson Education.

Wellington, J., & Osborne, J. (2001). *Language and literacy in science education*. New York, NY: McGraw-Hill International.

KEY TERMS AND DEFINITIONS

Assistive Technology: Technology tools provided to individuals with disabilities to allow them to complete tasks independently and with greater efficiency than without.

Audio Technology: Technology that is able to provide information aurally to individuals.

iPads: A touch screen tablet marketed by Apple Inc. that can be loaded with apps to perform similar functions as those of a computer.

Learning Disabilities: A classification of disabilities in which a person is unable to learn in a specific manner.

Phonological Deficit Hypothesis: The explanation that students with language learning impairments such as dyslexia struggle with connecting the visual letters to the corresponding sounds of the language.

Science Education: The teaching of science to individuals that lack knowledge of the content and principles within the subject.

Scientific Literacy: The clear understanding of science to allow an individual to make personal decisions, have an understanding of the world around them, and be able to engage in decision making that can impact society.

APPENDIX 1

Box 1. T Chart used for taking written notes while reading from iPad

Vocabulary/ Main Idea	Details

APPENDIX 2

Semi-structured interview questions before technology use.

Student Interview Questions

1. What do you find difficult about school and learning?
2. What do you struggle with?
3. Explain if you like or dislike science and why?
4. Do you find learning new science words, vocabulary, and concepts difficult? If so, what do you find difficult about it?
5. What do you do to help you learn and remember new words, ideas, and topics in science or other subjects?

6. Do you use any technology to help you learn? Which ones do you or have you used and how is it helpful?
7. Is there anything else you'd like to say about learning science and/ or using technology to learn?
8. Anything other questions or comments?

Adult Interview Questions

1. How old is your child? How long have you known this student?
2. What do you think your child/ the student finds difficult about school and learning?
3. What do you think your child/ the student struggles with in school?
4. Do you think your child/ the student likes or dislikes science and why?
5. Does your child/ the student seem to find learning new science words, vocabulary, and concepts difficult? If so, what do you notice he or she finds difficult about it?
6. What do you do to help your child/ the student learn and remember new words, ideas, and topics in science or other subjects?
7. Do you use any technology to help your child/ the student learn? Which ones do you or have you used and how is it helpful?
8. Is there anything else you'd like to say about your child/ the student's learning in science and/ or using technology to learn?
9. Anything other questions or comments?

APPENDIX 3

Semi-structured interview questions after technology use.

Student Interview Questions

1. Now that you are able to listen to the science textbook on audio format on the iPad what are some things that you find helpful?
2. Did you find anything difficult?
3. Would you change anything about the technology?
4. Do you want to continue using it?
5. Do you prefer books on audio?
6. Which format of audio book did you prefer: Natural voice or automated voice?
7. Do you read aloud?
8. Do you think being able to hear the textbook will affect your learning in science?
9. Is there anything else you'd like to say about learning science and/ or using technology to learn?
10. Anything other questions or comments?

APPENDIX 4

Pretest and posttest questions for each body system unit.

Nervous System

1. What is the major organ of the Nervous system?
2. What does the nervous system control?
3. What is a nerve?
4. How is information passed from one place to another?
5. What are neurons made up of?
6. What are the pathways called for messages to go from one place to another?
7. Explain step by step how a message travels from the brain to the other parts of the body.
8. Why is the nervous system important?

Circulatory System

1. What is the major organ of the circulatory system?
2. What does the circulatory system control?
3. What is blood?
4. How does blood move from one place to another?
5. What is blood made up of?
6. What are the tubes called for blood to go from one place to another?
7. Explain step by step how blood travels from the heart to the other parts of the body.
8. Why is the circulatory system important?

Respiratory System

1. What is the major organ of the Respiratory System?
2. What does the respiratory system control?
3. What is oxygen?
4. How is oxygen passed from one place to another?
5. What is air made up of?
6. What are the tubes called for oxygen to go from one place to another?
7. Explain step by step how oxygen travels from the lungs to the other parts of the body.
8. Why is the respiratory system important?

Chapter 4

Promoting English Language Acquisition in Secondary Mathematics through Dialogic Integration of Instructional Technology

Bethany Reichen
State University of New York at Albany, USA

Gretchen Oliver
State University of New York at Albany, USA

Alandeom W. Oliveira
State University of New York at Albany, USA

Autumn Joy Florencio-Wain
State University of New York at Albany, USA

ABSTRACT

This chapter uses the theoretical perspective of dialogism to examine how two suburban secondary math teachers use technology in the classroom to enhance language and content knowledge development for English learner students. Data for this study includes teacher lesson plans, transcripts of recorded lessons, and teacher reflections and is analyzed using a collective case approach. Results indicate that communicative acts in the classroom fall along a communication spectrum, and uses of specific technologies to increase dialogic interaction among students and between students and teachers are discussed. Thoughtful use of certain technologies may enhance opportunities for English learner students to claim a voice in the classroom and improve their language skills.

INTRODUCTION

STEM educators have increasingly relied on learning-focused technologies as cognitive tools for the promotion of conceptual mastery in K-12 classrooms. Technologies as varied as spreadsheet programs (Moore & Huber, 2009), online simulations (Glynn, 2008; Limson, Witzlib, & Desharnais, 2007), computer-based investigations (Eslinger, White, Frederiksen, & Brobst 2008; Tabak & Baumgartner, 2004) and digital devices (Freeman, 2012; López, 2010; Morgan & Alshwaikh, 2012) have become commonplace in sci-

DOI: 10.4018/978-1-4666-9616-7.ch004

ence and mathematics classrooms. Similarly, growing numbers of language educators have emphasized how instructional technologies can serve as linguistic tools for the promotion of language acquisition among English learners (ELs), or students for whom English is not a first language (Cummins, Sayers & Brown, 2006; Meskill et al., 1999). This growth stems partially from the potential of technology integration to provide ELs with opportunities to make more authentic use of English, and hence to acquire ability in a second language. When effectively integrated with instruction, technology can afford ELs the opportunity to practice performing a wide variety of *speech acts* (i.e., make purposeful discursive moves) in English such as asking for help, requesting confirmation or clarification, giving directives, posing questions, declaring their opinions, agreeing, disagreeing, thanking, apologizing, challenging others' ideas, building on others' ideas, acknowledging, etc. This practice can help develop ELs' *speech act ability* (Cohen, 2005), that is, help them learn how to use a second language in accordance with the social conventions of the English-speaking classroom community. As emphasized in the specialized literature, acquiring a second language entails learning its social *pragmatics* as well as its grammatical forms and vocabulary. Speaking a language fluently involves not only skill in referring to states of affairs in the world but also ability to verbally perform a variety of social acts (i.e., do things with words).

Despite this potential, educational researchers have yet to examine the extent to which technology integration in secondary STEM classrooms does indeed provide ELs with such opportunities for acquisition of the pragmatics of English. The present study attends to this issue by examining the types of speech acts that ELs have a chance to perform as a result of their teachers' integration of technology. More specifically, this study seeks to answer the research question: What types of speech act opportunities are English learners' afforded by their mathematics teachers' integration of technology? In this study, the term *technology integration* is used in reference to teacher pedagogical action centered on mobile network devices such as iPads and/or interactive whiteboard systems (SMART boards). Rather than serving as an immersive environment for electronically mediated instruction, digital technology is utilized in support of face-to-face teacher-student interaction, namely whole-class discussions.

BACKGROUND

Technology and Language

New technology has been shown to impact language use in certain social settings and drastically change traditional modes of communication (Cook, 2004). Affordances such as higher speeds of information exchange, additional modes of communication (texts, images, videos, etc.), and relative freedom from spatial confinement give new technology the potential to engender major changes in established patterns and norms of verbal interaction. Not only is new technology accompanied by the emergence of new language varieties such as Netspeak (Crystal, 2011) but it also often produces social changes such as the emergence of new rules of discourse and new patterns of identity construction that change how people see themselves in the real world (Richardson, 2001). A good example is the common emergence of a *cyberself* (a hybrid, virtual identity) in electronically mediated communication (Kolko et al., 2000). As such, new technology has the potential to provide users with an emancipatory sphere of interaction as well as the possibility of socio-cultural transformation. In the specific context of STEM classrooms, this transformative potential can result in a shift away from institutional discourse (formal and authoritative) and toward dialogism (language use that resemble real-life dialogue).

The relationship between new technology and language use has also been conceptualized in terms of the notion of *media ideologies* (Gershon, 2010), that is, peoples' attitudes and beliefs about the functionality, interactional affordances, and material limitations of a particular channel of communication such as iPads and smartphones. People's media ideologies shape their *media practices* (i.e., how people use particular media to communicate), often being influenced by local concepts of selves, social relationships, and communication in general. Central to media ideologies are people's perceptions of technologies as affording intimacy (a feeling of social closeness), spatio-temporal immediacy (a sense direct contact or access to interlocutors), transparency (the impression of an invisible channel or medium of contact), and simultaneity (no time lag). One good example is the view of texting as a medium for accomplishing more intimate communicative tasks such as causal exchanges with close friends. Bolter and Grus (1999) argue that the introduction of new media triggers a process of *remediation* whereby people's perceptions of an old medium affect their understandings and use of a new medium, and vice-versa (postal mail becoming "snail mail" with the advent of email). The extent to which similar technology-mediated linguistic processes also occur in STEM classrooms remains to be examined.

Technology and Learning

As the availability, affordability and ubiquity of technology grows, so does the expectation that teachers will find ways to harness it to support and improve student learning. Among the educational researchers and authors who sing the praises of technology in the classroom are Suh, Johnston, and Douds (2008) who claim "a technology-rich environment for mathematical learning influences...the nature of classroom tasks, the mathematical tools as a learning support, the role of the teacher, the social culture of the classroom, and equity and accessibility" (p. 235). Similarly, Latif and Shafipoor, (2012) weigh in as advocates of CALL (computer assisted language learning). In their report on the adoption of technology in English classes, they state that these technologies can be harnessed to facilitate an "intriguing and stimulating atmosphere to learn".

Additionally, several authors see technology as a potential leveler of the playing field for groups whose learning needs are often unmet by traditional teaching techniques. Freeman (2012) describes how technology can be employed to benefit ELs stating that "by providing both empowering and supportive learning environments with targeted and specific instructional scaffolds, digital technologies can overcome some of the barriers that currently obstruct the progress of ELs on the road to realizing their potential..." (p. 51). Green (2005) points out the ways in which technology can be utilized to create a language-rich environment for EL students in the absence of the teacher's immediate presence (e.g., when the teacher is attending to another student, another task or when the student is outside of the classroom). Waschauer and Liaw (2011) emphasize how digital media (podcasts, blogs, wikis, online writing sites, text-scaffolding software, concordancers, multiuser virtual environments, multiplayer games, and chatbots) can be used to support language learners.

Coyle, Yañez and Verdú (2010), in their study of interactive white board use in ESL classrooms in Spain, comment on the importance of two key qualities of teachers; their familiarity with the technology and ability to value and support student voice. They point out that "teachers' classroom interactional competence as well as their technological skills" must be strengthened if technology's potential is to be maximized in classrooms. While recent research indicates that the integration of new technologies to their full potential continues to elude many educators (Andrei, 2014; Stroud, Drayton, Hobbs & Falk, 2014), these studies emphasize that strategic integration and adequate support of teacher's tech skills are key in realizing technology's potential as a valuable pedagogical tool.

There are several examples of how technology can be integrated specifically for the benefit of ELs in STEM classes. Freeman (2012) reports on HELP math, a "flexible digital learning environment" (p. 53) designed to provide support to ELs as they progress through mathematics in grades K-12. He states that the system served to increase student comprehension through various means including facilitating collaboration among students. Another successful use of technology in mathematics comes from Lopez (2010), who finds that the use of the interactive white board (IWB) and an electric slate increased the pass rates on standardizes tests for all students including ELs. The potential for IWB to foster interactive, dialogic teaching is also documented in several others studies (Beauchamp & Kennewell, 2007; Kennewell, 2008; Kennewell, 2008) which identify among its main benefits a "collective focus of reference" for interactions, provision of immediate feedback, and opportunity for students to perform goal-oriented action (e.g., discussing sentences being translated into another language). Evident in these studies is the potential for interactive technology to support the emergence of dialogic classrooms discourse (more flexible and less authoritarian interaction), which can afford ELs increased exposure and opportunity to practice a wide variety of speech acts, and hence acquire pragmatic ability in English.

DIALOGIC INTEGRATION OF TECHNOLOGY

This chapter is theoretically informed by Bakhtin's (1981) and Voloshinov's (1995) seminal work on dialogism. Central to this theoretical perspective is the notion that dialogism is a universal and defining feature of discursive interaction, irrespective of communicative channel (face-to-face, online) or setting (conversational, institutional). Dialogism refers to language use that shares the stylistic attributes of naturally occurring, casual conversations, including plurality of voices (i.e., heteroglossia), interactivity (turn-taking), transactivity (uptake and elaboration of each other's ideas), social equality (interactional symmetry), spontaneity (emergent and unplanned topic development), and social closeness (informal and supportive relationships). Verbal exchanges invariably have a certain degree of dialogism and can be placed along a continuum spanning from complete monologism (authoritative and non-interactive) to complete dialogism (non-authoritative and highly interactive). Further, use of instructional technology can produce a shift toward either end of this discursive continuum.

In classroom settings, the emergence of dialogism typically entails a shift away from traditional interactional patterns such as Initiation-Response-Evaluation (or IRE) (Lemke, 1990; Mehan, 1979; Wells, 1999). When engaged in IRE, the teacher and students take turn performing a sequence of three speech acts. In the first speech act (I), the teacher initiates the exchange by posing a closed question whose answer s/he already knows (a query aimed at testing students' knowledge). In the second speech act (R), a student then responds with a short answer (one or two words). Lastly, the teacher performs the third speech act (E) by evaluating the student as being right or wrong. What makes this IRE turn-taking structure authoritative is the fact that the teacher invariably performs the two powerful moves (i.e., asking questions and evaluating students' responses), thus establishing him/herself as a knowledgeable experts while simultaneously assigning students to a subordinate role of respondents. By continuously holding authoritative speaking rights, the teacher is dominates the classroom discussion, constraining students' contributions, and encouraging students to focus on providing the "right" answers known only by the teacher (as opposed to encouraging students to articulate their own ideas and thoughts). Predominant in traditional, teacher-centered classrooms, IRE exchanges do not give students the opportunity to perform any speech act other than responding. As such IREs provide ELs with limited opportunities to acquire knowledge and skill in the pragmatics of English (i.e., to develop speech act ability).

The metaphorical concept of *voice* also figures prominently in the theoretical perspective adopted by this study. Like previous research on dialogism (Keane, 2000), our stance on classroom integration of technology is concerned mainly with matters such as "having a voice" and "claiming a voice." It should be noted that the notion of *voice* deals with issues of vocalization (who is speaking?) as well as relational issues such as authorship, agency, and responsibility for words. Having a voice entails more than simply being able to utter words in the course of a verbal exchange. As previous research has shown, classroom discussions can be characterized by "pseudo-dialogism" in the sense that students remain without a voice even when allowed to speak. This is particularly evident in IREs or *triadic dialogues* (Lemke, 1990) wherein students' oral contributions are limited to isolated words aimed at guessing the answer being sought after by the teacher (far from a "true dialogue"). In truly dialogic classrooms, students display their "voices" by making oral contributions to discussions that go beyond the mere provision of responses to teachers.

Technological resources are not inherently dialogic or monologic by virtue of their materiality or design. Rather than resorting to simplistic design distinctions (e.g., dialogic devices, monologic tools) or making deterministic assumptions (e.g., viewing classroom interaction as simply determined by technological design), this study conceives of technology-centered dialogism as an emergent interactional phenomenon. From this perspective, instructional technology invariably has dialogic potential (i.e., can be used to foster dialogic interactions in classroom settings). Whether this dialogic potential is fulfilled depends on the participant structures that emerge as a result of how technology is integrated into classroom activity. Like other researchers (Polman, 2004; Tabak & Baumgartner, 2004), the present work uses the term *participant structure* in reference to teachers' and students' ways of organizing their social interactions around instructional technology (i.e., social arrangements surrounding technological resources). Emergence of dialogically structured social interaction is contingent upon participants' media ideologies, media practices, and ongoing interactional negotiation.

For this study, a dialogic participant structure is a technology-centered type of classroom discourse wherein students' ideas and views are listened to and taken into account by teachers and peers (Mortimer & Scott, 2003); takes the form of exploratory and responsive discussion wherein participants collaboratively build on each other's ideas (rather than being limited to expository transmission or direct instruction) (Chin, 2006); teachers provide constructive feedback to students (Polman, 2004); and, students have the opportunity to articulate a variety sense-making connections (Pappas, Varelas, Barry, & Rife, 2003). These are essential features of technology integration practices that can effectively provide ELs with epistemic and linguistic support in STEM classrooms.

METHODOLOGY

As part of a broader research and professional development project called the Technology-Enhanced Multimodal Observation Protocol (MOP) (Meskill et al., 2014; Oliveira et al., 2015), this study takes a qualitative case study approach (Creswell, 2013) to understand how STEM teachers strategically use technology to promote language acquisition in content classes. Specifically, this investigation uses a two case approach (Yin, 2014) in an effort to highlight a contrasting situation of the uses of technology in mathematics classrooms. Further, this study employs what Creswell (2012) describes as a "purposeful maximal sampling" as the selected cases demonstrate different perspectives and approaches to the integration of technology in secondary mathematics classrooms.

Our adoption a case study methodology was informed by Yin's (2009) argument that a case study design should be utilized when one needs to understand a real-life phenomenon in depth and when such understanding encompasses important contextual conditions highly relevant to the phenomenon of study. Dialogism is undoubtedly such a phenomenon given the highly elusive, dynamic, and complex nature of the sociolinguistic processes involved. Such a methodological approach allowed us to dedicate a fair amount of attention to each teacher's approach to technology integration and its dialogic affordances to ELs. Further, this study does not aim at making generalizations beyond the two cases that are discussed herein. Focusing on a few discreet cases enabled our thorough analyses, not for generalizing beyond the case, but for understanding the complexity of each case (Creswell, 2013). This is in line with Yin's (2009) argument that in analytical generalization through case studies "the investigator is striving to generalize a particular set of results to some broader theory" (p. 43), not a larger sample like in the quantitative paradigm.

Participants

The participants in this study were two suburban high school mathematics teachers, Marie and James (pseudonyms), each of whom had a cohort of EL students and native speakers of English in one section of their Common Core Algebra classes. Both Marie and James were selected for the project because they were veteran teachers who had prior experiences with teaching ELs. This was the first year that their respective schools had implemented the new Common Core curriculum as well as the first time that both teachers had a cluster of EL students in their classes.

As part of the year-long professional development project, Marie and James engaged in a formal collaboration with their building language specialist and participated in face-to-face and online meetings with the language specialists and researchers to discuss strategy implementation and assessment. The overarching goal of this collaboration was to design, implement and assess strategies that would assist EL students in learning content through academic language and academic language through content. The teachers also participated in self-paced training modules, designed by project staff, related to the Sheltered Instruction Observation Protocol (SIOP®) Model of instruction and the use of technology to contextualize and integrate instruction. The specific goal of these training modules was to assist teachers in reflecting upon how they could use technology in their classrooms as a means of promoting communication among their EL students and facilitating EL student engagement with the mathematics content while developing language proficiency. After participating in the training modules, the teachers were asked to collaboratively develop a plan of action for the implementation of strategies to meet this end. James and Paula, his schools' language specialist, recognized that the use of technology in their mathematics classroom had previously been limited to a Smart Board and calculators, but with the recent incorporation of Wi-Fi into the school building, there was now room to expand upon this basic use of instructional technology, specifically with the use of tablets. James planned on designing lessons that would require students to use iPads with a partner to reinforce concepts he would teach in the larger group setting.

Marie and her school's language specialist, Sarah, also identified the existing ways she used technology to support instruction in the mathematics classroom, as well as several potential ways to expand upon this current use. They recognized that the use of an iPad and Apple TV allowed instructional affordances that a chalkboard could not, making lessons more visual and easier for students to follow with their guided notes. In this vein, technology was used primarily to support Marie's teaching and to facilitate students' note-taking and ability to engage with the content. Acknowledging that this use of technology was more teacher-centered in nature, Marie and Sarah focused on ways to implement other types of technology to support student learning, such as using applications, simulations, videos and tutorials to reinforce the mathematical concepts.

Data Collection and Analysis

In an effort to develop an in-depth understanding of each case (Creswell, 2013), multiple forms of data were collected during the implementation phase. These data included lesson plans that the teachers developed in collaboration with their building language specialists and video-recorded lessons which were transcribed. These recordings were shared with Marie, James, and the language building specialists for their viewing and analysis. In addition, each teacher wrote reflections on the lesson planning and implementation after viewing the recorded lessons for their classes.

Each lesson constitutes an analytical unit or a case. Through an embedded analysis (Yin, 2009), specific instructional strategies used by James and Marie were identified. The transcripts were subsequently analyzed using a cross-case comparison of dialogic and monologic integration of technology. Following an inductive qualitative method (Bogdan & Biklen, 1998), patterns of both dialogic and monologic integration of technology emerged, spanning a communicative spectrum (Figure 1).

Central to our discourse analysis was the systematic classification of speech acts (Austin, 1962) performed by teachers and students. Doing so involved identifying each turn taken by speakers in the course of classroom discussion as a particular type of discursive move: Initiation (a move that initiates discussion of a particular topic), Response (a move wherein the speaker simply responds to another speaker and continues the discussion of a given topic), Evaluation (a move wherein a speaker explicitly or implicitly evaluates the correctness of another speakers' utterance), and Feedback (a move wherein a speaker expands on another speakers' utterance).

Figure 1. Communication spectrum

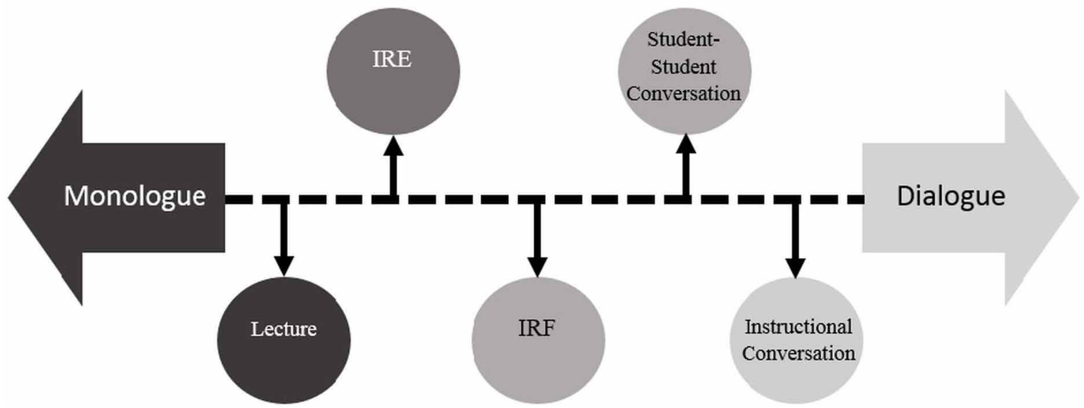
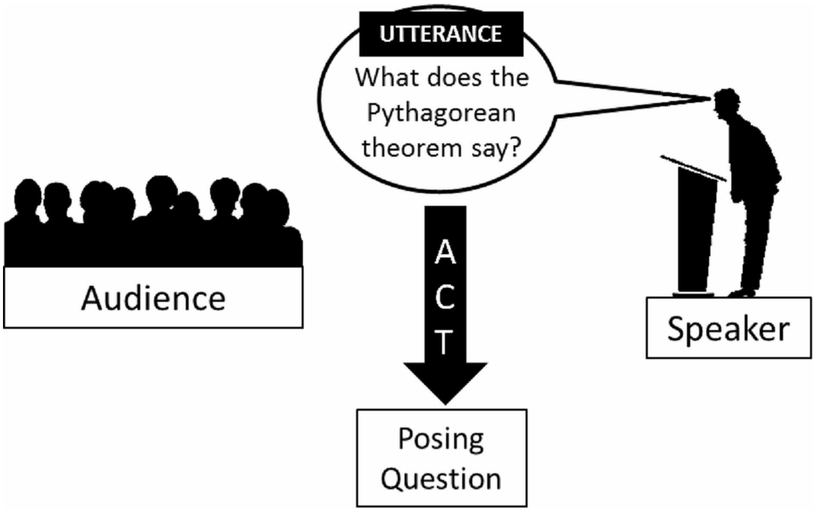


Figure 2. Speaker performance of a speech act



Conducted at the analytical level of utterance, speech act identification entailed explicit labelling of what the speaker accomplished in uttering certain words. For example, when a mathematics teacher poses a question such as "What does the Pythagorean theorem say?," s/he performs the speech act of posing a question (Figure 2). Such an act can be performed with varied levels of politeness (would you please tell me…?), informality (Can you guys tell me..?), and indirectness ("I forgot what the Pythagorean Theorem says.") depending on the specific social context. Further, appropriateness of particular speech acts depends upon social context (e.g., classroom vs. informal conversation) as well as cultural affiliation. In linguistics, this is known as the performative dimension of language use (Silverstein, 1995; Jacobson, 1960), which also must be learned by nonnative speakers in order to become proficient in a second language.

Three primary data sources, including lesson plans, transcriptions of video recorded lessons, and teacher reflections, were used in this study. To ensure validity of the interpretations and results, these data were triangulated and shared among researchers. In addition to analyzing multiple sources of data, validity measures included peer debriefing and member checking.

James' lesson was centered on the Pythagorean Theorem. In his lesson plan, James identified both content and language objectives for this lesson. In terms of content, James wrote "Students will be able to understand that the sum of the squares of the sides of a right triangle is equal to the square of the hypotenuse" and for language, "Students will be able to use mathematical vocabulary to explain orally and in writing the attributes of a right triangle. He identified a variety of learning strategies (hands-on manipulatives, video from iPads, bring your own device activity, as well as key vocabulary (right angle, right triangle, legs, hypotenuse, square and area of a square). To assess his students learning, James planned on allowing his students to use their own mobile devices to answer three questions on an online exit ticket.

After James viewed the video of this lesson, both he and Paula wrote a reflection on what they saw in James' teaching and student learning. Both teachers recognized the benefits of splitting the whole class into two groups and using the video to make the concept more visual and less abstract. Referring to ELs students, James noted "…some of the students from the first group did not initially grasp what the video was trying to portray. However, after guiding them with questions, they were able to make the connections from the video." Paula added "not only did it [the video] present the material in a different way, it also gave the students the freedom to re-watch it if they hadn't understood the first time. James was also available to guide them and clarify the material when necessary." Further, James explained that he felt both language and content objectives for this class were realized because of use of technology as students were able to correctly set up problems in subsequent classes and performed well both in the review activities and on the quiz for this topic.

While James put technology into the hands of his students, Marie took a different approach to her use of technology in this intervention phase. The conceptual topic for the lesson Marie taught was solving quadratic equations by completing the square. Like James, Marie identified both content ("Students will be able to manipulate an equation into the form of: a perfect square trinomial – a constant") and language objectives ("Students will be able to recognize and describe a perfect square trinomial and describe the roots of an equation as rational, irrational or non-real"), as well as key vocabulary (standard form, trinomial, binomial, factor, perfect square, constant, square root, roots, real / non-real numbers, rational, irrational, like terms, completing the square, GCF) for the lesson. Marie placed a heavy emphasis on students' understanding and use of vocabulary around the topic, rather than the simply the concept of "solving equations by completing the square" itself. As such, Marie planned to use her iPad and the Apple TV in her classroom to organize notes and model the task of solving an equation with this method. In presenting the material, she planned to reinforce mathematical vocabulary by color coding, highlighting and underlining key words and phrases. In addition, she would give each student a vocabulary card with one of the mathematical terms on it, along with the instruction to stand up when they heard the word on their card. Marie wrote in her lesson plan, "When I say the word in class, the students with that card must raise their hand, they can define the word for a bonus point, and as a class, we will discuss the meaning of the word/term." During the class, Marie worked through the simplified steps with her iPad and circulated around the room, and when students heard the term on the card, they stood up, sometimes simply showing it, other times giving a definition in their own words. In each case, some form of student-teacher communication was present. After viewing the recording of this lesson Marie wrote a reflection on what she saw in terms of her teaching and student learning. Sarah also wrote a reflection on what she saw in the lesson, but did not make an explicit mention to the use of technology. Rather, she commented more about the lesson planning process and commended Marie on developing a lesson that was "comprehensible… more accessible to her ELs, since repetition, visuals, and tangible participation are what language teachers routinely use every day."

RESULTS

James' Lesson: Pythagorean Theorem

James used a SMART Board® to present information to his students in a way that allowed for constant manipulation of text and images as he taught. James used the SMART Board to display sample problems, which he then solved in front of the class to serve as a model, and other relevant information to the lesson including text and visuals which could then be emphasized with underlining or circling. In this lesson, he displayed the image of an entertainment center to provide a real-world scenario in which the Pythagorean Theorem could be used (determining the appropriate TV size for a given stand). This presentation served as an introduction to the new concepts, and from there James was able to model for and with the students how to use the theorem to solve the problem using the SMART Board. The SMART Board allowed James to move between several displays including the worksheet that students had in front of them, images from the Internet, and a blank screen for solving the problem and displaying the work. James also used a set of Apple® iPads to allow students, in pairs, to watch a video on the Pythagorean Theorem. While half of the students engaged in watching the video and discussing the concepts, the other half of the class participated in a hands-on activity in which they used paper manipulatives to explore the concepts in a more concrete way. In his lesson plan, James had intended to end class by asking students to answer questions online using their own devices, but he was unable to do so due to time constraints.

Integration of each of these technologies led to the emergence of distinct communicative practices and participant structures. Use of the SMART Board supported EL students' language acquisition by providing visuals to accompany the traditional teaching. As James used the SMART Board, he lectured or asked the students short-answer questions and responded with evaluative remarks, in the traditional IRE format. See table 1 for an example.

Using the SMART Board as a focal point, James also engaged students in another typical communication structure: initiation-response-feedback (IRF), which allowed for more uptake of student ideas into the conversation but was still teacher-initiated and directed, as can be seen in table 2.

Conversely, the participant structure of the class shifted dramatically when James allowed the students to work in pairs with the iPads. James decided to include the iPads after reflecting earlier in the school year that his EL students had very little opportunity to actually use any language in previous lessons. As the students manipulated what was happening on the screen, they engaged in lively conversation about what they were watching and doing. Communication in this case moved from monologic (with lecture, IRE, and IRF) to dialogic as student-student conversations became the dominant form of discourse. The EL students in this lesson were engaging not only with the technology, but also with their peers as they discussed and questioned what they were viewing. Through these conversations, EL students were

Table 1. Example of IRE

James:	Is there anything else that you can think of when I say square?	**Initiation**
EL Student:	Square feet.	**Response**
James:	Square feet, what else?	**Response/initiation**
EL Student:	Something squared.	**Response**
James:	A number squared, very good.	**Evaluation**

Table 2. Example of IRF

James:	Can the legs and the hypotenuse go anywhere they want?	**Initiation**
Students:	No.	**Response**
James:	No. What has to go where?	**Evaluation/Initiation**
EL Student:	The legs are always the bottom.	**Response**
James:	The legs are always the bottom? So you're saying that…	**Initiation**
EL Student:	Never mind, never mind, never mind.	**Response**
James:	No, that's a good point because a lot of people might think that. What if I draw it like this? Where would the legs go? This one, here? The two sides that make up the right angle, those are the legs.	**Feedback/Initiation**

Table 3. Sample utterances from student-pair discussions

Utterance(s)	Discursive Move (Form)
Student: So A is 25.	Initiation (Declarative)
Student 1: You count this one too. **Student 2:** Oh, so all these together?	Initiation (Directive) Response (Confirmation Request)
Student: Is that A?	Initiation (Confirmation Request)
Student 1: We need to do this. **Student 2:** So how are we supposed to do it?	Initiation (Declarative) Response (Clarification Request)
Student: This is nine and sixteen.	Initiation (Declarative)
Student: Look, just go like this, you don't have to put every single one in.	Initiation (Directive)
Student 1: I've got 16 bro. **Student 2:** 16?	Initiation (Declarative) Response (Confirmation Request)
Student 1: We already did this. **Student 2:** Yeah, we already did it.	Initiation (Declarative) Response (Declarative)

given an opportunity to use new vocabulary and further develop their understanding of abstract math concepts such as the Pythagorean Theorem. Some examples of student utterances are shown on Table 3.

The use of the iPads and grouping the students also allowed James to move freely about the classroom and interact with the students as they worked. Using the iPads as the focal point, James and several students engaged in meaningful instructional conversations that enhanced students' content knowledge and language development, as can be seen in table 4.

In this lesson, James was able to use technology to enhance communication in his classroom and, in doing so, allow his students to claim a voice and participate in authentic dialogic communication.

Marie's Lesson: Solving Quadratic Equations

Marie also used an iPad as part of her lesson, but in a different way than James. Whereas James had given students the iPads in his class, Marie only had access to one iPad and therefore used it more to support her own instruction than to support student interaction or learning. Marie had an Apple® TV in her room for the second lesson, which allowed her to project the iPad screen onto a larger screen in the

Table 4. Example of instructional conversation

EL Student: **James:** **EL Student:** **James:** **EL Student:**	I don't get this. You don't get this either [turning the pair's iPad]? How many squares are here [pointing to the iPad screen]? The Pythagorean theorem says sum, add, the squares of the legs, 9 here and the 16. *The student is pointing to the screen as well. James is making eye contact with the pair and waiting for them to ask their questions.* So all together it would be 25. It shows you [pointing to the iPad screen] that all of those will fit into there. Oh, okay.	**Initiation** **Response** **Response** **Response** **Response**

Table 5. IRE in Marie's class

Marie: **EL Student:** **Marie:**	Alright (Student), how do we know those roots are irrational? Um, it has a square root in the answer. Exactly. There's a square root in the answer and you can't simplify the square root if there's no perfect square. Are we experts at this? You're gonna be by the time I am done with you this week.	**Initiation** **Response** **Evaluation**

front of the classroom. She took advantage of this technology by walking around the room while she taught; she did not need to be next to the board in order to show examples or information on it, and was able to monitor student work throughout the lesson.

Marie began her lesson on solving quadratic equations by asking students to complete a starter activity and then going over the previous day's homework. As the class went on, Marie used the iPad and Apple TV to model the problems and display worksheet in front of the students, much in the same way that James had used the SMART Board. In order to emphasize the new vocabulary to support ELs (and all students), Marie passed out notecards with words related to the lesson and asked students to stand up when they heard the word on their card. As students heard their words, they stood up, and Marie asked them to define the word. This gave students a small opportunity to speak in the lesson, but the interaction largely took the form of IRE. Some students were able to claim a voice in this lesson when they were asked to define the vocabulary terms in their own words as they stood up.

As was the case with James, this use of presentational technology in front of the classroom supported EL students' language and content knowledge development by providing visuals to make abstract mathematical concepts more concrete, but it did very little to promote dialogic interaction in the class. Communication in her lessons mainly took the form of lecture and IRE questioning, as in table 5 below.

Throughout the class, students were given very little, if any, opportunity to express themselves or to demonstrate or explain their understandings of the concepts; they had almost no voice in the classroom for this lesson beyond simple responses and recognizing vocabulary words.

DISCUSSION AND CONCLUSION

As shown above, integration of technology can, *but does not always*, shift classroom discourse toward higher degrees of dialogism, and thus afford ELs more opportunities to develop speech act ability (i.e., to learn the social pragmatics of English). Such a finding is consistent previous literature emphasizing the importance of purposefulness in instructional efforts aimed at technology integration (Chval & Chavez, 2012; Meskill et al., 2000; Suh, Johnston & Douds, 2008; Warschauer et al., 2004). Despite its potential to have a drastic impact on language use, new technology can also simply change the way we do things, not necessarily what we do (Wilson & Petterson, 2002). In other words, it is possible for technology integration to simply reinforce traditional discourse patterns rather than engender meaningful changes in language use. Purposefully, in this case, means thoughtful integration with the goal of enhancing and sustaining dialogic communication.

Our findings reveal that classroom technology may indeed serve as a springboard for dialogic communication, which in turn increased opportunities for EL students to become exposed and practice a variety of speech act behaviors commonly performed by native speakers in mathematics classroom settings. James accomplished this by using technology in the form of iPads as the starting and focal point of student-student dialogue, which allowed EL students to use English for a variety of social purposes (e.g., giving directives, requesting confirmation, requesting clarification, responding, and declaring knowledge) while simultaneously learning mathematics concepts such as the Pythagorean theorem. The benefits of dialogic integration of iPads in James' class were clear. As collaboration result of this technological integration, students were able to engage in authentic, natural dialogue stemming from the "collective focus of reference" in the form of the device in front of them (Beauchamp & Kennewell, 2008). The authenticity of these student-student conversations was particularly evident in the fact that ELs were given an opportunity to "do a variety of thing with words," that is, to perform varied speech acts (Austin, 1962). Rather than simply continuing to perform Responses by uttering isolated words in reply to teacher questions, students had an opportunity to engage in the production of a variety of speech acts. As emphasized by language scholars (Levinson, 1983; Searle, 1972), speaking a language is largely a matter of verbal performance,that is, being able to perform a multitude of social acts through the uttering of words in a particular language. This is precisely what James accomplished through his dialogic use of iPads. By encouraging his ELs to perform a variety of discursive moves in English, his students were able to "claim a voice" in a second language while simultaneously being exposed mathematical concepts.

The two mathematics teachers also used technology in ways that did not lend themselves to promoting, enhancing, or sustaining dialogic classroom communication. Both James and Marie relied heavily on presentational forms of technology (the SMART Board and iPad/Apple TV Combination) which were used to accommodate ELs by providing visuals and allowing for emphasis to be made in the form of circling, use of color, highlighting, etc. These types of technology, however, did not promote dialogic communication. When James and Marie used their different types of displays, they were in complete control and there was little room for student voice. The communication types most often supported by these technologies were lecture, IRE questioning, and IRF questioning, which only left room for students to perform Response acts, which were rarely then taken up into the larger conversation or shared much resemblance with real-life dialogue. In this sense, James and Marie engaged in what Wilson and Peterson (2002) termed "cultural reproduction;" they used new technologies in the classroom to do the same things typically done in traditional classrooms but in a slightly new way. However, as evident in her student performance of solely Response acts, using SMART Boards in the same monologic way that overhead projectors are typically used is offers little opportunity for dialogism or student development of speech act ability in English. To dialogically support ELs' acquisition of the social pragmatics of a second language alongside development of content knowledge, teachers need to integrate technology into their lessons in ways that allow students to naturally and casually engage in dialogue with each other and the teacher, thus giving them a voice in the classroom and the opportunity to use their new language knowledge.

REFERENCES

Andrei, E. (2014). Digital Technology in Three Middle School ESL Language Arts Classrooms. *TESL Reporter*, *47*(1/2), 35–50.

Austin, J. L. (1962). *How to do things with words*. Cambridge, MA: Harvard University Press.

Bakhtin, M. M. (1981). *The dialogic imagination*. Austin, TX: University of Texas Press.

Beauchamp, G., & Kennewell, S. (2008). The influence of ICT on the interactivity of teaching. *Education and Information Technologies*, *13*(4), 305–315. doi:10.1007/s10639-008-9071-y

Bogdan, R. C., & Biklen, S. K. (1998). *Qualitative research for education: An introduction to theory and methods* (3rd ed.). Boston: Allyn & Bacon.

Bolter, J. D., & Grus, R. (1999). *Remediation: Understanding new media*. Cambridge, MA: MIT Press.

Chin, C. (2006). Classroom interaction in science: Teacher questioning and feedback to students' responses. *International Journal of Science Education*, *28*(11), 1315–1346. doi:10.1080/09500690600621100

Chval, K. B., & Chavez, O. (2012). Designing math lessons for English language learners. *Mathematics Teaching in the Middle School*, *17*(5), 261–265. doi:10.5951/mathteacmiddscho.17.5.0261

Cohen, A. D. (2005). Strategies for learning and performing L2 speech acts. *Intercultural Pragmatics*, *2-3*, 275–301.

Cook, S. E. (2004). New technologies and language change: Toward an anthropology of linguistic frontiers. *Annual Review of Anthropology*, *33*(1), 103–115. doi:10.1146/annurev.anthro.33.070203.143921

Coyle, Y., Yañez, L., & Verdú, M. (2010). The impact of the interactive whiteboard on the teacher and children's language use in an ESL immersion classroom. *System*, *38*(4), 614–625. doi:10.1016/j.system.2010.10.002

Creswell, J. W. (2012). *Educational research: Planning, conducting and evaluating quantitative and qualitative research* (4th ed.). Upper Saddle River, NJ: Pearson Education.

Creswell, J. W. (2013). *Qualitative inquiry and research design: Choosing among five approaches* (3rd ed.). Thousand Oaks, CA: Sage.

Crystal, D. (2011). *Internet linguistics*. New York: Routledge.

Cummins, J., Sayers, J., & Brown, K. (2006). *Literacy, technology and diversity*. Boston: Allyn & Bacon.

Eslinger, E., White, B., Frederiksen, J., & Brobst, J. (2008). Supporting inquiry processes with an interactive learning environment: Inquiry island. *Journal of Science Education and Technology*, *17*(6), 610–617. doi:10.1007/s10956-008-9130-6

Freeman, B. (2012). Using digital technologies to redress inequities for English language learners in the English speaking mathematics classroom. *Computers & Education*, *59*(1), 50–62. doi:10.1016/j.compedu.2011.11.003

Gershon, I. (2010). Media ideologies: An introduction. *Linguistic Anthropology*, *20*(2), 283–293. doi:10.1111/j.1548-1395.2010.01070.x

Glynn, S. M. (2008). Making science concepts meaningful to students: Teaching with analogies. In S. Mikelskis-Seifert, U. Ringelband, & M. Bruckmann (Eds.), *Four decades of research in science education: From curriculum development to quality improvement* (pp. 112–125). Munster, Germany: Waxmann.

Green, T. (2005). Using technology to help English language students develop language skills: A home and school connection. *Multicultural Education*, *13*(2), 56.

Jakobson, R. (1960). Closing statement: Linguistics and poetics. In T. Sebeok (Ed.), *Style in language* (pp. 350–377). Cambridge, MA: MIT press.

Keane, W. (2000). Voice. *Journal of Linguistic Anthropology*, *9*(1-2), 271–273. doi:10.1525/jlin.1999.9.1-2.271

Kennewell, S., & Beauchamp, G. (2007). The features of interactive whiteboards and their influence on learning. *Learning, Media and Technology*, *32*(3), 227–241. doi:10.1080/17439880701511073

Kennewell, S., Tanner, H., Jones, S., & Beauchamp, G. (2008). Analysing the use of interactive technology to implement interactive teaching. *Journal of Computer Assisted Learning*, *24*(1), 61–73. doi:10.1111/j.1365-2729.2007.00244.x

Kolko, B., Nakamura, L., & Rodman, G. (2000). *Race in cyberspace*. New York: Routledge.

Latif, F., & Shafipoor, M. (2012). Innovative teaching methodology: Application of computer and technology in Iranian business English courses. *Theory & Practice in Language Studies*, *2*(11), 2284–2290. doi:10.4304/tpls.2.11.2284-2290

Lemke, J. L. (1990). *Talking science: Language, learning and values*. Norwood, NJ: Ablex.

Levinson, S. C. (1983). *Pragmatics*. Cambridge, UK: Cambridge University Press.

Limson, M., Witzlib, C., & Desharnais, R. A. (2007). Using web-based simulations to promote inquiry. *Science Scope*, (February): 36–42.

López, O. S. (2010). The digital learning classroom: Improving English language learners' academic succes in mathematics and reading using interactive whiteboard technology. *Computers & Education*, *54*(4), 901–915. doi:10.1016/j.compedu.2009.09.019

Mehan, H. (1979). *Learning lessons: Social organization in the classroom*. Cambridge, MA: Harvard University Press. doi:10.4159/harvard.9780674420106

Mercer, N., Warwick, P., Kershner, R., & Staarman, J. K. (2010). Can the interactive whiteboard help to provide "dialogic space" for children's collaborative activity? *Language & Education: An International Journal*, *24*(5), 367–384. doi:10.1080/09500781003642460

Meskill, C., Mossop, J., & Bates, R. (1999). *Electronic text and English as a second language environment*. Albany, NY: National Research Center on English Learning and Achievement.

Meskill, C., Mossop, J., & Bates, R. (2000). Bilingualism, cognitive flexibility, and electronic texts. *Bilingual Research Journal*, *23*(2-3), 235–246. doi:10.1080/15235882.1999.10668689

Meskill, C., Oliveira, A., Gregory, K., Oliver, G., Reichen, B., & Witmer, P. (2014). Professional development in support of English learner achievement: Science and ESOL educator collaborations. In L. Minaya-Rowe (Ed.), *Effective Educational Programs, Practices, and Policies for English Learners* (pp. 83–107). Charlotte, NC: Information Age Publishing.

Moore, C., & Huber, R. (2009). Roadkill data analysis: Using spreadsheets to integrate math and science. *Science Scope*, 26–29.

Morgan, C., & Alshwaikh, J. (2012). Communicating experience of 3D space: Mathematical and everyday discourse. *Mathematical Thinking and Learning*, *14*(3), 199–225. doi:10.1080/10986065.2012.682960

Mortimer, E. F., & Scott, P. H. (2003). *Meaning making in secondary science classrooms*. Maidenhead, UK: Open University Press.

Nystrand, M. (1997). *Opening dialogue: Understanding the dynamics of language and learning in the English classroom*. New York: Teachers College Press.

Oliveira, A. W., Meskill, C., Judson, D., Gregory, K., Rogers, P., Imperial, C. J., & Casler-Failing, S. (2015). Language repair strategies in bilingual tutoring of mathematics word problems. *Canadian Journal of Science. Mathematics and Technology Education*, *15*(1), 102–115. doi:10.1080/14926156.2014.990173

Pappas, C. C., Varelas, M., Barry, A., & Rife, A. (2003). Dialogic inquiry around information texts: The role of intertextuality in constructing scientific understandings in urban primary classrooms. *Linguistics and Education*, *13*(4), 435–482. doi:10.1016/S0898-5898(03)00004-4

Polman, J. L. (2004). Dialogic activity structures for project-based learning environments. *Cognition and Instruction*, *22*(4), 431–466. doi:10.1207/s1532690Xci2204_3

Richardson, K. (2001). Risk news in the world of Internet newsgroups. *Journal of Sociolinguistics*, *5*(1), 50–72. doi:10.1111/1467-9481.00137

Searle, J. R. (1972). What is a speech act? In P. P. Giglioli (Ed.), *Language and social context* (pp. 136–154). Baltimore, MD: Penguin Books.

Silverstein, M. (1995). Shifters, linguistic categories and cultural description. In B. G. Blount (Ed.), *Language, culture and society*. Prospect Heights, IL: Waveland Press.

Stroud, R., Drayton, B., Hobbs, K., & Falk, J. (2014). Interactive Whiteboard Use in High-Tech Science Classrooms: Patterns of Integration. *International Journal of Emerging Technologies in Learning*, *9*(9), 41–49. doi:10.3991/ijet.v9i9.4141

Suh, J. M., Johnston, C. J., & Douds, J. (2008). Enhancing mathematical learning in a technology-rich environment. *Teaching Children Mathematics*, 235–241.

Tabak, I., & Baumgartner, E. (2004). The teacher as partner: Exploring participant structures, symmetry, and identity work in scaffolding. *Cognition and Instruction*, *22*(4), 393–429. doi:10.1207/s1532690Xci2204_2

Voloshinov, V. N. (1995). *Marxism and the philosophy of language, Bakhtinian thought: An introductory reader*. London: Routledge.

Walqui, A., & van Lier, L. (2010). *Scaffolding the academic success of adolescent English language learners*. San Francisco, CA: WestEd.

Warschauer, M., Grant, D., Del Real, G., & Rousseau, M. (2004). Promoting academic literacy with technology: Successful laptop programs in K-12 schools. *System*, *32*(4), 525–537. doi:10.1016/j.system.2004.09.010

Wells, G. (1993). Reevaluating the IRF sequence. *Linguistics and Education*, *5*(1), 1–38. doi:10.1016/S0898-5898(05)80001-4

Wells, G. (1999). *Dialogic inquiry: Toward a sociocultural practice and theory of education*. Cambridge, UK: Cambridge University Press. doi:10.1017/CBO9780511605895

Wilson, S. M., & Peterson, L. C. (2002). The anthropology of online communities. *Annual Review of Anthropology*, *31*(1), 449–460. doi:10.1146/annurev.anthro.31.040402.085436

Yin, R. K. (2014). *Case study research: Design and methods* (5th ed.). Thousand Oaks, CA: Sage.

KEY TERMS AND DEFINITIONS

Dialogism: Authentic language use involving two or more speakers interacting in true conversation.

Discursive Move: The interactional purpose of a given utterance.

Instructional Conversation: Conversations involving two or more participants with the goal of furthering conceptual knowledge and using language.

Monologism: Language use in which only one person has the opportunity to speak.

Participant Structure: Teachers' and students' ways of organizing their interactions in the classroom.

Technology Integration: The use of digital technologies (such as tablets and interactive white boards) in the classroom to support teaching and learning.

Voice: The ability to speak, assume ownership of and claim responsibility for utterances, and to have those utterances recognized and taken up into the larger conversation.

APPENDIX

Transcription Conventions

The following notation is adopted in all transcript excerpts included in the present manuscript:

? indicates rising intonations
. indicates falling intonations
[ ] indicates speaker actions
Italics indicates observer comments
(Student) indicates a student's name has been removed for anonymity

Chapter 5

Examining the Levels of Reasoning Used by Urban Elementary Black Girls Engaging in Technology-Enhanced Inquiry

Gayle A. Buck
Indiana University, USA

Nicole Beeman-Cadwallader
Project Lead the Way, USA

Amy Trauth-Nare
University of Delaware, USA

ABSTRACT

Technological tools such as interfaces, sensors and probeware are increasingly prevalent in science classrooms. With increased prevalence comes a need to improve the research base on how to use technology in ways that maximize student learning. These resources potentially support inquiry-based learning approaches through the collection and transformation of data. Furthermore, by making data trends evident, these technologies have the potential to support construction of scientific explanations and complex reasoning. The purpose of this study was to analyze the levels of reasoning displayed by African American girls engaged in technology-enhanced inquiry so as to better understand the extent to which technology can support scientific literacy. Our results indicated modest gains in the girls' ability to display data and connect data trends to scientific phenomenon. We believe that studying the experiences and learning of students from historically underrepresented backgrounds in STEM is critical for ensuring equitable educational experiences and access to STEM-related professions.

DOI: 10.4018/978-1-4666-9616-7.ch005

INTRODUCTION

Black girls have historically performed lower on a number of academic measures when compared to girls as a whole, according to a report released by the National Women's Law Center and the NAACP Legal Defense and Education Fund (Smith-Evans & George, 2014). Black girls continue to encounter deeply embedded racial and gender stereotypes and harsher disciplinary actions for non-conforming behaviors such as expressing their opinions. These girls, disproportionately concentrated in under resourced schools and less likely to be taught by highly qualified teachers, often have limited access to rich, meaningful science, technology, engineering and mathematics (STEM) instruction (Brickhouse, Lowry, & Schulz, 2000; Carlone, 2004). They are often overlooked for, or discouraged from taking advantage of, STEM learning opportunities by educators holding stereotypical beliefs about the girls' abilities or interests. With less access to high quality science learning opportunities that lead to postsecondary STEM education and higher wage professions, Black girls face long-term socioeconomic effects (Smith-Evans & George, 2014).

Maintaining the status quo in under resourced schools located in low socioeconomic (SES) neighborhoods reinforces the achievement gap for Black girls, especially in the face of major learning standards reforms such as the *Common Core State Standards for Mathematics* (National Governors Association Center for Best Practices, 2010) and the *Next Generation Science Standards* (NGSS Lead States, 2013) for science and engineering. In particular, science education reform efforts (National Research Council, 2012; NGSS Lead States, 2013) emphasize scientific practices such as analyzing and interpreting data; using mathematics, information and computer technologies and computational thinking; and constructing explanations of scientific phenomena.

To be successful in STEM, students increasingly need to perform at higher levels of complex reasoning, such as analyzing empirical evidence and generating arguments and explanations (NRC, 2012). Yet, the situation in schools with high percentages of Black girls continue to engender pedagogical approaches that do not promote student ownership for learning or the development of complex reasoning skills (Songer, Lee & Kam, 2002). In addition, the Black girls in these low SES schools continue to be less likely to use technology for creativity, problem-solving, or higher-order thinking required in science inquiry (Songer et al., 2002).

As postsecondary science educators, we were invited to support one urban school district's efforts to establish an effective STEM learning environment for students at an all-girls elementary STEM academy. The partnership involved securing science equipment, such as data collection technologies, establishing science labs, and providing ongoing professional development to teachers for science inquiry instruction. To better understand the influence of the partnership on science learning, we examined the girls' efforts in collecting and analyzing data, as well as their ability to reason and generate explanations as they engaged in STEM inquiry activities. This case study was guided by the following research questions:

1. To what extent did the girls use technology proficiently to collect and represent data during inquiry?
2. What categories of complex reasoning were displayed in the girls' interpretations of data collected during technology-enhanced inquiry?
    a. Did the categories of complex reasoning change over subsequent encounters with technology? If so, how?

BACKGROUND

Technology-Enhanced Inquiry

Technology-enhanced inquiry has been shown to promote science learning (Lee, Linn, Varma, & Liu, 2010; Harskamp, Suhre, & VanStreun, 2000; Kwon, 2002; Parr, Jones, & Songer, 2004; Webb, 2008; Zucker, Tinker, Staudt, Mansfield, & Metcalf, 2008). Linn (2003) described important trends with regard to the use of technology in science education in the past few decades. First, technologies such as probeware and interfaces have become more tailored to specific topics, audiences, and disciplines and these technologies have become more customizable to suit particular users. Linn contended that with improvements to curricular programs that incorporate data collection technologies, students' performance and experiences also improve exponentially. Furthermore, the studies by Campbell et al., (2015) and Wilson et al. (2010) presented data that suggest the use of technology-enhanced instruction has more dramatically positive effects on the student achievement of non-white students and students with low socioeconomic status, which demonstrates the potential for reducing the achievement gap. Many data collection technologies used in contemporary science and mathematics classrooms are relatively inexpensive compared to their precursors (Kwon, 2002). As a result, these technologies are promising for implementation in schools in underserved and low SES communities. Furthermore, data collection technologies tend to be better tailored to classroom use than computers, which in turn influences the ways in which these technologies can be incorporated into instruction (Krajcik, Marx, Blumenfeld, Soloway, & Fishman, 2000).

Owing to increased implementation in classrooms, the role of data collection technologies on students' learning is of rising interest to the science education research community. Lee et al. (2010) found students were more likely to develop integrated understanding of science concepts from technology-enhanced inquiry units than from typical instructional methods. Parr et al. (2004) showed the effectiveness of hand-held data collection technologies and software for facilitating student observations of animal biodiversity in elementary schoolyards. Analysis of data logs indicated students' ability to notice a range of animal sightings beyond that of live animals, such as animal tracks, signs, smell, or sounds. Kwon (2002) explored the effect of calculator-based ranger (CBR) devices on middle school students' ability to interpret, model, and transform graphical information of physical phenomena. Students used the CBRs to collect real-time data on distance, time, and velocity. Using pre/post-implementation of Graphing Interpretation Skill Test (GIST) (McKenzie & Padilla, 1986), Kwon found significant differences in graphing ability of students using CBR technology when compared to students in traditional lecture-style science classes. Using word problem prompts, Mitchemore and Cavanagh (2000) investigated how students interpret linear and quadratic graphs on a graphing calculator screen. They found students lacked attention to scale and had difficulty connecting the graph to its symbolic representation. In a 10th grade mathematics class, Harskamp et al. (2000) compares students who used graphing calculators with those who did not. They found the more time students spent using graphing calculators, the more they used graphical strategies to solve problems. Zucker et al. (2008) studied the impact of their Technology Enhanced Elementary School Science II project that included computer and probeware to support inquiry-based units for grades 3-8. They found students benefitted from the incorporation of sensors and probeware (e.g., temperature, pressure) into curriculum units dealing with science topics where graphs are critical to conceptual learning. Overall, this set of research has demonstrated the benefits of technology-enhanced data collection in regards to student outcomes.

To further support this set of individual research studies, three reviews, Kastberg and Leatham (2005), Thornton (2008) and Forgas, Vale and Ursisi (2010) synthesized findings of studies that specifically examined the use of graphing calculators and data collection technologies. A key finding from Kastberg and Leatham (2005) was that increased access of graphing calculators in schools did not necessarily translate to increased use by students. This finding indicates the need for teacher investment in incorporating graphing calculators into instruction. Thornton's (2008) review indicated students make substantial gains from physics curricula that utilize real-time data collection in an activity-based environment. Forgasz et al. (2010) focused on literature related to gender and equity issues when implementing technology in mathematics classrooms. They reported that in studies conducted in classrooms with mostly high SES students, participants were more likely to hold gender-stereotyped views of computer use on learning. By contrast, in classrooms with mostly low SES students, such gender stereotypes regarding technology were challenged, due in part to the novelty of such resources in those classrooms. By highlighting inherent complexities of technology-enhanced inquiry, these reviews also problematize the individual studies noted earlier by providing evidence that questions the benefits of technology-enhanced data collection with regard to student outcomes.

There are a number of educational studies that examined the use of web-based technologies in science classrooms. Specifically, these studies focused on the integration of web data, software, and tools into science teaching and learning. While not specifically related to the use of data collection technologies, these studies provide valuable insights regarding the use of technology in science classrooms. Songer, Lee, and Kam (2002) documented patterns in student learning during technology-rich, inquiry science; they found students made significant gains in learning, but constraints such as lack of computer time and reliable internet connections hindered their ability to fully engage in science concepts. In a follow-up study, Lee and Songer (2003) examined the impact of collecting of the real-time, web-based weather data on students' learning. They found that when students were able to relate forecasting situations to real-time weather data, they were better able to provide detailed scientific explanations. Krajcik et al. (2000) examined the impact of project-based units taught in conjunction with Investigators' Workshop, a computational tool intended to support the development of data collection, visualization and analysis. Based on pre-/post-tests designed to match the district's curriculum standards, student performance showed improvement across implementation of all projects.

To summarize, two consistent themes were identified in this set of research on technology-enhanced inquiry in science classrooms. First, nearly all studies revealed benefits of "real-time" data collection and analysis with regard to students' learning. Specifically, such technologies afford rapid, efficient graphical representation of data related to the physical phenomenon under investigation. Second, owing to the usage of technology such as graphing calculators, some of the burden of technical/procedural aspects of computational tasks is removed. As a result, students have more time to consider the meaning and relationship of data to the phenomenon, thus they have the capacity to develop deeper and more connected science conceptions. As Kastberg and Leatham (2005) cautioned, however, simply having access to data collection technologies does not necessarily mean those technologies are being used effectively in classroom instruction. Unfortunately, few studies have focused on uses of data collection technologies in K-12 science classrooms. In addition, few studies directly correlate the use of data collection technologies to students' skills for generating, representing and interpreting data. For example, little is known about the ways in which data collection technologies afford or hinder students' interpretations of data. As technology becomes increasingly prevalent both inside and outside the classroom, we need a better understanding of how data collection technology promotes or undermines students' opportunities to learn science (Forgasz et al., 2010). Our research extends upon prior studies by examining the benefits of utilizing of technology-enhanced data collection tools on low SES girls' ability to effectively collect, analyze and interpret data.

Data Interpretation and Complex Reasoning

Complex reasoning is the ability to analyze and interpret empirical data and formulate explanations from evidence (Songer & Gotwals, 2004). Complex reasoning differs from declarative knowledge in that complex reasoning requires students to understand the connections of claims and evidence to underlying science concepts (Songer, 2000). Tytler and Peterson (2003) showed that children as young as seven can distinguish between competing explanations and can design investigations to test them. Complex reasoning is most effectively developed in the context of authentic science inquiry, where students can build explanations from data as well as develop an understanding of underlying science concepts (Chinn & Malhotra, 2002).

Several studies have described the levels of reasoning among urban students engaged in curricula interventions. For instance, Songer (2000) described the outcomes of a systemic curricular and assessment program on biodiversity implemented in grades 4-7 in an urban school district. Data indicated students in experimental cohorts significantly differed from control cohorts in their ability to develop hypotheses and predictions, interpret data and formulate scientific explanations from evidence. This study suggests increasing the ability of students to engage in complex reasoning is fostered by carefully designed curricular and assessment programs that specifically scaffold such skills. Songer and Gotwals (2004) showed students who engaged in an 8-week inquiry unit significantly increased in their ability to formulate scientific explanations from evidence on scaffolded assessment tasks. Songer, Kelcey, and Gotwals (2009) suggested using learning progressions as templates for organizing sequences of lessons in curricular units that would scaffold increasingly complex reasoning by students. Dolan and Grady (2010) studied inquiry in high school classrooms and found students displayed complex scientific reasoning about the meaning of data, the connections of data to research questions, how to effectively communicate findings when they were able to conduct their own investigations.

With regard to data analysis and interpretation, the majority of science education studies have focused on understanding how to better support students' skill development in data-related science practices (Bowen & Roth, 2003, 2005; Bencze & Bowen, 2007). Roth et al. (1998) found that students' graphic representations became increasingly elaborate over the course of 10 weeks, with increasing experiences with open-inquiry and data they collected cascaded. Roth (1996) sought to understand the role the open-inquiry context takes among 8th grade students who did not participate in field studies. Both field study and non-field study groups were presented with similar storied word problems that presented data. The non-field study groups had a less difficult time completing the word problems, but the field studies group was far more capable of producing defensible arguments their responses to word problems. Wu and Krajcik (2006) used a case study to characterize the inscriptional practices of seventh graders, particularly their use of data tables and graphs, during an 8-month instructional unit. They found teacher scaffolding was critical for students in learning how to collect data, construct graphs, and interpret data.

In sum, the research shows that the more students engage in their own, open-ended inquiry investigations, the more supported they will be in developing sophisticated data collection, inscription, and analysis skills. Also, opportunities to collaborate and discuss are critical to the development of skills related to data inscription and interpretation. Our research extends upon prior studies by exploring the factors that influence urban Black girls' ability to effectively analyze and interpret data during guided inquiry.

An Imperative to Include Research on Elementary Black Girls

Scientific practices are used to establish, extend and refine our current understandings of the world (NRC, 2012). Engaging in these practices helps students to understand how scientific knowledge develops, makes that knowledge more meaningful, and embeds it more deeply into their worldview. Research has shown technology-enhanced instruction that engages students in the scientific practices can have a positive impact on the depth of students' science understandings (NRC, 2012; Thornton, 2008; Zucker et al., 2008). Clearly, understanding students' abilities to use technology to collect, analyze and interpret empirical data and formulate explanations is important in science education and studies are increasingly advancing our understandings in this regard. Although this research has done much to increase our understanding of elementary children's science and technology-based experiences, it has not gone far enough. Very few inquiries in this area consider gender, race and SES. Some question the value of research that focuses the educational experiences of one specific group of students when all students need attention; however, an equitable science education demands that we understand the experiences of all students and do not assume the experience of the majority speaks for all (American Association of University Women Educational Foundation, 1999). Research has shown that some of the claims for elementary children in science and technology are not true for children of all situations and raises critical questions in regards assuming the applicability of research findings (e.g., Fordham, 1993; Pringle, Brkich, Adams, West-Olatunii & Banks, 2012; Rollock, 2007)

Black girls' from low SES communities are uniquely affected by school experiences. For example, Rollock (2007) demonstrated that silencing is critical to understanding the often-ignored Black females, as much of the focus on achievement gaps tend to highlight only their male counterparts. This silencing may explain why Black girls often adopt negative academic strategies such as underperforming and selecting lower level courses to avoid negative interactions (Fordham, 1993). However, there is also research that raises questions about whether these findings are only a reflection of Black girls or the educational settings of which they are a part. Pringle, Brkich, Adams, West-Olatunii and Archer-Banks (2012) found educators who hold stereotypes of girls informed by race and gender often steer female students away from STEM courses. Furthermore, significant differences in class, ethnicity, and gender have made the distribution of resources, such as technology-based data collection instruments, a major contributing factor to differential success among groups of learners (Barton, 2007). The teachers in schools with a substantial proportion of students from low SES and/or minority backgrounds frequently reported a lack of the materials necessary to teach science (Smith-Evans & George, 2014). Findings such as these raise questions whether gendered relationships are influenced by the individual student or overall school experience (Chavous, Rivas-Drake, Smalls, Griffin & Cogburn, 2008). These emerging findings enhance our understanding of the factors that can negatively influence efforts to reduce the achievement gap in minority, urban, and gendered groups, an understanding that led us to question any preconceived notions we may have held about the unique educational experiences of these girls. Realizing such differences leads to an imperative to assure a research base that includes finding generated from research on Black girls in low SES school districts.

The existing gap in K-12 STEM achievement for Black girls leads to fewer opportunities in postsecondary education and STEM professions. While women make up 24 percent of the STEM workforce, only

2 percent of this population is Black (Economics and Statistics Administration, 2011). The challenges inherent in advancing the success of Black girls in STEM are deeply rooted in the ongoing struggle for racial, class, and gender equity. Straying from a deficit model to one of understanding and empowering non-mainstream students will foster a attention to the need to provide adequate opportunities to diverse students tend so they can excel in science (Tal, Krajcik, & Blumenfeld, 2006). Our work extends upon prior studies by examining the experiences of urban elementary Black girls as they engaged in technology-enhanced inquiry.

METHOD

Methodological Approach

To best understand the levels of complex reasoning of the urban elementary Black girls during technology-enhanced scientific instruction, an exploratory case study design was utilized (Creswell, 2002). A case study is defined as an exploration of a "bounded system" over time through detailed, in-depth data collection involving multiple sources of information (Creswell, 1998). Case studies are particularly appropriate for understand the details and complexity of a situation (Stake, 1995).

Case

The single case examined in this study was the sixth-grade Black girls attending an all-girl elementary academy in a large urban district in the Midwest. Of the 350 girls that attend this academy, the majority live in public housing developments close to the school. The student population is 99% Black and 1% Multiracial, and 88% qualify for free lunch. Participants in this study included 41 sixth grade Black girls. It should be noted, however, that not all 41 girls participated in every lesson. The number of girls who took part in any single lesson is noted in the findings below. The research team worked with the teachers to assist them in creating lessons that both addressed standards and used technology-enhanced instruction. An individual from the research team also supported the implementation of the lessons during instruction, aiding in making necessary curricular adjustments and assisting in orienting students to the graphing calculators and data collection probeware.

Each lesson incorporated TI-73 graphing calculators (Texas Instruments, 2011) with CBL data collection units and Vernier probeware sensors. This technology was intended to support data collection and analysis during inquiry and facilitate students' interpretations of complex data sets, while building on conceptual understandings of temperature, seasons, and weather. These topics were selected by the teachers in an effort to address the state science standards as well as the school district's curriculum expectations. An overview of the relevant standards is provided in Table 1. During the time of this study, the teachers were also expected to address the topics in a chapter on weather in the district's adopted science textbook. The lessons were created from adapted activities from Volz (2000) and Johnson, DeMoss, & Sorensen (2003). An initial decontextualized activity on collecting temperature data, graphing data and interpreting results was used to address the prerequisite knowledge of the scientific process and technological skills necessary to engage in subsequent inquiry-based lessons on seasonal light and temperature changes, the capacity of sunglasses to block UVB radiation, air particulates, and relative humidity. In all lessons, students developed questions from prior knowledge and initial explorations.

Table 1. Listing of State Science Standards Addressed in Lessons

Type of Standard	Standard
Process Standards	1. Make predictions and develop testable questions based on research and prior knowledge, 2. Plan and carry out investigations-often over a period of several class lessons-as a class, in small groups or independently, 3. Collect quantitative data with appropriate tools and technologies and use units to label numerical data, 4. Incorporate variables that can be changed, measured or controlled, 5. Use the principles of accuracy and precision when making measurements, 6. Test predictions with multiple trials, 7. Keep accurate records in a notebook during investigations, 8. Analyze data, using appropriate mathematical manipulation as required, and use it to identify patterns. Make inferences based on these patterns. 9. Compare the results of an experiment with the prediction, 1-0. Communicate findings through oral and written reports by using graphs, charts maps and models.
Content Standards	Demonstrate that the seasons in both hemispheres are the result of the inclination of the earth on its axis, which causes changes in sunlight intensity and length of day.

Then, they designed experiments, used technology-enhanced data collection tools, tabulated their quantitative data in tables and applied their understanding of related science concepts during interpretation of data trends and infer about their significance. With the exception of the first lesson, students were required to produce graphs to appropriately represent data in all lessons. In Lessons 4, 5, and 6 students were expected to do simple mathematical calculations. Writing prompts and classroom questioning by the teachers guided students' written interpretations. Table 2 provides an overview of the lessons in sequence, along with the goals of the lessons and technology employed.

Table 2. Overview of lessons using TI-73 calculator, CBL collection unit and corresponding Vernier sensor(s). Lessons included adapted activities from Volz, (2000) and Johnson, DeMoss, & Sorensen (2003).

Lesson	Learning Goal(s)	Sensor
Temperature	Become familiar with inquiry skills and technology.	temperature
Seasons Part 1	Build and reinforce conceptual understanding of the effect of the tilt of Earth's axis on its seasons. Collect temperature data from various places on a globe with light directed at it simulating the Sun.	temperature
Seasons Part 2	Reinforce understanding of relationship between light and temperature in producing seasonal changes. Develop and implement scientific investigations on the relationship between light and temperature.	temperature
UVB	Build and reinforce conceptual understanding of UVB. Gather data about the amount of UVB light that passes through sunglasses.	UVB
Air Pollution	Build and reinforce conceptual understandings of air pollution. Draw inferences about collected air particulates from various sites/times.	light
Relative humidity	Build and reinforce conceptual understanding of relative humidity. Calculate relative humidity levels in various sites on school grounds.	temperature

Data Sources and Analysis

Data were collected over the course of the six lessons. Each of these class sessions was video and audio-recorded. The girls' written graphic representations and responses to prompts from each of the lessons was also collected and analyzed. Follow-up interviews with the girls were also conducted and recorded.

Content analysis (Ary et al., 2006; Stemler, 2001) was conducted using *a priori* categories to code: students' written data, audio data from focus groups during class, and transcripts of interviews with the students. Dolan and Grady (2010) described "an analytic tool for recognizing when students engage in complex reasoning during teaching by inquiry" (p. 32). Dolan and Grady situated their study in the context of high school science. The offered a continuum of levels of complexity in reasoning: least, somewhat, more, and most complex. By their definition, most complex reasoning reflects, "the depth of reasoning associated with the work of research scientists" and least "when information is provided to students rather than gathered or reasoned by them" (p. 38). We modified their matrix, using categories of cognitive processes that fit with the intended goals of the inquiry lessons (see Table 2). We found this tool offered us the capacity to extricate nuances among the complexity in students' reasoning. Often, students demonstrated more than one category of complexity. For example, the data in Table 3 were extracted from analysis of students' notebooks, where we analyzed complexity of reasoning of both graphic representations and written explanations. This particular student's graphic representations fell in both the *least complex* and *more complex* categories. She included multiple forms of graphic representation, which categorized them as *more complex*, however, many were copied directly from the calculator, or were incomplete to the point where they were incomprehensible, putting them in the *least complex* category. Her written explanations fell in both the *somewhat complex* and *more complex* categories. She did defend her findings, but did not extend data back to the research question explicitly. She wrote what surprised her about the data, but not how or why. The student wrote, "No, my results were not [what we] expected, because winter turned out to be a little higher…When we moved the globe around the light bulb, the temperatures started to change." (science notebook, 3-12-10) This student's responses are typical in regards to the multiple levels of complexity present.

FINDINGS

To What Extent did the Girls use Technology Proficiently to Collect and Represent Data During Inquiry?

To understand the extent to which the girls used technology proficiently to collect and represent data, we analyzed the data tables and graphs in girls' written documents. A summary of results is shown in Table 4. In general, the girls showed an increase across the lessons in their ability to organize and represent data appropriately in tabular form. By Lesson 6, all girls produced a data table in their written documents. They also became more proficient in their ability to produce appropriate graphs to represent data. In Lesson 2, only 23 of 35 girls correctly identified the independent and dependent variables from their investigations and accurately plotted them on the x- and y-axis, respectively. By Lesson 6, more girls were producing accurate graphs, with 28 of 29 girls doing so. Finally, there was an increase in the girls' ability to accurately calculate using data collected from investigations. Although the girls were only required to complete mathematical calculations in last three lessons, by Lesson 6, 80% of them were able to complete these calculations correctly.

Table 3. Modified version of the matrix developed by Dolan & Grady (2010) for evaluating students' complexity of reasoning

Cognitive process	**Complexity of Reasoning on Scientific Tasks**			
	Least complex	**Somewhat complex**	**More complex**	**Most complex**
Considering the meaning of the data representations	Students are provided with a formatted data table and do not consider meaningful representation of data	Students design their own data tables giving little consideration to the meaning of representations of data	Students represent data in multiple ways including tables, drawings, graphs, photographs, or statistical representations with little consideration of the meaning of representations	Students represent data in multiple ways including tables, drawings, graphs, photographs, or statistical representations, thoughtfully considering the meaning of representations
Communicating and defending findings	Students do not communicate or defend their findings either orally or in writing	Students give limited attention to communicating and defending their findings orally or in writing	Students communicate their findings orally or in writing with some emphasis on defending their findings	Students communicate their findings orally or in writing. Students use logical arguments to defend their findings
Connecting data to scientific concepts	Students do not connect data to research questions	Students use their data to answer questions other than the primary research question	Students use different forms of reasoning (e.g., contrastive, deductive, inductive) to connect data to the primary research question. Reasoning may require inferences involving several layers of connections	Students use results from different studies, as well as different forms of reasoning (e.g., contrastive, deductive, inductive) to connect their data to the primary research question. The reasoning may require inferences involving several layers of connections
Generating questions	The overarching research question is provided; students do not generate or explore other questions during the inquiry	The overarching research question is provided; students generate and/or explore other questions based on observations during inquiry	The overarching research questions is provided; students generate and/or explore other questions based on observations and wider exploration of the research topic during the inquiry	Students generate their own research question; other questions are generated and explored based on observations and wider exploration of the research topic during the inquiry

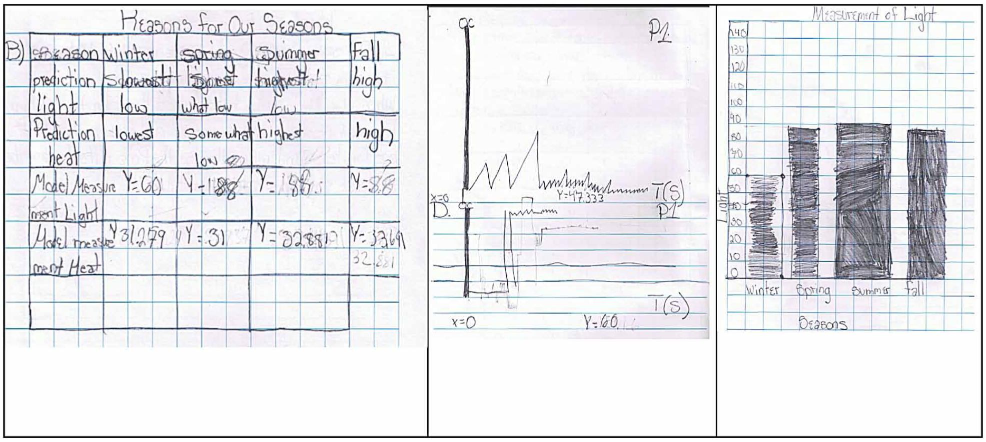
Table 4. Levels of proficiency in data collection and representation shown in written documents

	Produced complete data table	Accurate mathematical calculations	Appropriate graph with proper x, y-axes
Season I (n = 35)	80%	n/a	66%
Season II (n = 30)	67%	n/a	73%
UVB (n = 30)	97%	37%	77%
Air Pollution (n = 30)	90%	83%	77%
Relative Humidity (n = 29)	100%	80%	97%

What Categories Of complex Reasoning were Displayed in Girls' Interpretations of Data Collected During Technology-Enhanced Inquiry? Did the Categories of Complex Reasoning Change Over Subsequent Encounters with Technology? If so, how?

Considering the meaning of the representations of data. The girls' graphic representations and considerations of their meaning exhibited modest increase in complexity over time. Graphic representations became more independently created, accurate, and varied. Students increased the variations used in their graphic representations as a result of following scaffolds to use different graphic representations to communicate data in different ways. However, girls would commonly copy directly what they saw presented on the calculator screen (see middle image in Figure 1), without adding information that would make the graphic comprehensible. Or, they included several representations without connecting them or offering meaning for why they illustrated the data they did.

Figure 1. A student's multiple representations of data collected in an inquiry experience illustrating a model of seasonal temperature and light changes. The image on the left is a table which was provided to the students to input their predictions and actual light and heat measurements. The image in the middle is a student's drawing of what she saw on the calculator screen. The image to the right is a student's graph representing light data she recorded.



Reasons for Our Seasons

B)

Season	Winter	spring	Summer	Fall
prediction light	lowest low	highest Some what low	highest! low	high
Prediction heat	lowest	Some what low	highest	high
Model Measurement Light	Y=60	Y=188	Y=188	Y=88
Model measurement Heat	Y 31.279	Y=31	Y=32.881	Y=33.69 32.881

Towards the end of the study period, the girls consistently submitted graphs such as that displayed in Figure 2. Over time, the girls became more adept, though not fully proficient, at labeling their graphs. They also illustrated data on their graphs with greater accuracy. Figures 2 and 3 illustrate one girl's graphs at three points in the case study period. They show characteristic growth and change in graphic representation skill. The graphic representations in Figure 2 are from an inquiry experience at a mid-point in the case study period. The numerical labeling on units does not represent comprehensible information, creating graphs that lack desired meaning. They are also missing labels and data points. Figure 3 shows a graphic representation from the last inquiry experience in the case study period. It is a more accurate and meaningful representation, with clear labels and numerically correct spacing of units. Still, graphs such as this one lack some important labels, such as units for light measurements, and are not arranged in a way that optimally illustrates the meaning of the findings.

Figure 2. A students' graphic representations of data from the middle of the case study period

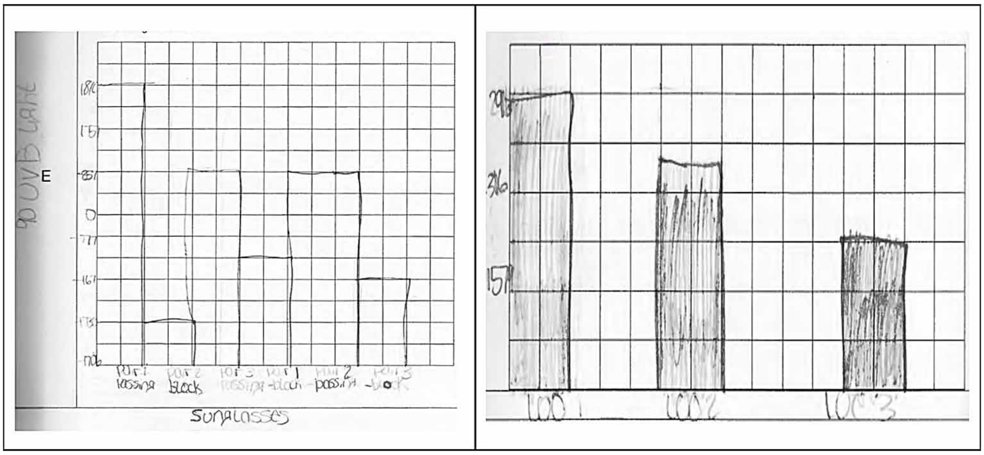
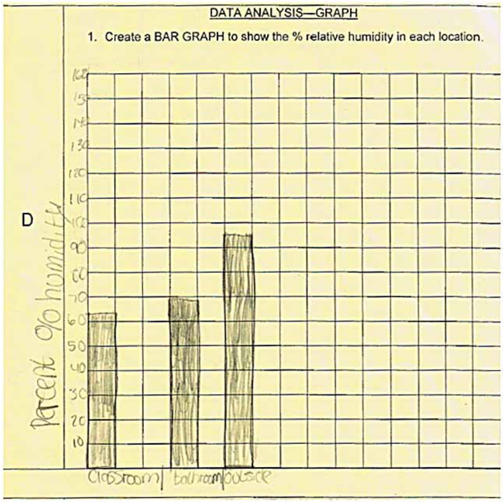


Figure 3. A student's graphic representation of relative humidity data from the end of the case study period


DATA ANALYSIS—GRAPH

1. Create a BAR GRAPH to show the % relative humidity in each location.

To a great extent, many inaccuracies persisted in students' graphic representations throughout the case study period. There are a few possible explanations for these inaccuracies. The girls may not fully consider graphic representations as a means for displaying their findings. They also may simply have not fully developed the skills for graphing, or the understanding that graphing is a way to model findings and communicate them. Also, the standards and concepts around graphing may not have been clearly communicated to the girls.

Communicating and defending findings. Most often, students communicated their findings orally or in writing, but did not draw on specific data or use logical arguments to defend them. When the girls were asked to use examples from their investigations to explain why there are seasons, they either provided specific data points, or explained by talking through the investigation, but not both. One student said,

I learned that with the globe and the temperature and the light, you tilt it over and the season for the winter, or fall, or spring or whatever. Whatever temperature it is tells us what season it is. For example, put the temperature probe on the globe…you tilt it over a little bit, and then the temperature comes up as 92. And then if you tilt it back, from the right, then it will be like, 20… (interview, 3-17-10)

This student offered specific data, but did not explain it. Another girl said,

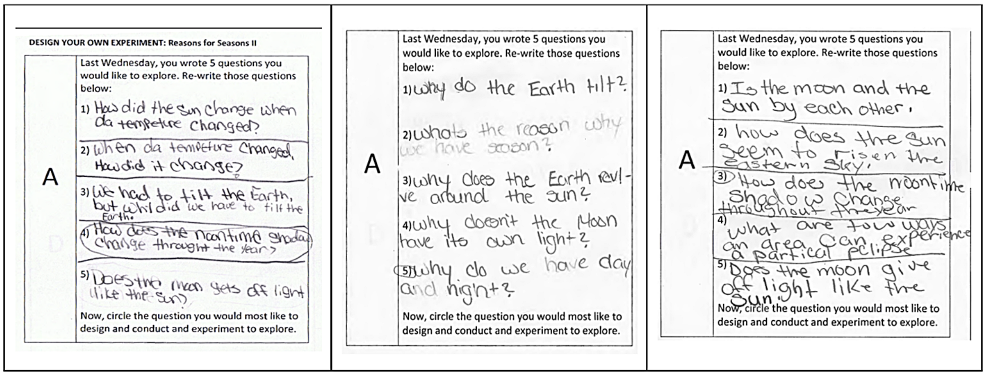
Well, the Earth is tilted as it moves towards the Sun… We found that if you tilted it more, it's more sunny… And if you tilt it a little bit back it's Spring, and sometimes Fall, but if you tilt it all the way back, where it's not getting direct sunlight, it's going to get indirect Sun and it's going to be winter… I noticed with the temperature it would get lower [in indirect light]. It could because direct sunlight produces more heat than indirect sunlight. (interview, 3-17-10)

This student did not offer specific data, yet did have a more rich explanation for the phenomenon. In this technology-enhanced inquiry experience, the student exhibited increasing complexity in communicating and defending findings, as she used her experiences and data to defend conclusions. Complexity in communicating and defending findings increased over time.

Connecting data to scientific concepts. In some respects, the connections students made to scientific concepts exhibited the greatest gains in complexity. Towards the beginning of the case study period, very few connections were made between data and scientific concepts. Typically, the girls either explained in narrative form the data they showed in their graphic representation, or they offered explanations of the scientific concepts that were similar to what they had read in their science textbooks. Across the lessons, the girls increasingly linked data to scientific concepts. However, such connections remained superficial. For example, after an inquiry experience using dry and wet temperature probes to find relative humidity in several sites in and around their school, the girls were asked to describe the sites which had the lowest and highest relative humidity, and provide reasoning for their findings. The following students' written response typifies the responses students offered:

The wet temperature was always lower than the dry temperature. The classroom [had the lowest relative humidity] because the classroom has a warm temperature. Outside [had the highest relative humidity] because outside it was cold and just got finish[ed] raining. (artifact, 5-7-10)

Figure 4. Students' questions generated during technology-enhanced inquiry



DESIGN YOUR OWN EXPERIMENT: Reasons for Seasons II

A

Last Wednesday, you wrote 5 questions you would like to explore. Re-write those questions below:

1) How did the sun change when da tempeture changed?
2) when da tempeture Changed, How did it change?
3) We had to tilt the Earth, but whi did we have to tilt the Earth.
4) How does the noontime shadow change throught the year?
5) Does the moon gets off light like the sun?

Now, circle the question you would most like to design and conduct and experiment to explore.

A

Last Wednesday, you wrote 5 questions you would like to explore. Re-write those questions below:

1) why do the Earth tilt?
2) whats the reason why we have season?
3) why does the Earth revlve around the sun?
4) why doesn't the Moon have its own light?
5) why do we have day and night?

Now, circle the question you would most like to design and conduct and experiment to explore.

A

Last Wednesday, you wrote 5 questions you would like to explore. Re-write those questions below:

1) Is the moon and the Sun by each other.
2) how does the Sun seem to risen the eastern sky.
3) How does the noontime Shadow change throughout the year
4) what are tow ways an area can experience a partical eclipse
5) Does the moon give off light like the Sun.

Now, circle the question you would most like to design and conduct and experiment to explore.

Although this student offered no specific data points, and only made simple connections to scientific concepts, the effort to link data to scientific concept was evident.

Generating questions. Three factors influenced the girls' complexity of reasoning as it relates to generating new questions: 1) flexibility in the inquiry task structure, 2) opportunities for peer interaction, and 3) encouragement from the teacher. After the second inquiry experience, students were tasked with generating new questions to explore in writing, such as those in Figure 4. In this case, they were explicitly prompted to devise questions to be investigated in the third inquiry experience. Based on the modified version of Dolan and Grady's (2010) matrix, these questions mostly demonstrated somewhat complex reasoning, with some more complex reasoning. These questions contain elements of being investigable, an aspect of more complex reasoning.

In the second inquiry experience the girls generated their own research questions, and in the third inquiry experience, girls had opportunities to revise, select, and design experiments to explore these questions with their peers. During opportunities for peer interaction, where the girls generated questions informally, they exhibited more complex reasoning as indicated in Table 2. For example, at the end of one of the investigations modeling seasonal changes in light and temperature, one group had the following interaction:

S1: *[operates the graphing calculator in a way to show the data differently]*
S2: *[overlooking S1's shoulder] I didn't even know you could do that.*
S1: *What are the values, so that I can put them in my table?*
S2: *540 and 541.*
S1: *Ugh. Sheesh.*
S2: *Let's try somewhere on the Southern Hemisphere now.*
S1: *I'm gonna look at Colombia. Right there [pointing to Colombia on the globe].*

This pair of students moved beyond modeling seasonal changes in the Northern Hemisphere to experimenting with such changes in a different geographic location. They were offered ample time with each other to generate and try new investigations which stemmed from, but moved beyond, the original assignment.

The following example from observations of a focus group illustrates encouragement from the teacher during technology-enhanced inquiry experiences:

S1: *[To teacher, pointing to her group member] Tell her this is a good question. I wonder if we do summer twice, will we get the numbers changed?*

T: *Ok, so you're talking about doing repeats. What do you think of that question? …here's what I want you to think about. You know the equipment that we've been using, right? Which one could you use to design an experiment to do? If you want to alter it a little bit you can do that. Like, if you want to add something in there, you can do that. Maybe you want to do it three times, or maybe you want to do something different.*

S2: *That would be too much work! Oh, I want to do that one…[points to another student's paper]*

T: *Yeah, you might have to revise it a little, but yeah, you could do that. So, start thinking about what you could do, because you're gonna want to get a lot of data, right? To be able to say, is it the same. And what might make it change? Start thinking about that. But I like that, that's a great question! [to S1, then turns to S3] I like yours too, just so you know.*

S1: *See? We can do it again...or we could do yours [referencing S3's question]. (classroom observation, 3-26-10)*

Of note in this interaction is the encouragement offered by the teacher. Even in earlier teacher prompting for question generation, the girls exhibited greater complexity in reasoning when instruction moved beyond written prompts to verbal encouragement from the teacher.

Complex reasoning changed over subsequent encounters with technology. Across the four cognitive processes analyzed, the girls exhibited increases in their complexity of reasoning, some more modestly than others. Table 5 offers calculated percentages of responses exhibiting varying levels of complexity. Most responses analyzed showed more than one level of complexity, resulting in total percentages higher than 100%. Of particular note is the considerable drop in least complex responses for Lesson 4. Also, the percentage of responses in the somewhat complex category increased to 100% by the end of the case study period. However, no responses analyzed exhibited most complex reasoning.

DISCUSSION AND IMPLICATIONS

Increasingly, K-12 students are being asked to perform at high levels of complex reasoning in science classrooms. This process involves learning experiences that include using data collection technologies

Table 5. Percentage of written responses exhibiting varying levels of complexity

Complexity of reasoning	Least complex	Somewhat complex	More complex	Most complex
Temperature	44%	65%	19%	0%
Seasons I & II	42%	78%	32%	0%
UVB	29%	82%	43%	0%
Air Pollution	40%	83%	43%	0%
Relative Humidity	38%	100%	31%	0%

to collect and analyze data, interpreting results, and constructing scientific explanations. Unfortunately, the situation in schools with high percentages of Black girls has not traditionally provided experiences in these areas. This study provided an opportunity for us to collaborate with urban teachers to develop and implement instructional experiences that would further foster Black girls' abilities to engage in technology-enhanced scientific inquiry. As we review the findings in regards to generating, representing and interpreting data, we can see that our attempts fostered an improvement. We must, however, continue to seek a higher degree of reasoning from students about the data. To that end, we now turn our attention back to our own pedagogy.

Across the technology-enhanced inquiry lessons, girls increasingly used technology proficiently, and made positive progress towards proficiency in their graphic representations of data. These findings are reflective of some studies of technology-enhanced inquiry (e.g., Lee et al., 2010; Parr et al., 2004). In general, our series of technology-enhanced inquiry-based activities were associated with an increase in the girls' ability to organize and represent data appropriately, as is similar to the findings of Kwon's (2002) study. However, with regard to our efforts to increase the girls' abilities to reason and interpret the data accurately, our findings were mixed, much as in some studies in science courses with a strong emphasis on mathematical reasoning (Mitchemore & Cavanagh, 2000; Harskam et al., 2000). Perhaps, then, technology-enhanced inquiry has a greater impact on conceptual reasoning than it does complex reasoning about data. During the study, we observed many girls did not use data collected from their inquiry investigations, either partially or extensively, to reason about scientific phenomena.

Working within this urban classroom has afforded us new insights with regard to our overall goals. Such insights include the need of a longitudinal approach to fostering inquiry practices and an explicit structuring and scaffolding approach to guiding the girls to reason through the inquiry process. We believe that a longitudinal approach that would afford us more time to scaffold the process is necessary given the limited prior inquiry experiences of the girls and teachers, as well as the authoritative context. In regards to the later, Delpit (1995) cautioned against dismissing such issues of power in the school setting; in this case, the teacher-centered approach to teaching and learning. Although this has been found to be a consideration in many schools, it is particularly evident in urban schools (Songer, et al., 2002; Barton, 2007; Kahle, Meece & Scantlebury, 2000). We suggest the solution to this climate must lie with the urban teachers. Our future professional development opportunities need to illustrate to the teachers how to redirect ownership of the learning process by students through constructive formative dialogues. Furthermore, we now realize that teachers' potential for scaffolding the girls' reasoning abilities was never fully realized due the limited use of constructive feedback, which we contend is necessary to guide the girls' reasoning skills.

Although prior studies indicate elementary students are capable of pursuing significant, productive explorations, which result in complex reasoning about data and its relationship to science concepts (Songer & Gotwals, 2004; Tytler & Peterson, 2003), our initial findings in regards to highlighting these capabilities of urban elementary Black girls are mixed. We posit that a combination of factors including school climate and the types of scaffolding contributed to low levels of reasoning displayed in their written documents. It is these considerations we take with us as we further seek to address the gap between the classroom experience provided in our urban schools and Black girls' potential competencies.

FUTURE RESEARCH DIRECTIONS

In terms of enhancing urban elementary Black girls' efforts in collecting and analyzing data, as well as generating arguments and explanations as they engage in technology-enhanced inquiry, our research demonstrated that a short-term collaboration was associated with modest improvements in the girls' ability to engage in complex reasoning. Although our collaboration with teachers at this school was only four months long and included six technology-enhanced inquiry lessons, the progress made by the girls raises questions about the levels of reasoning that could have been achieved with a more long-term intervention with systemic professional development with teachers. Our research also raises further questions about advancing the success of these young women. As noted, studies have shown that scaffolding is needed to engage students in increasingly higher levels of reasoning. We understood this as we began this process; but the extent and duration of scaffolding appears to be greater than what we anticipated. Throughout the process, our collaborative group utilized formative assessment strategies. In our future efforts, we intend to explore ways to better scaffold the process – specifically formative dialogues. We question whether student-teacher dialogues will provide the needed opportunities for teachers to identify reasoning and respond in a manner that encourages further progress. We believe this is critical as our findings also revealed that we attempted to move from scaffolding the first few activities and reach full inquiry too quickly. This, of course, raises further questions about the level of professional development and support, for teachers and students, needed to foster such dialogues in underserved schools.

CONCLUSION

This inquiry came out of our efforts to establish an effective STEM learning environment for elementary Black girls. We sought to understand the influence of technology-enhanced data collection on learning, specifically girls' abilities to collect and analyze data, and generate explanations as they engaged in technology-enhanced inquiry. The technology-enhanced inquiry experiences were associated with modest gains in complex reasoning over the four-month period study period. The girls became more proficient at labeling their graphs and illustrating data, making connections between the data and science content, and explaining the phenomenon. They did not, however, become fully proficient at using graphic representations to communicate results. On occasion they generated their own graphic representations, but more often they copied directly from the calculator screen. Also, while on occasion their reasoning about data was rich and complex, often they did not adequately elaborate or offer necessary explanations.

If we are to support efforts to close the achievement gap for Black girls, we must continue to carefully monitor these experiences. This process must continue to focus on uncovering whether our approach to integrating these technologies into the learning environment leads to the desired student outcomes; however, we believe our focus must expand beyond the experiences of the classrooms. If we are to understand whether we are truly preparing these teachers to meet the needs of youth populations underserved in science education, we must include the learning experiences of students from underserved populations. These future inquiries must continue to inform our practice.

REFERENCES

American Association of University Women Educational Foundation. (1999). *Gender gaps: Where schools still fail our children*. New York: Marlowe & Company.

Ary, D., Jacobs, L. C., Razavieh, A., & Sorensen, C. (2006). *Introduction to Research in Education* (7th ed.). Belmont, CA: Thomson Wadsworth.

Barton, A. C. (2007). Science learning in urban settings. In S. K. Abell & N. G. Lederman (Eds.), *Handbook of research on science education* (pp. 319–343). Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Bencze, J. L., & Bowen, G. M. (2007). Student-teachers' dialectically developed motivation for promoting student-led science projects. *International Journal of Science and Mathematics Education*, *7*(1), 133–159. doi:10.1007/s10763-007-9115-6

Bowen, G. M., & Roth, W.-M. (2003). Graph interpretation practices of science and education majors. *Canadian Journal of Science. Mathematics and Technology Education*, *3*(4), 498–512. doi:10.1080/14926150309556585

Bowen, G. M., & Roth, W.-M. (2005). Data and graph interpretation practices among preservice science teachers. *Journal of Research in Science Teaching*, *42*(10), 1063–1088. doi:10.1002/tea.20086

Brickhouse, N. W., Lowery, P., & Schultz, K. (2000). What kind of girl does science? The construction of school science identities. *Journal of Research in Science Teaching*, *37*(5), 441–458. doi:10.1002/(SICI)1098-2736(200005)37:5<441::AID-TEA4>3.0.CO;2-3

Campbell, T., Longhurst, M., Wang, S.-K., Hsu, H.-Y., & Coster, D. (2015). Technologies and reform-based science instruction: The examination of a professional development model focused on supporting science teaching and learning with technologies. *Journal of Science Education and Technology*, *24*(5), 562–579. doi:10.1007/s10956-015-9548-6

Carlone, H. B. (2004). The cultural production of science in reform-based physics: Girls' access, participation and resistance. *Journal of Research in Science Teaching*, *41*(4), 392–414. doi:10.1002/tea.20006

Chavous, T., Rivas-Drake, D., Smalls, C., Griffin, T., & Cogburn, C. (2008). Gender matters, too: The influences of school racial discrimination and social identity on academic engagement outcomes among African American adolescents. *Developmental Psychology*, *44*(3), 637–654. doi:10.1037/0012-1649.44.3.637 PMID:18473633

Chinn, C. A., & Malhotra, B. M. (2002). Epistemologically authentic inquiry in schools: A theoretical framework for evaluating inquiry tasks. *Science Education*, *86*(2), 175–218. doi:10.1002/sce.10001

Creswell, J. (1998). *Qualitative inquiry and research design: Choosing among five traditions*. Thousand Oaks, CA: Sage.

Creswell, J. (2002). *Educational research: Planning, conducting, and evaluating quantitative and qualitative research*. Upper Saddle River, NJ: Pearson Education.

Dolan, E., & Grady, J. (2010). Recognizing students' scientific reasoning: A tool for categorizing complexity of reasoning during teaching by inquiry. *Journal of Science Teacher Education*, *21*(1), 31–55. doi:10.1007/s10972-009-9154-7 PMID:21113314

Economics and Statistics Adminstiration. (2011). *Women in STEM: A gender gap innovation.* Washington, DC: U.S. Department of Commerce. Retrieved December 11, 2014 from http://www.esa.doc.gov/Reports/women-stem-gender-gap-innovation

Fordham, S. (1993). "Those loud black girls": (Black) women, silence, and gender "passing" in the academy. *Anthropology & Education Quarterly*, *24*(1), 3–32. doi:10.1525/aeq.1993.24.1.05x1736t

Forgasz, H. J., Vale, C., & Ursini, S. (2010). Technology for mathematics education: Equity, access and agency. In C. Hoyles & J.-B. Lagrange (Eds.), *Mathematics Education and Technology—Rethinking the Terrain* (pp. 385–403). New York: Springer.

Harskamp, E., Suhre, C., & Van Streun, A. (2000). The graphics calculator and students' solution strategies. *Mathematics Education Research Journal*, *12*(1), 37–52. doi:10.1007/BF03217073

Johnson, R., DeMoss, G. S., & Sorensen, R. (2003). *Earth science with Vernier*. Beaverton, OR: Vernier Software and Technology.

Kahle, J., Meece, J., & Scantlebury, K. (2000). Urban African-American middle school students: Does standards-based teaching make a difference? *Journal of Research in Science Teaching*, *37*(9), 1019–1041. doi:10.1002/1098-2736(200011)37:9<1019::AID-TEA9>3.0.CO;2-J

Kastberg, S., & Leatham, K. (2005). Research on graphing calculators at the secondary level: Implications for mathematics teacher education. *Contemporary Issues in Technology & Teacher Education*, *5*(1), 25–37.

Keeley, P., Eberle, F., Farrin, L., & Oliver, L. (2005). Uncovering student ideas in science: Vol. 1. *25 formative assessment probes*. Alexandria, VA: NSTA Press.

Krajcik, J., Marx, R., Blumenfeld, P., Soloway, E., & Fishman, B. (2000). Inquiry based science supported by technology: Achievement among urban middle school students. Washington, DC: National Science Education Standards. (ERIC Document Reproduction Service No. ED443676).

Kwon, O. N. (2002). The effect of calculator-based ranger activities on students' graphing ability. *School Science and Mathematics*, *102*(2), 57–67. doi:10.1111/j.1949-8594.2002.tb17895.x

Lee, H.-S., Linn, M. C., Varma, K., & Liu, O. L. (2010). How do technology-enhanced inquiry science units impact classroom learning? *Journal of Research in Science Teaching*, *47*(1), 71–90. doi:10.1002/tea.20304

Lee, H.-S., & Songer, N. B. (2003). Making authentic science accessible to students. *International Journal of Science Education*, *25*(8), 923–948. doi:10.1080/09500690305023

Linn, M. (2003). Technology and science education: Starting points, research programs, and trends.'. *International Journal of Science Education*, *25*(6), 727–758. doi:10.1080/09500690305017

McKenzie, D. L., & Padilla, M. J. (1986). The construction and validation of the test of graphing in science (TOGS). *Journal of Research in Science Teaching*, *23*(7), 571–579. doi:10.1002/tea.3660230702

Mitchelmore, M., & Cavanagh, M. (2000). Students' difficulties in operating a graphics calculator. *Mathematics Education Research Journal*, *12*(3), 254–268. doi:10.1007/BF03217088

National Governors Association Center for Best Practices (NGACBP). (2010). *Common Core State Standards for mathematics.* Retrieved from: http://www.corestandards.org/ Math/

National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts and core ideas*. Washington, DC: National Academies Press.

NGSS Lead States. (2013). *Next generation science standards*. Retrieved from: http://www.nextgenscience.org/

Parr, C. S., Jones, T., & Songer, N. B. (2004). Evaluation of a handheld data collection interface for science learning. *Journal of Science Education and Technology*, *13*(2), 233–242. doi:10.1023/B:JOST.0000031262.22712.e0

Pringle, R. M., Brkich, K. M., Adams, T. L., West-Olatunii, C., & Archer-Banks, D. A. (2012). Factors influencing elementary teachers' positioning of African American girls as science and mathematics learners. *School Science and Mathematics*, *112*(4), 217–229. doi:10.1111/j.1949-8594.2012.00137.x

Rollock, N. (2007). Why Black girls don't matter: Deconstructing gendered and racialised discourses of academic success in an inner city school. *British Journal of Learning Support*, *22*(4), 197–202. doi:10.1111/j.1467-9604.2007.00471.x

Roth, W.-M. (1996). Where is the context in contextual word problems?: Mathematical practices and products in grade 8 students' answers to story problems. *Cognition and Instruction*, *14*(4), 487–527. doi:10.1207/s1532690xci1404_3

Roth, W.-M., McGinn, M. K., & Bowen, G. M. (1998). How prepared are preservice teachers to teach scientific inquiry? Levels of performance in scientific representation practices. *Journal of Science Teacher Education*, *9*(1), 25–48. doi:10.1023/A:1009465505918

Smith-Evans, L., & George, J. (2014). *Unlocking opportunity for African American girls: A call to action for educational equity*. New York: The NAACP Legal Defense and Educational Fund and The National Women's Law Center. Retrieved December 11, 2014 from http://www.nwlc.org/resource/unlocking-opportunity-african-american-girls-call-action-educational-equity

Songer, N. B. (2000). *Persistence of inquiry: Evidence of complex reasoning among inner city middle school students*. Paper presented at the Annual Meeting of the American Educational Research Association, San Diego, CA.

Songer, N. B., & Gotwals, A. W. (2004). What constitutes evidence of complex reasoning in science? Paper presented at the 6th International Conference on Learning Sciences, Santa Monica, California.

Songer, N. B., Kelcey, B., & Gotwals, A. W. (2009). How and when does complex reasoning occur? Empirically driven development of a learning progression focused on complex reasoning about biodiversity. *Journal of Research in Science Teaching*, *46*(6), 610–631. doi:10.1002/tea.20313

Songer, N. B., Lee, H.-S., & Kam, R. (2002). Technology-rich inquiry science in urban classrooms: What are the barriers to inquiry pedagogy? *Journal of Research in Science Teaching*, *39*(2), 128–150. doi:10.1002/tea.10013

Stake, R. (1995). *The art of case study research*. Thousand Oaks, CA: Sage.

Stemler, S. (2001). An overview of content analysis. *Practical Assessment, Research & Evaluation*, *7*(17). Retrieved from http://PAREonline.net/getvn.asp?v=7&n=17

Tal, T., Krajcik, J., & Blumenfeld, P. C. (2006). Urban schools' teachers enacting project-based science. *Journal of Research in Science Teaching*, *43*(7), 722–745. doi:10.1002/tea.20102

Texas Instruments. (2011). *CBL 2*. Retrieved July 18, 2011 from http://education.ti.com/educationportal/sites/US/productDetail/us_cbl_2.html

Thornton, R. K. (2008). Effective learning environments for computer supported instruction in the physics classroom and laboratory. In M. Vicentini & E. Sassi (Eds.), Connecting research in physics education with teacher education. International Commission on Physics Education. Retrieved December 15, 2014 from vnr.st/sb4b

Tytler, R., & Peterson, S. (2003). Tracing young children's scientific reasoning. *Research in Science Education*, *33*(4), 433–465. doi:10.1023/B:RISE.0000005250.04426.67

Volz, D. L. (2000). *Middle school science with calculators: Science experiments using Vernier sensors with the LabPro or the CBL 2 interface*. Beaverton, OR: Vernier Software and Technology.

Webb, M. (2008). Impact of IT on science education. In J. Voogt & G. Knezek (Eds.), International handbook of information technology in primary and secondary education (pp. 133-148). Springer International Handbooks of Education, Volume 20. Springer. doi:10.1007/978-0-387-73315-9_8

Weber, R. P. (1990). *Basic Content Analysis* (2nd ed.). Newbury Park, CA.

Wilson, C., Taylor, J., Kowalski, S., & Carlson, J. (2010). The relative effects and equity of inquiry-based and commonplace science teaching on students' knowledge, reasoning, and argumentation. *Journal of Research in Science Teaching*, *47*(3), 276–301.

Wu, H.-K., & Krajcik, J. S. (2006). Inscriptional practices in two inquiry-based classrooms: A case study of seventh graders' use of data tables and graphs. *Journal of Research in Science Teaching*, *43*(1), 63–95. doi:10.1002/tea.20092

Zucker, A. A., Tinker, R., Staudt, C., Mansfiled, A., & Metcalf, S. (2008). Learning science in grades 3-8 using probeware and computers: Findings from the TEEMSS II project. *Journal of Science Education and Technology*, *17*(1), 42–48. doi:10.1007/s10956-007-9086-y

KEY TERMS AND DEFINITIONS

Complex Scientific Reasoning: The ability to analyze and interpret empirical data and formulate explanations from evidence.

Probeware: Scientific equipment, interfaced with software and computers, which allows data to be collected, interpreted and analyzed.

Scientific Argumentation: A rebuttal to a scientific claim, pointing to a weakness in the evidence or providing other evidence that counters the claim.

Scientific Explanations: Scientific claims, based on observable evidence that is sufficiently justified as relevant to the claim. They are developed in an attempt to capture the best understanding of the natural world.

Scientific Inquiry: The process through which people develop knowledge and understandings of the natural world.

Technology-Enhanced Instruction: The integration of technology into the learning process in order to provide a higher quality learning experience.

Chapter 6

Motivating Inquiry-Based Learning Through a Combination of Physical and Virtual Computer-Based Laboratory Experiments in High School Science

Niwat Srisawasdi
Khon Kaen University, Thailand

ABSTRACT

This chapter presents research about a combination of physical experimentation (PE) and virtual experimentation (VE) in computer-based inquiry learning as an instructional value to students' affective domain. For this study, the author has developed a science lesson for promoting interactive inquiry learning, and the researcher investigated whether orchestrating PE and VE in sequential learning affect students' learning perception and science motivation. To evaluate the lesson, questionnaires were used to examine how students perceived the lesson and their perceptions about how the lesson promotes science motivation. The results indicated students' positive perceptions that experiencing the lesson supported cognitive performance, emotional practice, and the social inquiry process. In addition, exposure to the lesson improved students' science motivation for both females and males. This highlights that the combination is an effective way to enhance the effectiveness of high school science learning.

INTRODUCTION

Based upon the recent demand for human resources in science, technology, engineering, and mathematics (STEM), there is a need for the development of high-quality programs for STEM teaching and learning in K through 12 environments. Many students need more robust STEM education to survive with accelerat-

DOI: 10.4018/978-1-4666-9616-7.ch006

ing changes in the 21st century society (Sanders, 2009; State Educational Directors Association, 2008). To create effective classroom environments for STEM teaching and learning, there is a requirement for comprehensive integration of technology as a fundamental building block into education in the following areas: (a) to develop proficiency in 21st century skills for students; (b) to support innovative teaching and learning; and (c) to create the robust education support system for both students and teachers (State Educational Technology Directors Association, 2008).

Technology has profound and lasting impacts in school classrooms as being a powerful instructional tool. It can transform the way core subjects are taught by facilitating both teachers' instructional practices and students' learning processes (Edelson, 2001; Jimoyiannis & Komis, 2007). STEM educators value the use of technology to support STEM instruction. They believe that several technologies including probeware, computer simulations, software applications, programmable instruments, mobile devices, and laptop/notebook computers could be used effectively to impact student learning in STEM subjects. To meet the challenges in teaching STEM subjects, the use of computer-based laboratories and features make it possible to envision dramatic changes in instructional environments and create unique STEM learning environments in particular support of STEM teaching strategies and active learning.

It is widely known that teaching science by way of memorizing scientific facts, describing what science is, and showing students how to do science does not work for motivating students into meaningful learning of the sciences and in developing a comprehensive understanding about science (Srisawasdi, Moonsara, & Panjaburee, 2013). The traditional, highly structured laboratories, which provide questions, theories, and experimental and analytical procedures of inquiry, produce a robotic style of thinking, and are not sufficient for developing mind-on learning about science and science literacy (Zion, 2006; Zion & Sadeh, 2007; Srisawasdi, 2012a). The traditional lab situation may prevent learners from obtaining valuable scientific experiences from the inquiry process, and in reality, may result in students' lack of understanding because of an inability to transfer what they learned (Srisawasdi, Kerdcharoen, & Suits, 2008; Srisawasdi, 2012a). Moreover, they cannot feel the ownership of learning because of their passive role in traditional science classrooms. The crucial idea, in promoting the students' involvement in active learning and the potential of scientific inquiry, was the use of technology to support their inquiry experience. Due to reform efforts in the science education community, computer-based laboratory environments are widely used in inquiry-based activities motivating and enabling students to experience science. In addition, they have been used to improve scientific inquiry activities by providing instructional affordances for more flexible inquiry-based learning experiences and by incorporating more features of authenticity in science (Buck, Bretz, & Towns, 2008; Chinn & Molhotra, 2002; Chinn & Hmelo-Silver, 2002; Srisawasdi, 2012b).

Physical and virtual laboratories promote favorable science learning environments for students. Integrating physical and virtual laboratories could be used as a platform to provide inquiry learning experience in science-based content for exploring the nature of science and scientific inquiry, developing team work abilities, cultivating interest in science and scientific attitudes, promoting conceptual understanding, and developing inquiry skills (de Jong, Linn, & Zacharia, 2013). Using physical laboratories, students develop practical laboratory skills and experience the challenges that scientists face when they conduct science-based experimentation. A related affordance of physical experimentation is taking advantage of tactile information that fosters the students' development of conceptual knowledge in science. Additionally, virtual experimentation offers less setup time, provides results of lengthy investigations instantaneously, and enables students to perform more experiments or gather more information in the same amount of time than means of physical experimentation. Moreover, virtual experimentation can enhance science learning by providing visualizations of unobservable and micro-world phenomena and also presenting necessary information in multiple representations (Suits & Srisawasdi, 2013). These features could promote interest in, and motivation to learn, science. Many well-controlled comparison studies have reported no difference between physical and virtual experimentation on student learning in science. However, some educational researchers state that physical labs provide rich context and multi-sensory experiences, but often fail in showing the underlying concepts clearly (Klahr, Triona, & Williams, 2007; Lazonder & Ehrenhard, 2014). Virtual labs help students focus on concepts through visual, interactive simulations, but often lack a sense of reality. Well-designed combinations of physical and virtual experiments can capitalize on the features of each approach and allow students to gain a more nuanced understanding of scientific phenomena and a more robust understanding of inquiry compared with either one alone (de Jong et al., 2013).

Based on the above mentioned rationale, the goal of this chapter is to present findings of a research project including the study of design and development, and efficacy study (Institute of Education Sciences [IES], U.S. Department of Education [ED], & National Science Foundation [NSF], 2013), in a sequence, on the use of combined computer-based physical experimentation (PE) and virtual experimentation (VE) in science learning. To investigate the success of this intervention design, the researcher has conducted a series of two distinct studies in which we have used the combination of PE and VE during inquiry-based learning process to facilitate students' science investigation. The author investigated students' perceptions about computer-based inquiry learning and science motivation delivered in the combination of PE and VE context to specifically answer the following questions:

1. What are students' self-reported experiences during inquiry-based learning with combined computer-based PE and VE? Qualitative and quantitative methods can be integrated for different purposes to provide a more comprehensive picture of students' perceptions of learning experience than either method can alone. Using qualitative analysis the author anticipated gaining information that would elaborate the results from another and provide additional details about students' perceptions of inquiry-based learning with the combined environment.
2. Do the students engaged in combined computer-based PE and VE inquiry-based learning experiences demonstrate significantly greater science motivation? The author hypothesized that there will be a significant difference in students' science motivation after participating in an alternative instructional setting compared to a conventional one.

CONTEXT OF THAILAND SCIENCE EDUCATION

Conceptions of Scientific Inquiry and Enactment in Compulsory Education

During the past two decades, Thailand's perspectives about teaching and learning have shifted from the teacher-centered approach toward the student-centered approach (ONEC, 2000). Before the period of the educational reform enactment of the first *National Education Act of Thailand* (ONEC, 1999), most teachers taught with an emphasis on content rather than on the processes of science, and with a focus on memorization of scientific facts rather than support in essential scientific and thinking skills (Keawdang, 1998). According to this act, promoting the implementation of the student-centered approach in science classroom has been the central focus of *The Thailand Basic Education Core Curriculum* considered by

Ministry of Education (MOE) and the Institution for the Promotion of Teaching Science and Technology of Thailand (IPST). Similar to many other countries around the world, achieving scientific literacy in precollege schooling is the central goal to the science education reform in Thailand. Improving scientific inquiry and understanding of the Nature of Science (NOS) are the emphasized cognitive and learning outcomes for students. Under the direction of MOE and IPST, to improve the quality of Thailand's science education, "Inquiry" has been a central term in the rhetoric of past and present Thailand science education reforms (IPST, 2002). The primary goal, coupled with specific inquiry-related objectives in the various science content areas, may be interpreted as a change to help Thai students in the following ways: (a) to understand basic principles and theories of science; (b) to understand the limitations and nature of science; (c) to gain skills of investigation, and scientific and technological formulation; (d) to develop the processes of thinking and imagination, and the ability to manage and solve problems, communicate, and make decisions (e) to recognize the relationships among science, technologies, human beings, and environments in terms of influence and affectation; (f) to apply the knowledge of science and technology to make it useful for society and for living; and (g) to think scientifically and ethically toward the original use of science and technology (MOE, 2008)

Currently, inquiry-based teaching and learning has served as the benchmark for Thailand science education. The *National Science Curriculum Standards: The Basic Education Curriculum B.E. 2551* (A.D. 2008) for science highlights the importance of inquiry learning processes in science by emphasizing the connection of scientific knowledge with scientific processes, acquiring essential skills to search and construct knowledge through investigative processes and diverse problem solving experiences, creating opportunities for student participation in all stages of learning, and organizing various hands-on activities suitable for learners in each level (IPST, 2008). The subject areas advance from simple to more complex conceptual concepts in ascending grade levels (Soydhurum, 2001). Inquiry-based learning cycles (e.g., 5E learning cycle of engagement, exploration, explanation, elaboration, and evaluation) and inquiry-type laboratories (e.g., guided- and open-inquiry experiments) provide exemplars for the enactment of inquiry in Thailand precollege science classrooms. These kinds of inquiry learning are embedded in most of the contemporary science textbooks and teachers manuals published by MOE and IPST (Soydhurum, 2001). To better serve this aim, not only do all students need to learn science through inquiry-based approaches, but teachers also need to be educated and prepared for implementing inquiry-based pedagogy into their classroom teaching practices (Srisawasdi, 2014). In addition, these inquiry-based pedagogies are an important part of science teacher professional development in most teacher education colleges in Thailand. For example, the Science Education Program at Khon Kaen University focuses on fostering pre-service and in-service science teachers' pedagogical knowledge of inquiry-based science learning in a variety of instructional strategies, both learning cycle-oriented (i.e. 4Es, 4Esx2, 5Es, 7Es) and openness-oriented approaches (i.e. confirmatory, structured inquiry, guided inquiry, open inquiry, authentic inquiry)(Srisawasdi, 2014). There is a shared perception among educational leaders that the implementation of these kinds of inquiry learning techniques will bring profound changes and replace the exclusive emphasis on confirmation and structured-inquiry learning activities. In addition, IPST has promoted science process skills, mathematical skills and other skills for the 21st century among learners by way of the integrated science, technology, engineering, and mathematics (STEM) curriculum (IPST, 2013). The IPST had started implementing STEM education into Thailand compulsory education by training in-service science teachers and students in school science since 2013. In order to equip students with contemporary knowledge and skills essential for addressing society's needs, STEM literacy would be the next benchmark of science education in Thailand (Reeve, 2013). Regarding development of the

STEM literacy, inquiry-based learning approaches very clearly contain the structure of learning activity as well as engages students think and act like scientists or engineering. As such, STEM education should emphasize using inquiry-based pedagogy (Reeve, 2013). However, the successful implementation of our vision for inquiry-based science learning has been a challenging undertaking. It seems that the curricular emphasis on inquiry, while necessary, is not sufficient for fruitful implementation of inquiry-based learning approaches of science in Thailand. The major potential problem is the absence of a clearly formulated philosophy of the nature of scientific inquiry. Another potential problem is that the scope of inquiry attributes presented (or inferred) from the curriculum is very limited. The curriculum seems to highlight the hands-on component of inquiry or doing science to the neglect of the minds-on component. Therefore, we need to reorganize inquiry-based learning contexts in science where the scientific inquiry involves mindful investigation based on scientific inquiry process, metacognitive scaffolds attending their scientific investigations for building and revising scientific understanding, and facilitating scientific collaborative construction of scientific knowledge and skills (Kim, Hannafin, & Bryan, 2007). Such implementation would require the prolonged commitment and concerted efforts of all parties involved in order to truly reform inquiry-based learning approaches in Thailand science education.

Digital Technology for Inquiry-Based Science Education

Over the past several decades, digital technologies and learning resources have played increasingly important roles in education, and recent research indicates that the digital technologies can effectively support teachers' teaching practices in integrating inquiry-based instruction into science classrooms. (Srisawasdi, 2014). In the context of Thailand, the first phase of ICT use in education in compulsory schooling began in 1984 aimed to provide students a basic understanding of computer systems and its applications (Waitayangkoon, 2007). Then, revisions were eventually made to cope with rapid technological advancements, but implementation of ICT as a tool to support inquiry-based learning in science was not explicitly mentioned in the *National Science Curriculum Standards*. Moreover, digital learning resources for science education at a basic education level are still limited, both in terms of curriculum coverage and alignment (Langkhapin, 2009). In 2005, the Joint Working Group of the Royal Thai Government and the Australian Government decided to use ICT to promote innovation in educational processes of Thailand and to foster the development of science and mathematics literacy by transferring the Australian multimedia learning objects into Thailand basic education level. Following this initial effort, the project built capacity within IPST to manage the development of digital learning objects in science and mathematics learning. This kind of digital learning technology is a new way of looking at curriculum in which content is broken up into discrete pieces or learning objects, ranging from a small chunk of instruction to a series of resources. With the learning objects in mind, teachers and students would interactively creating linkages between chunks in order to construct understanding of subject content (Polsani, 2003). A number of educationally sound Thai exemplar learning objects based on the Australian model have been developed and disseminated for compulsory schooling with an accompanying professional development program by IPST, with the cooperation of Ministry of Science and Technology, the MOE, and Thailand Cyber University Project (Waitayangkoon, 2007). Since 2010, the Office of the Basic Education Commission (OBEC) of the MOE has begun to train in-service science teachers to create computer-simulated experiments for physics and chemistry in school science by using the software program Yenka. This engaging software allows teachers to use and edit an ever-growing library of learning activities for science, math, technology, and computing. The features of Yenka enable teachers to create simulations to give students a model that they can manipulate to achieve a specific goal, and thereby test and develop their understanding of various scientific phenomena (Herga & Dinevski, 2012). For science teacher professional development, the Science Education Program faculty at Khon Kaen University utilizes interactive computer simulations obtained from the Physics Education Technology (PhET) Project (University of Colorado Boulder, 2015). These simulations are used as pedagogical tools to conduct classroom research through inquiry learning approaches and train both pre-service and in-service science teachers in competencies for applying the PhET simulation in science classes (Srisawasdi, 2014). In Thailand, learning objects and computer simulations (e.g. Yenka, PhET) have been used to encourage inquiry-based science learning by visualizing scientific phenomena and examining them in their everyday experiences. Srisawasdi and Kroothkeaw (2014), and Srisawasdi & Sornkhatha (2014), implemented simulation-based open inquiry in science classes with Thai secondary school students and found that the learning approach of simulation-based open inquiry effectively promoted better conceptual understanding in science and induced cognitive mechanisms of conceptual change for students. However, the use of both visualized digital technology still remains rare in Thai science classrooms. To serve the improvement of science-based education through inquiry-based investigation, a number of international high schools in Thailand and public schools for gifted and talented students in science and mathematics employ data loggers or data logging systems (also known as microcomputer-based laboratory or MBL) to support students' practical work in the science laboratory. The MBL is the most frequently used tool in school science laboratories to collect physical data and display them in a manner that can be manipulated; this tool could eliminate the drudgery associated with data collection and display and encourage an inquiry approach to science (Srisawasdi, 2012b). Srisawasdi (2012a) examined Thai secondary school students' perceptions towards authentic inquiry investigation with physical computer-based experimentation and the results indicated that students perceived a favorable effect on their cognitive performance, scientific inquiry skills, emotional practice, and social inquiry process. A number of Thai educators and science teachers are driving change in Thailand science education research and practices by promoting digital technologies (i.e., computer simulation, MBL, digital game, mobile device and app.) as appropriate inquiry tools to bring about benefits to investigative and inquiry learning environments for both science-based and integrated STEM education.

THEORITICAL BACKGROUND

Affordances of PE and VE in Science Instruction

Recently, computer-based technology became commonplace in the science education community at all levels as an integral part of the science classroom and laboratory experimentation. Researchers are now applying technology to bring students' science activities closer to authentic processes of doing science. With the support of technology, students can take advantage of computer simulated worlds to interact with and investigate how the real world works by using the tools, data collection techniques, models, and theories of science in physical experimentation (PE) or in virtual experimentation (VE) (de Jong et al., 2013). Over the past few decades, educators and researchers attempted to discover effective ways to engage students of all ages in interesting and motivating science learning experiences. As such, several researchers documented the value of PE and VE, and its affordances in science instruction (Jaakkola, Nurmi, & Veermans, 2010; Toth, Morrow, & Ludvico, 2009; Triona & Klahr, 2003; Winn, Stahr, Sarason, Fruland, Oppenheimer, & Lee, 2006; Zacharia & Anderson, 2003; Zacharia & Constantinou, 2008; Zacharia & Olympiou, 2011; Zacharia, Olympiou, & Papaevripidou, 2008). The National Research Council (2006) stated that using PE and VE can achieve similar educational objectives, such as exploring the nature of science, enhancing conceptual development, developing scientific inquiry skills, and cultivating interest and motivation in science.

The uses and applications of PE and VE are recognized differently by researchers depending on their individual attributes, possibilities for interaction interaction, quality of materials, and methods used for science instruction (de Jong, Linn, & Zacharia, 2013; Finkelstein, Adams, Keller, Kohl, Perkins, & Podolefsky, 2005; Winn et al., 2006; Zacharia 2007; Zacharia et al., 2008). For instance, Olympiou and Zacharia (2012) detailed that only PE can offer students experiences that involve the manipulation of the actual items of an experiment, and only VE can provide students with opportunities to manipulate the conceptual objects involved in an experiment. VE may be used to visualize things at a molecular level and may directly link unobservable processes to symbolic equations and observable phenomena, encouraging learners to make abstractions over different representations; whereas PE cannot (McElhaney & Linn, 2011; van der Meij & de Jong, 2006). Considering time need for conducting experiments, VE offers efficiencies over PE because it typically requires less setup and provides the results of lengthy investigations instantaneously (Zacharia et al., 2008). Finally, by performing scientific investigations in PE, students learn about the complexities of science by dealing with unanticipated events, instead of any potential VE-specific aberrations in equipment or software (de Jong et al., 2013).

Both PE and VE involve numerous overlapping applications. Both provide opportunities to manipulate laboratory experimentation that under certain conditions, provide similar effects on students' conceptual learning (Triona & Klahr, 2003; Zacharia & Constantinou, 2008; Zacharia & Olympiou, 2011). PE and VE can provide the same kinds of challenging experiences that many scientists face when planning experiments requiring careful setup of variables and observations (de Jong et al., 2013). Moreover, both PE and VE can provide high levels of interaction and learner engagement. In terms of learning processes, using both PE and VE could provide a perceptual grounding for concepts that might otherwise be too abstract to be easily understood (Winn et al., 2006), and promote active participation that, in turn, fosters a deeper understanding of a phenomenon or phenomena (Triona & Klahr, 2003). Additionally, the use of both PE and VE can meet the goals for investigation in science courses where students must use and apply tools, data collection techniques, models, and theories of science, as main part of their learning process (National Research Council [NRC], 2006).

Research has shown that combining the use of PE and VE is more beneficial than using them separately (Campbell, Bourne, Mosterman, & Brodersen, 2002; Jaakkola & Nurmi, 2008; Jaakkola et al., 2010; Toth et al., 2009;Winn et al., 2006; Zacharia & Constantinou, 2008; Zacharia & Olympiou, 2011; Zacharia et al., 2008), allowing instructors to capitalize on the features of each approach, maximize the potential for science laboratory learning. Olympiou and Zacharia (2012), and Zacharia, Olympiou, and Papaevripidou (2008), have suggested that using PE and VE should be learning-objective dependent.

PE Through Microcomputer-Based Laboratory

In science-based education, physical hands-on experimentation with microcomputer-based laboratory (MBL) is a major recommendation for use to enhance science learning, and have been in use for science laboratory experimentation in school science for more than three decades. In terms of the use, MBL is a computerized data-logging instrument, which has a number of computers with electronic sensor interfaces, to measure, collect, and analyze data of physical systems on computers or handheld devices such as tablets and smart phones. A MBL instrument includes the hardware and software used for collecting data (data acquisition) and using sensors/probes (such as temperature, pH sensors, gas sensors, cameras, and so on) connected to a microcomputer (or laptop) through an interface (Lavonen, Juuti, & Meisalo, 2003). MBLs have been recognized by educators and researchers as a computing tool for providing learners with opportunities to conduct science in the context of PE (Russell, Lucas, & McRobbie, 2003), interacting directly with naturally occurring phenomena (Nakhleh, 1994; NRC, 2006; Thornton, 1987), and fostering inquiry-based experiences (Lavonen et al., 2003). Several advantageous features of MBLs could contribute to instructional design of technology-integrated laboratories (e.g. quick setup of an experiment, speed of data capture, real-time processing and display, immediately transforming data into screen graphs, data captured by multiple sensors simultaneously, autonomous data collection and storing, immediate feedback) (Gil-Perez & Carrascosa-Allis 1994; Kelly & Crawford, 1996; Rogers, 1995; Thornton, 1987). Regarding affective benefits to students, the high-tech novelty of MBLs could motivate science learning as well as its facilitate ease of use by novices and reduce the drudgery of data collection and manipulation (Russell et al., 2003). In terms of pedagogical gain, Thornton (1987) and Russell, Lucas, and McRobbie (2003) suggested that the use of MBLs make science laboratory experimentation more engaging and effective for developing useful scientific intuition, allowing students to concentrate on the scientific ideas, avoiding robotic-style experimentation through cook-book laboratory activities, and encouraging an inquiry approach to science.

In comparing the effectiveness of MBL to traditional laboratory activities, researchers have concluded that MBLs are more effective in promoting science learning than traditional laboratories (Nakhleh & Krajcik, 1994; Nicolaou, Nicolaidou, Zacharia, & Constantinou, 2007). Results of many studies about the effectiveness of MBL strategies have been ambiguous, especially in respect to science achievement. According to a study by McRobbie and Thomas (2000), MBL in a chemistry classroom had negligible influence on students' development of conceptual understanding. Nakhleh and Krajcik (1994) also studied the contribution of MBL methods in a chemistry context and reported that the MBL displayed left the most enduring visual image for students to analyze, the MBL methods affected students more actively involved during the tasks, and that students generated more concepts and propositions. In addition, Roth, Woszczyna, and Smith (1996) investigated the roles of the computer in contributing to group interactions and learning in a physics course and suggested that MBL might have the capacity to present the phenomena better than a simulation, using real events of actual experiments in place of computer-generated diagrams. Clark and Jackson (1998) investigated the impact of technology in Year 9 physics classes to determine any effects on student motivation and concurrent cognitive changes and found that the students showed positive motivational gains when using MBL methods and they expressed confidence in the accuracy of computer measurements. Further, students enjoyed working in science with a computer. Additionally, Friedler, Nachmias and Songer (1989), and Friedler, Nachmias, and Linn (1990) reported a positive effect on the development of scientific enquiry skills for students using MBL technology. Attempting to find the role of MBL in supporting the construction of new scientific understanding, Russell, Lucas and McRobbie (2003) conducted MBL of kinematics with a predict-observe-explain learning task to a Year 11 physics class; they found that the MBL displays led to a deeper level of mental engagement, and better understanding of processes of conceptual change.

VE Through Computer Simulation

Computers can play important roles in the science classroom and laboratory, and one type of computer application in science education is the simulation (or computer simulation). Computer simulations have been used extensively as a visual representation tool to advocate presenting dynamic theoretical or simplified models of real world components, phenomena, or processes; enabling students to observe, explore, recreate, and receive immediate feedback about real objects, phenomena, and processes (Srisawasdi & Kroothkeaw, 2014; Srisawasdi & Sornkhatha, 2014). Considering its attributes, computer simulation employs visual information, such as pictures, graphic symbols, animations, two or three-dimensional simple shapes, to model a dynamic system's structures and inherent causal relationships over time helping explanation of the system. Moreover, simulations provide more access to science experiments that are normally impossible, dangerous, inaccessible, too slow or too fast (Strauss & Kinzie, 1994; Sahin, 2006). With the support of visualization features, virtual experimentation delivered with computer simulations add value to science learning processes by allowing students to explore unobservable phenomena; link observable and unobservable phenomena; point out salient information; enable learners to conduct multiple experiments in a short amount of time; and provide learners online, adaptive guidance (de Jong et al., 2013). In terms of pedagogy, computer simulations can provide students with theoretical or simplified models of real-world phenomena and invite students to change features of the models so that they can use inquiry in observing the results.

Computer simulations can be classified into different types. Gredler (1996) distinguishes between two types of simulations: symbolic and experiential. During symbolic simulations, students are not active participants of the program environment. Although students may execute any of several tasks such as predicting population trends in a demography simulation, students remain external to the evolving events. Experiential simulations immerse the students in a complex, changing environment as active components. They allow students to execute multidimensional problem-solving strategies as part of their role in the program. They also provide learners with opportunities to develop their cognitive strategies by learning to organize and manage their own thinking and learning. Similarly, de Jong and van Jooling (1998) divided computer simulations into two main categories: simulations containing a conceptual model, and those based on an operational model. Conceptual models hold principles, concepts, and facts related to the systems being simulated, but operational models include sequences of cognitive and non-cognitive operations procedures that can be applied to the simulated systems.

Computer simulation adds several educational values to science learning activities. Researchers have found that computer simulation works well with remediation by producing change to the alternative conceptions held by learners (Bell & Trundle, 2008; Zacharia & Anderson, 2003; Windschitl & Andre, 1998; Muller, Sharma, & Reimann, 2008). Some researchers explored benefits of computer simulation when it was embedded in an environment intended to support specific aspects of discovery learning, called simulation-based discovery learning; they found that simulations improved the performance of gaining intuitive domain knowledge, more qualitative knowledge than formalized knowledge (de Jong et al., 1999; Veemans, van Joolingen, & de Jong, 2006). Using computer simulation as a prelab exercise, researchers found that the simulation influenced students by helping them gain theoretical focus and developing a more coherent understanding of the concepts (Winberg & Berg, 2007). A study was conducted using computer-simulated experiments combined with a problem solving approach and the results showed that the simulation produced significantly greater achievement in the subject area, science process skills, and led to a more positive attitude towards science studies (Geban, Askar, & Ozkan, 1992). In addition, Russel et al. (1997), Srisawasdi and Kroothkeaw (2014), and Srisawasdi and Sornkhatha (2014), showed that computer simulation aids students in visualizing observable and unobservable worlds, and helps increase their mastery understanding of science concepts. Suits and Srisawasdi (2013) reported that computer simulation enhanced students' acquisition of more advanced mental models.

THE STUDY

The Computer-Based PE-VE Combination

Teaching students how to conduct inquiry-based processes in science through practical experience in contemporary scientific laboratory research has been an essential aspect of recent efforts to reform science education. As such, a series of computer-based physical (hands-on) experimentation and virtual (computer-simulated) experimentation representing superhydrophobic surface phenomena, which is a part of self-cleaning nanoscience studies, were created to motivate students' learning of science and promote practical experience in emerging science. Due to the nature of the phenomena, there is an interaction among macro-scale (explicit) and micro-scale (implicit) views. Previous research described a pedagogy wherein students were provided an opportunity to construct scientific understanding of a phenomenon by first eliciting descriptions of how something behaves within certain circumstances (macro view), and then by adding detailed explanations for why the phenomenon behaved the way it did (micro view) (Simon, 2000). The combination of PE and VE in this study was strategically designed to provide a rich context of knowledge representations where macro- and micro-scale representations were employed coordinately to visualize how the physical phenomena work.

Following a similar approach, the author developed a low-cost laboratory instrument for measuring the contact angle, or angle at which the vapor/liquid interface meets another solid/liquid interface resulting from intermolecular interactions between a liquid and a solid surface. Basically, the characteristic angle of wetting is defined by an observed contact angle of less than 90^o, while perfect wetting would have a contact angle of 0^o. A hydrophilic surface exhibits angles in this range. An observed contact angle of larger than 90^o characterizes a non-wetting phenomenon and the surface could be classified as hydrophobic (Lages & Mendez, 2007; Schwarz, Eisenmenger-Sittner, & Steiner, 2008). Figure 1 illustrates a simplified schematic of the contact angle measurement instrument for physical experimentation.

To promote student learning about science, an integration of computer simulation was considered pedagogically important. In this study, an interactive computer simulation representing nanoscale science phenomena created by the researcher was used as the source of inquiry experience for students. Figure 2 displays an example of the computer-simulated experimentation on contact angle in this study.

To promote students' active learning about self-cleaning surfaces in this study, there were three integrated computer-based laboratory learning experiences about surface wettability in the lesson: (1) cohesive and adhesive properties in capillary action; (2) properties of hydrophilic and hydrophobic surface; and (3) contact angle and wetting properties. Table 1 displays the covered content of the combined computer-based experimentation about surface wettability.

Figure 1. A simplified schematic of a physical computer-based experiment instrument for contact angle measurement

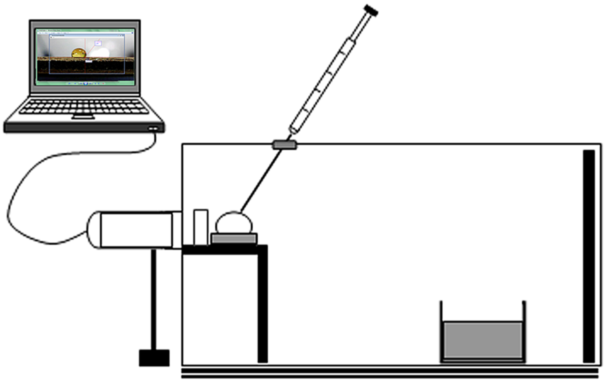
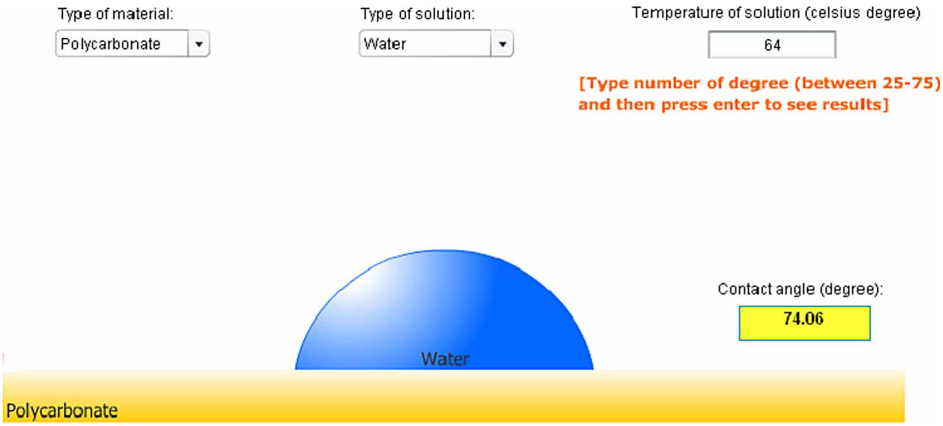


Figure 2. A screen of virtual computer-simulated experimentation of contact angle measurement



Type of material: Polycarbonate

Type of solution: Water

Temperature of solution (celsius degree): 64

[Type number of degree (between 25-75) and then press enter to see results]

Contact angle (degree): 74.06

Table 1. Details of the combined computer-based PE and VE about surface wettability

Lab	Concept	Description	Scientific Phenomenon
Lab Activity 1	Cohesive and adhesive force; hydrogen bonds	This lab provided an independent inquiry opportunity in order to discover factors related to the phenomenon of capillary action.	Capillary action
Lab Activity 2	Hydrogen bonds; hydrophilicity and hydrophobicity	This lab provided an independent inquiry opportunity in order to discover factors related to surface wetting situations.	Hydrophilic/ Hydrophobic substances
Lab Activity 3	Cohesive and adhesive force; hydrophilicity and hydrophobicity; hydrogen bonds	This lab provided an independent inquiry opportunity in order to discover factors related to surface wetting and dewetting situations.	Contact angle phenomenon

Study One: Design and Development

Design and development research (IES, ED, & NSF, 2013), refers to study in developing solutions to achieve a goal related to education or learning, such as improving student engagement or mastery of a set of skills. This kind of study may include pilot tests of fully developed interventions to determine whether they achieve their intended outcomes under various conditions. With this in mind, the first study was conducted as a pilot investigation to explore students' perceptions of inquiry-based learning in combination with computer-based PE and VE environment. The author developed a low-cost laboratory instrument measurement and a series of computer simulations for physical experimentation of contact angle and its virtual experimentation.

Subjects and Procedures

The study was conducted with 32 tenth-grade students at a large public girls' secondary school located in central Thailand. All were females aged between 15-16 years old. The students signed up voluntarily to participate in a special workshop on self-cleaning nanotechnology conducted by the researcher and two laboratory assistants. The workshop was conducted in three 3-hour laboratory class in the school. Two weeks before attending the workshop, the students were asked to provide a profile about their pre-existing learning backgrounds in conducting science experiments. The submissions revealed that the students had neither science laboratory experience relating to surface wettability nor had used technological tools for doing science laboratory work. After completing their laboratory work in the workshop, a survey instrument was administrated to the students. The purpose of the survey was to determine how they perceived the learning environment of this laboratory workshop. The survey instrument consisted of 15 rating scale items on three constructs (five items for each of the three constructs) and two open-ended questions. The three constructs were cognitive performance, emotional practice and social inquiry process. Students responses to the questionnaire were coded on a scale of 1 (strongly disagree) to 5 (strongly agree) based on their experience with the combined laboratory environment. So that higher scores represented more positive perceptions toward the laboratory environment. Quantitative data of students' perceptions was measured and analyzed by the average item mean and standard deviation for each issue construct. Also, the students were asked to respond to two open-ended questions in the survey. The answers were analyzed qualitatively and diagnosed to explain their learning perceptions for improving the laboratory learning environment.

Results and Discussions

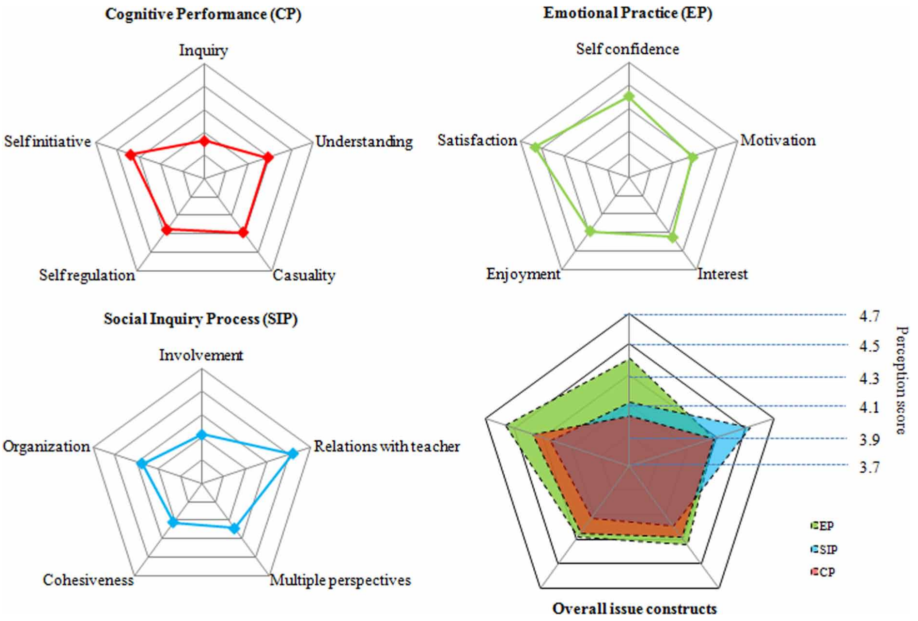
Table 2 shows the results of the quantitative data analysis on students' inquiry learning perception and Figure 3 is used to visualize graphically the results from Table 2.

Table 2 summarizes the average item mean and standard deviation scores of the students' inquiry learning perceptions for the three constructs related to the laboratory learning environment. For the cognitive performance construct, the item mean scores of the students' inquiry learning perceptions in decreasing order were ranked as self-initiative, understanding, causality, self-regulation and inquiry. The overall mean score of the cognitive performance construct was 4.24 (SD = 0.72) which on a scale of 1-5, indicated that on the whole, students perceived relatively highly of their mental effort during performing the experiments of surface wettability by using a simple real-time contact angle measure-

Table 2. Descriptive statistics of students' perceptions toward laboratory learning environment of nanoscale science experiment of surface wettability

Issue constructs	Description of issue construct	Characteristics of Learning environment	Average item mean	Average item S.D.
Cognitive performance	Extent to which students made the effort to perform learning during open-inquiry experimentation	Inquiry	4.03	0.78
		Understanding	4.28	0.63
		Causality	4.28	0.77
		Self regulation	4.25	0.72
		Self initiative	4.38	0.71
		Average mean	4.24	0.72
Emotional practice	Student feelings about open-inquiry experimentation	Self confidence	4.41	0.67
		Motivation	4.28	0.73
		Interest	4.34	0.70
		Enjoyment	4.28	0.77
		Satisfaction	4.56	0.50
		Average mean	4.38	0.67
Social inquiry process	Extent to which students communicated and negotiated during open-inquiry experimentation	Involvement	4.13	0.71
		Relations with teacher	4.53	0.67
		Multiple perspectives	4.19	0.69
		Cohesiveness	4.13	0.71
		Organization	4.25	0.62
		Average mean	4.24	0.68

Figure 3. Graphical representation of students' inquiry learning perception scores on each construct and overall



ment device. With the emotional practice construct, their average item mean scores in decreasing order were satisfaction, self-confidence, interest, motivation and enjoyment, respectively. For the emotional practice construct, the overall mean score was 4.38 (SD = 0.67), indicating a relatively high degree of students' satisfaction about the experimentation. As for the social inquiry process construct, their mean perception scores were, in order from the highest to lowest: had a relationship with teacher, organization, multiple perspectives, involvement and cohesiveness. For the construct of social inquiry process, the overall mean score was 4.24 (SD = 0.68) suggesting a relatively high degree of communication and negotiation while conducting the experiment. Figure 3 displays a graphical representation of students' inquiry learning perceptions of cognitive performance, emotional practice, and social inquiry process, toward the laboratory learning environment in using a simple real-time contact angle measurement device for a surface wettability experiment.

In summary, the average item mean for each construct had a score above 4.00, indicating that the students generally perceived a high level of affordability to develop, within the laboratory learning environment, their cognitive performance, emotional practice and social inquiry processes. The results also suggested that the degree of the perceived emotional practice construct was higher than the cognitive performance and social inquiry process; the latter was equally rated. This statistical evidence indicated that the laboratory learning environment had a greater impact on the development of the students' emotional practice when compared to their cognitive performance and the social inquiry process.

Figure 2 displays mean score distributions and a comparison of the mean scores for each issue construct and reveals the differences in what students perceived from the laboratory learning environment in terms of cognitive performance, emotional practice and social inquiry process. This finding shows that compared to their cognitive performance and social inquiry process, students' emotional practice was more strongly affected by the laboratory learning environment. Students' responses to the two open-ended questions suggested several improvements to the laboratory learning environment. The qualitative responses were read as a whole in order to gain a comprehensive insight into their learning perceptions. Key points of the responses to the open-ended questions were coded and summarized in Table 3.

Overall results of students' perceptions toward the laboratory learning environment revealed that their prevalent perception was the environment afforded them better opportunities to develop emotional practice and both cognitive performance and the social inquiry process. The result was consistent with the research findings that microcomputer-based laboratories encouraged students to play active roles in their learning tasks, reinforced their comprehension of scientific conceptual understanding and awareness of science–technology relationships, and made science more comprehensible and attractive to larger numbers of students (Trumper & Gelbman, 2001). Freedman (1997) also provided evidence that laboratory experiences had a positive effect on secondary students' attitudes towards science and achievement in science knowledge and there was a highly significant correlation between attitude and achievement. Based on meta-analysis of a number of studies, Hofstein and Lunetta (2004) mentioned the need to focus on the use of technology in the science classroom and that technology provided students with unique benefits to learn science. Also, it could lead to a more complete understanding than other teaching methods. By increasing opportunities for authentic hands-on experiences (Zumbach, Schmitt, Reimann, & Starkloff, 2006) and helping students to construct links between theories and phenomena (Hennessy, Deaney, Ruthven, 2006), computer technology and educational software provide new learning opportunities that could change the look and feel of traditional science classrooms (Chi-Yan & Treagust, 2004).

Table 3. Summary of students' responses on open-ended questions

Open-ended Questions	Students' Response	Frequency	%
What did you get from this experimental learning experience?	Cognitive performance		
	• Helped me understand the lotus effect phenomenon	21	65.63
	• Provided a contemporary scientific method in scientific research	20	62.50
	• Stimulated more thinking in everyday things or phenomena	12	37.50
	Emotional practice		
	• Provided a real working experience with nanoparticles	29	90.63
	• Provided easy and interesting ways to measure the contact angle	25	78.13
	• Made learning interesting and enjoyable by practice with modern technology	17	53.13
	• Allowed interaction with technology-based scientific laboratory instruments	15	46.88
	• Enhanced scientific practice skills through the use of computer technology	10	31.25
	Social inquiry process		
	• Gave an opportunity to design the experiment with group members	12	37.50
What improvements should be made to this experimental experience?	Cognitive performance		
	• Incorporate nanotechnology into the current curriculum	6	18.75
	Emotional practice		
	• Provide the device individually for each group to gain more experience with it	13	40.63
	• Provide more time for performing practical laboratory work	12	37.50
	• Provide a larger variety of instruments for laboratory work (e.g. scanning probe microscope)	11	34.38

Study Two: Efficacy

In order to generate reliable estimates of the ability of a fully-developed intervention or strategy to achieve its intended outcomes, efficacy research studies allows for testing of the strategy or intervention under ideal circumstances or optimal conditions (IES, ED, & NSF 2013; Plass, Milne, Homer, Schwartz, Hayward, Jordan, Verkuilen, Ng, Wang, & Barrientos, 2012). The efficacy study may limit the investigation to a single population of interest (IES, ED, & NSF 2013; Plass et al., 2012); in our case this involved the use of combined computer-based PE and VE during a single science class period, with the research team in a prominent support role. Study 2 was conducted with this view to examine students' science motivation delivered by inquiry-based learning in the combined laboratory environment.

Subjects and Procedures

A total of 46 eleven-grade students, from a class, aged between 17-18 years old in a large public secondary school located in Northeast Thailand (N=46) were involved in this study. The students signed up voluntarily to participate in a special workshop on self-cleaning nanotechnology conducted by the researcher and two laboratory assistants. The results of an informal interview with the regular class instructor before starting this study indicated that all of the participants had satisfactory skills on using basic computers and communication technology but they had not experienced using computer-based hands-on experimentation and computer simulations in science learning. In addition, they had never experienced having a formal class with open-ended scientific inquiry in any formal class, implying that they were homogeneous before participating in this study.

Measuring students' science motivation was a challenge for science educators and teachers in order to explain why students strive to learn science, what emotions or feelings characterize how much they strive, how intensively they strive, and how long they strive (Glynn, Taasoobshirazi, & Brickman, 2007). In order to investigate their science motivation, the *Science Motivation Questionnaire II* (Glynn, Brickman, Armstrong, & Taasoobshirazi, 2011) based on social cognitive theory was revised by rephrasing the word "science" into "nanoscience" for using as a discipline-specific version of the questionnaire, and used in this study to explore secondary school students' motivation to learn nanoscience. The questionnaire involved five constructs to capture the essence of science motivation: Intrinsic Motivation (IM), which involves the inherent satisfaction in learning science for its own sake; Self-determination (SDT), which refers to the control students' believe they have over their learning of science; Self-efficacy (SEC), which refers to students' beliefs that they can achieve well in science; and Career Motivation (CM) and Grade Motivation (GM), which involves learning science as a means to science careers and learning achievement in science subjects, respectively (Glynn et al., 2007; Glynn et al., 2011). The questionnaire was translated from English into the Thai language by the researcher and it was administered to Thai eleven-grade students (N=106) to assess its internal consistencies by Cronbach's alphas. The results of the Thai nanoscience motivation questionnaire follow: IM (0.79), CM (0.81); SDT (0.81); SEC (0.89); and GM (0.85). The Cronbach's alpha of all 25 items in Thai version was 0.92. Students responded to each item on a rating scale of agreement level: strongly disagree (1), disagree (2), neutral (3), agree (4), and strongly agree (5). The maximum score on each of the five 5-item scales was 25. The students took 15 minutes to fill out the nanoscience motivation questionnaire in class on the first and last weeks of the lesson. These two tests represented pre- and post-nanoscience motivation test scores. In order to answer the abovementioned research questions, a paired-sample t-test was conducted to evaluate whether there was significant difference between scores from pre- and post-nanoscience motivation.

Results and Discussions

The paired t-test indicated a significant difference between the pre- and post-test mean scores of the males ($t(19)= -2.609$, $p= .017$), and of the females ($t(25)= -3.794$, $p= .001$) in respect to their improvement in nanoscience motivation. The results showed significant differences in all constructs of nanoscience motivation for females but only in three constructs (i.e. IM, SDT, SEC) for males as shown in Table 4.

Table 4 indicates that after participating in the inquiry-based learning in the combined computer-based PE and VE environment, both male and female students increased their motivation to learn nanoscience. For males, there was a statistically significant difference between the mean scores from pre-test to post-test, $t(19)= -2.33$, $p<.05$ for IM. The analysis also found a statistical difference between the mean scores from pre-test and post-test, $t(19)= -2.11$, $p<.05$ for SDT as well as the mean scores from pre-test and post-test, $t(19)= -3.56$, $p<.01$ for SEC, the highest improvement score. However, there was no statistical difference between the mean scores from pre-test and post-test for CM ($t(19)= -1.63$, $p=.120$) and GM ($t(19)= -1.41$, $p=.175$) within the males. These data indicate that male students' IM, SDT, and SEC increased significantly ($p<.01$) after participating in the inquiry-based learning module. For females,

Table 4. A comparison of pre- and post-science motivation scores on the motivation components

Motivation Construct	**Pre-test**		**Post-test**		***t***	***p*-value**
	Mean	**S.D.**	**Mean**	**S.D.**		
Male (N=20)						
IM	18.23	3.69	21.69	2.38	-2.33	.031*
CM	18.73	3.89	21.27	2.54	-1.63	.120
SDT	16.88	3.09	19.69	2.67	-2.11	.049*
SEC	15.85	3.64	18.92	3.55	-3.56	.002**
GM	19.12	3.36	21.58	2.58	-1.41	.175
Female (N=26)						
IM	18.55	3.27	21.00	2.66	-4.02	.000**
CM	19.35	2.85	20.80	2.33	-2.73	.011*
SDT	16.90	2.73	19.00	3.26	-3.44	.002**
SEC	15.35	3.31	19.40	3.56	-3.29	.003**
GM	19.70	4.14	21.035	3.42	-2.73	.011*
*significant at p<.05; **significant at p<.01						

Table 4 indicates that female students' nanoscience motivation on all constructs increased significantly (p<.01) after participating in the inquiry-based learning module: IM, t(25)= -4.02, p<.01; CM, t(25)= -2.73, p<.05, SDT, t(25)= -3.44, p<.01, SEC, t(25)= -3.29, p<.01; and GM t(25)= -2.73, p<.05.

The paired sample t-test results showed that at the end of the inquiry lesson, both females and males expressed enhanced motivation to learn nanoscience. Significant effects of the computer-assisted inquiry learning module about self-cleaning nanotechnology on students' nanoscience motivation were found on IM, SDT, and SEC for both genders. These results are in line with Plant et al. (2009) who examined gender influences on the use of motivating animated pedagogical agents as a learning companion in an inquiry learning environment and reported that both females and males' self-efficacy increased significantly after interacting with the agent. This could be supported by Messaris (1998) who suggested that the quality of education and motivation for achieved learning is becoming increasingly dependent on the quality of the visual aids incorporated in teaching materials. In addition, previous studies (Gibson & Chase, 2002; Piraksa & Srisawasdi, 2014; Shimoda et al., 2002; Tuan et al., 2005) reported that inquiry-based lessons could increase students' learning motivation in science. However, only females exhibited an overall significant increase in nanoscience motivation at the end of the learning module. This is consistent with Arroyo, et al. (2011) and Van der Meija, Van der Meijb, & Harmsen (2012), who found that females showed a gender-specific motivation effect during and after program training, and the use of an inquiry learning environment influenced females' motivation to learn science more than males. With regard to the inquiry lesson it is important to note that the combined computer-based PE and VE environment improved secondary school students' nanoscience motivation.

CONCLUSION

The goal of this study was to examine if inquiry-based learning supported by combined computer-based PE and VE environments could make a positive difference in student perceptions of science learning and their motivations to learn science when integrated into high school science classrooms. The results of this study have important implications for current reform efforts in Thailand science education. Moreover, it could be used to strengthen learning in the field of STEM education. This study demonstrated a pedagogical way to encourage student to independently design and collaboratively work on doing science utilizing technology-based inquiry materials, and combine physical hands-on experimentation and virtual computer-simulated experimentation. Students in this study reported a stronger desire to learn with combined computer-based PE and VE environments. The results of study one showed students perceived a relatively high degree of supporting during inquiry learning experience by the combined laboratory environment. In this study, inquiry-based learning conducted with combined environments was seen as mostly favorable by the students in terms of supporting their cognitive performance, emotional practice, and social inquiry process. Moreover, a unique inquiry learning environment integrating computer-based hands-on and computer-simulated experimentation could promote, according to study two, motivation to learn science for both female and male students, but likely enhance female secondary school students' science motivation more than male students' motivation. These findings suggest that the incorporation of combined computer-based PE and VE environments for inquiry-based learning in science can have a positive impact on how high school students learn science and affect student attitudes about learning science. As such, the author recommends combining the two to strengthen science learning.

ACKNOWLEDGMENT

This work was financially supported by the Thailand Research Fund (TRF), the Commission on Higher Education (CHE) and Khon Kaen University (KKU) and (Grant MRG5480058). The author would like to express his sincere appreciation to his mentor, Assoc. Prof. Tassanee Burnterm, for her enthusiastic guidance and advice throughout this research. The author would like to thank Dr. Supan Yodtingyong, Lecturer and Lab Specialist of the Institute for Innovative Learning, Mahidol University, for his assistance for preparing the silica aerogel nanocomposite coating for self-cleaning surface material.

REFERENCES

American Association for the Advancement of Science. (1993). *Benchmarks for science literacy*. New York: Oxford University Press.

Arroyo, I., Woolf, B. P., Royer, J. M., & Tai, M. (2009). Affective gendered learning companion. In *Proceedings of International Conference on Artificial Intelligence and Education* (pp. 41-48). Brighton, UK: IOS Press

Bell, R. L., & Trundle, K. C. (2008). The use of a computer simulation to promote scientific conceptions of moon phases. *Journal of Research in Science Teaching*, *45*(3), 346–372. doi:10.1002/tea.20227

Buck, L. B., Bretz, S. L., & Towns, M. H. (2008). Characterizing the level of inquiry in the undergraduate laboratory. *Journal of College Science Teaching*, *38*(1), 52–58.

Campbell, J. O., Bourne, J. R., Mosterman, P. J., & Brodersen, A. J. (2002). The effectiveness of learning simulations for electronic laboratories. *The Journal of Engineering Education*, *91*(1), 81–87. doi:10.1002/j.2168-9830.2002.tb00675.x

Chi-Yan Tsui, W., & Treagust, D. (2004). Motivational aspects of learning genetics with interactive multimedia. *The American Biology Teacher*, *66*(4), 277–285. doi:10.1662/0002-7685(2004)066[0277:MAOLGW]2.0.CO;2

Chinn, C. A., & Hmelo-Silver, C. E. (2002). Authentic inquiry: Introduction to the special section. *Science Education*, *86*(2), 171–174. doi:10.1002/sce.10000

Chinn, C. A., & Malhotra, B. A. (2002). Epistemologically authentic inquiry in schools: A theoretical framework for evaluating in inquiry tasks. *Science Education*, *86*(2), 175–218. doi:10.1002/sce.10001

Clark, S. A., & Jackson, D. F. (1998). *Laboratory technology and student motivation in a conceptual physics classroom: A year-long case study.* Paper presented at the annual meeting of the National Association for Research in Science Teaching, San Diego, CA.

de Jong, T., Linn, M. C., & Zacharia, Z. C. (2013). Physical and virtual laboratories in science and engineering education. *Science*, *340*(6130), 305–308. doi:10.1126/science.1230579 PMID:23599479

de Jong, T., Martin, E., Zamarro, J., Esquembre, F., Swaak, J., & van Joolingen, W. R. (1999). The integration of computer simulation and learning support: An example from the physics domain of collisions. *Journal of Research in Science Teaching*, *36*(5), 597–615. doi:10.1002/(SICI)1098-2736(199905)36:5<597::AID-TEA6>3.0.CO;2-6

de Jong, T., & van Joolingen, W. R. (1998). Scientific discovery learning with computer simulations of conceptual domains. *Review of Educational Research*, *68*(2), 179–201. doi:10.3102/00346543068002179

de Jong, T., van Joolingen, W. R., Giezma, A., Girault, I., Hoppe, U., & Kindermann, J. et al.. (2010). Learning by creating and exchanging objects: The SCY experience. *British Journal of Educational Technology*, *41*, 909–921. doi:10.1111/j.1467-8535.2010.01121.x

Edelson, D. C. (2001). Learning-For-Use: A framework for the design of technology-supported inquiry activities. *Journal of Research in Science Teaching*, *38*(3), 355–385. doi:10.1002/1098-2736(200103)38:3<355::AID-TEA1010>3.0.CO;2-M

Edelson, D. C., Gordin, D. N., & Pea, R. D. (1999). Addressing the challenges of inquiry-based learning through technology and curriculum design. *Journal of the Learning Sciences*, *8*(3), 391–450. doi:10.1207/s15327809jls0803&4_3

Finkelstein, N. D., Adams, W. K., Keller, C. J., Kohl, P. B., Perkins, K. K., & Podolefsky, N. S. et al.. (2005). When learning about the real world is better done virtually: A study of substituting computer simulations for laboratory equipment. *Physical Review Special Topics—Physics. Education Research*, *1*, 1–8.

Freedman, M. P. (1997). Relationship among laboratory instruction, attitude toward science, and achievement in science knowledge. *Journal of Research in Science Teaching*, *34*(4), 343–357. doi:10.1002/(SICI)1098-2736(199704)34:4<343::AID-TEA5>3.0.CO;2-R

Friedler, Y., Nachmias, R., & Linn, M. C. (1990). Learning scientific reasoning skills in microcomputer-based laboratories. *Journal of Research in Science Teaching*, *27*(2), 173–192. doi:10.1002/tea.3660270208

Friedler, Y., Nachmias, R., & Songer, N. (1989). Teaching scientific reasoning skills: A case study of a microcomputer-based curriculum. *School Science and Mathematics*, *89*(1), 272–284. doi:10.1111/j.1949-8594.1989.tb11890.x

Geban, O., Askar, P., & Ozkan, I. (1992). Effects of computer simulations and problem-solving approaches on high school students. *The Journal of Educational Research*, *86*(1), 5–10. doi:10.1080/00220671.1992.9941821

Gibson, H., & Chase, C. (2002). Longitudinal impact of an inquiry-based science program on middle school students' attitudes toward science. *Science Education*, *86*(5), 693–705. doi:10.1002/sce.10039

Gil-Perer, D., & Carrascosa-Allis, J. (1994). Bringing pupils' learning closer to a scientific construction of knowledge: "A permanent feature in innovations in science teaching. *Science Education*, *78*(3), 301–315. doi:10.1002/sce.3730780310

Glynn, S. M., Brickman, P., Armstrong, N., & Taasoobshirazi, G. (2011). Science Motivation Questionnaire II: Validation with science majors and nonscience majors. *Journal of Research in Science Teaching*, *48*(10), 1159–1176. doi:10.1002/tea.20442

Glynn, S. M., Taasoobshirazi, G., & Brickman, P. (2007). Nonscience majors learning science: A theoretical model of motivation. *Journal of Research in Science Teaching*, *44*(8), 1088–1107. doi:10.1002/tea.20181

Gredler, M. (1996). Educational games and simulations: A technology in search of a (research) paradigm. In D. H. Jonassen (Ed.), *Handbook of research for educational communications and technology* (pp. 521–540). New York: Macmillan.

Hennessy, S., Deaney, R., & Ruthven, K. (2006). Situated expertise in integrating use of multimedia simulation into secondary science teaching. *International Journal of Science Education*, *28*(7), 701–732. doi:10.1080/09500690500404656

Herga, N. R., & Dinevski, D. (2012). Virtual laboratory in chemistry – experimental study of understanding, reproduction and application of acquired knowledge of subject's chemical content. *Organizacija*, *45*(3), 108–116. doi:10.2478/v10051-012-0011-7

Hofstein, A., & Lunetta, V. N. (2004). The laboratory in science education: Foundation for the 21st century. *Science Education*, *88*(1), 28–54. doi:10.1002/sce.10106

Hofstein, A., & Mamlok-Naaman, R. (2007). The laboratory in science education: The state of the art. *Chemistry Education: Research and Practice in Europe*, *8*(2), 105–108.

Hofstein, A., Navon, O., Kipnis, M., & Mamlok-Naaman, R. (2005). Developing students' ability to ask more and better questions resulting from inquiry-type chemistry laboratories. *Journal of Research in Science Teaching*, *42*(7), 791–806. doi:10.1002/tea.20072

Institute for the Promotion of Teaching Science and Technology (IPST). (2002). *The manual of content of science learning*. Bangkok: Curusaphaladphoa.

Institute for the Promotion of Teaching Science and Technology (IPST). (2008). *The Basic Education Core Curriculum B.E. 2551 (A.D. 2008) Science*. Retrieved May 3, 2015 from http://www.ipst.ac.th/web/images/files/SciCur_2008_EngVersion.pdf

Institute for the Promotion of Teaching Science and Technology (IPST). (2013). *IPST annual report summary 2013*. Retrieved May 3, 2015 from http://www.ipst.ac.th/eng/files/AnnualReport_ 2013_Eng.pdf

Institute of Education Sciences. U.S. Department of Education, & the National Science Foundation. (2013). *Common guidelines for education research and development*. Retrieved October 24, 2011, from http://www.nsf.gov/pubs/2013/nsf13126/nsf13126.pdf

Jaakkola, T., & Nurmi, S. (2008). Fostering elementary school students' understanding of simple electricity by combining simulation and laboratory activities. *Journal of Computer Assisted Learning*, *24*(4), 271–283. doi:10.1111/j.1365-2729.2007.00259.x

Jaakkola, T., Nurmi, S., & Veermans, K. (2010). A comparison of students' conceptual understanding of electric circuits in simulation only and simulation-laboratory contexts. *Journal of Research in Science Teaching*, *48*(1), 71–93. doi:10.1002/tea.20386

Jimoyiannis, A., & Komis, V. (2007). Examining teachers' beliefs about ICT in education: Implications of a teacher preparation programme. *Teacher Development*, *11*(2), 149–173. doi:10.1080/13664530701414779

Keawdang, R. (1998). *The binding of Thai Educational Article in Years 1997-1998*. Bangkok: The Institute of National Education Committee.

Kelly, G. J., & Crawford, T. (1996). Students' interaction with computer representations: Analysis of discourse in laboratory groups. *Journal of Research in Science Teaching*, *33*(7), 693–707. doi:10.1002/(SICI)1098-2736(199609)33:7<693::AID-TEA1>3.0.CO;2-I

Kim, M. C., Hannafin, M. J., & Bryan, L. A. (2007). Technology-enhanced inquiry tools in science education: An emerging pedagogical framework for classroom practice. *Science Education*, *91*(6), 1010–1030. doi:10.1002/sce.20219

Klahr, D., Triona, L. M., & Williams, C. (2007). Hands on what? The relative effectiveness of physical vs. virtual materials in an engineering design project by middle school children. *Journal of Research in Science Teaching*, *44*(1), 183–203. doi:10.1002/tea.20152

Kubicek, J. (2005). Inquiry-based learning, the nature of science, and computer technology: New possibilities in science education. *Canadian Journal of Learning and Technology*, *31*(1), 51–64.

Lages, C., & Mendez, E. (2007). Contact angle measurements under thermodynamic equilibrium conditions. *Analytical and Bioanalytical Chemistry*, *388*(8), 1689–1692. doi:10.1007/s00216-007-1373-1 PMID:17546444

Langkhapin, S. (2009, November). *Achieving educational soundness for science mathematics and technology digital resource instructional design*. Paper presented at the Third International Conference on Science and Mathematics Education (CoSMEd2009), Penang, Malaysia.

Lavonen, J., Juuti, K., & Meisalo, V. (2003). Designing MBL package for school science. In the V. Uskov (Eds.). In *Proceedings of the IASTED International Conference Computer and Advanced Technology in Education* (pp. 664-669). Anaheim: ACTA Press.

Lazonder, A. W., & Ehrenhard, S. (2014). Relative effectiveness of physical and virtual manipulatives for conceptual change in science: How falling objects fall. *Journal of Computer Assisted Learning*, *30*(2), 110–120. doi:10.1111/jcal.12024

McElhaney, K. W., & Linn, M. C. (2011). Investigations of a Complex, Realistic Task: Intentional, Unsystematic, and Exhaustive Experimenters. *Journal of Research in Science Teaching*, *48*(7), 745–770. doi:10.1002/tea.20423

McRobbie, C. M., & Thomas, G. P. (2000). Epistemological and contextual issues in the use of microcomputer-based laboratories in a Year 11 Chemistry classroom. *Journal of Computers in Mathematics and Science Teaching*, *19*(2), 137–160.

Messaris, P. (1998). Visual aspects of media literacy. *Journal of Communication*, *48*(1), 70–80. doi:10.1111/j.1460-2466.1998.tb02738.x

Ministry of Education. (2008). *The Basic core curriculum education B.E. 2551 (A.D. 2008)*. Bangkok: Kurusapa Ladprao Publishing.

Muller, D. A., Sharma, M. D., & Reimann, P. (2008). Raising cognitive load with linear multimedia to promote conceptual change. *Science Education*, *92*(2), 278–296. doi:10.1002/sce.20244

Nakhleh, M. B. (1994). A review of microcomputer-based labs: How have they affected science learning? *Journal of Computers in Mathematics and Science Teaching*, *13*(4), 368–681.

Nakhleh, M. B., & Krajcik, J. S. (1994). The effect of level of information as presented by different technologies on students' understanding of acid, base and pH concepts. *Journal of Research in Science Teaching*, *31*(10), 1077–1096. doi:10.1002/tea.3660311004

National Research Council. (2000). *How People Learn: Brain, Mind, Experience, and School*. Washington, DC: National Academy Press.

National Research Council. (2006). *America's lab report: Investigations in high school science*. Washington, DC: National Academy Press.

Nicolaou, C. T., Nicolaidou, I. A., Zacharia, Z. C., & Constantinou, C. P. (2007). Enhancing fourth graders' ability to interpret graphical representations through the use of microcomputer-based labs implemented within an inquiry-based activity sequence. *Journal of Computers in Mathematics and Science Teaching*, *26*, 75–99.

Office of the National Education Commission. (1999). *National Education Act of B.E. 2542 (1999)*. Retrieved May 3, 2015 from http://planipolis.iiep.unesco.org/upload/Thailand/Thailand_ Education_ Act_1999.pdf

Office of the National Education Commission. (2000). *Learning reform: A learner-centered approach.* Bangkok: Watana Paint Printing & Publishing Company Limited.

Olympiou, G., & Zacharia, Z. C. (2012). Blending physical and virtual manipulatives: An effort to improve students' conceptual understanding through science laboratory experimentation. *Science Education*, *96*(1), 21–47. doi:10.1002/sce.20463

Piraksa, J., & Srisawasdi, N. (2014). Promoting students' physics motivation by blended combination of physical and virtual laboratory environment: A result on different levels of inquiry. In *Proceedings of the 22nd International Conference on Computers in Education.* Asia-Pacific Society for Computers in Education.

Plant, E. A., Baylor, A. L., Doerr, C. E., & Rosenberg-Kima, R. B. (2009). Changing middle-school students' attitudes and performance regarding engineering with computer based social models. *Computers & Education*, *53*(2), 209–215. doi:10.1016/j.compedu.2009.01.013

Plass, J. L., Milne, C., Homer, B. D., Jordan, T., Schwartz, R. N., Hayward, E. O., & Barrientos, J. et al. (2012). Investigating the effectiveness of computer simulations for chemistry Learning. *Journal of Research in Science Teaching*, *49*(3), 394–419. doi:10.1002/tea.21008

Polsani, P. R. (2003). Use and abuse of reusable learning objects. *Journal of Digital Information, 3*(4). Retrieved May 3, 2015, from https://journals.tdl.org/jodi/index.php/jodi/article/view/89/88

Reeve, E. M. (2013). *Implementing Science, Technology, Mathematics, and Engineering (STEM) Education in Thailand and in ASEAN.* Retrieved fromhttp://dpst-apply.ipst.ac.th/specialproject/images/IPST_Global/document/Implementing%20STEM%20in%20ASEAN%20%20-%20IPST%20May%207%202013%20-%20Final.pdf

Rogers, L. T. (1995). The computer as an aid for exploring graphs. *The School Science Review*, *76*(276), 31–39.

Roth, W.-M., Woszczyna, C., & Smith, G. (1996). Affordances and constraints of computers in science education. *Journal of Research in Science Teaching*, *33*(9), 995–1017. doi:10.1002/(SICI)1098-2736(199611)33:9<995::AID-TEA3>3.0.CO;2-Q

Russell, D. W., Lucas, K. B., & McRobbie, C. J. (2003). The role of the microcomputer-based laboratory display in supporting the construction of new understandings in kinematics. *Research in Science Education*, *33*(2), 217–243. doi:10.1023/A:1025073410522

Russell, J. W., Kozma, R. B., Jones, T., Wykoff, J., Marx, N., & Davis, J. (1997). Use of simultaneous- synchronized macroscopic, microscopic, and symbolic representations to enhance the teaching and learning of chemical concepts. *Journal of Chemical Education*, *74*(3), 330–334. doi:10.1021/ed074p330

Sahin, S. (2006). Computer simulations in science education: Implications for Distance Education. *Turkish Online Journal of Distance Education*, *7*(4), 132–146.

Sanders, M. (2009). STEM, STEM education, STEMmania. *Technology Teacher*, *68*(4), 20–26.

Schwarz, B., Eisenmenger-Sittner, C., & Steiner, H. (2008). Construction of a higher-temperature sessile drop device. *Vacuum*, *82*(2), 186–188. doi:10.1016/j.vacuum.2007.07.033

Shimoda, T. A., White, B. Y., & Frederiksen, J. R. (2002). Students goal orientation in learning inquiry skills with modifiable software advisors. *Science Education*, *86*(2), 244–263. doi:10.1002/sce.10003

Simon, H. A. (2000). Observations on the sciences of science learning. *Journal of Applied Developmental Psychology*, *21*(1), 115–121. doi:10.1016/S0193-3973(99)00055-6

Soydhurum, P. (2001). *Science education in Thailand*. Bangkok: The Institute for the Promotion of Teaching Science and Technology.

Srisawasdi, N. (2012a). Introducing students to authentic inquiry investigation by using an artificial olfactory system. In K. C. D. Tan, M. Kim, & S. W. Hwang (Eds.), *Issues and challenges in science education research: Moving forward*. Dordrecht, The Netherlands: Springer. doi:10.1007/978-94-007-3980-2_7

Srisawasdi, N. (2012b). Student teachers' perceptions of computerized laboratory practice for science teaching: A comparative analysis. *Procedia: Social and Behavioral Sciences*, *46*, 4031–4038. doi:10.1016/j.sbspro.2012.06.192

Srisawasdi, N. (2014). Developing technological pedagogical content knowledge in using computerized science laboratory environment: An arrangement for science teacher education program. *Research and Practice in Technology Enhanced Learning*, *9*(1), 123–143.

Srisawasdi, N., Kerdcharoen, T., & Suits, J. P. (2008). Turning scientific laboratory research into innovative instructional material for science education: Case studies from practical experience. *The International Journal of Learning*, *15*(5), 201–210.

Srisawasdi, N., & Kroothkeaw, S. (2014). Supporting students' conceptual learning and retention of light refraction concepts by simulation-based inquiry with dual-situated learning model. *Journal of Computers in Education.*, *1*(1), 49–79. doi:10.1007/s40692-014-0005-y

Srisawasdi, N., Moonsara, R., & Panjaburee, P. (2013). Students' motivation of science learning in integrated computer-based laboratory environment. In *Proceedings of the 21st International Conference on Computers in Education*. Asia-Pacific Society for Computers in Education.

Srisawasdi, N., & Sornkhatha, P. (2014). The effect of simulation-based inquiry on students' conceptual learning and its potential applications in mobile learning. *International Journal of Mobile Learning and Organisation*, *8*(1), 24–49. doi:10.1504/IJMLO.2014.059996

State Educational Technology Directors Association. (2008). *Science, technology, engineering and math*. Retrieved April 9, 2011 from http://www.setda.org/wp-content/uploads/2013/11/Science-Technology-Engineering-and-Mathematics-STEM-Report.pdf

Strauss, R., & Kinzie, M. B. (1994). Student achievement and attitudes in a pilot study comparing an interactive videodisc simulation to conventional dissection. *The American Biology Teacher*, *56*(7), 398–402. doi:10.2307/4449869

Suits, J. P., & Srisawasdi, N. (2013). Use of an interactive computer-simulated experiment to enhance students' mental models of hydrogen bonding phenomena. In J. P. Suits & M. J. Sanger (Eds.), *Pedagogic roles of animations and simulations in chemistry courses.* American Chemical Society.

Thornton, R. K. (1987). Tools for scientific thinking - microcomputer-based laboratories for physics teaching. *Physics Education*, *22*(4), 230–238. doi:10.1088/0031-9120/22/4/005

Toth, E. E., Morrow, B. L., & Ludvico, L. R. (2009). Designing blended inquiry learning in a laboratory context: A study of incorporating hands-on and virtual laboratories. *Innovative Higher Education*, *33*(5), 333–344. doi:10.1007/s10755-008-9087-7

Triona, L., & Klahr, D. (2003). Point and click or grab and heft: Comparing the influence of physical and virtual instructional materials on elementary school students' ability to design experiments. *Cognition and Instruction*, *21*(2), 149–173. doi:10.1207/S1532690XCI2102_02

Trumper, R., & Gelbman, M. (2001). A microcomputer-based contribution to scientific and technological literacy. *Journal of Science Education and Technology*, *10*(3), 213–221. doi:10.1023/A:1016673931746

Tuan, H. L., Chin, C. C., Tsai, C. C., & Cheng, S. F. (2005). Investigating the effectiveness of inquiry instruction on the motivation of different learning styles students. *International Journal of Science and Mathematics Education*, *3*(4), 541–566. doi:10.1007/s10763-004-6827-8

University of Colorado Boulder. (2015). *PhET interactive simulations for science and mathematics*. Retrieved from https://phet.colorado.edu

van der Meij, H., van der Meij, J., & Harmsen, R. (2012). *Animated pedagogical agents: Do they advance student motivation and learning in an inquiry learning environment*? Internal report, Center for Telematics and Information Technology (CTIT), University of Twente. Retrieved May 03, 2015 from http://doc.utwente.nl/79575/1/CTIT-TR-12-02.pdf

van der Meij, J., & de Jong, T. (2006). Learning with multiple representations: Supporting students' learning with multiple representations in a dynamic simulation-based learning environment. *Learning and Instruction*, *16*(3), 199–212. doi:10.1016/j.learninstruc.2006.03.007

Veemans, K., van Joolingen, W., & de Jong, T. (2006). Use of heuristics to facilitate scientific discovery learning in a simulation learning environment in a physics domain. *International Journal of Science Education*, *28*(4), 341–361. doi:10.1080/09500690500277615

Waitayangkoon, P. (2007). ICT professional development of teachers in Thailand: The lead-teacher model. In E. Meleisea (Eds.), *ICT in Teacher Education: Case Studies from the Asia-Pacific Region*. UNESCO Thailand. Retrieved May 4, 2015 from http://unesdoc.unesco.org/images/0015/001567/156757e.pdf

Winberg, T. M., & Berg, R. (2007). Students' cognitive focus during a chemistry laboratory exercise: Effects of a computer-simulated prelab. *Journal of Research in Science Teaching*, *44*(8), 1108–1113. doi:10.1002/tea.20217

Windschitl, M., & Andre, T. (1998). Using computer simulations to enhance conceptual change: The roles of constructivist instruction and student epistemological beliefs. *Journal of Research in Science Teaching*, *35*(2), 145–160. doi:10.1002/(SICI)1098-2736(199802)35:2<145::AID-TEA5>3.0.CO;2-S

Winn, W., Stahr, F., Sarason, C., Fruland, R., Oppenheimer, P., & Lee, Y.-L. (2006). Learning oceanography from a computer simulation compared with direct experience at sea. *Journal of Research in Science Teaching*, *43*(1), 25–42. doi:10.1002/tea.20097

Zacharia, Z. C. (2007). Comparing and combining real and virtual experimentation: An effort to enhance students' conceptual understanding of electric circuits. *Journal of Computer Assisted Learning*, *23*(2), 120–132. doi:10.1111/j.1365-2729.2006.00215.x

Zacharia, Z. C., & Anderson, O. R. (2003). The effects of an interactive computer-based simulations prior to performing a laboratory inquiry-based experiments on students' conceptual understanding of physics. *American Journal of Physics*, *71*(6), 618–629. doi:10.1119/1.1566427

Zacharia, Z. C., & Constantinou, C. P. (2008). Comparing the influence of physical and virtual manipulatives in the context of the physics by inquiry curriculum: The case of undergraduate students' conceptual understanding of heat and temperature. *American Journal of Physics*, *76*(4), 425–430. doi:10.1119/1.2885059

Zacharia, Z. C., & Olympiou, G. (2011). Physical versus virtual manipulative experimentation in physics learning. *Learning and Instruction*, *21*(3), 317–331. doi:10.1016/j.learninstruc.2010.03.001

Zacharia, Z. C., Olympiou, G., & Papaevripidou, M. (2008). Effects of experimenting with physical and virtual manipulatives on students' conceptual understanding in heat and temperature. *Journal of Research in Science Teaching*, *45*(9), 1021–1035. doi:10.1002/tea.20260

Zion, M. (2006). On line forums as a "rescue net" in an open inquiry process. *International Journal of Science and Mathematics Education*, *6*(2), 351–375. doi:10.1007/s10763-006-9051-x

Zion, M., & Sadeh, I. (2007). Curiosity and open inquiry learning. *Journal of Biological Education*, *41*(4), 162–168. doi:10.1080/00219266.2007.9656092

Zumbach, J., Schmitt, S., Reimann, P., & Starkloff, P. (2006). Learning life sciences: Design and development of a virtual molecular biology learning lab. *Journal of Computers in Mathematics and Science Teaching*, *25*(3), 281–300.

KEY TERMS AND DEFINITIONS

Combined Laboratory: The sequential combination of physical experimentation (PE) and virtual experimentation (VE) to address a certain learning goal in curriculum (e.g., students conduct the first set of the experiments of a certain variables with PE and the other set (or the same set of another variables) with VE).

Data Loggers: An electronic device that records data over time either from a built-in instrument or external instruments and sensors, allowing for computerized (or a digital processor) experiments in the classroom and to plug electronic sensors into the computer at the same time.

Inquiry Learning Perception: An internal process that extracts relevant or meaningful information from the inquiry learning environment, a stimulus array of learning tasks or activities, as the result of inquiry learning experience in terms of three constructs: cognitive performance, emotional practice, and social inquiry process.

Microcomputer-based Laboratory: A computerized data-logging instrument, which has a number of electronic sensors connected with a data logger, that enables students to measure, collect, and analyze data of physical systems through a software on computers or handheld devices such as tablets and smart phones simultaneously.

Physical Experimentation: An actual learning experience that involves a process in which students physically manipulate real-world physical or concrete material and apparatus to observe and understand the natural or material world.

Science Motivation: The internal state of motivation to learn science in terms of five dimensions: intrinsic motivation and personal relevance, self-efficacy and assessment anxiety, self-determination, career motivation, and grade motivation.

Simulation: A computer-based visual representation application presenting dynamic, theoretical, or simplified models of real world components, phenomena, or processes that involves a process in which students virtually manipulate/interact with this application to observe, explore, recreate, and receive immediate feedback about real objects, phenomena, and processes.

Simulation-Based Open Inquiry: An active learning process based on an inquiry approach in which students investigate scientific or natural phenomena by interacting with simulations, wherein instructors provide an open-ended inquiry question and basic science background wherein learners have to develop their own procedure, analysis, communication, and conclusions to address an instructor-provided question.

Virtual Experimentation: An onscreen (active touching of computer screen) learning experience that involves a process in which students virtually manipulate or interact with onscreen objects (e.g. virtual materials and apparatus) to observe and understand the natural or material world.

Chapter 7

The Power of Computational Modeling and Simulation for Learning STEM Content in Middle and High Schools

Mahnaz Moallem
University of North Carolina – Wilmington, USA

Sridhar Narayan
University of North Carolina – Wilmington, USA

Shelby P. Morge
University of North Carolina – Wilmington, USA

Gene A. Tagliarini
University of North Carolina – Wilmington, USA

ABSTRACT

Using Squeak Etoys to Infuse Information Technology (USeIT) was designed to offer expanded information technology experiences to 155 middle and high school students over a three-year period by exploiting the Squeak Etoys media authoring tool as a simulation and modeling environment. Through problem-solving activities and development of Squeak Etoys modeling projects, USeIT investigated the impact of Problem-Based Learning (PBL) and utilization of Squeak Etoys on student understanding of scientific and mathematical concepts. A design-based research method was used to collect data. The results revealed that when simulation and modeling are used under specific learning conditions, a deeper level of understanding of key science and mathematics concepts is observed. In addition, problem-based simulation tasks cognitively engaged students, particularly those who otherwise did not see the relevancy of STEM content in their lives. Less motivated students developed interests in STEM content and showed confidence in their abilities to learn mathematics and science.

INTRODUCTION

As a result of growing concern that the United States is not preparing a sufficient number of students, teachers, and practitioners in the areas of **S**cience, **T**echnology, **E**ngineering, and **M**athematics (STEM), improving learning in STEM education continues to be a priority for American policymakers (Congressional Research Service, 2011). In recent years, the National Science Foundation (NSF) and other

DOI: 10.4018/978-1-4666-9616-7.ch007

organizations have supported innovative projects that aimed to develop examples of rich, learner-centered educational reform in STEM fields. “Using Squeak to Infuse Information Technology (USeIT)” was one of these projects. In partnership with local schools, the USeIT project was designed to develop examples of rich, learner-centered simulation and modeling learning activities in STEM fields.

The purpose of this chapter is to report the impact of integrating Problem Based Learning (PBL) and computational modeling using *Squeak Etoys* technology on student learning of STEM contents. It specifically describes the changes in students’ understanding of the key scientific and mathematical concepts and students’ thinking skills when constructing models of complex systems.

BACKGROUND AND RELATED LITERATURE

STEM Education

STEM Education is defined in many ways by different groups. A common definition of STEM education refers to science, mathematics, and technology educators working together to explore and implement integrative alternatives to traditional, disconnected STEM education (Congressional Research Services, 2012; National Science and Technology Council, 2011). The integrative STEM education is expected to combine technological design purposefully with scientific inquiry, engaging students or teams of students in scientific inquiry situated in the context of technological problem solving. STEM educators have made an increasing effort to employ the integrative approaches using various strategies (Becker & Park, 2011). However, in spite of the emphasis and many efforts to disseminate and implement STEM education, there is limited research on the effects of the integrative approaches among STEM subjects on the students’ understanding of scientific and mathematical concepts (Becker & Park, 2011; Hurley, 2001; Judson & Sawada, 2000; Pang & Good, 2000; Venville, Wallace, Rennie, & Malone, 2000). Moreover, recent meta-analysis of effects of integrative approaches in STEM on student learning (Becker & Park, 2011) shows that while integrative approaches provide a rich learning context and improve student learning and interest, the types of integration impact the effects of these approaches among STEM subjects.

Problem Based Learning Pedagogy for STEM Education

PBL is a non-traditional, active, inductive, student-centered approach that focuses on the introduction of a real-life problem (Ehrlich, 1998). In PBL environments students are presented with complex, authentic, meaningful problems as a basis for inquiry and investigation. Sometimes called a project, an inquiry, or an authentic investigation, the problem, as a complex task, is formed by the need to design, create, evaluate, revise, and/or improve something. Research on PBL--particularly in medical fields--suggests that PBL results in gaining complex levels of knowledge, such as comprehension and analysis of problems and improving student attitude and satisfaction. While not abundant, a growing body of research also suggests that PBL is an effective strategy for increasing students’ understanding of STEM content, IT, and problem-solving skills (e.g., Barron & Darling-Hammond, 2010; Denner, 2007; Dischino, et. al. 2011; Huelskamp, 2009; McGrath, Lowes, Lin, & Sayres, 2009; Stone, 2011). PBL strategies also have been shown to enhance students’ attitudes and interest toward learning STEM subjects and to help them explore future opportunities (e.g., Dischino, et. al. 2011; Cerezo, 2004; Kuo-Hung, Chi-Cheng, Shi-Jer, & Wen-Ping, 2013; Lou, Shih, Diez, & Tseng, 2011).

However, research shows that effective implementation of PBL requires proper scaffolding or guidance as learners engage in complex tasks that would otherwise be beyond their current abilities (e.g., Hmelo-Silver, Duncan & Chinn, 2007; Jonassen, 2011; Sweller, Kirschner, & Clark, 2007). Scaffolds are tools, strategies, or guides that support students in gaining higher levels of understanding that would be beyond their reach without the scaffolds (Jackson, Stratford, Krajcik, & Soloway, 1996; Simons & Ertmer, 2006). Scaffolding makes the learning more enjoyable for students by changing complex and difficult tasks in ways that make these tasks accessible, manageable, and within a student's zone of proximal development (Rogoff, 1990; Vygotsky, 1978).

PBL, Metacognitive and Critical Thinking Skills

Current reform initiatives in education have solidified that one of the goals of education is for students to think critically. Critical thinking is defined as an analytical process of reasoning to arrive at logical, rational, and reasonable judgments within a given context (Ennis, 1981). It is postulated that critical thinking occurs when individuals use metacognitive strategies (knowledge about cognition and control of cognition (Flavell, 1979)) to increase the possibility of achieving desired learning outcome (Black, 2005; Halpern, 1998; Kuhn & Dean, 2004; Nickerson, 1994; Schroyens, 2005). On the basis of this argument, some researchers suggest that there is a relationship between critical thinking and metacognitive skills, and that using metacognitive strategies can facilitate development of critical thinking. The relationship between critical thinking and metacognitive skills suggests that critical thinking can also be developed by PBL in which students are using their metacognitive skills to critically analyze and consider one best possible solution for the problem at hand. In addition, studies have shown that critical thinking can be promoted through implementation of scientific experiments that use specific metacognitive strategies (e.g., Choy & Cheah, 2009; Kogut, 1996; Kuhn & Dean, 2004; Orion & Kali (2005). In sum, although the literature has yet to establish the links between PBL and critical thinking ability outside of medical field, the process of hypothesizing, testing, reflecting and retesting when solving a problem using modeling and simulation technology tool creates learning conditions that trigger students' metacognitive thinking and as a result improves critical thinking skills.

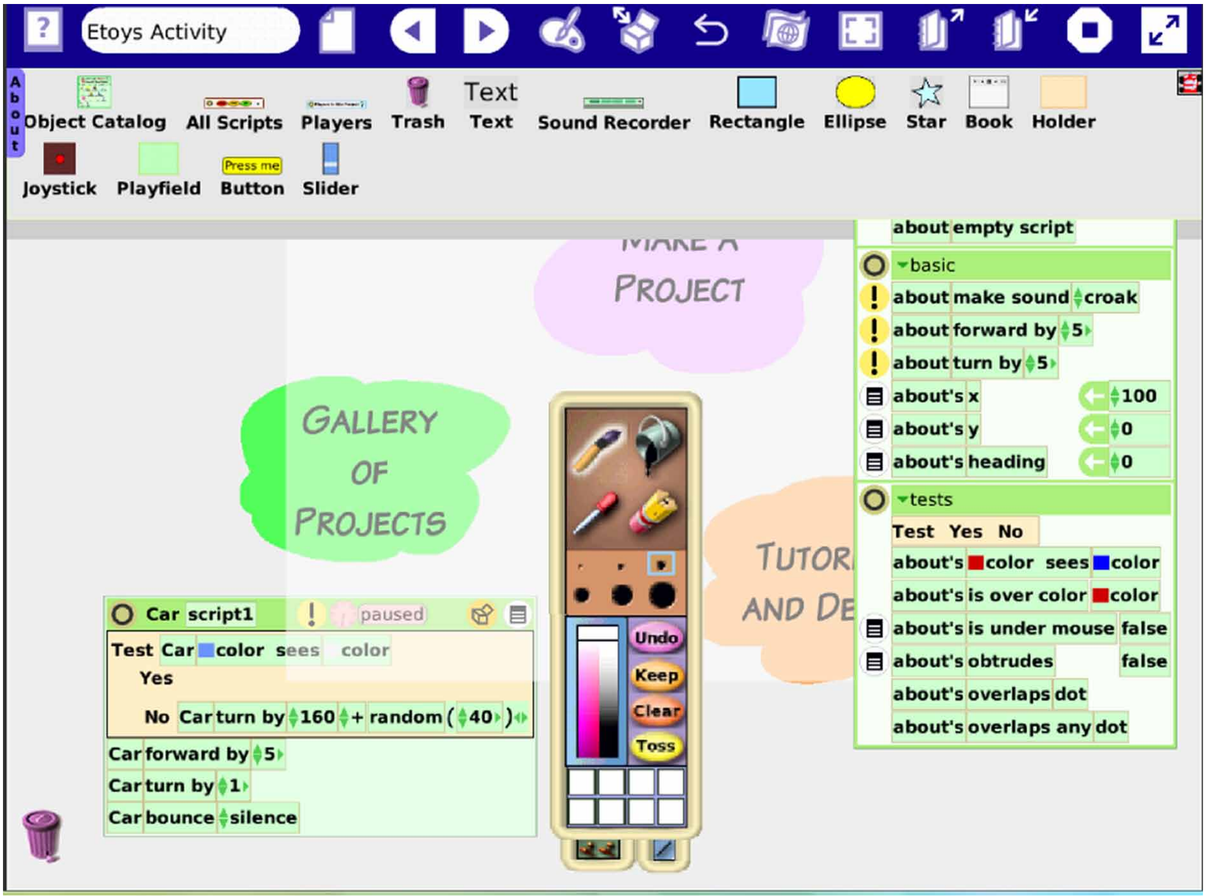
Squeak Etoys: A Technological Environment for Design Challenges

The use of technology is not only a tool, but an important catalyst to enhance STEM education in the context of PBL (Jonassen, 2000). Technologies that provide an opportunity to simulate real world phenomena in which the learner can engage in purposeful design and inquiry (Hallinger, 2005; Jonassen, 2011) open new ways of learning and are at the heart of STEM education. The literature establishes that modeling tools and system dynamics simulations provide multiple representations and help students develop an understanding of problems in situations that involve many interrelated components (e.g., Anderson & Lawton, 2004, 2007; Tan, 2007). Anderson and Lawton (2004) point out that students working with simulations are faced with an unclear problem and incomplete information to solve the problem. There are many possible ways to solve it, and there is more than one correct answer. Therefore, the goal of utilizing simulation and dynamic modeling or computational technology (Panoff, 2009) is to enable teachers and students to experience the excitement of discovery, the power of inquiry, and the joy of learning. *Squeak Etoys* (http://www.squeakland.org) has emerged as an excellent dynamic modeling environment for both young learners and educators alike (Kay, 1991).

An early example of a visual programming language, *Squeak Etoys* has a lot in common with languages like Scratch and Snap or Alice that represent more recent entrants into this space. Often designed for novice programmers, especially children, visual programming languages enable computer programs to be created by piecing together graphical artifacts that represent programming constructs like variables, arithmetic expressions, assignment statements, and program control structures like selection (if statements), and iteration (while statements). In text-based programming environments, novice users are often plagued by syntax errors like missing commas, and semi-colons, or unbalanced parenthesis. Users must address the syntactic issues before they can focus on the meaning of their program. In sharp contrast, visual programming languages relieve users of the responsibility of mastering the syntax of the programming language. With every program guaranteed to be syntactically correct, users are free from the outset to focus on the semantics of their program.

Functioning as a “virtual laboratory,” the open source *Squeak* authoring environment has been used to study student performance ranging from elementary to high school in subjects as diverse as music, biology, mathematics, physics, and engineering. *Squeak Etoys* (see Figure 1) as a media authoring environment can play an important role in enhancing the STEM curriculum (Bouras, Poulopoulos & Tsogkas, 2010). For example, by creating computer models students learn both information technology skills and the scientific features of the phenomenon being modeled. Other computer-based approaches,

Figure 1. Squeak Etoys



```
Car script1   paused
Test Car color sees color
  Yes
  No Car turn by 160 + random (40)
Car forward by 5
Car turn by 1
Car bounce silence
```

```
about empty script
basic
about make sound croak
about forward by 5
about turn by 5
about's x 100
about's y 0
about's heading 0
tests
Test Yes No
about's color sees color
about's is over color color
about's is under mouse false
about's obtrudes false
about's overlaps dot
about's overlaps any dot
```

for example Java applets, allow users to passively explore dynamic representations, visualizations, and simulations of mathematical and scientific concepts, *Squeak Etoys, on the other hand*, requires teachers and students to *actively* and independently construct software artifacts that represent their own understanding of the concept being studied, thus making learning personal. Modeling in *Squeak* is intrinsically hands-on and leads to inquiry-based investigation because the models can be easily changed. Students can share their findings and their projects with others through a Web publishing tool that enables a model to be explored and extended by anyone with a browser equipped with the *Squeak plug-in*. In addition, the *Squeak* media authoring tools are free, which makes the “virtual laboratory” experiences available to a diverse student population, especially to underserved students in schools with dwindling resources.

PROJECT OVERVIEW

USeIT (https://sites.google.com/site/useitwebsite/home) was a collaborative project between a School of Education, a Computer Science Department, and middle and high schools in three counties in a Southeastern North Carolina. The project utilized the *Squeak Etoys* media authoring tool as a modeling environment to infuse IT skills into the core STEM curriculum. USeIT was funded by the National Science Foundation (NSF) to be implemented over three years (2007 through 2010). The targeted audience for this project was practicing STEM teachers and their students in grades 7-12 (middle and high school) in a variety of classroom settings, from science and mathematics courses to technology education and computer courses. USeIT exposed students to science, mathematics, and engineering concepts by integrating the use of *Squeak Etoys* and the tools’ modeling capabilities and PBL. Through problem-solving activities, metacognitive strategies, and development of *Squeak Etoys* modeling projects, one of the USeIT project’s goals was to improve students’ content knowledge in STEM areas, and to promote students’ problem-solving and critical-thinking skills.

Throughout the life of the project, the project team offered a variety of training activities for middle and high school students. Students’ learning activities included: 1) week-long Student Summer Institutes (SSI), 2) classroom learning activities implemented by project teachers, and 3) elective courses and after school activities (e.g., clubs) offered by some schools.

CONCEPTUAL FRAMEWORK AND QUESTIONS OF THE STUDY

USeIT used a combination of PBL and modeling and simulation approach as its theoretical foundation. The key to developing dynamic models was to provide students with a meaningful, real-world, authentic problem to solve. When solving a problem, students were encouraged to use metacognitive strategies to engage in critical thinking, including solving complex and ambiguous problems over extended periods of time, using tools and collaborating with each other and being guided by an expert or a knowledgeable teacher or facilitator.

Using this conceptual framework, the project team formulated the following set of research questions to guide the project’s data collection strategies during implementation, evaluate progress toward and achievement of the project outcomes, and make changes as needed.

- What are the effects of PBL learning conditions and utilization of *Squeak Etoys* on student understanding of scientific and mathematical concepts?
- What are the effects of PBL learning conditions and utilization of *Squeak Etoys* on student critical thinking skills, problem-solving and collaborative learning strategies?
- What are learning conditions, which best foster PBL to influence significant learning gains?

METHODOLOGY

Design Based Research (DBR) was used as an overall method for the USeIT project. DBR, with its focus on promoting, sustaining, and understanding innovation in the real world (Bell, 2004), allowed the researchers to consider a complex learning system, involving many variables (Brown, 1992) and to refine theory and practice continuously (Edelson, 2002; Collins, Bielaczyc, & Joseph 2004). Furthermore, in DBR, development and research take place through continuous cycles or iterations of design, enactment, analysis, and redesign (The Design-Based Research Collective, 2003; Wang & Hannafin, 2005). This refinement process was ideal for the project team who was committed to not only design and explore application of a whole range of theories, activities, artifacts, scaffolds, and curricula, but also to reflect on them after implementation and make adjustments and revisions as needed. In addition, DBR methodology was suitable for participating teachers and students as they tested and evaluated their products and built on what they had learned through implementation in authentic settings.

Data Collection Strategies

DBR typically triangulates multiple sources and kinds of data to connect intended and unintended outcomes to processes of enactment (The Design-Based Research Collective, 2003; Stake, 1995). Thus, using DBR as a research framework, a mixed methodology was used to collect various sources of data. During refinement and revision, the team added new data sources to each component as needed. Data from various sources were triangulated to document the processes of implementation and reflection. The following provides a summary of the data collection strategies and instruments.

Students' final Squeak Etoys products and script of thinking during PBL activity. Students' final *Squeak Etoys* products were evaluated using an analytical rubric developed by the project team. The mathematics educator and computer science members of the team scored students' products collaboratively. Students' presentations of their final Student Summer Institute (SSI) projects were video-taped during the 2009 and 2010 SSIs. Students' conversations during PBL activities were also audio-taped during the 2010 summer institute. Audio and video tapes were reviewed and parts of the conversations that were related to PBL activities were recorded and coded using the following eight critical thinking criteria derived from the literature.

1. Sets realistic goals to solve the problem.
2. Clarifies the question or problem to be solved (creation or reformulation of the question to be answered or problem to be solved).
3. Defines frame of reference or point of view (e.g., from what perspective or angle the student/team is looking at the problem).

4. Collects/Identifies evidence, data, experiences or raw materials that are appropriate for the problem and actively decides which of the possible experiences, data and evidence will be used.
5. Identifies concepts or ideas (theories, principles, or rules) with which can reason a possible source of the problem.
6. Formulates assumptions/hypotheses on the basis of the data and application of concepts or ideas.
7. Makes inferences (deducting from the data, evidence, and application of concepts or ideas).
8. Generates ideas/thoughts for further investigation.

Two members of the project team coded the data. The project team met and reviewed the coding to validate it. In addition, students were instructed to use the flap feature of *Squeak Etoys* to record their progress (metacognitive strategy) in developing their *Squeak* models. Students' explanation of their progress in developing the *Squeak* models was analyzed using the eight critical thinking criteria mentioned earlier. Two members of the project team coded students' narratives. The project team met and reviewed the coding to validate it.

Student survey. Prior to and after participating in the 2009 and 2010 SSIs, students completed a survey (see Appendix A) developed by the project team (some survey items were adopted from instruments created by previously funded projects). The survey consisted of 25 items and using a rating scale of 1 to 4, measured students' attitudes toward mathematics and science (i.e., Mathematics is important in everyday life; High/middle school math courses would be very helpful no matter what I decide to study); their interest and willingness to take more mathematics and science courses (i.e., In general, how do you feel about working on science assignments? Would you take more math courses if you did not have to?); and their technology and *Squeak* skills (i.e., how do you rate your overall technology skills). Moreover, prior to and after participating in the 2009 and 2010 SSIs, students self-assessed their *Squeak Etoys* skills using a checklist of 22 items (i.e., I can create an object or select one from the object catalog: I can locate and identify the *Squeak* objects (e.g., project files, paint, ellipse, or playfield)).

Reflective questions and blogs at the end of SSIs. During the 2009 SSI students were asked to keep an online blog reflecting on their daily events. During the 2010 SSI, students were also given a series of reflective questions to respond to at the end of each day both individually and as a team (metacognitive strategies). Daily individual questions included: "What did I learn today as a result of working with my team?; What role did I play as a team member?; How do I feel about working with a team?; and What do I need to work on to be more effective in my team?" Daily team questions included: "What did we learn today (What did we accomplish today)?; What scientific and mathematical concepts did we learn today?; How do we feel about today's work as a team?; and What do we plan to do next?" A secure online blog and the project's Survey Monkey account were used to record students' responses.

Teachers' integrated PBL and Squeak Etoys lesson plans. Teachers' lesson plans for 2009 and 2010 SSIs were collected. These lesson plans were analyzed using a revised list of criteria for developing lesson plans that integrated PBL and *Squeak Etoys* (i.e., problem/scenario resembles a real world task (is loosely structured and gives a feeling of authenticity to students); problem/scenario does not provide all needed information (students need to identify facts & brainstorm ideas); problem/scenario explains proper process for investigation & group work; problem/scenario "derives" students to encounter and struggle with the targeted concepts and principles (is linked to the desired objectives [learning outcomes] & standards); problem/scenario uses *Squeak* as a hands-on kit to construct knowledge and/or test hypotheses and generate new facts based on scientific experimentation; problem/scenario is linked to the essential questions).

Refinement and Revision of Data Collection Methods

Upon refinement of the strategies and reflecting on the quality of the data and effectiveness of data collection strategies at the end of the first year implementation (2007-2008), the team added new data sources such as: a student attitude survey mentioned earlier (consisted of 25 items); assessment of students' *Squeak Etoys* skills using a checklist of 22 items; assessment of students' *Squeak Etoys* projects using a rubric developed by the project team; audio recording of students' thinking processes during development of *Squeak Etoys* models and video tapes of students' presentations of their *Squeak* projects; analysis of teachers' integrated PBL and *Squeak Etoys* lesson plans (using a revised list of criteria developed by the team) for their focus on STEM concepts; and interviews with a sample of students who continued to use *Squeak Etoys* above and beyond their STEM courses.

Analysis

Both quantitative and qualitative analyses were used to make sense of the data. Data was analyzed at several levels. Level one of the data analysis offered immediate and specific indications regarding the relations between the project design specifications and learning events. These quick analyses served as input for adjustment of designs, and at the same time, accumulated to support more intermediate and comprehensive analysis. Intermediate analysis took place each year, revisiting the design of tools and activities in light of the evidence collected throughout the year. The final stage of analysis, which took place at the end of the third year, was a critical phase of the project. Data collected during the first year of implementation (2007-2008) lacked details and reliable and systematic record of student interest and learning, thus the final analysis included more data from year two (2008-2009) and year three (2009-2010) of the project implementation. Quantitative analysis was used for the survey data. The data was entered into SPSS and descriptive analysis was conducted. Observation and interview data and responses to reflective questions were analyzed using an open coding system (Table 4) and finding themes and patterns (Strauss, 1987). Students' reflective blogs and responses, conversations, and flap notes were also analyzed using the critical thinking criteria listed earlier, as a coding system. For example, if in their reflective thoughts, notes, or group conversations students noted the need for collecting data to develop their model, the portion of the text was coded as "identifies and collects new data". Similarly, if they examined their scripts and the sketch of the model and made a prediction (e.g., "I think they would fall at the same rate" or "I think they would hit the ground at the same time"), it was coded as "making inferences." Miles and Huberman's (1994) guidelines for data management and data analysis were followed to triangulate the data and to link qualitative and quantitative data before developing final propositions and interpretation.

THE CONTEXT OF THE STUDY

The project targeted students in middle and high school grades 7-12 from three counties. The three school districts were representative of others within the southeastern region of the state, which is largely rural. Two of the three counties targeted in the project represented the traditional rural-poor with a large number of economically disadvantaged student populations, while one of the counties is in a more urban area, with a lower number of economically disadvantaged student populations. Similarly, the schools from

Table 1. Student summer institute profile

Summer Institute	Gender	Grade Level	Total
Year 1 (Summer 2008)	25 Male 27 Female	19 (6 Grade) 22 (7 Grade) 11 (8 Grade)	52 (58% White; 11% Black; 7% Hispanic; 24% Other)
Year 2 (Summer 2009)	33 Male 23 Female	13 (6 & 7 Grades) 12 (8 Grade) 18 (9 & 10 Grade) 13 (11 & 12 Grades)	56 (50% White; 36% Black; 7% Hispanic; 7% other)
Year 3 (Summer 2010)	29 Male 18 Female	4 (5 Grade) 10 (7 Grade) 6 (8 Grade) 17 (9 & 10 Grades) 10 (11 & 12 Grades)	47 (49.9% White; 38.3% Black; 4.3% Hispanic; 6.4% Other)
Total	87 Male 68 Female	68 (5, 6 & 7 Grades) 29 (8 Grade) 35 (9 & 10 Grades) 23 (11 & 12 Grades)	155

which the participating teachers were selected were different in their student populations, ranging from low to high percentages of black or other minority students and economically- disadvantaged students.

Project Participants

Each year, participating teachers and district technology coordinators collaborated with the project team to select a group of students for the Student Summer Institute (SSI). Table 1 shows the student demographics for the SSIs that took place in 2008, 2009 and 2010.

Students participating in the 2008 SSI ranged across the grades. Table 1 shows the number of students in each grade level who participated in SSI 2008, 2009, and 2010. Four fifth grade students participated in the 2010 SSI, although the SSI in 2010 was focused on middle and high school. These students were children of the teacher leaders.

The students were nominated for the SSI by their teachers. The nominated students were asked to write an essay describing their reasons for wanting to attend the SSI. Participating teachers reviewed students' essays. If students' essays showed their interests, and their academic work for the year was satisfactory (all scores were at least proficient on the state exams), they were selected for the SSI.

FINDINGS

The study attempted to explore the impact of integrating PBL and computational modeling using *Squeak Etoys* technology on student learning of STEM contents. It specifically examined the changes in students' understanding of the key scientific and mathematical concepts as well as students' critical thinking skills when constructing models of complex systems. The following sections summarize the findings using the questions of the study.

Research questions 1 and 2: What are the effects of PBL learning conditions and utilization of Squeak Etoys on student understanding of STEM concepts? What are the effects of PBL learning conditions and utilization of Squeak Etoys on student critical thinking skills, problem-solving and collaborative learning strategies?

Analyses of multiple sources of the data showed that due to the changes in learning conditions and learning tasks in SSI 2008, 2009 and 2010, their effects on student understanding of STEM concepts and student critical thinking and problem-solving skills were different. Thus, the following sections will first summarize the results for SSI 2008 and 2009 and then SSI 2010.

Effect of PBL Learning Conditions and Utilization of Squeak Etoys on Student Understanding of STEM Concepts in SSI 2008 and 2009

PBL learning conditions. During the 2008 and 2009 SSI, participating teachers were tasked to develop real world problem-solving tasks for each day. The problem-solving tasks were to offer a series of guiding questions, which required students to use their mathematical and scientific skills to develop a *Squeak Etoys* project to suggest a solution. Each day of the SSI, the students were led through a different task and they created a new *Squeak Etoys* project. To connect student problem-solving tasks/activities (for mathematical and scientific concepts) with their curriculum and state standards, teachers created lesson plans for each day of the 2008 and 2009 SSI (daily problem-solving tasks) in which they specified their targeted objectives for the activity/task, the investigative questions to guide the activity/task and a warm-up activity in which they attempted to recall student prior knowledge.

Analysis of teachers' lesson plans for both SSIs showed that in spite of the emphasis on PBL and its required conditions during professional development, teachers' lessons and their problem-solving tasks were prescriptive and well defined, rather than descriptive and ill-defined. The lessons were narrow in their focus, and often provided students with a base *Squeak Etoys* model, requiring students to expand on the model, rather than prompting students to develop their own models. This issue was also observed in teachers' practices in their classrooms. Observations of teachers in their classrooms indicated that teachers designed and implemented similar well-defined daily assignments, rather than ill-defined longer projects. Hence, it was not surprising that they adopted the same strategies for SSIs. In their lesson plans, teachers neither identified formal pre- and post-assessment strategies nor did they specifically indicate how they would form collaborative teams (they often let students choose a partner). In addition, teachers did not indicate how they would monitor students' progress during the development of their *Squeak Etoys* model or how they would assess their students' *Squeak Etoys* products and their critical thinking skills. Analysis of various data during SSIs further showed that teachers did not focus on developing process and product assessment criteria and specific strategies for scaffolding and guiding students in learning mathematical and scientific concepts. In other words, teachers did not fully apply and exercise the following suggested analytical processes of 1) establishing goals for the problem-solving task, 2) brainstorming and discussing the problem domain, 3) investigating the factors that affect the problem in order to acquire the knowledge and skills needed to develop a model of the problem using *Squeak*

Etoys, 4) visualizing the result of the model using *Squeak Etoys*, and 5) forming hypotheses to test and simulate, and finally reflecting on proposed problem-solving process to formulate more questions. Most teachers' lesson plans and guidance during the SSIs emphasized *Squeak Etoys* functions and features regardless of the listing of a number of targeted content-related objectives and investigative questions. Content-specific scaffolding and questioning were minimal.

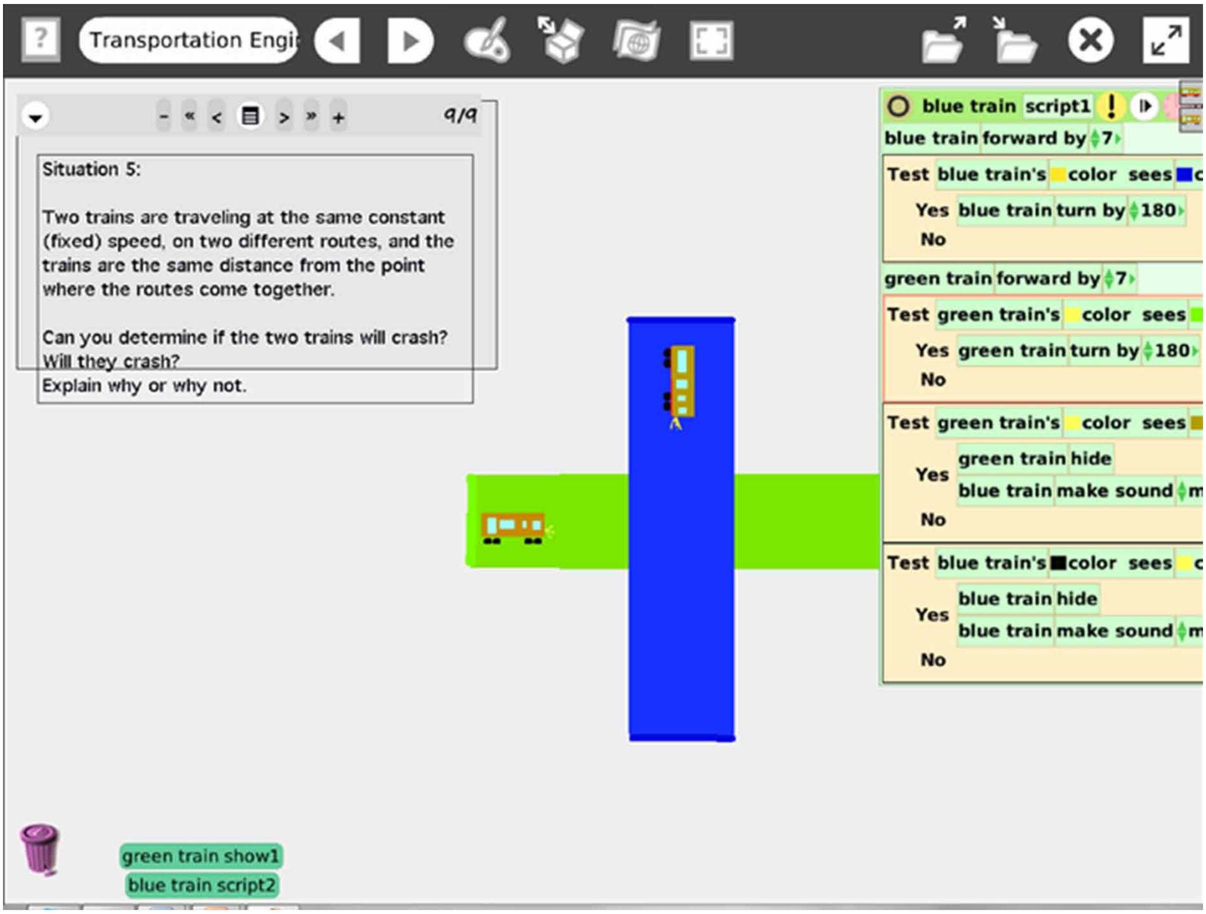
This issue, combined with change of the topic and the task for each day of SSI and lack of teachers' planning for helping students use metacognitive strategies to monitor and assess their own learning, resulted in students' *Squeak Etoys* products that were incomplete and difficult to score in order to identify whether students were able to achieve the targeted learning outcomes. In addition, since teachers did not require or expect students to record the process of developing the model, results of their experience, and what they learned from it, they faced the following challenges in assessing students' learning using *Squeak Etoys* products at the end of the SSIs. First, teachers used their general knowledge of students' understanding of the content instead of systematically assessing students' knowledge and skills for PBL learning tasks/activities. Therefore, identifying whether students learned anything new or deepened their prior understanding of the mathematical and scientific concepts or *Squeak Etoys* skills was not possible. Second, analysis of various sources of data indicated that teachers did not seem to have a clear idea about what a model and simulation was in order to guide students by asking higher level content-related questions and to move their thinking from developing animations to creating models and simulations; thus, the resulting students' projects were not deep enough to be considered models, and the achievement of the targeted mathematical and scientific concepts was limited to a few already learned concepts. Third, with no guiding criteria for assessing students' content knowledge and critical thinking skills, teachers were unable to formally score students' products for their understanding of the targeted mathematical and scientific concepts. In their daily and end of SSI reflections, teachers often cited student engagement, interest, and on-task behavior and ability to use *Squeak Etoys* as their achievements.

Despite extensive professional development on the integration of PBL and Squeak Etoys, SSI 2008 and 2009 lacked full implementation of PBL conditions.

Student understanding of STEM content. Assessment of students' *Squeak Etoys* products by the project team indicated that the majority of the products involved animations with little correlation to the important mathematical and scientific content and objectives targeted for the activity. See Figure 2 and 3 for a screen shot of two example projects: *"All Aboard"* and "*Mike Motion*."

As mentioned earlier, this result could have been due to the fact that the students started new projects each day; thus did not have quality time developing their work into a model to simulate and test the phenomenon and learn from it. Furthermore, even though students kept a daily log throughout 2009 SSI, the probing questions for the log were general and did not provide tangible evidence of learning new concepts or deepening their prior content knowledge. For example, for one of the SSI 2008 projects, *All Aboard*, participating teachers identified the following concepts and procedures as prerequisite knowledge: x and y axis (location); basic mathematical operations; and solving for a variable. They also conducted a quick warm-up activity to activate students' prior knowledge. However, at the end of the day, in addition to submitting their *Squeak* products, students (often in pairs) were only asked to respond to the following questions related to the problem-solving task: How did the *Squeak Etoys* model help you solve the *All Aboard* problem? Do you feel successful with the Train Task *Squeak* model you created? Table 2 summarizes students' responses to these questions for the *All Aboard* example.

Figure 2. Example of All Aboard Project



Situation 5:

Two trains are traveling at the same constant (fixed) speed, on two different routes, and the trains are the same distance from the point where the routes come together.

Can you determine if the two trains will crash? Will they crash? Explain why or why not.

```
blue train script1
blue train forward by 7
Test blue train's color sees c
  Yes blue train turn by 180
  No
green train forward by 7
Test green train's color sees
  Yes green train turn by 180
  No
Test green train's color sees
  Yes green train hide
      blue train make sound m
  No
Test blue train's color sees c
  Yes blue train hide
      blue train make sound m
  No
```

While assessment of students' *Squeak* products did not provide evidence of students' understanding of the content, the projects and students' logs indicated that even if some students were not able to complete their products, they felt they had learned just from trying to figure out how to write scripts and develop an animation or what they called a model. The following are a few examples of the students' comments:

. . . I think I found out just what I needed to know by observing my model.

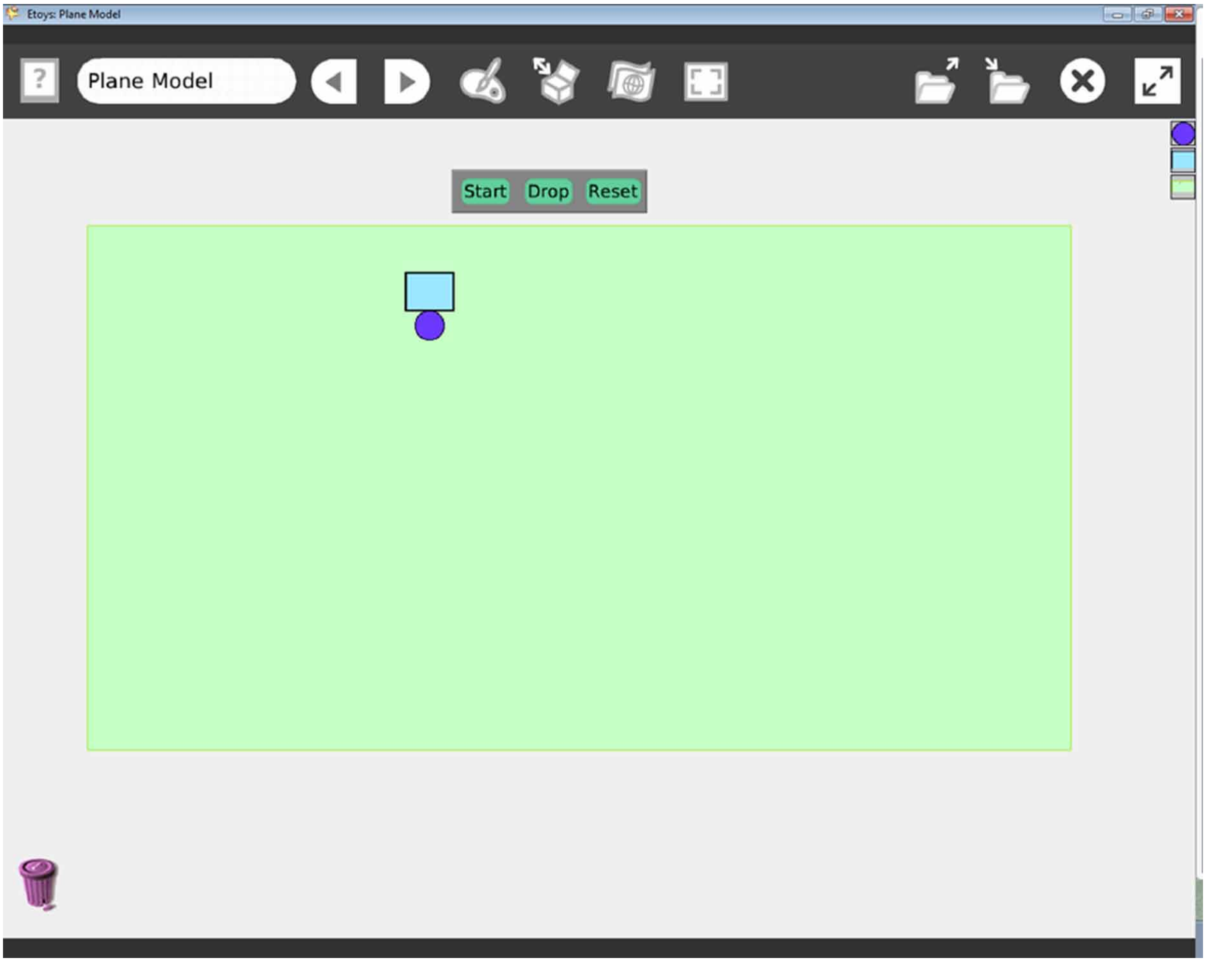
. . . I made them crash but I am going to do more things to it.

. . . I had help from one of my classmates it really helped me a lot and it made clearer for me.

. . . Yes. It showed there were multiple answers when I changed the speed of the trains.

Interviews with a sample of students after SSI 2009 showed that in many cases as a result of being introduced to *Squeak Etoys*, students continued to use it outside of their classrooms and explored creating models and simulations. Triangulation of students' daily logs, observations of SSI sessions in 2008

Figure 3. Example of Mike Motion Project



and 2009 by the project evaluator and student survey data provided evidence that students (1) were highly engaged during daily *Squeak Etoys* activities, (2) thought *Squeak Etoys* helped them visualize and understand the targeted concepts better, (3) felt they were successful in solving their problems, (4) enjoyed working on their *Squeak Etoys* projects, and (5) became more confident in math and science and interested in STEM area as a career choice (see Table 3).

As Table 3 shows, students' interest in STEM career choices increased as a result of participating in SSI 2009, although the difference between pre-and-post survey results was not significant. Students' confidence in various STEM subject areas either remained the same or changed slightly. However, students showed more noticeable increase in their confidence level in subjects such as middle grade algebra and mathematics and high school calculus (although the difference was not significant).

Further analysis was conducted to examine if there were any significant differences across gender and race. The results showed that there was a significant difference between male and female students at both pre (F (1, 43) = 22.326 p<.000) and post surveys (F (1, 44) = 8.231 p<006) regarding interest in engineering and health care career choices (F (1, 43) = 14.150 p<001). In other words, more male students were interested in engineering as a career choice than females and more female students were interested

Table 2. Content analysis of students' blogs for "All Aboard" project

How did the Squeak Etoys model help you solve the All Aboard problem?	
Category of Students Responses	**Frequency of Response**
Helped me solve the problem / answer to my situation.	14
Helped visualizing what would happen.	12
Helped me solve the problem.	12
Helped me see how it really happen when the trains crash.	10
Showed me it depends on the rate of the train if they hit each other.	5
See all possibilities of the situation at hand / Multiple answers to the situation.	3

Table 3. Students' interest in math, science and technology careers before and after participating in the 2009 SSIs

Pre-Post-SSI Survey Comparison Scale of 1-4	SSI 2009 Pre (N = 47) Mean (SD)	SSI 2009 Post (N= 47) Mean (SD)
• How interested are you in jobs as a scientist in a possible future career?	2.36 (1.08)	2.51 (1.06)
• How interested are you in jobs as an engineer in a possible future career?	2.16 (1.09)	2.20 (.98)
• How interested are you in jobs as a mathematician in a possible future career?	1.86 (.89)	1.93 (.998)
• How interested are you in jobs as a computer scientist in a possible future career?	2.40 (1.05)	2.56 (1.07)
• How interested are you in a job in which you would have to use computers frequently?	2.83 (.79)	2.92 (.78)
• Rate your confidence in middle grades algebra. • Rate your confidence in high school calculus.	3.69 (.81) 2.09 (1.3)	4.00 (.96) 2.50 (1.2)
• Rate your confidence in middle grades math.	4.28 (.83)	4.44 (.73)

in health care career options than males. However, this difference was not present between pre-and-post surveys. Analysis also showed no significant difference between White and African American students. However, as Table 4 shows, African American students' interest in mathematics and health care career slightly increased after SSI. This result points to possibility of greater impact of the project on African American students. Long term observation of the impact of the project is needed to confirm this result.

Overall, assessment of students' daily *Squeak* projects showed their basic *Squeak Etoys* skills and suggested their attempt to apply their content knowledge. In addition, the project showed slight improvement in student interest in STEM career choices. However, there was limited evidence to account for deeper level of understanding of STEM content.

Development of critical thinking, problem solving and collaborative learning strategies. As indicated earlier, teachers' lessons for SSI 2008 and 2009 and their implementation of the lessons did not require students to write a project report or record their thinking processes while completing their *Squeak Etoys* projects. In addition, teachers did not form teams and often paired students on the fly. This approach provided limited data to show thinking skills. Thus, while students' *Squeak Etoys* projects exhibited more functionality each day, there was limited evidence of development of critical thinking and problem-solving skills.

Table 4. Comparison across gender and race for students' interest in math, science and technology careers before and after participating in the 2009 SSIs

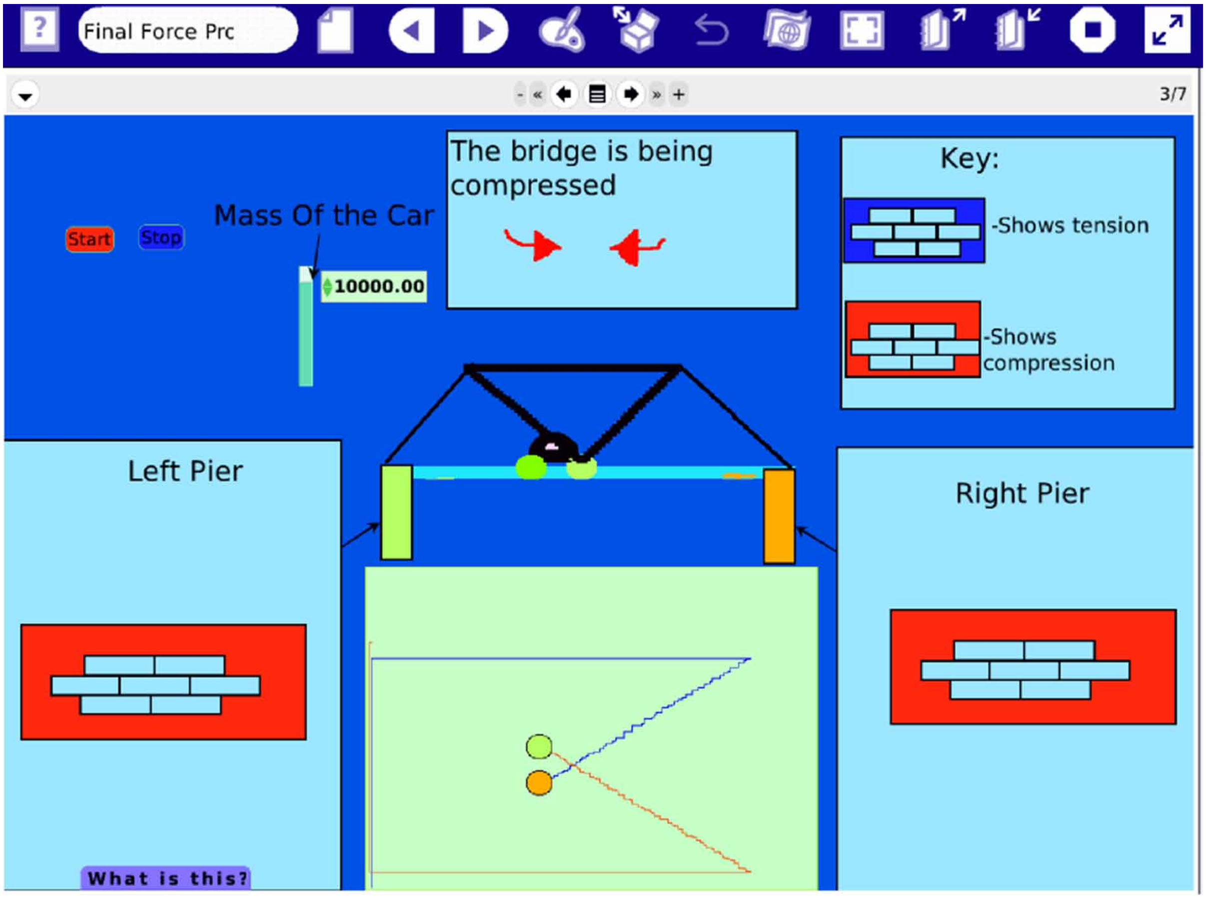
SSI 2009	Male (M)/Female (F)		African American (A)/White Caucasian (W)	
Questions	**Pre SSI N =25 (M) N = 19 (F)**	**Post SSI N =26 (M) N – 19 (F)**	**Pre SSI N = 15 (A) N = 22 (W)**	**Post SSI N = 17 (A) N = 22 (W)**
How interested are you in jobs as a scientist in a possible future career?	M 2.3 (.99) F 2.4 (1.21)	M 2.5 (1.10) F 2.5 (1.02)	A 2.1 (1.10) W 2.6 (1.01)	A 2.2 (1.11) W 2.9 (.97)
How interested are you in jobs as an engineer in a possible future career?	M 2.7 (.97)* F 1.4 (.77)	M 2.5 (.98)* F 1.7 (.81)	A 2.0 (1.27) W 2.28 (.98)	A 2.0 (1.17) W 2.5 (.74)
How interested are you in jobs as a mathematician in a possible future career?	M 1.8 (.85) F 2.0 (.94)	M 1.8 (.99) F 2.1 (1.03)	A 1.8 (.85) W 2.0 (.94)	A 2.1 (1.20) W 1.9 (.91)
How interested are you in jobs as a computer scientist in a possible future career?	M 2.5 (1.02) F 2.3 (1.10)	M 2.8 (1.08) F 2.2 (.98)	A 2.5 (1.02) W 2.3 (1.10)	A 2.4 (1.15) W 2.9 (.89)
How interested are you in jobs as a health care provider in a possible future career?	M 1.8 (.85)* F 2.8 (1.0)	M 1.9 (1.04) F 2.2 (.98)	A 1.8 (.85)* W 2.8 (1.0)	A 2.8 (1.13) W 1.1 (1.17)
How interested are you in a job in which you would have to use computers frequently?	M 3.0 (.76) F 2.6 (.76)	M 3.1 (.78) F 2.7 (.72)	A 3.0 (.76) W 2.6 (.76)	A 2.7 (.84) W 3.1 (.71)

*Significant Difference (p<.001)

Effect of PBL Learning Conditions and Utilization of Squeak Etoys on Student Understanding of STEM Concepts in SSI 2010

Effects of PBL learning conditions. As a result of reflection on the results of the 2008 and 2009 SSI, the process of developing problem solving tasks was revised in 2010. For 2010, teachers were asked to team up and identify four themes or powerful ideas (Motion, Forces, Ecosystems, and Disasters) across curricula and grade levels. Once the powerful ideas were identified, the teachers formulated problem solving tasks that were not only linked to a set of state standards, but were also complex enough to be broken into smaller and simpler tasks for each day of the SSI. Teachers were asked to require students to document their daily progress toward completing the tasks and write a final report, explaining their models using the flap feature of the *Squeak Etoys*. Teachers were also instructed to form student teams (three or four members) on the basis of students' prerequisite *Squeak Etoys* skills and content knowledge. This new structure and sequence of tasks allowed the students to spend more time investigating the mathematical and scientific content and building it into their *Squeak Etoys* projects with fidelity. To assist teachers in providing soft scaffolds, defined as "dynamic, situation-specific aid provided by a teacher or peer to help with the learning process" (Brush & Saye, 2002, p. 2), during development of the *Squeak Etoys* models, and to assess students' final products, a set of assessment criteria was developed by teachers. The criteria allowed the teachers and the project team to score students' products. The criteria further used to determine whether or not what students developed could be considered a computational model or simulation and, if it could, what characteristics defined the product as a model. The criteria also evaluated whether or not the targeted STEM concepts, principles and procedures were used in the model to allow the student to use it as a test bed for determining the solutions.

Figure 4. Forces Project (Day 1): In this project students showed the apportioning of a load across a bridge. They attempted to show that a bridge will break with too much weight, how gravity weight &speed of a car will affect a bridge.

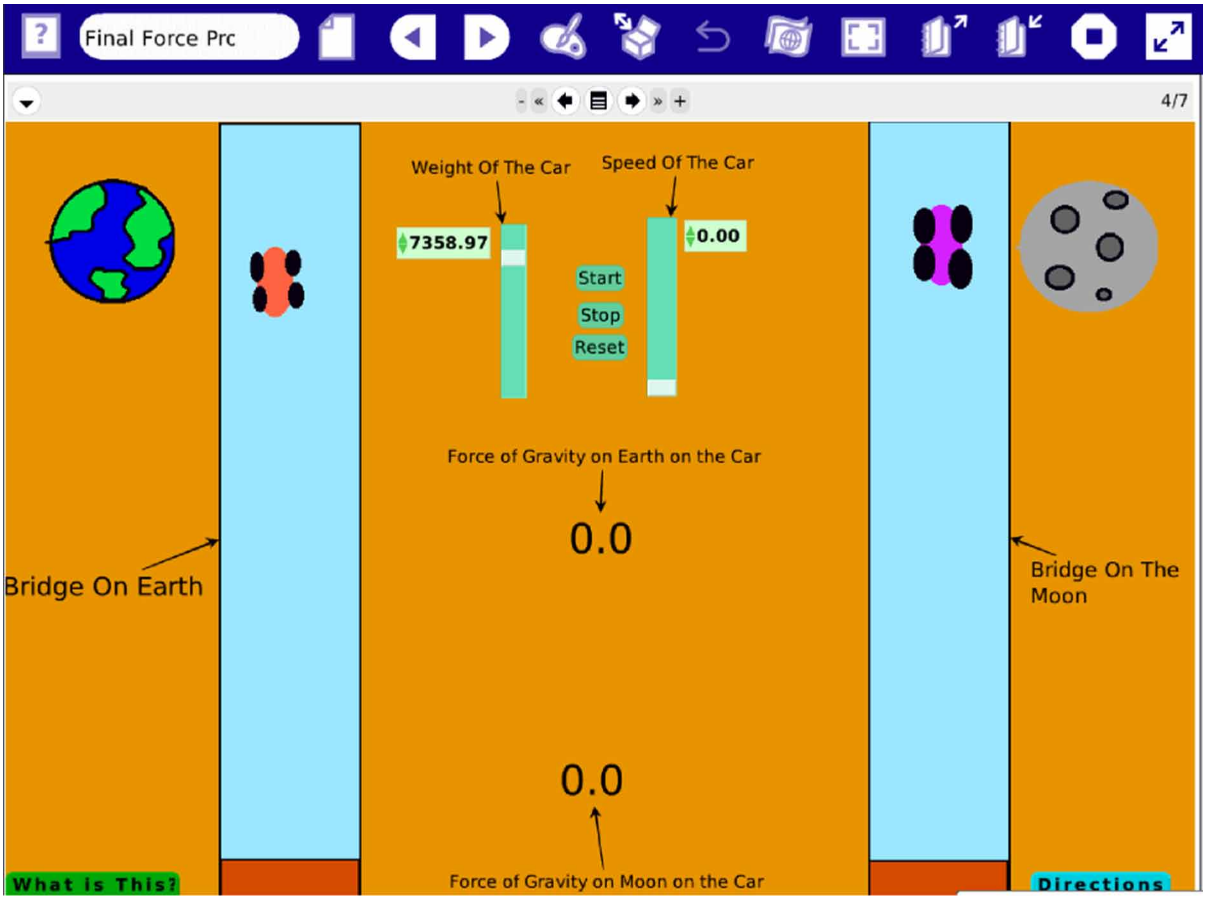


The bridge is being compressed

Student understanding of STEM content. Four members of the project teams (two computer science faculty, one mathematics educator, and one science educator) independently scored students' projects and then met to discuss and agree on the final rating. As a result of the SSI 2010 PBL-*Squeak Etoys* tasks, students developed various types of *Squeak Etoys* projects to demonstrate their understanding of STEM concepts. Figure 4, Figure 5, Figure 6 and Figure 7 provide screen shots of some teams' projects for *Forces* and *Motion* tasks.

Analysis of the *Forces* PBL products revealed that the teams were able to develop *Squeak Etoys* projects with a range of complexity levels. For example, one team's project(s) did not show any correlation to the important mathematics and scientific concepts, principles, and procedures. This team's project did not provide any indication that force has to be accelerated or that when an object is submersed in fluid there is a buoyant force (scale of 1 to 4, 1= lowest and 4 = highest). Another team demonstrated a strong understanding of the important mathematics and science concepts; however, their project included parts that did not work and *Squeak Etoys* scripts that were not used, leading to a score of a 3. Overall, all teams demonstrated an understanding of the concepts of forces, mass, and weight. Depending on

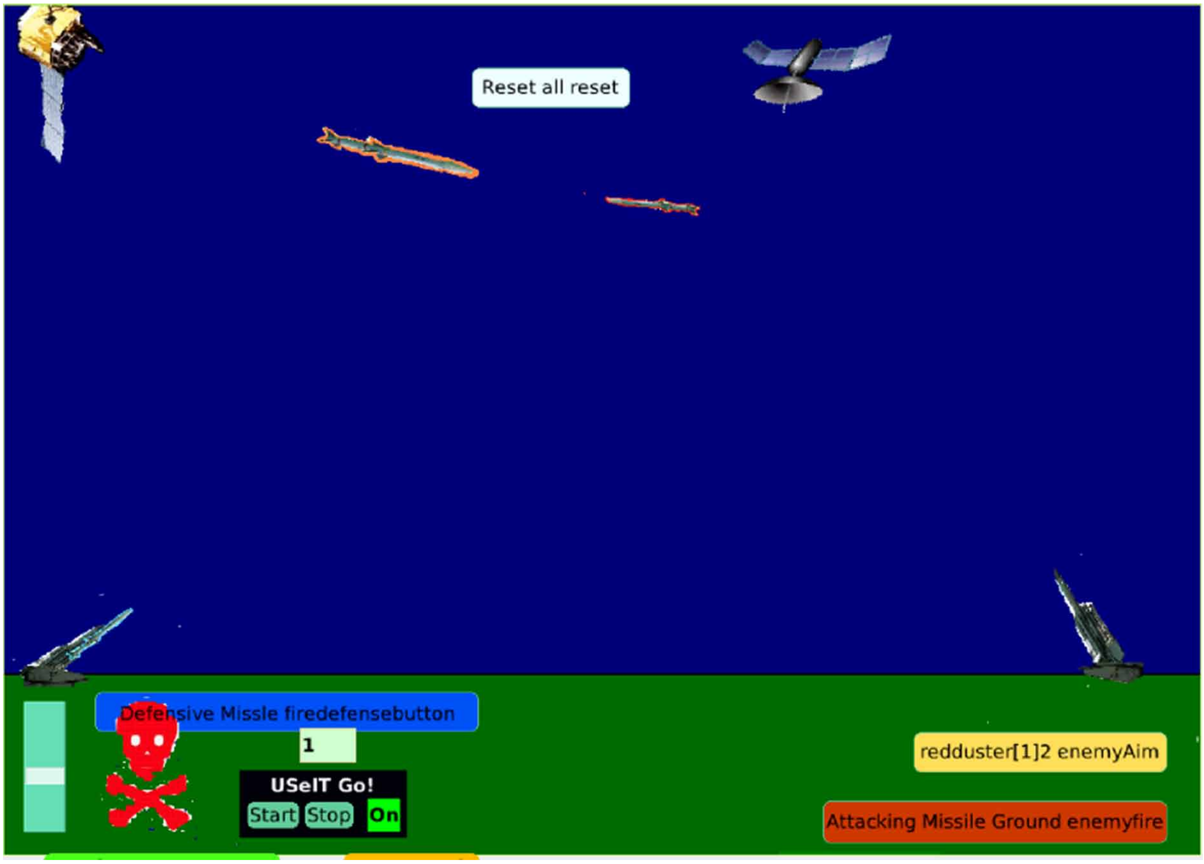
Figure 5. Forces Project (Day 2): In this part of the project students wanted to show the differences in gravity forces acting on objects.



the project they created, students' work also evidenced understanding of buoyancy, acceleration, moments and simply supported beams. Each project also demonstrated understanding of the relationship between mass, weight, and gravity and Newton's third law in addition to other important mathematics and scientific principles. Likewise, the projects also demonstrated an understanding of the procedure of simulating the effects of forces.

Analysis of students' motion projects demonstrated a range of evidence of implementation of an analytical model. For example, one team's project, scoring a 1 in the simulation/model category, showed no evidence of a connection to the underlying mathematical and scientific concepts, principles, and procedures. Another team's project received a 4 in this category because it showed clarity of thought by virtue of the way students wrote the program. Not only was this team's project tied to the important mathematics and scientific concepts, principles, and procedures, but their *Squeak Etoys* programming skills (writing scripts, calling scripts, etc.) made their understanding of the targeted concepts very clear and easy to evaluate. The level of understanding of the concepts, principles and procedures also varied for these projects. The teams that worked on the motion PBL task demonstrated some level of understanding of the concepts of gravity, time, motion, and velocity. Because they developed analytic

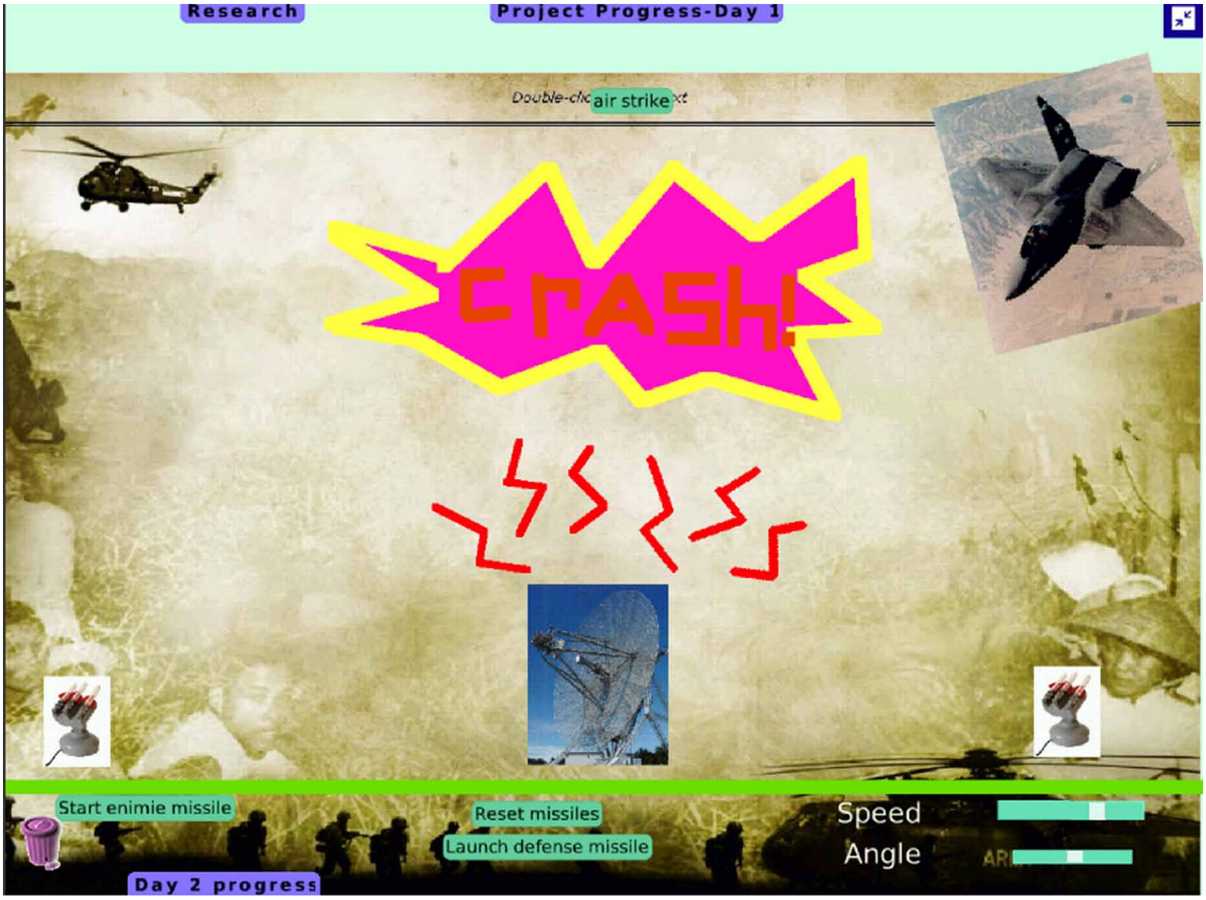
Figure 6. Motion Project (Day 1): Students made an offensive missile fly toward defensive missile in an arc shaped path. They also made a point for missiles to collide and when they hit they explode.



expressions for their calculations, most demonstrated a level of understanding of the principles of scaling and vertical speed. In addition, all teams that worked on this project understood the procedure of calculating a parabolic trajectory.

The level of correlation to the important mathematics and scientific concepts, principles, and procedures was not maintained in the Ecosystems and Disasters projects. This could be attributed to two possible factors. One is that the choice of task with a biology focus hindered students' abilities to model mathematics and science because the topic was very broad and open-ended. The domain for the environment was also broad; it was harder to demonstrate mathematics and science, so the students tended to focus on the graphic representations and researching the phenomena. Another possible factor was the soft scaffolding provided by teachers who were mentoring the teams working on the projects. Analysis of audio recordings suggested that the team scoring the highest on the Ecosystems project worked with teacher mentors who asked more higher-order thinking questions (e.g., "How is this model different from the real world?"; "I see that you made the small molecule travel faster; tell me more about that."). These teacher mentors guided the students to explore mathematics and science concepts, principles, and procedures and encouraged them to use their research results to design a more simplified and mathematically correct model of the phenomenon.

Figure 7. Motion Project (Day 2): Students used the trajectory motion formula to create a flight path to move the land-based enemy missile towards another missile.



The team scoring the highest on the Ecosystems project moderately demonstrated most of the important concepts, principles, and procedures. This team's project was superior to the others who worked on the same PBL project because they accounted for the birth/death process and reproductive maturity. The other teams created projects that fairly simulated the essential scientific and mathematical interactions within their ecosystem.

Analysis of the audio tapes of students' conversations with their teacher mentors during development of the models provided further evidence that the teachers who challenged students to think about targeted mathematical and scientific concepts developed higher quality projects and listed learning mathematical and scientific concepts in their daily reflections compared with those who scored lower. Student teams who scored lower in their final projects, on the other hand, pointed to learning general knowledge by conducting research in their topic areas and improving their *Squeak Etoys* skills.

In conclusion, the analysis of students' products and thinking processes (scripts, reports) from SSI 2010 suggests that when students are given a challenging problem to solve, and are provided appropriate time to think, plan, and design their simulation model and then evaluate it, and are further challenged by their teachers to apply mathematical and scientific concepts in their model, they not only show interest and high engagement in their own learning, but they also construct a much deeper understanding of the STEM concepts. The students' processes of developing *Squeak Etoys* projects also showed that when they were guided and had received proper scaffolds, students showed improvement in their thinking and problem-solving skills. The analysis of students' products further showed that a number of students were able to develop complex *Squeak Etoys* models and demonstrate higher level thinking skills. These students also demonstrated application of advanced technology skills in using *Squeak Etoys* as well as a higher level of engagement in the PBL tasks.

Development of critical thinking, problem solving and collaborative learning strategies. In order to improve students' critical thinking skills, help them think strategically (metacognitive skills) about their projects, evaluate their work for the day and plan for the next day, the students were asked to respond to a series of questions both individually and as a team at the end of each day. Daily individual questions included: "*What did I learn today as a result of working with my team?; What role did I play as a team member?; How do I feel about working with a team?*; and *What do I need to work on to be more effective in my team?*" Daily team questions included: *"What did we learn today? (What did we accomplish today)?; What scientific and mathematical concepts did we learn today?; How do we feel about today's work as a team?*; and *What do we plan to do next?"* To respond to the questions, students were asked to talk about the questions as a team, and then one member of the team was responsible for posting the team's responses to each question. In addition to daily questions, individuals and teams were also asked to reflect on their own learning at the end of the last day of SSI 2010 and upon completion of the models. The last day team and individual questions included:

1. After four days of working on a specific project, what do you think you have learned about science, math and technology? What do you think you learned about math, science and technology that you did not know before?
2. Throughout the week you had a chance to work with a partner (or two partners) to complete your project. How do you feel about your accomplishments as a team? What strategies did you use (as a team) that you think were effective? What strategies did you use that you think were not effective and you would change if you would have to work with a team again?
3. Assess your overall experience of participating in SSI. What do you think about the various events and activities that you participated in? Which one you think had major impact on your thinking about what you would do in the future?

Students' and teams' responses to the questions were coded using an open coding strategy. Students' narrative responses to daily questions were first organized by the PBL tasks and then grouped using open coding system (identifying, naming, categorizing, and describing phenomena found in the text) (Strauss & Corbin, 1990). The results showed that students who worked on the *Forces* and *Motion* PBL tasks thought they learned more specific math and science content compared with students who worked on the *Disasters* and *Ecosystems* PBL tasks. The following are examples of students' comments

I learned different formulas used in computations in math and physics;

I have learned a lot about gravity y and x axis buoyancy Velocity Pressure Air Resistance;

I [know] that there is different [gravitational] pull forces for each object and that gravity affects everything differently;

I learned trigonometry and laws for motion.

The same pattern of response appeared in student individual responses to daily questions. In response to “What did I learn today?” students who worked on the *Forces* and *Motion* PBL tasks described learning more math- and science-specific content, compared with students who worked on the *Disasters* and *Ecosystem* PBL tasks. For instance, for day 1 of the SSI, students who worked on the *Forces* PBL task indicated learning “the balancing of force is not always equal,” “gravity and velocity,” and “better applying gravity.” Similarly, students who worked on the *Motion* PBL task explained learning “. . . making missiles and trajectory,” “make the offensive missiles” and “making missiles move.” However, this pattern was not seen in daily responses to *Disasters* and *Ecosystems* PBL tasks. Students appeared to focus on researching about the topic of hurricanes and ecosystems more than focusing on how to identify factors affecting the problem and how to design a simple model of the phenomenon (e.g., “learned about hurricanes, food webs, dessert, and more advanced Squeak,” “learned about landslides,” “how a hurricane formed,” “how ecosystems operate and with environment and people fishing” and “. . . the animals are gone or all the trees are gone then everything else will die”).

All individual students’ (42 out of 42) and teams’ responses to the second question regarding team work were positive. Students appeared to benefit from working in teams. Fourteen out of 42 students’ responses showed evidence of critical thinking skills by listing specific strategies that they would use to help them work more effectively as a team. This result was also confirmed in the analysis of teams’ conversations during the PBL task. The following are example excerpts of some of these strategies.

I feel that we accomplished a lot working as a team. Some of the strategies that we used were to write things down and plan before we do something. I wouldn’t just jump into something the next time as a team we would rather just take some time to think about our strategy then implement it.

I feel pretty good because we completed many things, we each had a certain role and when one person had finished his/her part for that day, he or she would help another person with [their] work.

We took things step by step and we worked good as a team. I do not think any of our strategies and I would not change if I had a chance.

I think we completed a pretty good project, it showed what we wanted it to show and the hard work [paid] off. Communicating made it very effective, and agreeing to do what we said we would. One thing that wasn’t effective was how one person would do too much work or not enough work.

I feel good about the team accomplishments. We used the strategy if you understand something help the other people understand it. That strategy worked. The one that didn’t work was if you didn’t have anything to do you could play instead of helping the others.

Students’ daily responses to the second and third questions showed that during the first and second day some teams had difficulty communicating with each other (e.g., “I like working alone when I am working on the computer with Squeak, but I think that it will work out," "[need to be more effective in] communication with partner," "put more ideas in," "I think I need to help my partner with the research instead of her doing it and I just write" and "try and do a better job of helping") and some were not able to equally participate in the development of their work (e.g., "I did most of the work," "I was laborer and talker" and "I was the pack leader, I kept the people on task."). However, during the third and fourth day, except for two, all students' responses were positive and did not point to any problems. The project team's observation notes also confirmed this result.

Consistent with SSI 2008 and 2009, follow-up interviews with a sample of students after SSI 2010 showed that students continued to use *Squeak Etoys* outside of their classrooms and explored creating models and simulations. Triangulation of students' reflective thoughts at the end of each day and at the end of SSI and observations of SSI sessions in 2010 confirmed the results noted in SSI 2008 and 2009. Table 5 provides example excerpts of students' reflection at the end of SSI 2010.

Table 6 shows students' interest in STEM area as a career choice. Although it is difficult to compare descriptive data regarding students' interest in pre-and-post survey due to unequal number of responses, students' reflective thoughts (Table 5) combined with other sources of data pointed to an increase in student interest in some STEM areas as a career. For example, as shown in Table 6, analysis of post-survey data indicates that students' interest in jobs that frequently used computers is higher compared with other career choices while interest in jobs as a mathematician still among the lowest. However, further inspection of the data showed that more minority students (African American and Hispanic) (47% (N=17)) were interested (or a little interest (29% (N=17)) in jobs as a mathematician after SSI

Table 5. Students' reflective thoughts at the end of the 2010 SSI

Categories	Example Excerpts	Frequency of Responses
Positive and Fun Experience	"I had a very good experience. It was fun and I learned lot. . ." "I think this was a great learning experience. I enjoyed all the activities here. . ." "It was very fun and i had a great time." "I think this overall experience was a very good learning experience for me and will help me tremendously in the future to be successful." "i would love to do this [again it's] an [awesome] experience . . ."	39
Impact on Career Interest	"I enjoyed everything we did, and it made me decide that i might take a Virtual design class in college." "I think this program would have [an] impact on me later on because i love math and now [I] know that math and science can be used in everyday life and it made me really think and be creative." "I enjoyed the experience of working in an actual college so [I definitely] want to go to college" ". . . This has made a definite impact on my future career choices. Thank you."	12
Challenging Experience	"They have taught me that math isn't easy and it takes lots of work but you can't give up. Now that I have been to this institute and learned what I did, I can take it with me throughout my life." "It was tough and made my brain hurt, but it was very worthwhile and helped me realize that math is something I really want to do for the rest of my life."	4
Learned about Squeak	". . . but finally being able to understand Squeak and present a good project helped me understand computers and myself better for the future." ". . . and I learned a lot about Squeak. I like making SQUEAK projects and want to do more on my own." "I believe I did well. I learned a lot more on how to use SQUEAK."	5

Table 6. Students' interest in math, science and technology careers before and after participating in the 2010 SSI

Pre-Post-SSI Survey Comparison Scale of 1-4	**SSI 2010 Pre (N= 23*) Mean (SD)**	**SSI 2010 Post (N = 44) Mean (SD)**
• How interested are you in jobs as a scientist in a possible future career?	2.50 (1.06)	2.35 (1.02)
• How interested are you in jobs as an engineer in a possible future career?	2.74 (1.06)	2.48 (1.03)
• How interested are you in jobs as a mathematician in a possible future career?	1.96 (.98)	1.93 (.93)
• How interested are you in jobs as a computer scientist in a possible future career?	2.60 (1.06)	2.58 (.96)
• How interested are you in a job in which you would have to use computers frequently?	3.13 (.76)	3.10 (.77)

*For the 2010 SSI, teachers were asked to have students in their classes who were selected to participate in the 2010 SSI complete the survey in order to save time during the first day of SSI. Unfortunately, half of the teachers did not submit their students' responses to the survey items before SSI. Thus, only 23 student responses were available for analysis.

2010 compared with White students (21% (N=23) and 34% (N=23) a little interest). The same pattern is shown for jobs as computer scientists. While 59% (10/17) minority students showed interest in jobs as computer scientists 54% (N=24) of White students showed interest in computer scientists' career option. Again, this result suggests that the impact of the project might be higher for African American and Hispanic students, although longer term data would have to confirm this claim.

Research Question 3: What Are Learning Conditions Which Best Poster PBL to Influence Significant Learning Gains?

To answer this question, the following sources of data were analyzed and cross checked: teachers' lesson plans for SSIs and for their classrooms, observation field notes, teachers' conversation and guiding questions during SSIs and classroom visits as well as student learning data. The results showed that the conditions under which students completed their PBL tasks using *Squeak Etoys* influenced student learning gains. One of these conditions was identification of powerful learning (targeted concepts, principles, and procedures) and problems that are appropriate for instruction. As was evidenced in SSI 2010 PBL tasks, the nature of the tasks and their targeted concepts, principles and procedures, and the complex and ill-defined problem scenario that required time and effort to solve were key in promoting students' learning gains in the STEM content areas and their level of understanding. Another related condition was teachers' ability to shift student focus and thinking from recall and retention of information (e.g., "What is distance?", "What is population density?", "What factors determine where people live?") to application of STEM concepts and principles (e.g., "What kind of Squeak model could we use to show pH readings?", "How could we do this?"). Teachers' focus on the state exams influenced their decisions about how much time students could spend on *Squeak Etoys* projects in the regular classroom setting (e.g., **"…** it will be extremely difficult because we don't have time to teach things not in the curriculum.", "I think it will be hard since I don't have a lot of time, I need to teach the curriculum.", "Integrating *Etoys* into the high school curriculum appears to be extremely difficult due to our tight time schedule."). Having to comply with their schools' short term goal of test results and principals' expectations regarding weekly testing, high school teachers often had to limit student engagement in meaningful tasks and have them refocus on tests. Such daily practices had become a conventional method of teaching to the extent that teachers had a difficult time planning for long-term and open-ended tasks and problems during SSIs. The impact of this condition was confirmed when teachers were observed using *Squeak Etoys* in the context of elective courses. In elective courses, teachers felt less pressured and were empowered to give students more time to work on their *Squeak Etoys* projects which, in turn, seemed to influence student interest and learning gains.

Another influential condition was whether or not the teacher felt comfortable allowing students to use *Squeak Etoys* beyond his/her ability of using the tool. Teachers who became skillful in using it tended to be more open to assigning complex tasks that required advanced use of functions. These teachers allowed their students to develop a wide range of *Squeak Etoys* projects in their classes that corresponded to their course content and added to student learning by making it more meaningful. These students were not only able to develop *Squeak Etoys* models, but they also acquired problem-solving and critical thinking skills. Many of these students' projects were disseminated among schools and used by other teachers as examples.

Comparative analysis of lesson plans for SSIs, teachers' guiding questions as they led students' *Squeak* projects and teachers' reflection at the end of SSIs showed that both soft and hard scaffolds were conditions that influenced this PBL. Breaking the complex problem-solving task into a sequence of simpler and less complex tasks during 2010 SSI provided hard scaffolds, defined as "static supports that can be anticipated and planned in advance based upon typical student difficulties with a task" (Brush & Saye, 2002, p. 2), for both teachers and students and allowed students to start developing simple models before progressing to more complex models and representations. As it was shown in SSI 2010 and was also confirmed by observation of teachers who emerged as leaders in the project, when teachers were able to embed hard scaffolds in their problem-solving tasks, they were also able to become more prepared to provide soft scaffolds (defined as "dynamic, situation-specific aid provided by a teacher or peer to help with the learning process (Brush & Saye, 2002) and ask questions that helped students advance to the next level. Learning how to scaffold student learning from concrete and entry level to the application level proved to be a critical condition. As indicated earlier, when teachers did not rely on telling, explaining, and fixing students' problems, but rather engaged in asking questions and providing critical analysis and feedback, the quality of student learning was higher.

Finally, comparative analysis of teachers' practices during SSIs showed that not surprisingly, assessment of learning processes, monitoring of student learning progress to provide just-in-time support and scaffolding and assessment of student products to offer critical analysis and feedback were among most critical conditions. Accepting students' responses without comments or guidance - as evidenced by teachers' practices throughout the academic year and during 2008 SSI - regardless of the quality of student responses, did not create optimal conditions for higher-order learning and development of high quality simulation projects.

DISCUSSION

Key Findings

The purpose of this paper was to report the impact of problem-based simulation and modeling tasks on students' learning of STEM content using a generative technology tool named *Squeak Etoys*. The results show that when simulation and modeling, as an integrative approach are used under specific learning conditions, the result is a deeper level of understanding of key science and mathematics concepts. The project confirms that the multiple functionality offered by *Squeak Etoys,* the versatility of the *Squeak Etoys* environment, and problem-solving pedagogy and its principles, encourage students to clarify the problem, pose necessary questions, investigate the questions and produce a product that applies scientific processes of thinking and problem solving (Gott & Duggan, 1995). In addition, problem based simulation tasks can cognitively engage students, particularly those who otherwise would not see the relevancy of STEM content in their lives. As a result of working with *Squeak Etoys,* less motivated students are fostered to develop interests in STEM content and show confidence in their abilities to learn mathematics and science.

Implications for Practice

The results of the study pointed to several implications for practice. First, the mismatch between the implicit culture of standardized testing in our schools and the concept of deep and powerful learning (higher-order thinking skills and conceptual understanding) limits initiatives' efforts to change teacher practice and their pedagogical content knowledge. Attempts to change teaching practices thus require commitment from school principals and other administrators to change this culture. Current adoption of the new *Common Core Standards* for math and science and the state's plan to change the end-of-year assessment system is a step in the right direction. System-wide commitment is needed to reform the teaching and learning processes that were targeted in this project.

Second, the study showed that STEM teachers do not have a clear understanding of what a computational model is in order to guide students. This finding indicates that computing and computer modeling should be integrated into STEM courses or professional development opportunities for teachers. Once the relationship between computing and the STEM concepts is made explicit and teachers have the knowledge of what modeling and simulation techniques are, and once they understand how to formulate a problem statement and see their applications in fields as diverse as physics, chemistry, biology, economics, mathematics and computer science, they are able to provide learning conditions that allow students to learn by combining modeling and simulation tasks.

Third, the findings of this study suggest that in addition to providing a problem scenario that is open-ended and provides an opportunity for students to solve it, students should be required to articulate their mental models before making them into a plan for solving the problem. They should also be questioned on how they used their mental models to develop the physical model (*Squeak Etoys* Model) and observed on how well they adhere to the plan, what strategies they use for dealing with inconsistent data and events, and finally what kinds of generalizable conclusions they can draw from the solution (von Aufschnaiter & Rogge, 2010; Jonassen & Strobel, 2006). Without exploring and assessing student thinking processes, the development of progressively more complex conceptual understanding of STEM content may not occur.

Many scholars who explored meaningful learning through modeling and simulations and problem solving processes confirm that meaningful learning requires meaningful tasks (Jonassen, 2011). Meaningful tasks are "those that emerge from or are at least simulated from some authentic context" (Jonassen & Strobel, 2006, p. 2). The results of this project show that when students are given a real world task, they are able to not only understand the concepts better as they wrestle with the problem, but they are also able to see the relevancy of what they are learning. However, while solving complex, real-world problems by modeling and simulation attention must be given to prevent oversimplification of viewing the world and application of knowledge. In order to be successful in solving complex problems using modeling, students should be able to solve simpler problems first. Thus, breaking the complex, problem-solving modeling tasks into simpler tasks with two or three variables at a time (Alessi, 2000) allows students to learn progressively more complex concepts, while still trying to solve the overarching complex problem (Jonassen, 1997; Hmelo-Silver, Duncan, & Chinn, 2007; Sweller, Kirschner, & Clark, 2007; Schmidt, Loyens, van Gog, & Paas, 2007; Schmidt, Rotgans, & Yew EH, 2011). In addition, the smaller models reflect, support, and refine students' mental models of the main and complex task (Clariana & Strobel, 2008). This hard scaffolding strategy can be faded gradually as students improve in their problem-solving skills.

Finally, *Squeak Etoys* as a "microworld," generative, and generic (domain general) computerized modeling and simulation tool has a steep learning curve for teachers. It requires time and effort before teachers feel confident using all functions of *Squeak Etoys* to generate content-related learning tasks. The results of this project show that until teachers are able to build models and simulations and understand the process of thinking when building a model, it is likely that they will focus on teaching *Squeak Etoys* as a technology tool, rather than using the tool to learn STEM content. Professional development activities should focus first on developing teachers' knowledge and skills in building models for deepening students' conceptual understanding.

ACKNOWLEDGMENT

This paper is based upon work supported by the National Science Foundation under Grant No. ESI-0624615. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

REFERENCES

Anderson, P. H., & Lawton, L. (2004). Simulation exercises and problem-based learning: Is there a fit? *Developments in Business Simulations and Experiential Exercises*, *31*, 183–188.

Anderson, P. H., & Lawton, L. (2007). Simulation performance and its effectiveness as a PBL problem: A follow-up study. *Developments in Business Simulation and Experiential Learning*, *34*, 43–50.

Barron, B., & Darling-Hammond, L. (2010). Powerful learning: Studies show deep understanding derives from collaborative methods. *Edutopia*. Retrieved Oct., 2014, from www.edutopia.org/inquiry-project-learning-research

Becker, K. H., & Park, K. (2011). Integrative approaches among Science, Technology, Engineering, and Mathematics (STEM) subjects on students' learning: A meta-analysis. *Journal of STEM Education: Innovations and Research, 12*(5-6), 23-37. (EJ943196)

Bell, P. L. (2004). On the theoretical breadth of design-based research in education. *Educational Psychologist*, *39*(4), 243–253. doi:10.1207/s15326985ep3904_6

Black, S. (2005). Teaching students to think critically. *Education Digest*, *70*(6), 42–47.

Bouras, C. J., Poulopoulos, V., & Tsogkas, V. (2010). Squeak Etoys: Interactive and collaborative learning environments. In *Handbook of research on social interaction technologies and collaboration software: Concepts and trends* (pp. 417–427). Hershey, PA: IGI Global; doi:10.4018/978-1-60566-368-5.ch037

Brown, A. L. (1992). Design experiments: Theoretical and methodological challenges in creating complex interventions in classroom settings. *Journal of the Learning Sciences*, *2*(2), 141–178. doi:10.1207/s15327809jls0202_2

Brush, J. W., & Saye, T. A. (2002). A Summary of research exploring hard and soft scaffolding for teachers and students using a multimedia supported learning environment. *Journal of Interactive Online Learning*, *1*(2), 1–12.

Cerezo, N. (2004). Problem-based learning in the middle school: A research case study of the perceptions of at risk females. *RMILE Online Research in Middle Level Education*, *27*, 1–13.

Choy, S. C., & Cheah, P. K. (2009). Teacher perceptions of critical thinking among students and its influenceon higher education. *International Journal of Teaching and Learning in Higher Education*, *20*(2), 198–206.

Clariana, R. B., & Strobel, J. (2008). Modeling technology. In *Handbook of research on educational communications and technology* (3rd ed., pp. 329–342). Taylor & Francis.

Collins, A., Bielaczyc, K., & Joseph, D. (2004). Design experiments: Theoretical and methodological issues. *Journal of the Learning Sciences*, *13*(1), 15–42. doi:10.1207/s15327809jls1301_2

Congressional Research Service (CRS). (2012). *Science, technology, engineering and mathematics (STEM) education: A primer* (CRS Report for Congress). R42642. Retrieved on Dec., 2014, from http://www.fas.org/sgp/crs/misc/R42642.pdf

Congressional Research Services. (2011). *Selected STEM Education Legislative Activity in the 112th Congress*. Retrieved on Dec., 2014, from http://www.stemedcoalition.org/wp-content/uploads/2011/10/CRS_STEMEdin112th_asof10172011.pdf

Denner, J. (2007). The girls creating games program: an innovative approach to integrating technology into middle school. *Meridian, A Middle School Computer Technologies Journal, 1*(10). Retrieved on Dec., 2014, from www.ncsu.edu/meridian/win2007/girlgaming/index.htm

Dischino, M., DeLaura1, J. A., Donnelly, J., Massa, N. M., & Hanes, F. (2011). Increasing the STEM pipeline through problem-based learning. In *Proceedings of The 2011 IAJC-ASEE International Conference.*

Edelson, D. C. (2002). Design research: What we learn when we engage in design. *Journal of the Learning Sciences*, *11*(1), 105–121. doi:10.1207/S15327809JLS1101_4

Ehrlich, T. (1998). Reinventing John Dewey's "pedagogy as a university discipline". *The Elementary School Journal*, *98*(5), 489–509. doi:10.1086/461911

Ennis, R. H. (1981). Problems in testing informal logic critical thinking reasoning ability. *Informal Logic*, *6*(1), 3–9.

Flavell, J. H. (1979). Metacognition and cognitive monitoring: A new area of cognitive-developmental inquiry. *The American Psychologist*, *341*(10), 906–911. doi:10.1037/0003-066X.34.10.906

Gott, R., & Duggan, S. (1995). *Investigating work in the science curriculum: Developing science and technology education*. Buckingham, UK: Open University Press.

Hallinger, P. (2005). Integrating learning technology and problem-based learning. In *Proceedings of the Second International Conference on eLearning for Knowledge-Based Society.*

Halpern, D. F. (1998). Teaching critical thinking across domains: Dispositions, skills, structure training, and metacognitive monitoring. [PubMed]. *The American Psychologist*, *53*(4), 449–455. doi:10.1037/0003-066X.53.4.449

Hmelo-Silver, C. E., Duncan, R. G., & Chinn, C. A. (2007). Scaffolding and achievement in problem-based and inquiry learning: A response to Sweller, Kirschner, and Clark (2007). *Educational Psychologist*, *42*(2), 99–107. doi:10.1080/00461520701263368

Huelskamp, L. (2009). *The Impact of problem-based learning with computer simulation on middle level educators' instructional practices and understanding of the nature of middle level learners*. ProQuest LLC, Ph.D. Dissertation, The Ohio State University. Retrieved on Dec., 2014, from http://rave.ohiolink.edu/etdc/view?acc_num=osu1242662952

Hurley, M. M. (2001). Reviewing integrated science and mathematics: The search for evidence and definitions from new perspectives. *School Science and Mathematics*, *10*(5), 259–268. doi:10.1111/j.1949-8594.2001.tb18028.x

Jackson, S., Stratford, S. J., Krajcik, J. S., & Soloway, E. (1996). Making system dynamics modeling accessible to pre-college science students. *Interactive Learning Environments*, *4*(3), 233–257. doi:10.1080/1049482940040305

Jonassen, D. H., & Strobel, J. (2006). Modeling for meaningful learning. In D. Hung & M. S. Khine (Eds.), *Engaged learning with emerging technologies* (pp. 1–27). Dordrecht: Springer; doi:10.1007/1-4020-3669-8_1

Jonassen, D. H. (1997). Instructional design models for well-structured and ill-structured problem-solving learning outcomes. *Educational Technology Research and Development*, *45*(1), 65–95. doi:10.1007/BF02299613

Jonassen, D. H. (2000). Toward a design theory of problem-solving. *Educational Technology Research and Development*, *48*(4), 63–85. doi:10.1007/BF02300500

Jonassen, D. H. (2011). Supporting problem-solving in PBL. *Interdisciplinary Journal of Problem-based Learning*, *5*(2), 95–119. doi:10.7771/1541-5015.1256

Judson, E., & Sawada, D. (2000). Examining the effects of a reformed junior high school science class on students' math achievement. *School Science and Mathematics*, *100*(8), 419–425. doi:10.1111/j.1949-8594.2000.tb17330.x

Kay, A. C. (1991, September). Computers, networks and education. *Scientific American*, *265*(3), 138–148. doi:10.1038/scientificamerican0991-138

Kogut, L. S. (1996). Critical thinking in general chemistry. *Journal of Chemical Education*, *73*(3), 218. doi:10.1021/ed073p218

Kuhn, D., & Dean, D. Jr. (2004). Metacognition: A bridge between cognitive psychology and educational practice. *Theory into Practice*, *43*(4), 268–274. doi:10.1207/s15430421tip4304_4

Kuo-Hung, T., Chi-Cheng, C., Shi-Jer, L., & Wen-Ping, C. (2013). Attitudes towards science, technology, engineering and mathematics (STEM) in a project-based learning (PjBL) environment. *International Journal of Technology and Design Education*, *23*(1), 87–102. doi:10.1007/s10798-011-9160-x

Lou, S. J., Shih, R. C., Diez, C. R., & Tseng, K. H. (2011). The impact of problem-based learning strategies on STEM knowledge integration and attitudes: An exploratory study among female Taiwanese senior high school students. *International Journal of Technology & Design*, *21*(2), 195–215. doi:10.1007/s10798-010-9114-8

McGrath, E., Lowes, S., Lin, P., & Sayres, S. (2009). *Analysis of middle and high school student learning of science, mathematics and engineering concepts through a LEGO underwater robotics design challenge*. American Society for Engineering Education.

Miles, M. B., & Huberman, A. M. (1994). *Qualitative data analysis* (2nd ed.). Thousand Oaks, CA: Sage Publications.

National Research Council (NRC). (2011). *Successful K-12 education: Identifying effective approaches in Science, Technology, Engineering and Mathematics*. Washington, DC: National Academy Press.

Nickerson, R. S. (1994). The teaching of thinking and problem-solving. In R. J. Sternberg (Ed.), *Thinking and problem-solving* (pp. 121–132). San Diego, CA: Academic; doi:10.1016/B978-0-08-057299-4.50019-0

Orion, N., & Kali, Y. (2005). The effect of an earth-science learning program on students' scientific thinking skills. *Journal of Geoscience Education*, *53*, 387–394.

Pang, J. S., & Good, R. (2000). A review of the integration of science and mathematics: Implications for further research. *School Science and Mathematics*, *100*(2), 73–82. doi:10.1111/j.1949-8594.2000.tb17239.x

Panoff, R. (2009). Simulations deepen scientific learning. *ASCD Express, 4*(19). Retrieved on Dec., 2014, from http://www.ascd.org/ascd_express/vol4/419_panoff.aspx

Rogoff, B. (1990). *Apprenticeship in thinking: Cognitive development in social context*. New York: Oxford University Press.

Schmidt, H. G., Loyens, S. M. M., van Gog, T., & Paas, F. (2007). Problem based learning *is* compatible with human cognitive architecture: Commentary on Sweller, Kirschner, and Clark (2007). *Educational Psychologist*, *42*(2), 91–97. doi:10.1080/00461520701263350

Schmidt, H. G., Rotgans, J. I., & Yew, E. H. (2011). The process of problem-based learning: What works and why. [PubMed]. *Medical Education*, *45*(8), 792–806. doi:10.1111/j.1365-2923.2011.04035.x

Schroyens, W. (2005). Knowledge and thought: An introduction to critical thinking. *Experimental Psychology*, *52*(2), 163–164. doi:10.1027/1618-3169.52.2.163

Simons, K. D., & Ertmer, P. A. (2006). Scaffolding disciplined inquiry in problem-based learning environments. *International Journal of Learning*, *12*(6), 297–305.

Stake, R. (1995). *The art of case research*. Newbury Park, CA: Sage Publications.

Stone, R. J., III. *(2011). Delivering STEM education through career and technical education schools and programs.* Paper prepared for the workshop of the Committee on Highly Successful Schools or Programs for K-12 STEM Education, Washington, DC. Retrieved on Dec., 2014, from http://sites.nationalacademies.org/DBASSE/BOSE/DBASSE_080128#.Uai4CcHD-Uk

Strauss, A. L., & Corbin, J. (1990). *Basics of qualitative research: Grounded theory procedures and techniques*. Newbury Park, CA: Sage Publications, Inc.

Strauss, A. L. (1987). *Qualitative analysis for social scientists*. Cambridge, UK: Cambridge University Press; doi:10.1017/CBO9780511557842

Sweller, J., Kirschner, P. A., & Clark, R. E. (2007). Why minimally guided teaching techniques do not work: A reply to commentaries. *Educational Psychologist*, *42*(2), 115–121. doi:10.1080/00461520701263426

Tan, O. S. (2007). Using problems for e-learning environments. In O. S. Tan (Ed.), *Problem based learning in eLearning breakthrough* (pp. 1–14). Singapore: Thomson Learning.

The Design-Based Research Collective. (2003). Design-based research: An emerging paradigm for educational inquiry. *Educational Researcher*, *32*(1), 5–8. doi:10.3102/0013189X032001005

Venville, G., Wallace, J., Rennie, L., & Malone, J. (2000). Bridging the boundaries of compartmentalized knowledge: Student learning in an integrated environment. *Research in Science & Technological Education*, *18*(1), 23–25. doi:10.1080/713694958

Von Aufschnaiter, C., & Rogge, C. (2010). Misconceptions or missing conceptions? *Eurasia Journal of Mathematics. Science and Technology Education*, *6*(1), 3–18.

Vygotsky, L. S. (1978). *Mind in society*. Cambridge, MA: Harvard University Press.

Wang, F., & Hannafin, M. J. (2005). Design-based research and technology-enhanced learning environments. *Educational Technology Research and Development*, *53*(4), 5–23. doi:10.1007/BF02504682

KEY TERMS AND DEFINITIONS

Animation: Before objects are rendered in a simulation model, they must be placed (laid out) within a scene. This is what defines the spatial relationships between objects in a scene including location and size. Animation refers to the *temporal* description of an object, i.e., how it moves and deforms over time. Animation in simulation models helps the user quickly understand what the simulation model does. A simulation model can do without animation. Thus, the quality of animation does not influence simulation results.

Critical Thinking: Critical thinking is an analytical process of reasoning to arrive at logical, rational, and reasonable judgments within a given context.

Design Based Research: Is a research methodology that combines quantitative and qualitative methods to view how development and research take place through continuous cycles of design, enactment, analysis, and redesign in authentic settings.

Integrated STEM: Combine technological design purposefully with scientific inquiry, engaging students or teams of students in scientific inquiry situated in the context of technological problem solving.

Metacognitive Strategies: Are knowledge about cognition and control of cognition

Model: Is a simplified representation of a system over some time period or spatial extent intended to promote understanding of the real or constructed system. A model is similar to but simpler than the system it represents.

Problem Based Learning: A non-traditional approach in which students are presented with complex, authentic, meaningful problems as a basis for inquiry and investigation.

Simulation: Is the manipulation of a model in such a way that it operates on time and/or space to compress it, thus enabling one to perceive the interactions that would otherwise not be apparent because of their separation in time or space. This compression also provides a perspective on what happens within the system, which, because of the complexity of the system, would probably otherwise not be evident.

Squeak Etoys: Squeak Etoys is a free and open source media-rich authoring system with a user-friendly visual interface designed to be a fully programmable and explorable multi-threaded graphical environment for learning.

APPENDIX

USeiT Project (Student Survey)

Dear Student,

Thank you in advance for completing this survey. The purpose of this survey is to explore what you value and what you find effective in your learning experiences in school. It is sponsored by an NSF grant, which has helped provide the Summer Institute for your enrichment. Your answers will help us determine if the Summer Institute has been effective. **Your participation is greatly appreciated.** Your information will be kept confidential and will not be part of student or teacher evaluation.

1. What is your name? ____
2. What is your gender?
    ____ Male
    ____ Female
3. What is your Racial/Ethnic Background?
    ____ African America
    ____ Asian American
    ____ Caucasian/White
    ____ Native American
    ____ Hispanic/Latino
    ____ Other (Specify) ______________________
4. What is your grade level?
    ____ 6th grade
    ____ 7th grade
    ____ 8th grade
    ____ 9th grade
    ____ 10th grade
    ____ 11th grade
    ____ 12th grade
5. Rate your overall skill with using technology.
    ____ Novice user
    ____ Intermediate user
    ____ Advanced user

6. Mark the courses you have taken at least once?
(Middle grades)
____ Science
____ Algebra
____ Geometry
____ Math
(High school)
____ Calculus
____ Chemistry
____ Physics
____ Biology
____ Math

7. Rate your confidence level in the following subject areas, presented in Box 1 and Box 2.

Box 1. Middle grades

	Strongly confident (5)	Confident (4)	Neutral (3)	Not confident (2)	Not strongly confident (1)
Science					
Algebra					
Geometry					
Math					

Box 2. High school

	Strongly confident (5)	Confident (4)	Neutral (3)	Not confident (2)	Not strongly confident (1)
Calculus					
Chemistry					
Biology					
Math					

8. On a scale of 1 to 10, with 10 being the highest, how much do you like math?

1	2	3	4	5	6	7	8	9	10

9. On a scale of 1 to 10, with 10 being the highest, how much do you like science?

1	2	3	4	5	6	7	8	9	10

10. How do you like math in comparison to other subjects?

Very much like it (5)	like it (4)	Neutral (3)	Not like it (2)	Not like it all (1)

11. How do you like science in comparison to other subjects?

Very much like it (5)	like it (4)	Neutral (3)	Not like it (2)	Not like it all (1)

12. How good at math are you?

Very well (5)	Well (4)	Alright (3)	Not well (2)	Not at all well (1)

13. If you were to rank all the students in your math class from the worst to the best in math, where would you put yourself?

Much better (5)	Better (4)	Equal (3)	Worse (2)	Much worse (1)

14. Compared to most of your other subjects, how good are you at math?

Much better (5)	Better (4)	Equal (3)	Worse (2)	Much worse (1)

15. Compared to most of your other subjects, how good are you at science?

Much better (5)	Better (4)	Equal (3)	Worse (2)	Much worse (1)

16. How well do you think you did in math this year?

Very well (5)	Well (4)	Alright (3)	Not well (2)	Not at all well (1)

17. In general, how do you find working on math assignments?

Very interesting (5)	Interesting (4)	Neutral (3)	Boring (2)	Very boring (1)

18. In general, how do you find working on science assignments?

Very interesting (5)	Interesting (4)	Neutral (3)	Boring (2)	Very boring (1)

19. Would you take more math courses if you did not have to?
____ I would definitely take more math classes.
____ I probably would take more math classes.
____ Maybe I would take more math classes.
____ I am not sure

20. Would you take more science if you did not have to?
____ I would definitely take more science classes.
____ I probably would take more science classes.
____ Maybe I would take more science classes.
____ I am not sure.

21. What are you thinking about doing after graduating from high school (select one)?
____ Don't know yet
____ Attend a four-year college or university
____ Attend a two year community college
____ Attend a technical school or special training program
____ Work full time
____ Work-part time while enrolling in further education
____ Work-part time and take some off
____ Join military
____ Other (please describe) ____ ___________

22. How interested are you in each of the jobs below as possible future careers? Select one response for each job, presented in Box 3.

Box 3.

Job	Not at all interested	At little interested	Interested	Very interested
Scientist				
Engineer				
Mathematician				
Computer Sceintists				
Health care provider (e.g., doctor, nurse)				

23. How interested are you in a job in which you would have to use computers frequently?
____ Not at all interested
____ A little interested
____ Interested
____ Very interested

24. Below are beliefs and feelings that you may have about math or science. Read the statement and then decide if you:
Strongly agree (5), agree (4), Neither agree nor disagree (3), Disagree (2), Strongly disagree (1).
There are no right or wrong answers. Mark your view in Box 4.

Box 4.

	Strongly agree (5)	**Agree (4)**	**Neither agree nor disagree (3)**	**Disagree (2)**	**Strongly disagree (1)**
7. Mathematics is important in everyday life.					
8. Mathematics is one of the most important subjects for people to study.					
9. High/middle school math courses would be very helpful no matter what I decide to study.					
10. Science is important in everyday life.					
11. Science is one of the most important subjects for people to study.					
12. High/middle school math courses would be very helpful no matter what I decide to study.					

25. Below in Box 5 are beliefs and feelings that people have about themselves. Read the statement and then decide if you believe:
Exactly true (4), Moderately true (3), Hardly true (2), Not at all true (1)

Box 5.

	Exactly true (4)	**Moderately true (3)**	**Hardly true (2)**	**Not at all true (1)**
11. I can always manage to solve difficult problems if I try hard enough.				
12. If someone opposes me, I can find the means and ways to get what I want.				
13. It is easy for me to stick to my aims and accomplish my goals.				
14. I am confident that I could deal efficiently with unexpected events.				
15. Thanks to my resourcefulness, I know how to handle unforeseen situations.				
16. I can solve most problems if I invest the necessary effort.				
17. I can remain calm when facing difficulties because I can rely on my coping abilities.				
18. When I am confronted with a problem, I can usually find several solutions.				
19. If I am in trouble, I can usually think of a solution.				
20. I can usually handle whatever comes my way.				

Thank You!

Chapter 8

Visualizing Condensation:

Integrating Animation-Developing Technology in Chemistry Classes

Sevil Akaygun
Bogazici University, Turkey

ABSTRACT

Learning chemistry involves understanding chemical phenomena at macroscopic, symbolic and submicroscopic levels. Even though chemistry instructors integrate these levels in their lessons, it cannot be assumed that students relate them properly. Therefore, it is important to identify students' mental models that will reveal how they visualize and conceptualize chemistry. Mental models can be represented in various forms including static drawing and animations. Considering the dynamic nature of chemistry, animations prepared by students can be more informative conveying students' understandings. This study aimed to investigate how high school students visualize condensation and to compare their dynamic and static mental. The analysis of the results suggested that static and dynamic mental models were found to be significantly different ($p<0.05$). Static mental models were found to be more focusing on structure whereas dynamic ones included more macroscopic features and interactions. Finally, students revised their mental models towards more accurate models after preparing animations.

INTRODUCTION

Chemistry is a science where visualizing phenomena holds the utmost importance. Processes observed in laboratories, such as gas formation, are explained by unobservable phenomena, such as structures and the interaction of particles. Therefore, visualizing the particles are necessary to understand how particular reactions take place.

Learning chemistry involves understanding chemistry at three levels: the macroscopic level of the observable and tangible; the symbolic level of equations, symbols, and mathematics; and the submicroscopic level of the molecular, atomic and kinetic (Johnstone, 1993; Taber, 2013). In chemistry classes, these three levels are integrated through various teaching methods and techniques. For instance, laboratory experiments are used to emphasize the macroscopic level, equations and formulas are used to highlight

DOI: 10.4018/978-1-4666-9616-7.ch008

the symbolic level, and computer animations or simulations are used to represent the phenomena at submicroscopic levels. Including these levels via different methods or tools doesn't mean that students can relate to them all and conceptualize chemistry accurately; they may hold misconceptions (Griffith & Preston, 1992; Harrison & Treagust, 1996). Hence, chemistry educators need to uncover students' understandings, or mental models, which are small scale representations that people have developed based on their imagination and comprehension (Craik, 1943). Mental models could be represented in the form of verbal or visual explanations conveyed orally or statically on paper. However, the nature of chemistry involves not only structures but also dynamics, such as motion, processes and interactions. Therefore, verbal explanations or static drawings will be limited for fully revealing students' understandings, because students can hardly incorporate dynamics in these representations. For this reason, animation-developing software provides appropriate environments where students create animations displaying their understanding of chemical phenomena dynamically.

This chapter discusses a study investigating students' mental models of how students visualize the physical process of the condensation of water at the submicroscopic level. Specifically, student mental models represented on paper and by animations were identified with respect to the features emphasized and compared to identify if there was a significant difference between them in terms of the aspects focused.

BACKGROUND

Understanding Chemical and Physical Phenomena

Understanding chemistry is challenging for many students because they need to conceptualize and relate chemical phenomena at three levels: macroscopic, symbolic, and submicroscopic levels (Johnstone, 1993; Taber, 2013). Students cannot easily make connections between observable changes and submicroscopic explanations (Lekhavat & Jones, 2009) and they may have misconceptions about chemical or physical processes.

Even though students observe many physical phenomena, such as evaporation and condensation, in their everyday lives, they may not have a good understanding of what is really happening at a submicroscopic level. Recent studies have shown that tertiary students have a tendency not to refer to the submicroscopic level when describing the processes of evaporation and condensation (Gobal et. al., 2004). They also exhibit a weaker understanding of condensation than of evaporation, and tend to believe that the level of an open container of water would remain constant during evaporation. Many precollege students think that during evaporation, water separates into hydrogen and oxygen atoms (Osborne & Cosgrove, 1982). Azizoglu, Alkan, and Geban (2006) reported that pre-service teachers held many misconceptions about physical changes, for example, many of them believed that the vapor pressure of a liquid depends on the volume of its container and that the freezing point is independent of pressure. Canpolat, Pinarbasi, and Sozbilir (2006) found additional misconceptions in their study of pre-service teachers, namely that they tended to believe vaporization does not begin until a liquid boils and that different liquids boiling at atmospheric pressure have different vapor pressures at their boiling points.

Mental Models

Mental models or representations are personal constructions of reality and created as a result of people's imagination, interaction, perception and comprehension (Craik, 1943). In chemistry, mental models include visual structures and dynamics of chemical and physical phenomena (Briggs & Bodner, 2007). The nature of mental models are found to be complex; therefore, open-ended research methods are suggested to investigate them (Lesh, et. al., 2000; Kelly, 2014). In general, written or verbal explanations or drawings are used to elicit mental models of students (Akaygun & Jones, 2013; Domin & Bodner, 2012; Kelly & Jones, 2007; Kelly, 2014). Recently, researchers have suggested using drawings to understand students' conceptualizations because they can provide in-depth understanding of mental models (Davidowittz, et. al, 2010; Nyachwaya et al., 2011).

In chemistry, the nature of phenomena involves dynamics such as motion, processes and interactions. Therefore, the visual representations demonstrated utilizing illustrations would be limited in real-time motion imagery. Another method, using student-generated animations, can be used to investigate students' mental models including dynamics, or dynamic mental models. Various animation-developing software such as Chemsense, Molecular Workbench, and K-Sketch, have been used to elicit dynamic mental models of learners facilitating higher order understandings of chemical phenomena. As animation- developing software have been used in high school and college chemistry classes as a part of regular instruction, their effectiveness in chemical education research studies are positive. For instance, in one study, high school students who created more drawings and animations in a ChemSense Solubility module over a 3-week period showed greater representational competence, which is the ability to create and analyze representations, and better understanding of chemical phenomena in their animations (Michalchik et. al., 2008; Trunfio et. al., 2003).

Metavisualization

Metavisualization is a process used to monitor and regulate individuals' internal representations (Locatelli, Ferreira, & Arroio, 2010). It includes both visualization and metacognition, where individuals have control of their internal representations based on their metacognition. Metavisualization skills, which are defined as the ability to understand relationships and construct visual representations, are key to science learning and assessment (Gilbert, 2005). In visualizing phenomena, for educators, this process is definable. Gilbert (2005) identified three lines of evidence for metavisualization. The first is concerned with spatial intelligence, which can be improved by the interaction of the material in the environment; hence metavisualization capability is improved. The second is related to the interaction between object and meta levels, where there is a flow of information from object to the meta level, and wherein students become aware of monitoring, controlling the acquisition, retention, retrieval and modification of an image. The third piece of evidence for metavisualization is that visualization is at the center of the thinking process and is important for monitoring and regulating internal representations while constructing knowledge (Gilbert, 2005).

Chemistry involves visualizations at three levels, macroscopic, symbolic, and submicroscopic levels; the existence of metavisualization may contribute to restructuring of internal representations. Students encounter a variety of different types and styles of visualizations in chemistry and other science courses.

As students create their own visualizations at the object level, in the form of drawings or animations, it may help them monitor, regulate, and refine their mental models at the meta level. Therefore, in this study, students' static and dynamic mental models were investigated and compared to identify if there was any difference between the mental models in static or dynamic forms. Using chemistry animations may be considered a metavisualization activity that assists, modifies, or refines learners' mental models as they interact with their own visualizations and cognitive processes.

AN INVESTIGATION OF USING ANIMATION-DEVELOPING TECHNOLOGY IN CHEMISTRY CLASSES

Rationale of the Study

For chemistry educators, it is important to understand how students visualize and conceptualize chemical and physical phenomena. Students' understandings or mental models can be elicited through open-ended methods such as verbal or written explanations and drawings. However, considering the dynamic nature of chemistry, these methods could be limited; and environments which allow users to represent motion and interactions will be more appropriate. For this reason, in order to investigate students' mental models, participants were asked to generate explanations and drawings on paper, as well as with animations, about the condensation of water, by using the animation-developing software K-Sketch (URL-1). Then features emphasized in students' static and dynamic mental models were identified and compared to see if they differed in certain features. In other words, students' drawings conveyed on paper as a part of before and after making an animation were compared with respect to the emerged features. Considering creating animations as a metavisualization activity, students' animations were compared with the static on-paper drawings to investigate probable improvement or refinement in their initial mental models. While creating animations, students develop metavisualization skills because they think, reflect and modify their thinking; as a result, they may revise their mental models. This study not only aimed to compare students' mental models conveyed through different tools, but also investigated the effect of using an animation-developing activity on the refinement of the understanding of a fundamental physical phenomenon that many students have misconceptions about, the condensation of water.

The specific research questions:

1. Is there a significant difference between students' initial static, paper-based, mental models on condensation of water vapor, and the dynamic ones generated by an animation?
2. Is there a significant difference between students' dynamic, animation-based, mental models on condensation of water vapor, and the static ones represented on paper afterwards?
3. Is there a significant difference between students' static, paper-based, mental models on condensation of water vapor generated before and after creating an animation on the same topic?

Participants

A total of 78 high school students participated in the study. Thirty-seven of them were in 11th grade and forty-one were in 10th grade. Because the topic of this study, condensation of water, is a basic topic in chemistry, the grade level did not make any difference in students' understanding of the concept. Students' initial static mental models were conveyed on paper by the *Test of Conceptual Understanding of Condensation (TCUC)* where they were asked to 'Draw and explain what is happening in water at room temperature at the submicroscopic level'. The analysis of the comparison of initial mental models of 10th and 11th grade students' was not shown to be significantly different ($p>0.05$), in terms of the features emphasized, thus, both groups were combined and considered as one group of participants.

Method

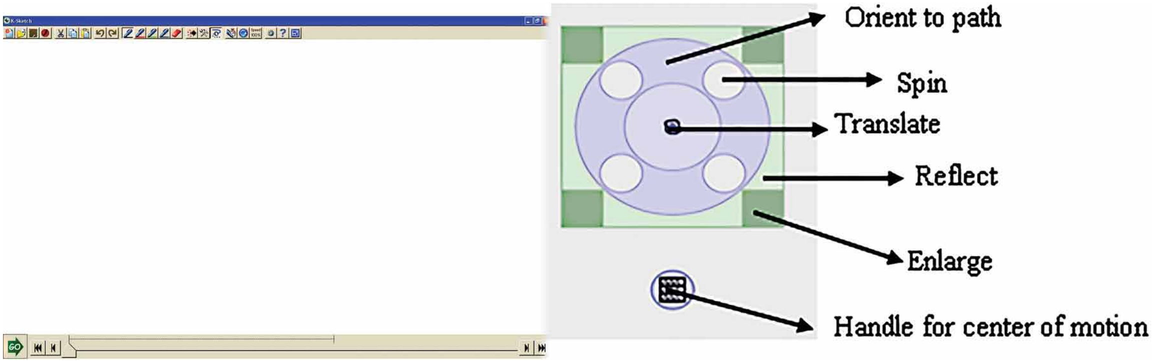
The nature of the study required in-depth understanding of mental models and comparison of the features appeared to be highlighted. Therefore, a mixed methodology, which embraces integration of quantitative and qualitative research methods, was adopted (Creswell, 2012). The data were first collected qualitatively, then coded, interpreted and analyzed quantitatively, as suggested by *exploratory sequential design* (Creswell & Clark, 2010). Specifically, one-group quasi-experimental pretest-posttest design was selected for the quantitative part. Phenomenography, which aims to discover different ways for how people conceptualize, realize and understand various phenomena in the world around them (Bowden et al., 1992), was chosen for the qualitative part.

Instruments and Tools

In the beginning of the study, students were asked to fill in a *Demographics Form* to learn more about the general profile and characteristics of the participants. Then before and after preparing animations, participants were administered the *Test of Conceptual Understanding of Condensation (TCUC)* and the *Test of Storyboarding Condensation* (TSbC). In the TCUC, participants were asked to 'Draw and explain what is happening in water at room temperature at the submicroscopic level'. In the TSbC, participants were given four empty boxes and lines to 'Draw and explain what is happening when water vapor condenses, at four consecutive seconds', respectively.

The animation-developing software, K-Sketch, was selected for this study because K-Sketch allows users to just utilize a pencil to draw their own representations and then animate their dynamic mental models in a fashion similar to producing a cartoon. Figure 1 shows the *drawing canvas* (a), and the *motion tool* (b) of K-Sketch.

Figure 1. (a) drawing canvas, (b) the motion tool of K-Sketch



Data Collection and Procedure

In the beginning of the study, tenth and eleventh grade students were administered the *Demographic Forms, Test of Conceptual Understanding of Condensation (TCUC)* and the *Test of Storyboarding Condensation* (TSbC) as pre-tests. Then, they participated in a two-hour workshop where they first, learned how to use K-Sketch by generating two animations on a topic unrelated to chemistry for 60 minutes, and second, generated two animations on the given chemistry topics for another 60 minutes. The workshop took place in the high school's computer laboratory where the students individually worked on personal computers. At the end of the workshop, students took the TCUC and the TSbC as post-tests. Through the Test of Storyboarding Condensation, students were asked to construct the pictures for condensation of water vapor at the particulate level as a storyboard including four frames, before and after they generated animations.

Data Analysis

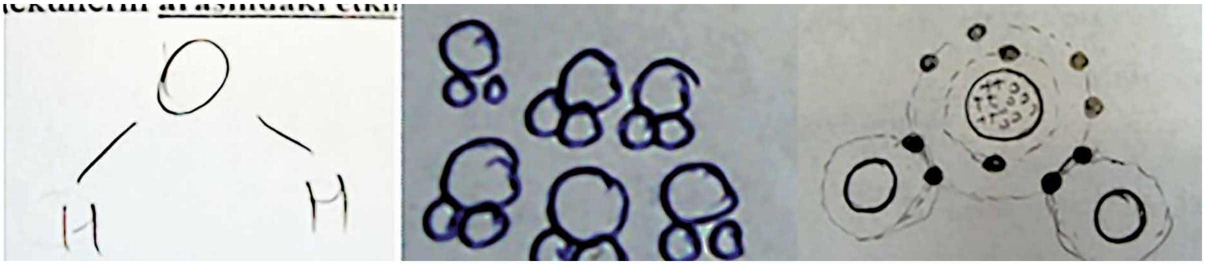
The static and dynamic mental models were coded through open coding and specific categories of features that emerged were determined. These categories included *representation of water molecules, motion, condensation, macroscopic features, hydrogen bonding,* and *accuracy*. These categories were all included in the analysis because they were all important for understanding the concept of condensation of water vapor. After an inter-rater reliability check, and reaching 95% agreement, the paper mental models were compared with the dynamic ones statistically by using a chi-square analysis for comparing the features categorically.

Findings

1. Features depicted in mental models
    a. Static mental models (Drawings)

In the first part of the analysis, the features of static mental models were identified, and it was determined that students tended to use several different representations for their water molecules, such as *symbolic*, *Lewis, space-filled, ball-stick, Bohr style,* and *any combination of representations.* Figure 2 shows some examples from students' representations of water molecules.

Figure 2. Students' representations of water molecules in the (a) Symbolic, (b) Space-filled, (c) Bohr style forms shown on paper



b. Dynamic mental models (Animations)

When the dynamic mental models of condensation, in other words animations, were analyzed, it was determined that students used different types of representations: *macroscopic, particulate,* and *a combination of macroscopic and particulate.* Students emphasized motion at these levels. Figure 3 shows different representations of water used in students' animations.

In addition, students' animations were found to be lacking in accuracy of the concept of condensation, orientation of molecules, and the representation of hydrogen-bonding (H-bonding). For instance, some students did not show the proper orientation of water molecules forming hydrogen-bonds as seen in Figure 4 (a), and some showed misconceptions about H-bonding as shown in Figure 4 (b).

2. Comparison of pre-static and dynamic mental models

When the static and dynamic mental models were compared in terms of the emergent features, the analysis showed that the static mental models were found to be limited to structural representations, whereas dynamic mental models focused more on the process of condensation, motion of the molecules, and the macroscopic changes. Specifically, chi-square analysis of *pre-static* and *dynamic* mental models showed that they were found to be significantly different ($p<0.05$) in terms of representing *macroscopic features, motion* and *processes*, favored in animations, and *hydrogen-bonding*, favored in drawings. Tables 1 through 4 show the significantly different features and the corresponding percentages for pre-static, post-static, and dynamic mental models.

Figure 3. Students' representations of water molecules (a) Only macroscopic, (b) Only submicroscopic, (c) Both macroscopic and submicroscopic forms shown in animations

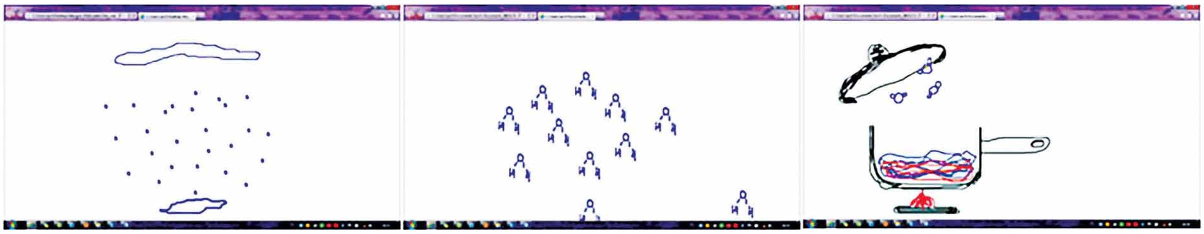
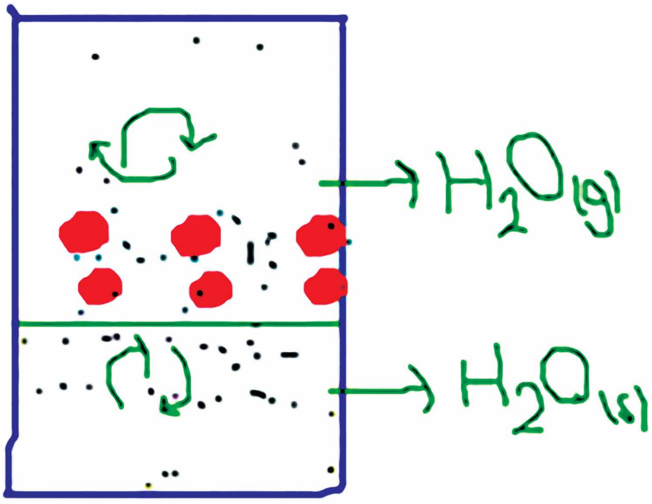


Figure 4. Students' representations of (a) water molecules in an improper orientation, (b) misconception about formation of H-bonding depicted in animations

Figure 5. One student's representation of process of condensation depicted in animations



On paper, students focused more on structural features such as hydrogen-bonding, whereas in animations they focused more on macroscopic features where they showed the process of condensation. Figure 5 shows one example of representation of process.

3. Comparison of post-static and dynamic mental models

When the *dynamic* mental models were compared with the *post-static* ones, it was determined that animations contained significantly ($p<0.05$) *more sophisticated representation of water molecules, processes* and *motion*. Tables 1 through 4 show how representation of water molecules, H-bonding, and process, differed significantly with the corresponding percentages for post-static and dynamic mental models. It was also observed that students were significantly more ($p < .05$) inclined to use symbolic representations both in pre- and post-drawings, and space-filled or ball-stick ones more in the animations, as seen in Table 1. This might have happened because most probably, symbols were easier to write on paper rather than drawing balls, and the animation-developing software, K-Sketch did not include any chemical symbols or notations, only a drawing tool.

Table 1. Comparison of pre-static, post-static, and dynamic mental models with respect to representation of water molecules

Representation of H_2O (p=.000)	Pre-Static (Drawing)	Dynamic (Animation)	Post-Static (Drawing)
Symbolic (Symbols, Bohr)	81%	45%	68%
Space-filled/ Ball-stick	19%	55%	32%

Table 2. Comparison of pre-static, post-static, and dynamic mental models with respect to representation of hydrogen bonding

Representation of H-bonding (p=.000)	Pre-Static (Drawing)	Dynamic (Animation)	Post-Static (Drawing)
No indication of H-bonding	45%	95%	42%
Indication of H-bonding	55%	5%	58%

Table 3. Comparison of pre-static, post-static, and dynamic mental models with respect to representation of macroscopic features

Representation of macroscopic features (p=.000)	Pre-Static (Drawing)	Dynamic (Animation)	Post-Static (Drawing)
No representation of macroscopic features	89%	56%	90%
Representation of macroscopic features	11%	44%	10%

Table 4. Comparison of pre-static, post-static, and dynamic mental models with respect to representation of process

Representation of process -	Pre-Static (Drawing)	Dynamic (Animation)	Post-Static (Drawing)
No indication of process	21%	7%	41%
Indication of process	79%	93%	59%

4. Comparison of pre-static and post-static mental models

When the *pre-static* and *post-static* mental models were compared, they were found to be significantly different in terms of more *sophisticated representation of water molecules*, and *process,* which were more likely seen in the post-static mental models. Tables 1 through 4 show how representation of water molecules, and process, differed significantly with the corresponding percentages for post-static and dynamic mental models.

As shown in Table 1, after generating animations, students were significantly more likely (p=0.000) to use space-filled or ball-stick type representations than symbolic or Bohr type representations. In other words, they represented the *structure* of water molecules in a more particulate way more than symbolically. It may be claimed that generating animations helped students improve their representations of water molecules as an outcome of metavisualization. On the other hand, the number of students who represented the *process* in their pre-static models did not change significantly (p=0.350) in the post-static representations even though they both differed significantly (p<.05) from the animations, as shown in Table 5. When the pre-static and post-static mental models were compared in terms of structure and process, as seen in Table 5, despite the fact that they were not significantly different, it was noticed that the number of students who represented the structure increased. This might have happened because they focused on static features (i.e. the structure of the particles and interactions on paper), rather than dynamic features. In other words, this could have occurred because static features could be more easily represented on paper rather than dynamic ones. Once they prepared the animations in K-Sketch, they might have considered the animation-developing software K-Sketch, to be the proper medium to present dynamics, and thus neglected to present the dynamic features on paper.

Table 5. Comparison of pre-static and post-static mental models with respect to representation of structure or process

Representation of process (p=.350)	Pre-Static (Drawing)	Post-Static (Drawing)
No indication of process or structure	2%	5%
Indication of process	79%	59%
Indication of structure	19%	36%

Table 6. Comparison of pre- storyboarding diagrams, post-storyboarding diagrams, and dynamic mental models with respect to representation of macroscopic features

Representation of macroscopic features (p=.000)	Pre-storyboarding Diagrams	Dynamic (Animation)	Post-storyboarding Diagrams
No representation of macroscopic features	97%	56%	88%
Representation of macroscopic features	3%	44%	12%

Table 7. Comparison of pre- storyboarding diagrams, post-storyboarding diagrams, and dynamic mental models with respect to representation of hydrogen bonding

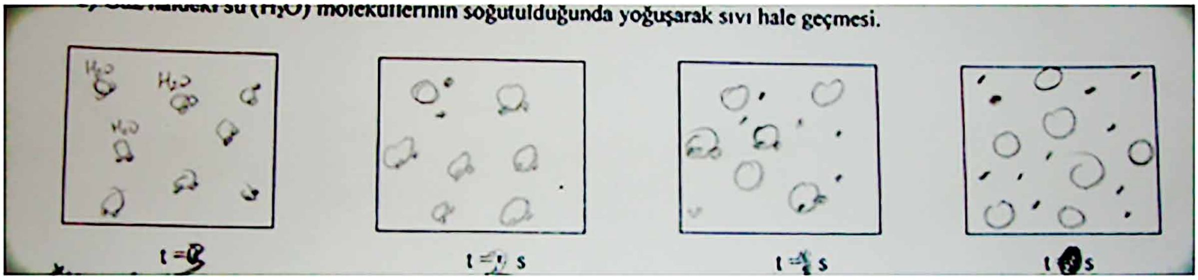
Representation of H-bonding (p=.000)	Pre-storyboarding Diagrams	Dynamic (Animation)	Post-storyboarding Diagrams
No indication of H-bonding	42%	95%	90%
Indication of H-bonding	58%	5%	10%

5. Comparison of pre-storyboarding diagrams and dynamic mental models

The last analysis was made for the comparison of storyboarding and animations, for static and dynamic representations of the processes. When the students' storyboards prepared before working with K-Sketch were compared with their animations, the results were similar to previous findings. It was observed that only two features appeared to be significantly different (p=.000) in both representations: *representation of macroscopic features* and *H-bonding*. Tables 6 and 7 show how representation of macroscopic feature, and H-bonding, differed significantly with the corresponding percentages for pre-storyboarding diagrams and dynamic mental models.

The other features such as representation of motion, process, and condensation, were not found to be significantly different (p>0.05). When students were provided scaffolding that reminded them representing dynamics, they were able to represent them in their drawings. In other words, the storyboarding diagrams which were given in the form of empty boxes and time notification (e.g. t=0 s, t=1 s, etc.) may have helped them organize their thinking of dynamics, including motion and interaction. So, if they are scaffolded, they might present more dynamics (processes and motion) in the drawing tasks. Figure 6 shows an example for storyboarding diagrams for condensation representing process, which includes also the typical misconception of splitting of water molecules into hydrogen and oxygen during condensation.

Figure 6. One student's representation of process of condensation, depicted in storyboarding diagrams



6. Comparison of post-storyboarding diagrams and dynamic mental models

Similarly, when the post-storyboarding diagrams and the animations were compared statistically by Chi Square, the macroscopic features, favored in animations (p=.000) were found to be significantly different, as shown in Table 5. However, one of the submicroscopic features, representation of Hydrogen bonding, was found not to be significantly different (p=.282) in post storyboarding diagrams and the animations.

7. Comparison of pre-storyboarding and post-storyboarding diagrams

Again, when the pre- and post-storyboards were compared, it was found that they were significantly different in terms of the macroscopic features ($p<0.05$), as shown in Table 5.

SOLUTIONS AND RECOMMENDATIONS

Chemistry instructors and educators need to understand students' conceptual understanding as shown in mental models, and different environments may help learners in different ways. In this study, students depicted their mental models about the condensation of water both in static (on-paper) and dynamic (with animations) ways. When the features shown in static and dynamic mental models were compared, the differences between them were found to be significant ($p < .05$) in terms of *structure* (type of representation) and dynamics (motion & process). Specifically, both pre- and post- static mental models were observed to emphasze *structure,* whereas dynamic ones included more *macroscopic features* ($p < 0.05$). For instance, hydrogen bonding was significantly more likely to be presented on paper than in animations. This could be because hydrogen bonding is a structural feature and more easily represented on paper, whereas macroscopic features such as water vapor and the processes of evaporation and condensation are dynamic, and more easily demonstrated by an animation. In addition, both in the pre- and post- static mental models displayed on-paper, the structure of water molecules was more likely to be represented by symbolic models rather than space filled or ball-stick representations, because it was easier for students to use symbols on paper and easier to show particulate representation in K-Sketch. After they prepared an animation at the particulate level focusing on the motion and processes of water molecules, even though the majority of them still used symbolic representations in the post-static mental models, the number of students who used space-filled representations significantly increased (p=.000) from pre- to post-static mental models. It can be claimed that preparing animations helped students improve their understanding of water molecules as individual particles, instead of focusing on their structural identities.

It was also observed that after preparing animations, students revised their mental models of condensation and conveyed more accurate models. For instance, in the post-static mental models they represented water molecules by focusing more on the particulate nature, rather less on the symbolic representation of structures. The activity of developing animations at the particulate level made students focus on the process of condensation, which involves separation of water molecules from each other and move into gas phase. As students prepared animations, they had to animate each water molecule in the liquid phase and the ones breaking apart from the liquid and passing to the gas phase. That activity required students visualize water molecules as separate particles rather than considering their composition and structure. Therefore, it may be claimed that preparing animations helped students improve their metavisualization skills in terms of understanding the nature of condensation and the behavior of water molecules, because metavisualization is a process of monitoring and regulating an individual's internal representation (Locatelli, Ferreira, & Arroio, 2010).

A recommendation for teachers and instructors is to utilize animation-developing software as an instructional and assessment tool in order to understand how students visualize physical processes at the submicroscopic level, like the condensation of water. Creating animations may help students improve their understanding at the metalevel. A recommendation for multimedia designers is to develop software enabling K-12 students to generate animations that can be used to create more effective animations and simulations.

FUTURE RESEARCH DIRECTIONS

This study showed how students' mental models differed in terms of the features depicted in different environments. The topic studied, condensation of water, was a fundamental concept for a physical phenomenon, where students had weak a understanding and misconceptions. As a future direction, students' mental models in other important physical and chemical phenomena, such as dissolving, reactions, and equilibrium can be investigated.

Additionally, research investigating how students revise their static mental models and start representing dynamic mental models, and what cognitive and metavisualization stages are involved until they refine their mental models, are other areas for future consideration.

CONCLUSION

The findings indicate that students portray more structural details in hand drawings, which are static, while they construct more processes when using animation tools. Thus instructors and educators might gain a better understanding of students' comprehension of submicroscopic processes if they have students construct animations of their understanding. This is important for researchers who study visualizations to know how students learn from technology.

In conclusion, understanding students' mental models are important for educators, researchers, and designers to develop more effective learning environments. Considering the dynamic nature of chemistry, animation-developing software is important tools to be used in chemistry classes, especially in assessing students' understanding of dynamics (motion and processes). On the other hand, a simple drawing on paper may convey more about students' understanding of structures and structural features, such as H-bonding, because they are static. Therefore, students can be asked to draw representations when it is necessary to understand their mental models of structures. In the modern classroom, it is important to know the affordances and functions of various tools and environments, and use them according to the desired purpose and objectives.

ACKNOWLEDGMENT

I would like to acknowledge Bogazici University Research Funds, Project Number 5588, to conduct this study, and Dr. Richard Davis for his support while implementing K-Sketch.

REFERENCES

Akaygun, S., & Jones, L. L. (2013). Research-based design and development of a simulation of liquid–vapor equilibrium. *Chemistry Education Research and Practice*, *14*(3), 324–344. doi:10.1039/C3RP00002H

Bowden, J., Dall'Alba, G., Martin, E., Laurillard, D., Marton, F., Masters, G., & Walsh, E. et al. (1992). Displacement, velocity, and frames of reference: Phenomenographic studies of students' understanding and some implications for teaching and assessment. *American Journal of Physics*, *60*(3), 262–269. doi:10.1119/1.16907

Briggs, M., & Bodner, G. (2007). A model of molecular visualization. In J. Gilbert (Ed.), *Visualization in science education* (pp. 61–72). Dordrecht, Netherlands: Springer.

Craik, K. (1943). *The Nature of Explanation*. Cambridge, UK: Cambridge University Press.

Creswell, J. (2012). *Educational research: Planning, conducting, and evaluating quantitative and qualitative research* (4th ed.). Upper Saddle River, NJ: Pearson Education.

Creswell, J. W., & Plano Clark, V. L. (2010). *Designing and conducting mixed methods research* (2nd ed.). Thousand Oaks, CA: Sage.

Davidowitz, B., Chittleborough, C., & Murray, E. (2010). Student-generated submicro diagrams: A useful tool for teaching and learning chemical equations and stoichiometry. *Chemistry Education Research and Practice*, *11*(3), 154–164. doi:10.1039/C005464J

Domin, D., & Bodner, G. (2012). Using students' representations constructed during problem solving to infer conceptual understanding. *Journal of Chemical Education*, *89*(7), 837–843. doi:10.1021/ed1006037

Gilbert, J. (2005). Visualization: A metacognitive skill in science and science education. In J. K. Gilbert (Ed.), *Visualization in Science Education* (pp. 9–27). Dordrecht, Netherlands: Springer. doi:10.1007/1-4020-3613-2_2

Griffiths, K. A., & Preston, R. K. (1992). Grade-12 students' misconceptions relating to fundamental characteristics of atoms and molecules. *Journal of Research in Science Teaching*, *29*(6), 611–628. doi:10.1002/tea.3660290609

Harrison, A. G., & Treagust, D. F. (1996). Secondary students' mental models of atoms and molecules: Implications for teaching chemistry. *Science Education*, *80*(5), 509–534. doi:10.1002/(SICI)1098-237X(199609)80:5<509::AID-SCE2>3.0.CO;2-F

Johnstone, A. H. (1993). The development of chemistry teaching: A changing response to changing demand. *Journal of Chemical Education*, *70*(9), 701–704. doi:10.1021/ed070p701

Kelly, R. M. (2014). Using variation theory with metacognitive monitoring to develop insights into how students learn from molecular visualizations. *Journal of Chemical Education*, *91*(8), 1152–1161. doi:10.1021/ed500182g

Kelly, R. M., & Jones, L. L. (2007). Exploring how different features of animations of sodium chloride dissolving affect students' explanations. *Journal of Science Education and Technology*, *16*(5), 413–429. doi:10.1007/s10956-007-9065-3

Lekhavat, P., & Jones, L. (2009). The effect of adjunct questions emphasizing the particulate nature of matter on students' understanding of chemical concepts in multimedia lessons. *Educación en la Química*, *20*(3), 351–359.

Lesh, R., Hover, M., Hole, B., Kelly, A., & Post, T. (2000). Principles for developing thought-revealing activities for students and teachers. In A. Kelly & R. Lesh (Eds.), Handbook of Research Design in Mathematics and Science Education (pp. 591-645). Mahwah, NJ: Lawrence Erlbaum.

Locatelli, S., Ferreira, C., & Arroio, A. (2010). Metavisualization: An important skill in the learning chemistry. *Problems of Education in the 21st Century, 24*, 75-83.

Michalchik, V., Rosenquist, A., Kozma, R., Coppola, B., Kreikemeier, P., & Schank, P. (2008). Representational resources for constructing shared understandings in the high school chemistry classroom. In J. Gilbert, M. Nakhleh, & M. Reiner (Eds.), *Visualization: Theory and practice in science education* (pp. 233–282). New York: Springer. doi:10.1007/978-1-4020-5267-5_11

Nyachwaya, J. M., Mohamed, A.-R., Roehrig, G. H., Wood, N. B., Kern, A. L., & Schneider, J. L. (2011). The development of an open-ended drawing tool: An alternative diagnostic tool for assessing students' understanding of the particulate nature of matter. *Chemistry Education Research and Practice*, *12*(2), 121–132. doi:10.1039/C1RP90017J

Osborne, R. J., & Cosgrove, M. M. (1982). Children's conceptions of the changes of state of water. *Journal of Research in Science Teaching*, *20*(9), 825–838. doi:10.1002/tea.3660200905

Taber, K. S. (2013). Revisiting the chemistry triplet: Drawing upon the nature of chemical knowledge and the psychology of learning to inform chemistry education. *Chemistry Education Research and Practice*, *14*(2), 156–168. doi:10.1039/C3RP00012E

Trunfio, P., Berenfeld, B., Kreikemeier, P., Moran, J., & Moodley, S. (2003). *Molecular Modeling and Visualization Tools in Science Education*. Symposium presented at the 2003 annual meeting of the National Association of Research in Science Teaching (NARST), Philadelphia, PA.

KEY TERMS AND DEFINITIONS

Animation: Frames that rapidly pass one after the other to create the effect of motion.

Animation-Developing Software: Software that provides an environment to develop animations.

Condensation: Changing phase from vapor to liquid.

Dynamic: Objects or items that are in motion.

K-Sketch: Specific software used to develop animations.

Mental Model: Visual or abstract representations that individuals develop through their perception or interaction with the environment.

Process: Activity showing how particles interact with each other.

Static: Objects or items that are stable, not moving.

Storyboarding: Drawing frames in a sequence such that they show the steps of motion or interaction.

Structure: Representation showing how particles are arranged.

Section 2

Real–World Contexts for STEM

Chapter 9

STEM Learning in Middle Grades by Technology-Mediated Integration of Science and Mathematics:

Results of Project SMILE

Pradeep Maxwell Dass
Northern Arizona University, USA

John T. Spagnolo
Appalachian State University, USA

ABSTRACT

In an attempt to foster inquiry-oriented learning in middle grades (grades 6 – 8), a technology mediated pedagogy integrating science and mathematics was promoted through Project SMILE (Science and Mathematics Integration for Literacy Enhancement). It involved in-service teachers in professional learning and classroom implementation over a period of two academic years, with the explicit goal of enhancing teachers' ability to foster more authentic inquiry in their classes. This chapter describes the design of Project SMILE in the context of recent reform efforts in science and mathematics education, along with the theoretical underpinnings for the design. Project activities, followed by the research methodology employed to investigate the impact on both teachers and students are described next. Finally, research results and their implications are discussed with an eye toward the usefulness of integrating science and mathematics and involving specific technological tools to foster greater inquiry-oriented learning in school science and mathematics.

INTRODUCTION

Understanding of and ability to perform inquiry and solve problems are critical components of developing scientific and mathematical literacy as promoted by most national reform efforts in science and

DOI: 10.4018/978-1-4666-9616-7.ch009

mathematics education in the recent past. Yet, in most cases, the extent of student opportunity to engage in inquiry and problem solving in science and mathematics classes is restricted to one or few "units" designed to teach inquiry and problem solving, rather than be integrated throughout the curriculum. Middle grades represent a kind of "turning point" in students academic career where important foundational components of science and mathematics literacy get established, leading students to either develop a strong interest in these subjects, followed by the desire to pursue them further; or a lack of confidence, which if left unaddressed, could lead to unrealized potential in science and mathematics futures. These realizations lead to the following questions:

- Can integrating science and mathematics instruction around real world issues, problems, etc., result in greater inquiry and problem solving that is embedded in the 'content' of curricular topics, rather than be taught separately for its own sake?
- What modern technological tools can be leveraged to effectively integrate science and mathematics?
- Can a technology mediated, integrated approach lead to better foundations of scientific and mathematical literacy in middle grades students?

These questions were investigated through Project SMILE (**S**cience and **M**athematics **I**ntegration for **L**iteracy **E**nhancement), a professional development project designed to enhance in-service teachers' ability to embed inquiry and problem solving throughout the curriculum in middle grades science and mathematics classes by integrating the two disciplines. Indeed, the ultimate outcome, which formed the basis for Project SMILE, was that teachers will learn to implement inquiry and problem solving as the standard tool for teaching and learning all curricular topics in science and mathematics. The integration of science and mathematics instruction was mediated through the use of a specific technological tool—the InspireData software—that enables collection, visualization and analysis of data seamlessly. Participating teachers experienced and designed instructional modules addressing topics mandated in the state science and mathematics curricula, setting them in the context of real life situations, problems, questions, etc., following a Science-Mathematics-Technology-Society (SMTS) pedagogical approach, and involving the use of InspireData for integrating science and mathematics topics in the modules. They taught these instructional modules in their respective classes and examined its impact on various aspects of student learning. Emulating the Iowa Chautauqua Program's (ICP) model of professional development, Project SMILE engaged teachers in three-week summer institutes for three consecutive years, involved them electronically in academic year professional learning and communication (virtual learning communities, video conferencing, etc.), and teaching of their self-designed instructional modules integrating science and mathematics during two school years.

The main goal of the project was to enhance teachers' ability to teach the entire science and mathematics curricula through an inquiry-oriented approach so that their students get opportunities to engage in authentic inquiry and problem solving on a regular basis as they learn the "content" of science and mathematics. Teacher enhancement toward this goal was examined through a combination of qualitative and quantitative methods. The objectives of this chapter are to provide a rationale and description of the design, activities, and research methodology of Project SMILE and discuss the usefulness of the integrated, technology mediated, SMTS pedagogy in the context of the teacher enhancement results.

WHY INTEGRATE SCIENCE AND MATHEMATICS IN MIDDLE SCHOOL?

Nationally, science, mathematics, engineering and technology professional organizations have long voiced support for the integration of science, mathematics, and technology teaching and learning. The number of organizations and their level of support for integrated instruction in the STEM disciplines have steadily accelerated since 1989 (Berlin & Lee, 2005). Some of these organizations include the American Association for the Advancement of Science (1989, 2008), International Technology Education Association (1996, 2000), National Council of Teachers of Mathematics (1989, 2000), National Research Council (1989, 1996), and National Science Teachers Association (1992, 1997). More recently, the National Research Council of the National Academies released *A Framework for K-12 Science Education* (2012, henceforth referred to as the *Framework*), which advocated a much stronger integration between the STEM disciplines as a characteristic of effective science education. The *Framework* guided the development of new standards for science education, which essentially formalize an integrated approach to science education (NGSS Lead States, 2013).

Overall, ‘integration’ (of STEM disciplines) is the key theme in the *Framework,* which provides the most current articulation of the goals of STEM education for the 21st century:

> *By the end of the 12th grade, students should have gained sufficient knowledge of the practices, crosscutting concepts, and core ideas of science and engineering to engage in public discussion on science-related issues, to be critical consumers of scientific information related to their everyday lives, and to continue to learn about science throughout their lives. …It is especially important to note that the above goals are for all students, not just those who pursue careers in science, engineering, or technology or those who continue on to higher education. (National Research Council, 2012, p. 9)*

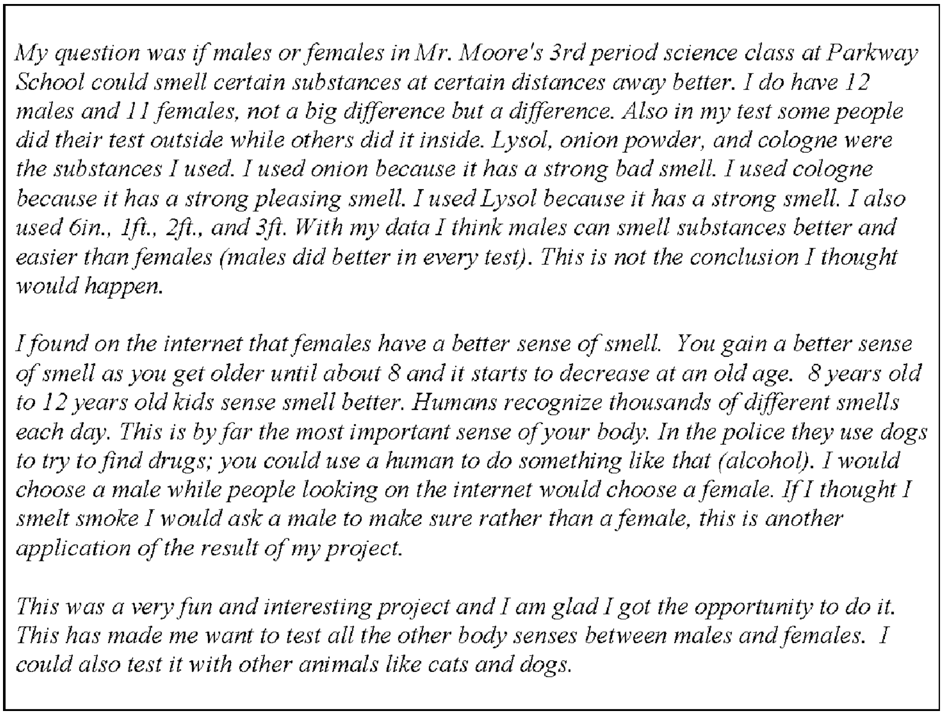
Given the technology and computation rich nature of modern science, these goals can only be realized when students experience the learning of science and mathematics in an integrated manner using appropriate technology tools. Efforts to integrate science and mathematics have in fact been going on for quite a while in the USA as indicated by Berlin & Lee (2005). In 2012, Rennie, Venville, and Wallace reported 15 years’ worth of efforts to integrate science, technology, engineering and mathematics by teachers in Australia and Canada. Most recently, the National Academy of Engineering and the National Research Council jointly published a research agenda for STEM integration in K-12 education (National Academy of Engineering & National Research Council, 2014).

INTEGRATION TOOL OF CHOICE: INSPIREDATA

Project SMILE selected *InspireData* (http://inspiration.com/Curriculum-Integration/InspireData), a software for data collection, organization, analysis and visualization, to create a virtual laboratory in which scientific inquiry can be integrated with a model-building approach to problem solving using mathematical information and principles.

Developed by TERC with grant support from NSF and later published by Inspiration Software, Inc., InspireData was launched in 2006 as a tool to visualize, investigate and understand data. According to TERC (https://www.terc.edu), InspireData applies "the proven strategies of visual learning to data analysis in science, mathematics and social studies to develop deeper content knowledge, build stronger critical thinking skills and develop data literacy." During its beta testing, InspireData promoted more higher-level questioning, better understanding of information, and greater discovery of answers by students in a visual representation. Allowing data visualization, InspireData enables students to collect original data and explore, analyze and interact with it in new dynamic inquiries. It helps students learn to question, explore, solve problems and draw conclusions in ways that mimic scientific inquiry and mathematical problem solving in tandem as is done in the professional setting. This software combines the work of collecting and analyzing data in a way that can involve each and every student as a contributing investigator. It motivates students by giving them the capability of formulating a question that can be posed to anybody that has access to the internet and receive a response from those people. By creating an electronic survey in InspireData, students can gather original data quickly, then query that data for answering the questions they formulated by generating a variety of graphs, which, in turn, allow them to interpret data and make sense of it themselves, rather than simply reading what sense someone else may have made of a data set. Preexisting data can also be entered in an InspireData spreadsheet and then queried by students to answer specific questions raised to address particular problems or issues. Thus, students can access large databases, such as the weather data from National Weather Service, and query them through InspireData to answer local weather related questions they may be investigating. Figure 1 and 2 show an example of the use of InspireData by a 7th grade student in a self-designed investigation about possible gender differences in smelling abilities among 7th grade boys and girls. The teacher of this student was a participant in Project SMILE.

Figure 1. Sample student project using InspireData: Gender Differences in Smelling Ability

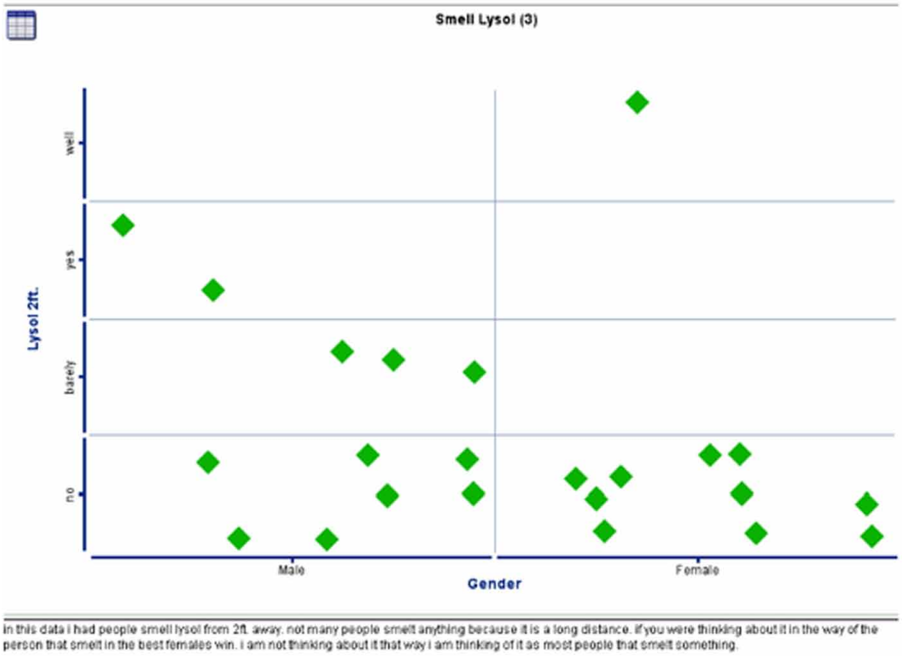


My question was if males or females in Mr. Moore's 3rd period science class at Parkway School could smell certain substances at certain distances away better. I do have 12 males and 11 females, not a big difference but a difference. Also in my test some people did their test outside while others did it inside. Lysol, onion powder, and cologne were the substances I used. I used onion because it has a strong bad smell. I used cologne because it has a strong pleasing smell. I used Lysol because it has a strong smell. I also used 6in., 1ft., 2ft., and 3ft. With my data I think males can smell substances better and easier than females (males did better in every test). This is not the conclusion I thought would happen.

I found on the internet that females have a better sense of smell. You gain a better sense of smell as you get older until about 8 and it starts to decrease at an old age. 8 years old to 12 years old kids sense smell better. Humans recognize thousands of different smells each day. This is by far the most important sense of your body. In the police they use dogs to try to find drugs; you could use a human to do something like that (alcohol). I would choose a male while people looking on the internet would choose a female. If I thought I smelt smoke I would ask a male to make sure rather than a female, this is another application of the result of my project.

This was a very fun and interesting project and I am glad I got the opportunity to do it. This has made me want to test all the other body senses between males and females. I could also test it with other animals like cats and dogs.

Figure 2. Sample student project using InspireData: Gender Differences in Smelling Ability



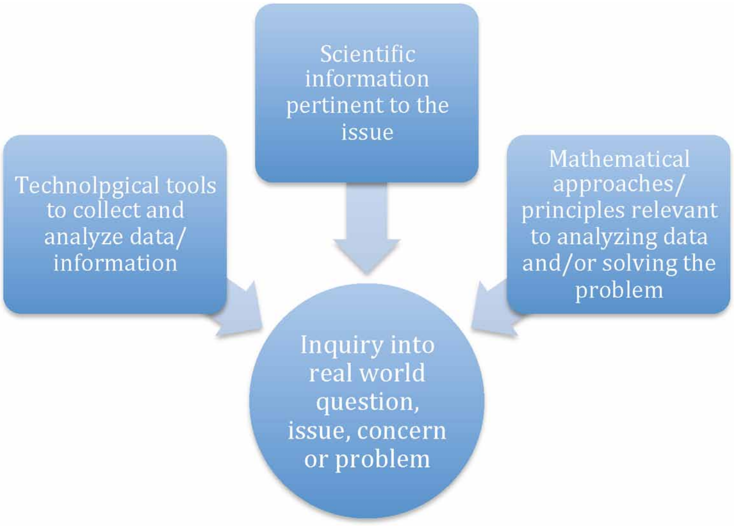
in this data i had people smell lysol from 2ft. away. not many people smelt anything because it is a long distance. if you were thinking about it in the way of the person that smelt in the best females win. i am not thinking about it that way i am thinking of it as most people that smelt something.

While these student samples are drawn from the 7th grade and all participating teachers of Project SMILE taught within the 6 – 8 grade band, the InspireData software is useful for instruction at the elementary as well as high school grades. The variety of features it contains make it possible to conduct very simple as well as complex functions within the software, thus making it a tool that can be used by students of various ages and grade levels. The pricing of the software package depends on the number of computer licenses required. Information about the pricing options and dealers can be found at the Inspiration web site.

THE INTEGRATION PEDAGOGY OF PROJECT SMILE

The integration pedagogy used in Project SMILE was based on the STS (Science-Technology-Society) approach, which can be characterized as the teaching and learning of science in the context of human experiences (Dass, 1999). Realizing the value of technological tools and mathematical knowledge in addressing real life issues and problems, the STS approach was expanded to SMTS (Science-Mathematics-Technology-Society) in which the teaching and learning of science and mathematics was integrated around specific questions or problems that were of real life relevance to middle school students. InspireData was used as a central tool to gather, organize, visualize and analyze data pertinent to addressing the questions at hand. In the process, students experienced how science and mathematics can be used in tandem to address the questions and problems that have real life relevance. This pedagogical approach is congruent with and fulfills the goals of STEM education for the 21st century laid out in the *Framework* (National Research Council, 2012, p. 9). A diagrammatic view of the integration pedagogy used in Project SMILE is presented in Figure 3.

Figure 3. Integration pedagogy of Project SMILE



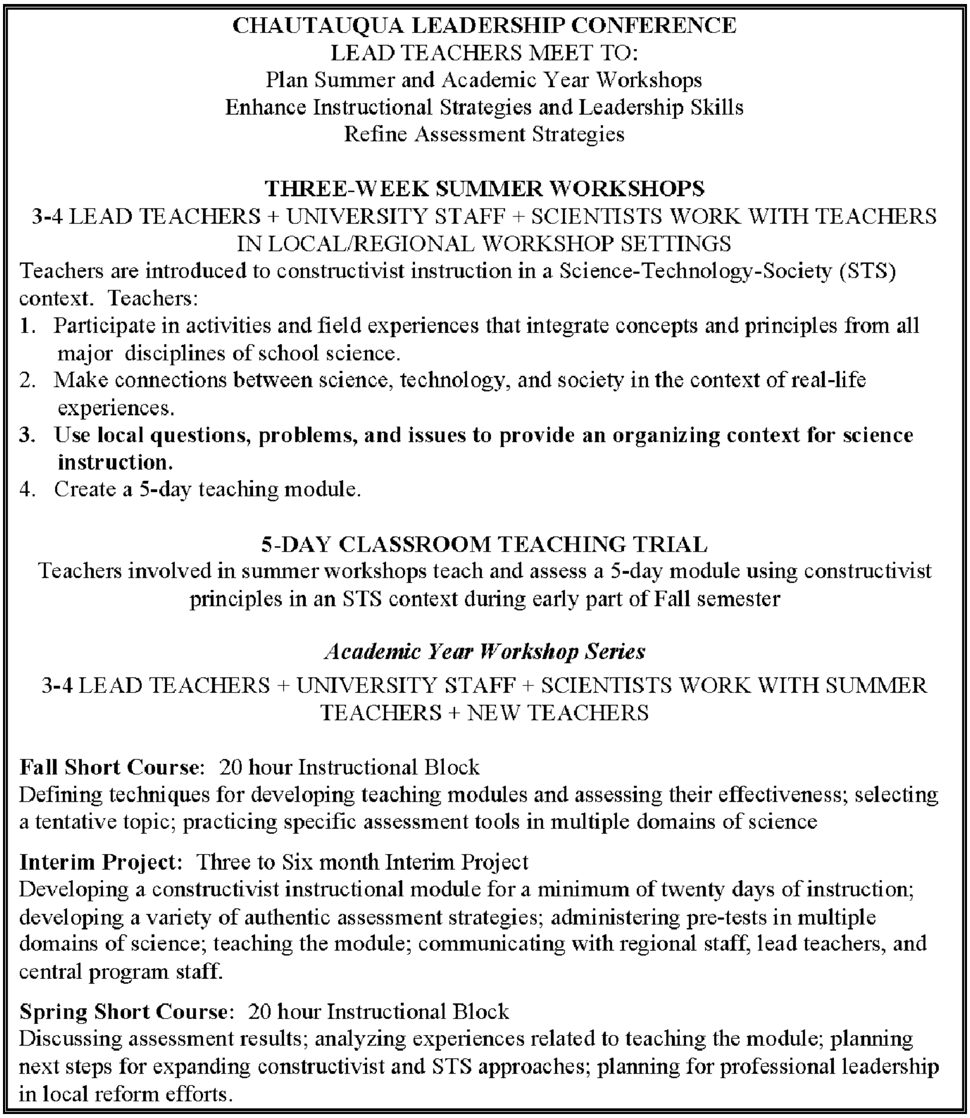
PROFESSIONAL DEVELOPMENT IN INTEGRATION PEDAGOGY

The focus of Project SMILE was to provide professional development to middle grades science and mathematics teachers in the integration pedagogy described above. To that end, the ICP model of professional development was employed with a few modifications to leverage the use of modern communication technology for teacher professional growth. The ICP model (Dass, 1996; Dass and Yager, 1999) is based on the premise that effective professional development leading to instructional change involves teachers in focused learning and collaboration over an extended period of time, has expectations from teachers to implement the instructional innovations being promoted, and offers structured mechanisms to support teachers during classroom implementation of the instructional innovations. Figure 4 outlines the structure of the ICP model based on these premises.

In order to better match the purposes of Project SMILE and leverage the potential of currently available information and communication technologies for teacher professional growth, the ICP model was modified in the following ways:

1. Instead of a Chautauqua Leadership Conference, the project leadership team had a series of meetings to develop instructional module outlines, work on the logistics of the summer institutes, develop teacher survey instruments, develop rubrics to assess teacher products, and recruit teachers for participation in the project.
2. The three-week summer institute focused on learning to use InspireData as a major tool for integrating scientific inquiry with mathematical problem solving within sample instructional modules developed by the project leadership team. After experiencing these modules as students, participating teachers developed modules for use in their own classes. These modules were organized around real-life contexts (such as water quality issues in local rivers and streams) to address specific science and mathematics topics in the state curriculum.

Figure 4. The ICP model of professional development



CHAUTAUQUA LEADERSHIP CONFERENCE
LEAD TEACHERS MEET TO:
Plan Summer and Academic Year Workshops
Enhance Instructional Strategies and Leadership Skills
Refine Assessment Strategies

THREE-WEEK SUMMER WORKSHOPS
3-4 LEAD TEACHERS + UNIVERSITY STAFF + SCIENTISTS WORK WITH TEACHERS IN LOCAL/REGIONAL WORKSHOP SETTINGS

Teachers are introduced to constructivist instruction in a Science-Technology-Society (STS) context. Teachers:

1. Participate in activities and field experiences that integrate concepts and principles from all major disciplines of school science.
2. Make connections between science, technology, and society in the context of real-life experiences.
3. **Use local questions, problems, and issues to provide an organizing context for science instruction.**
4. Create a 5-day teaching module.

5-DAY CLASSROOM TEACHING TRIAL
Teachers involved in summer workshops teach and assess a 5-day module using constructivist principles in an STS context during early part of Fall semester

Academic Year Workshop Series
3-4 LEAD TEACHERS + UNIVERSITY STAFF + SCIENTISTS WORK WITH SUMMER TEACHERS + NEW TEACHERS

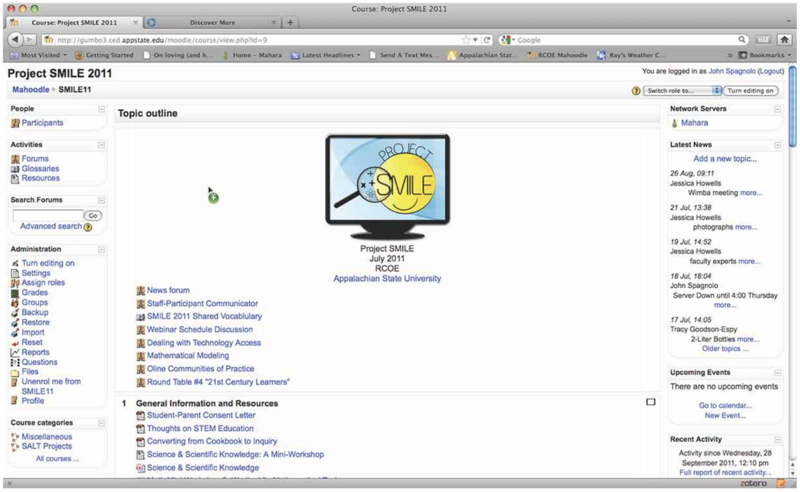
Fall Short Course: 20 hour Instructional Block
Defining techniques for developing teaching modules and assessing their effectiveness; selecting a tentative topic; practicing specific assessment tools in multiple domains of science

Interim Project: Three to Six month Interim Project
Developing a constructivist instructional module for a minimum of twenty days of instruction; developing a variety of authentic assessment strategies; administering pre-tests in multiple domains of science; teaching the module; communicating with regional staff, lead teachers, and central program staff.

Spring Short Course: 20 hour Instructional Block
Discussing assessment results; analyzing experiences related to teaching the module; planning next steps for expanding constructivist and STS approaches; planning for professional leadership in local reform efforts.

3. The Fall and Spring Short courses mentioned in the ICP model occurred electronically through the use of MOODLE (a free, open source, course management software, http://moodle.org; see Figure 5 for a screenshot of Project SMILE's MOODLE course), thus enhancing the frequency and ease of communication between participants and project staff. Using MOODLE, instead of face-to-face short courses, enabled the expansion of instructional time of the short courses from concentrated weekends to semester-long communication and interaction. Such expanded instructional interaction provided more sustained support and guidance to teachers. As needed, project staff also met with participants at their school sites to provide support in person.

Figure 5. Screenshot of Project SMILE's MOODLE course



26 Aug, 09:11
Jessica Howells
Wimba meeting more...

21 Jul, 13:38
Jessica Howells
photographs more...

19 Jul, 14:52
Jessica Howells
faculty experts more...

18 Jul, 18:04
John Spagnolo
Server Down until 4:00 Thursday more...

17 Jul, 14:05
Tracy Goodson-Espy
2-Liter Bottles more...

There are no upcoming events

Activity since Wednesday, 28 September 2011, 12:10 pm

THE CONTEXT AND PARTICIPANTS OF PROJECT SMILE

Project SMILE involved middle grades science and mathematics teachers from both rural and urban school districts in the northwestern region of North Carolina, USA. These teachers participated in 3-week long institutes during the summers of 2010, 2011, and 2012 and 2 consecutive academic years of classroom implementation and professional learning (August 2010 – May 2011 and August 2011 – May 2012). The project started with 20 teachers attending the first summer institute; however, only 11 teachers continued through all of the summer institutes and completed all project activities during the two academic years. The reasons why 9 of the original participants did not continue in the project include:

- New administrative reassignments in their schools, which pulled them out of the classrooms, thus making them unable to fulfill the classroom implementation requirement of the project;
- Personal circumstances that prevented them from participating in the after school, on-line, monthly communication meetings of the project;
- Lack of support from the school administration to enable team-based planning and teaching of integrated science and mathematics modules.

The 11 teachers who completed the project represented 6 schools and 5 school districts. Through these 11 teachers, a total of approximately 2000 students were impacted during the two academic years of implementation.

The invitation to participate in the project was announced openly to all school districts in the region, along with the following selection criteria.

- Individual applicants should teach both science and math at the same grade level or the same grade level science and mathematics teachers of a school apply as a team (so that they can work together to design and teach the integrated modules).

- Applicants should feel comfortable utilizing current computer technologies with access to the internet at their school in order to implement InspireData in the classroom, participate in the MOODLE online courses, and use the video recording equipment (provided by the project) to video record and submit classroom instruction of integrated modules.
- Applicants should have the support of the school principal to participate in the project and implement the integrated modules in their science and math classes (a letter of support from the principal was required).

Based on the pool of participants in the project, the following three instructional integration models emerged.

Type A: One teacher teaches both mathematics and science at the same grade level; creates integrated modules for that grade and teaches them herself/himself.

Type B: A pair of mathematics and science teachers of the same grade level in the same school jointly create integrated modules, which they team teach.

Type C: An individual science or mathematics teacher creates modules for the discipline she/he teaches and incorporates some (relevant) aspects of the other discipline into the module.

The following are some examples of modules developed and taught by project teachers, representing each of the integration models described above.

Type A

Both of the following samples were designed for 6th grade.

- **R U Dense?** An integrated module built around the scientific concept of density, involving mathematical computational strategies, factoring, and graphing. Activities included a book shipping problem, calculating densities of several wood samples, calculating densities of various liquids, sink-float activities, and designing clay boats.
- **People Explosion!** An integrated module built around the concepts of population growth and population control. Concepts included *birth and death rate, population doubling time, percent of population increase, causes of rapid increase of human population, consequences of rapid human population increase on the environment and control of human population growth.*

Type B

- **What happens when… We run out?** A module on renewable energy sources combining 8 grade science and math classes. Students designed and tested renewable energy devise in the science class and used the test data to learn graphing and analyzing skills in the math class. *(8th grade module)*
- **Fly Away!** A module focused on Newton's Laws of Motion. Among other activities, students designed and tested their own rockets. Data on several variables regarding rocket design and flight

tests were used in math class to learn how to analyze relationships between independent and dependent variables through graphs. *(7th grade module)*

Type C

- **Where am I and how did I get here?** A module focused on the concepts of GPS, Remote Sensing, and Ground Truthing. Mathematical concepts included understanding of coordinates, graphing coordinates, etc. *(8th grade module)*
- **Forces & Motion:** A module focused on Newton's Laws of Motion. Students conducted 'marble launch' and 'ramp design' activities that generated data to be analyzed mathematically in terms of dependent and independent variables. *(7th grade module)*

Detailed descriptions and instructional details of these and several other modules created by project participants can be found at http://projectsmile.appstate.edu.

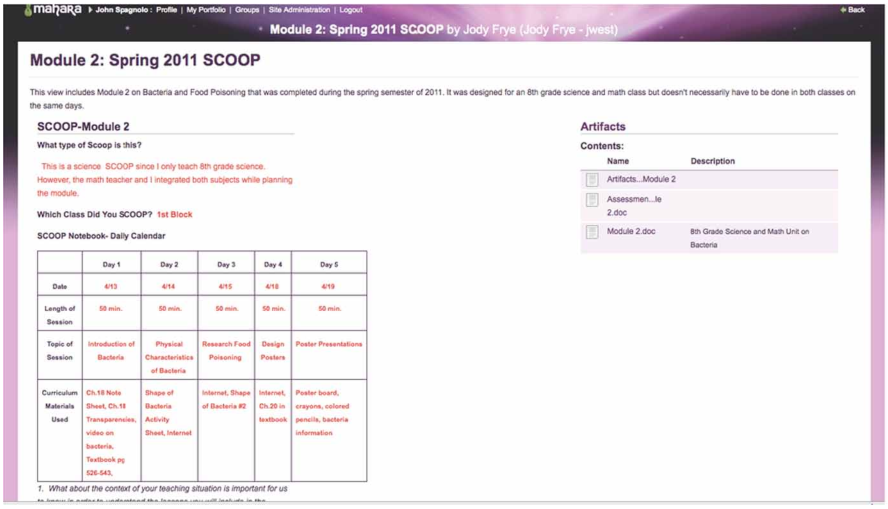
IMPACT OF PROJECT SMILE

Project SMILE was designed as a professional development project to enhance teachers' abilities to integrate science and mathematics instruction around real life issues, problems, questions and concerns, using the software InspireData to gather, organize, analyze, and visualize data pertinent to the topic being investigated. The purpose of promoting this type of integrated instruction, mediated by technology, was to foster greater experience of inquiry and problem solving by students as they learned the curricular topics of science and mathematics in real life contexts. In order to assess teacher enhancement toward these goals, three major sources of data were collected and analyzed: SCOOP Notebooks; Video Recordings of Instruction; and Teacher Survey and Interviews.

SCOOP Notebook

With funding from Educational Research and Development Centers Program of the Institute of Education Sciences (IES), U.S. Department of Education, the SCOOP Notebook instrument and analysis approach were developed by the National Center for Research on Evaluation, Standards, and Student Testing (CRESST, http://www.cse.ucla.edu/products/reports/R707.pdf) to examine reform-oriented instruction in middle school science and mathematics. Since it focuses on middle school science and mathematics instruction, it was considered to be the most appropriate instrument to study impact on teachers in Project SMILE. SCOOP Notebook is a collection of classroom artifacts (e.g. lesson plans, instructional materials, sample student work, etc.) assembled by the teacher to document pedagogical practices during specific instructional episodes. The SCOOP Notebook artifacts are rated for specific "dimensions", which are components of pedagogical practices being examined. The rating of artifacts

Figure 6. Screenshot of a participant's MAHARA page



Module 2: Spring 2011 SCOOP

This view includes Module 2 on Bacteria and Food Poisoning that was completed during the spring semester of 2011. It was designed for an 8th grade science and math class but doesn't necessarily have to be done in both classes on the same days.

SCOOP-Module 2

What type of Scoop is this?

This is a science SCOOP since I only teach 8th grade science. However, the math teacher and I integrated both subjects while planning the module.

Which Class Did You SCOOP? 1st Block

SCOOP Notebook- Daily Calendar

	Day 1	Day 2	Day 3	Day 4	Day 5
Date	4/13	4/14	4/15	4/18	4/19
Length of Session	50 min.	50 min.	50 min.	50 min.	50 min.
Topic of Session	Introduction of Bacteria	Physical Characteristics of Bacteria	Research Food Poisoning	Design Posters	Poster Presentations
Curriculum Materials Used	Ch.18 Note Sheet, Ch.18 Transparencies, video on bacteria, Textbook pg 526-543,	Shape of Bacteria Activity Sheet, Internet	Internet, Shape of Bacteria #2	Internet, Ch.20 in textbook	Poster board, crayons, colored pencils, bacteria information

1. What about the context of your teaching situation is important for us

Artifacts

Contents:

Name	Description
Artifacts...Module 2	
Assessmen...le 2.doc	
Module 2.doc	8th Grade Science and Math Unit on Bacteria

is done on a five-point scale where 1 is "low quality", 3 is "medium quality" and 5 is "high quality" for each dimension. Each point on the rating scale corresponds to a descriptor that determines the level of quality represented by the submitted artifacts. SCOOP Notebook artifacts were collected electronically through the MAHARA platform (a free, open source, ePortfolio, https://mahara.org; see Figure 6 for a screenshot of one participant's MAHARA page) in a pre-post format. Each participating teacher submitted artifacts from at least five consecutive days of instruction for each of the modules.

Pre- artifacts represented the quality and quantity of scientific inquiry and mathematical problem solving instruction in teachers' classes prior to participating in the project. Post- artifacts were collected after implementation of each of the integrated instructional modules created by participating teachers. Thus, a total of 4 sets of post- artifacts were collected and analyzed. The pre-post analysis and rating of artifacts in the SCOOP Notebook provided information with regard to the use of InspireData as well as the effectiveness of integrating scientific inquiry with mathematical problem solving. Each teacher's SCOOP Notebooks were analyzed independently by three raters from the project staff team, using the SCOOP Notebook Analysis Protocol (Borko, et al, 2007; Martinez, et al, 2012). Mean scores on each dimension for each of the four SCOOP Notebooks sets were used to conduct statistical analyses to indicate significant improvement from the first set to the final set. Generalizability Theory (G-Theory) based parametric (F-test) and non-parametric (Friedman's Test) tests were employed to analyze the difference between the first and final set of artifacts submitted in the SCOOP Notebooks. The results indicated significant teacher growth in the following dimensions of science and mathematics instruction:

- Science: Inquiry; Cognitive Depth; Science Discourse Community; Explanation and Justification; Assessment; Connections and Applications; and Overall.
- Mathematics: Structure of Lessons; Use of Mathematical Tools; Cognitive Depth; Problem Solving; Assessment; Mathematics Discourse Community; Explanation and Justification; and Overall.

The statistical test results for science section are presented in Table 1 and for the mathematics section in Table 2.

Table 1. Statistical comparison of science dimensions on a five-point scale (1=low, 5=high)

Science Dimension	Fall 2010 (a)	Spring 2012 (b)	Difference (b)-(a)	Relative Difference[1]	P-value F-test*	P-value Friedman's test*
Grouping	3.28	4.04	0.76	23.2%	0.042*	0.036*
Structure of Lessons	3.76	4.08	0.32	8.5%	0.277	0.084
Use of Scientific Resources	3.56	3.75	0.19	5.3%	0.539	0.064
Hands-on	3.08	3.21	0.13	4.2%	0.873	0.209
Inquiry	2.80	3.67	0.87	31.1%	0.011*	0.002*
Cognitive Depth	3.32	4.08	0.76	22.9%	0.019*	0.001*
Scientific Discourse Community	3.00	3.71	0.71	23.7%	0.022*	0.003*
Explanation and Justification	3.28	4.04	0.76	23.2%	0.007*	<0.001*
Assessment	3.32	3.96	0.64	19.3%	0.019*	0.008*
Connections/Applications	3.52	4.13	0.61	17.3%	0.020*	0.007*
Overall	3.04	3.79	0.75	24.7%	0.042*	0.003*

[1] Relative to the fall 2010 mean rating for each dimension.
* Statistically significant (5%).

Table 2. Statistical comparison of mathematics dimensions on a five-point scale (1=low, 5=high)

Math Dimension	Fall 2010 (a)	Spring 2012 (b)	Difference (b)-(a)	Rel. Difference[1]	P-value F-test*	P-value Friedman's test*
Grouping	2.88	3.42	0.54	18.8%	0.235	0.093
Structure of Lessons	2.68	3.29	0.61	22.8%	0.091	0.017*
Multiple Representations	2.84	2.88	0.04	1.4%	0.509	0.782
Use of Mathematical Tools	2.44	2.96	0.52	21.3%	0.153	0.009*
Cognitive Depth	2.56	3.00	0.44	17.2%	0.331	0.003*
Mathematical Discourse Community	2.36	3.08	0.72	30.5%	0.040*	0.017*
Explanation and Justification	2.40	3.08	0.68	28.3%	0.040*	0.006*
Problem Solving	1.96	2.46	0.50	25.5%	0.168	0.007*
Assessment	2.21	2.74	0.53	24.0%	0.149	0.003*
Connections/Applications	2.72	3.17	0.45	16.5%	0.241	0.155
Overall	2.32	2.96	0.64	27.6%	0.009*	0.003*

[1] Relative to the fall 2010 mean rating for each dimension.
*Statistical Significance (5%)

Video Recordings of Instruction

In order to corroborate the findings from SCOOP Notebooks, video recordings were collected of some of the lessons whose artifacts teachers included in SCOOP Notebooks. These video recordings provided first-hand account of the teaching and learning activities that occurred as teachers taught the integrated instructional modules they had developed. These video recordings were analyzed using the Reformed

Teaching Observation Protocol (RTOP, developed at Arizona Collaborative for Excellence in the Preparation of Teachers, Arizona State University, with funding from NSF <http://physicsed.buffalostate.edu/AZTEC/RTOP/RTOP_full/index.htm>). The RTOP is a 25-item instrument that assesses the quality of instruction in the following domains: Lesson Design and Implementation; Content (Propositional Knowledge and Procedural Knowledge); and Classroom Culture (Communicative Interactions and Student/Teacher Relationships). Using a five-point scale (0 – 4), the RTOP provides information about whether an instructional feature never occurred (0) or was very descriptive (4) of the instructional episode being analyzed.

In tandem with the SCOOP Notebook artifacts, each teacher submitted video recordings of classroom instruction on the same five days that match the SCOOP Notebook artifacts for each of the integrated modules they created and taught. Thus, each teacher submitted 4 sets of video recordings. Each set included five days of instruction during the module. All video recordings of each teacher were independently analyzed by three raters from the project staff team, using the RTOP instrument. Mean scores on each instructional dimension for each of the four video recording sets were used to conduct statistical analyses to indicate significant improvement from the first set to the final set. Generalizability Theory (G-Theory) based parametric test (F-test) was employed to analyze the difference between the first and final set of video recordings. The results indicated significant teacher improvement only in the dimension of Lesson Design and Implementation. Statistical results for all dimensions are presented in Table 3.

Teacher Survey and Interviews

In addition to the SCOOP Notebooks and instructional video recordings, the participating teachers were administered a survey questionnaire and were also interviewed, both in a pre-post manner. The questions in both the survey and the interview were similar and all aimed at finding teacher perceptions and practice with regard to the following instructional areas.

1. Inquiry-oriented and problem-solving based instruction
2. Integration of science and mathematics
3. Connection to real world contexts as organizers of curricular topics

Table 3. Statistical comparison of RTOP instructional dimensions on a five-point scale (0=never occurred, 4=very descriptive of the instructional episodes)

Dimension	Fall 2010 (a)	Spring 2012 (b)	Difference (b)-(a)	Relative Difference[1]	P-value
LESSON DESIGN AND IMPLEMENTATION	9.9	12.8	2.9	29%	0.027*
CONTENT	23.0	24.9	1.9	8%	0.417
Propositional Knowledge	*13.5*	*14.0*	*0.5*	*4%*	*0.636*
Procedural Knowledge	*9.4*	*10.9*	*1.5*	*16%*	*0.285*
CLASSROOM CULTURE	23.6	26.5	2.9	12%	0.135
Communicative Interactions	*10.4*	*12.1*	*1.7*	*16%*	*0.159*
Student/Teacher Relationships	*13.0*	*14.5*	*1.5*	*12%*	*0.103*
Total RTOP	***56.8***	***64.6***	***7.7***	***14%***	***0.192***

[1] relative to the fall 2010 mean score for each dimension.

* Statistically significant (5%).

Teacher enhancement in all of these three areas took place in most participants to varying degrees. A sampling of their responses indicating this enhancement is presented in Table 4.

Table 4. Teacher Survey and Interview Sample Responses

Teacher	Pre-Test	Post-Test
Inquiry & Problem Solving		
6th grade Math & Science Teacher	*When I get a chance to do it I would consider it using the scientific method to answer questions and solve problems, but in my classroom a lot of times it's hit or miss, just to be quite honest, as far as getting through the curriculum. …We try to do the activities.*	*I would just basically introduce a topic and have the students develop questions and try to develop the lessons from that, and it was very...I know of knew where the questions were wanting to go or needing to go to cover the objectives, and it was very difficult for me not to..."Well this is the question you need to ask to get to where we need to be and need to learn." and, on my part, that was very difficult.*
7th grade Science Teacher A	*They're just hands-on labs. Obviously anything that students can touch and feel and interact with gets them inquiring about what's happening.*	*I think the biggest light-bulb moment...not the biggest, one of the biggest light-bulb moments for me, in sparking inquiry, is allowing the students to ask their own questions. I think, as teachers we become so focused on teaching the curriculum that we forget that students have these literally endless numbers of questions in their mind. And, allowing them to ask those questions can begin the inquiry process. And then, from that we can piggy-back and guide their questions by using activities.*
8th grade Science Teacher	*You would give them the basics, you know, of things you needed, like this is density, mass divided by volume. Here's how you plug it into the calculator. Then you know, you give them the lab. And, at the end, once they work with their hands, then you tie it all back in together. And, for me, that was the inquiry.*	*I guess to me science inquiry is more of how the students view it, because when you show them an idea, show them a picture, or show them a video, they're the ones that want to inquire. It's not me forcing information in their heads. They're asking, "How do you do this? What's the answer to this? How can you do this?" Where I thought before that inquiry was basically just labs. But, if I just give them the lab, that's different than them asking to design something, or.... So that's what it is for me.*
7th grade Science Teacher B	*Inquiry, basically that's what they say to do, and I understand that the students construct their own knowledge. I believe that. I mean, that's the way all of us learn anything. But, if you just let them, I mean, there is a curriculum to teach, and there is, you know, the reality is not the ideal. So, you have to focus, you've got to focus on what it is you want them to learn and how you want to go about it…to some degree.*	*I always thought inquiry was just in a lab setting, but this is more general, more encompassing, I think, to have students to start asking questions. I think that's really my classroom now, how it's really different, is that...even if you show them a video or something, they generate the questions. And so it does increase interest and they asked almost all the questions that I would want them to ask.*
8th grade Math Teacher	*Solving problems. Figuring out how things are supposed to be worked out, I think, that would be my definition of it. I use it some with geometry, giving them the nets and letting them figure out the area of each part, and then we put that together, and they, you know, problem-solve to find out the area of a 3-dimensional figure all you're doing is finding the area of each side and adding them all together.*	*I think problem-solving is kind of putting to use what they know mathematically, using various tools if they need them to solve problems...to figure out why things work the way they do. And we've used the InspireData to compare with our last unit. They ended up doing various different, instead of all doing the same one and comparing, they did different types of renewable energy. So they created graphs and compared how well one thing heated vs. another thing. And they were able to do some comparisons and things like that. So it's that hands-on, putting to use their knowledge.*
Integrating Math & Science		
6 grade Math & Science Teacher	*The main area is with the data analysis. I don't think during the actual math time I touched on that section at all except right before the test is going to be coming.*	*It was so much easier this year, integrating kind of both of ways, because I was doing both the math and science. … One of the activities we did was comparing density to liquids, and comparing the way...and that sort of thing, and we'd use InspireData to graph all that...to graph it, analyze it, log the data in, and that covered in a couple of days about a month worth of math curriculum I was supposed to cover. Which freed me up to do other things. One thing we did with density, again, to bring in more of the math, we figured the density of boxes and how to ship. Which box would be...we had to ship X number of books back...which box would be the best, to give you the best rate to ship. And we had to figure out the volume of the box and the surface area. And the same with the volume of the surface area of the box, and the class worked together to come to a conclusion. And the students got a lot out of that activity.*

continued on following page

Table 4. Continued

Teacher	Pre-Test	Post-Test
8th grade Science Teacher	*Just the basics of putting information on a graph.*	*I think for me, I've always, whenever I've done a lab, I've always integrated math, but maybe not to the extent that we've been able to do, because they've been able to take it further in her class. Because I was mainly concerned with the science part, but, to understand the science, you had to do the numbers, and collect the data and understand what the data meant. But she's able to take it a step further in the math class and go in more detail with that. So I think we had more time to complete both instead of me trying to fit in science and math in the science classroom.*
8th grade Math Teacher	*Well I just find that a lot of kids really enjoy science, and I'm hoping that maybe pulling some of the science into the math curriculum is going to help with the student interest and, you know, their enthusiasm for math.*	*Well, and it really helped me, because scatter plots are heavy in 8th grade. So it helped me to be able to, as Allen said, use that as it was meaningful to them, and have them create scatterplots using InspireData. And they could use that and analyze scatterplots that way. And, I don't know, I feel like I'm not really integrating, but I really am, because it's just...to me it's just math, but I'm using the scientific data, so it is integration I guess...the true meaning. But it's just didn't feel like it was, but yet it was.*
Real World Scenarios as Organizers		
8th grade Science Teacher	*I'll have to say, for me, I feel like…not enough. Like we try to find real data, but I always feel a little bit like it's contrived. In other words I feel like we're sort of…I'm reaching to make it real world, you know? It's hard for me to make the connections, and with a lot of the activities that I've done.... Even with the weather thing, I mean, there were a ton of weather things. Like I said, we had some probes and everything. I feel like I'm just collecting data that they could easily just look up on the internet. And I'm making them collect it by hand, and it's useless. Like they can figure out what the temperature is by clicking on the internet and finding out what the temperature is. They don't have to go outside and measure the temperature. They can find a graph of the data of temperature anywhere they want to go on the internet for the last 24 hours, so why should I have to make that? You know what I mean? And so that's the, that's…I understand the value of us doing that, it's just trying to get the kids to understand the value of collecting the data yourself and how does that compare, and why do you think that's different that I struggle with a little bit.*	*I try to always find a video or clip or some kind of article or something to start, when we start a new unit or module in my class... or just a new topic. Like we used a fish kill video when we started talking about water quality. I used a video about GPS shoes way back when we started talking about that technology and how it works. I found one about the H1N1 flu and its spread and stuff when we started talking about disease. Just because it sort of gets their brains thinking.*
6th grade Math & Science Teacher	*This past year, I am continually updated in math. One of my big projects with statistics and percentages is with ACC basketball. I give them some, generally I just give each set of students a team and they follow a couple of players' statistics and they compare them with each other, and were just kind of constantly developing from there. In a lot of the problems in class I try to pull from real-world situations, sometimes talk about stuff in the news or read an article, we're this and that with that. That's just right off the top of my head.*	*The main thing I can think of is...one of the topics in 6th grade is the earthquakes, volcanoes, plate movement. And we're scheduled with our pacing guide to teach that in the spring. But at the start of last year they had the earthquake in the DC area. So we just did that first, and I pulled up a couple of clips from CNN and CBS News, and a couple of others, and we watched it, and we talked about that and asked them what they knew about earthquakes and volcanoes and what they would like to learn. And that...I felt like that was a good tie-in for the beginning of the year...got them used to this inquiry-based learning.*

CONCLUSION

Project SMILE was designed as a professional development project to enhance teacher ability to infuse inquiry-oriented and problem-solving based instruction by integrating science and mathematics through the use of the software InspireData and organizing integrated instruction around real life contexts, collectively using the SMTS pedagogy. While InspireData was the main technological tool to integrate science and mathematics instruction, the overall professional development approach also used a few other very important technological tools for teacher interaction. These are MOODLE, MAHARA, and

WIMBA (for on-line video conferencing). Thus, the overall growth, enhancement and improvement of instructional practices of participating teachers must be credited to the combined use of all of these technological tools since each of these tools played a different and distinct role in the professional learning and instructional practice of teachers. It must be emphasized that of all the technological tools used in Project SMILE, only InspireData has a price tag. All the others are open source, available for free downloads. All of these tools are easy enough to use and adaptable for instruction at any grade level.

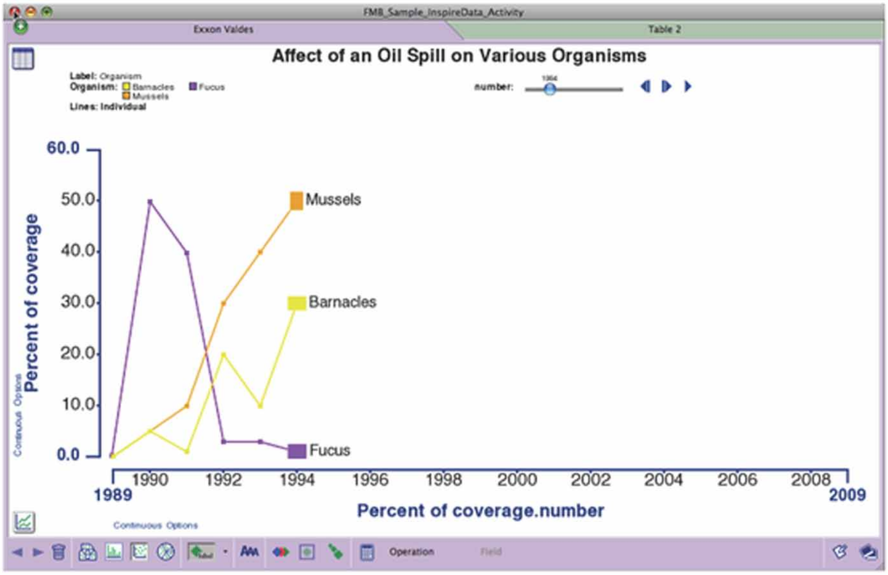
Several studies (Brand, 1997; Mouza, 2002; Mumtaz, 2000) have examined the factors that influence teacher use of technology in the classroom after having received technology oriented professional development. Results of these studies indicate that a variety of factors are involved in the extent to which teachers implement technology tools in their instruction after participating in professional development related to those technology tools. These factors include access to resources, ease of use of the tools, support and collegiality at the school, and administrative support. Additionally, teachers' own beliefs about using technology in instruction were found to be instrumental in determining both the extent of technology use and its effectiveness in improving instruction. As far as access of resources is concerned, Project SMILE teachers were provided with multicomputer licenses and software package of InspireData. All of the other technological tools used in the project were open access free downloads. Thus, the only resource needed to access and use these tools was a computer with internet access. Since most teachers participated in the project as science and mathematics teacher teams (pairs) and jointly developed instructional modules, there was collegiality and mutual support between the participants, which enhanced their use of technology tools. Administrative support varied between schools where Project SMILE teachers worked. Needless to say, teachers in schools with higher administrative support were more successful, than others, in taking full advantage of the potential of the technology tools in accomplishing the goals of increased inquiry and problem solving approaches in their instruction by effectively integrating science and mathematics.

Detailed examination of the results presented above indicates that over the two academic year time span of project participation, there was a distinct improvement in teachers' ability to plan and implement integrated science and mathematics modules that used InspireData to explore real world situations. Setting the science and mathematics content in real world contexts enabled students to experience science and mathematics learning in the way envisioned by the *Framework* (National Research Council, 2012). InspireData software played a key role in both the integration process and in effectively using real world contexts by allowing students to gather original data, set up eSurveys, and access and query already existing data from large data sets (such as weather data from the National Weather Service). Such integrated instruction around real world contexts could not have been as effective without the use of InspireData or other similar technological tools.

Increased integrated instruction around real life contexts and the use of InspireData allowed for greater inquiry and problem solving by students as they were able to query the data in ways that would not be possible otherwise. Thus, students were able to raise original questions and use InspireData to seek answers to those questions by analyzing the data in multiple ways. Another example of how InspireData makes this possible is presented as a screenshot in Figure 7.

Most importantly, as evident in the teacher survey and interview data presented in Table 4, the main influence of Project SMILE and the technologies used in it has been to bring about a shift in the "mindset" of teachers. Their understanding of inquiry and problem solving in science and mathematics

Figure 7. Screenshot of Animation of a large data set in InspireData



has developed to the point where it matches, for the most part, professional scientific practice. It also matches the view of inquiry and problem solving presented by the nexus of scientific and engineering practices using mathematical thinking in the *Framework* (National Research Council, 2012). It is safe to claim, therefore, that starting with minimal or inaccurate understandings of inquiry and problem solving, the teachers grew to more elaborate and accurate understandings over the two academic year time span of participation in Project SMILE. As teachers own understanding improved, it began to manifest itself in the design of their integrated modules, which offered increasingly more opportunities for students to raise new questions, determine what type of data to collect, and how to query the data for seeking answers to their questions; all characteristics of inquiry and problem solving in science and mathematics.

The results of Project SMILE attest to the strong potential of this technology mediated integration approach for transforming STEM education along the lines of the vision presented in the *Framework* (National Research Council, 2012). Therefore, professional development to enhance teacher ability to integrate science and mathematics instruction around real world contexts using technological tools such as the InspireData software, and to expand this integration beyond specific modules to all parts of the science and mathematics curriculum should be a continued area of focus as we seek to transform STEM education in the 21st century.

ACKNOWLEDGMENT

Project SMILE was supported by a grant award (#0918505) from the National Science Foundation (NSF) of the USA through its Discovery Research K-12 Program. All findings and opinions expressed here are solely the authors' and do not reflect any positions or views of this funding agency.

REFERENCES

American Association for the Advancement of Science. (1989, 2008). Project 2061. Science for all Americans. Washington, DC: Author.

Berlin, D., & Lee, H. (2005). Integrating science and mathematics education: Historical analysis. *School Science and Mathematics*, *105*(1), 15–24. doi:10.1111/j.1949-8594.2005.tb18032.x

Borko, H., Stecher, B. M., & Kuffner, K. (2007). *Using artifacts to characterize reform-oriented instruction: The Scoop Notebook and Rating Guide.* CSE Technical Report 707. The Regents of the University of California.

Brand, G. A. (1997). Training teachers for using technology. *Journal of Staff Development*, *19*(1).

Dass, P. M. (1996). Professional development: The Iowa Chautauqua model. *Science Education International*, *7*(1), 18–21.

Dass, P. M. (1999). Science education for the 21st century: Challenges and promising approaches. *International Journal of Curriculum and Instruction*, *1*(2), 264–277.

Dass, P. M., & Yager, R. E. (1999). The Iowa Chautauqua Program: Advancing reforms in K-12 science education. *Science Education International*, *10*(2), 33–38.

International Technology Education Association. (1996). *Technology for all Americans: A rationale and structure for the study of technology*. Reston, VA: Author.

International Technology Education Association. (2000). *Standards for technological literacy: Content for the study of technology*. Reston, VA: Author.

Martinez, J. F., Borko, H., & Stecher, B. M. (2012). Measuring instructional practice in science using classroom artifacts: Lessons learned from two validation studies. *Journal of Research in Science Teaching*, *49*(1), 38–67. doi:10.1002/tea.20447

Mouza, C. (2002). Learning to teach with new technology: Implications for professional development. *Journal of Research on Technology in Education*, *35*(2), 272–289. doi:10.1080/15391523.2002.10782386

Mumtaz, S. (2000). Factors affecting teachers' use of information and communications technology: A review of the literature. *Journal of Information Technology for Teacher Education*, *9*(3), 319–341. doi:10.1080/14759390000200096

National Academy of Engineering & National Research Council. (2014). *STEM integration in K-12 education: Status, prospects, and an agenda for research*. Washington, DC: The National Academies Press.

National Council of Teachers of Mathematics. (1989). *Curriculum and evaluation standards for school mathematics*. Reston, VA: Author.

National Council of Teachers of Mathematics. (2000). *Principles and standards for school mathematics*. Reston, VA: Author.

National Research Council. (1989). *Everybody counts. A report to the nation on the future of mathematics education*. Washington, DC: National Academy Press.

National Research Council. (1996). *National science education standards*. Washington, DC: National Academy Press.

National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. Washington, DC: The National Academies Press.

National Science Teachers Association. (1992). Scope, sequence and coordination of secondary school science: Vol. 1. *The content core: A guide for curriculum developers*. Washington, DC: Author.

National Science Teachers Association. (1997). *NSTA pathways to the science standards: Guidelines for moving the vision into practice, Elementary school edition*. Arlington, VA: Author.

NGSS Lead States. (2013). *Next generation science standards: For states, by states*. Washington, DC: The National Academies Press.

Rennie, L., Venville, G., & Wallace, J. (Eds.). (2012). *Integrating science, technology, engineering, and mathematics: Issues, reflections, and ways forward*. New York, NY: Routledge.

KEY TERMS AND DEFINITIONS

Inquiry: The ability to raise questions and design investigations to address those questions.

InspireData: A software to gather, organize, analyze, visualize and display data.

Integrated Instruction: Instruction in which more than one subject areas (science and mathematics in this case) are integrated to address a specific theme, problem or issue.

Mathematics Literacy: Understanding of basic mathematical principles and procedures and ability to apply them in real life contexts.

Problem Solving: Devising ways to address specific questions or issues; solving problems using mathematical procedures or engineering design principles.

Project SMILE: A professional development project designed to enhance teacher ability to integrate science and mathematics instruction around real life contexts using available technological tools in middle grades.

Science Literacy: Understanding of basic scientific principles and procedures and ability to apply them in real life contexts.

Technology-Mediated Instructional Integration: Integrating instruction in more than one subject area (science and mathematics in this case) by the use of one or more specific technological tools.

Chapter 10

A Qualitative Study of Teachers' Understanding of Sustainability:

Education for Sustainable Development (ESD), Dimensions of Sustainability, Environmental Protection

Hsiaowei Cristina Chang
San Jose State University, USA

Resa Marie Kelly
San Jose State University, USA

Ellen P. Metzger
San Jose State University, USA

ABSTRACT

This qualitative study was focused on exploring how in-service teachers' who were attending a three-day "Educating for Sustainability" workshop made sense of sustainability. Another goal of this study was to examine teachers' perceptions of the portrayal of the three dimensions of sustainability (environment, economy and social equity) in short movies that served as "real world" exemplars of sustainability that were freely available online through YouTube or other websites. Data was collected largely through individual semi-structured interviews, but also through questionnaires and written and drawn documentation. The findings, obtained through the constant-comparative method of coding, indicated that teachers' spontaneous descriptions of sustainability emphasized the environmental and economic dimensions of sustainability, but overlooked the equity dimension of sustainability. The videos helped teachers incorporate the 3E's into their sustainability discussions when all three dimensions were addressed, but when the social equity dimension was missing, then it tended to go unnoticed.

DOI: 10.4018/978-1-4666-9616-7.ch010

INTRODUCTION

Growing evidence for the substantial and accelerating impacts of human activities on our planet has led to global and national calls for an improved understanding of sustainability. The term "sustainability" has been defined in a multitude of ways (e.g., Little II, 2014), adding to the difficulty of conveying the concept to educators and their students. The definition below from the US Environmental Protection Agency captures elements that are common to many definitions of sustainability: the need to preserve the natural systems upon which life depends while meeting the social, economic and other needs of current and future generations:

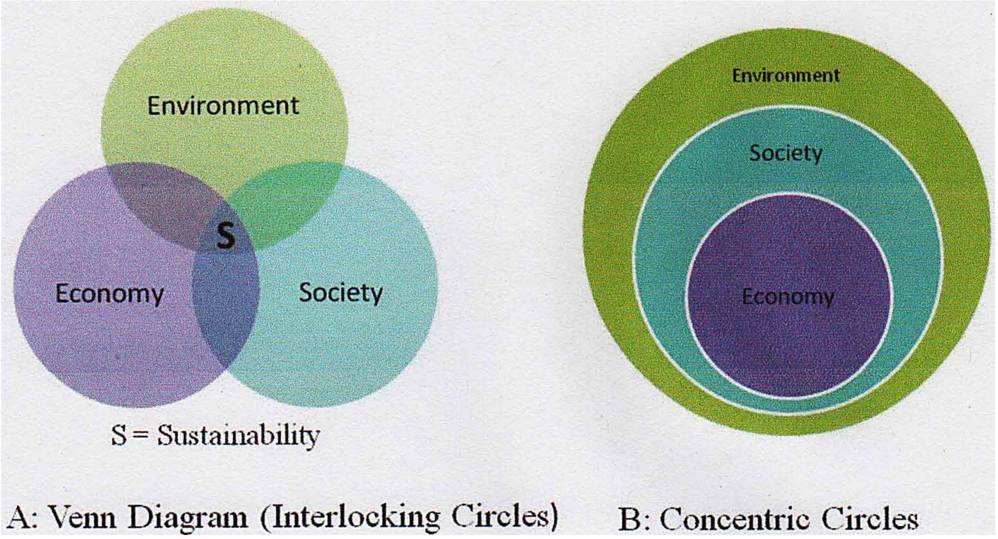
Sustainability is based on a simple principle: Everything that we need for our survival and well-being depends, either directly or indirectly, on our natural environment. Sustainability creates and maintains the conditions under which humans and nature can exist in productive harmony, that permit fulfilling the social, economic and other requirements of present and future generations (EPA, 2015)

Numerous scholars and practitioners have emphasized the importance of education in leading us toward sustainability (e.g., Sterling, 2001; Wheeler & Byrne, 2003; Edwards 2006, Feinstein, 2009; Nolet, 2009). Education for Sustainable Development (ESD) is an over-arching paradigm that develops knowledge, skills, and values essential to building communities that are environmentally sound, socially equitable, culturally sensitive, and economically just (United Nations, 2002). The United Nations proclaimed the 10-year period from 2005 to 2014 as the Decade of Education for Sustainable Development (DESD) to raise awareness and promote the teaching and learning of sustainability. The leading international agency's goal was to integrate the principles, values, and practices of sustainable development into all aspects of education (United Nations Educational, Scientific and Cultural Organization, UNESCO, 2004). ESD, in its broadest sense, is education for social transformation with the goal of creating more sustainable societies (United Nations Educational, Scientific and Cultural Organization, UNESCO, 2012).

Although considered by some as an oversimplification or misrepresentation of a complex and multifaceted concept (e.g., Lozano, 2008; Feinstein and Kirchgasler, 2014), sustainability is commonly portrayed as an integration of three "dimensions" involving a balance between environment, economy, and society. This is also referred to as the "3E's", where social equity makes up the third "E." Each dimension or "pillar" in this tripartite vision of sustainable development (SD) is subject to multiple interpretations, but as observed by Boström (2012) it is "nonetheless customary to characterize sustainable development in a familiar typology comprising three pillars: environmental, economic, and social (or sociocultural)" which are also referred to as the three 'Ps' (People, Planet, and Profit) or the three 'Es' (Environment, Economy, and Equity)." In a very broad sense, the environmental dimension is concerned with the world's natural resources and ecosystems; the economic dimension refers to the wealth and financial resources in terms of the production and consumption of goods and services; and the social equity dimension addresses respect for basic human rights, health, peace, security, and education (UNESCO, 2004). Boström further noted that "the relationships among these dimensions are generally assumed to be compatible and mutually supportive." Of the three pillars, the social dimension is widely described as "the most conceptually elusive pillar in SD discourse" and the social aspects of sustainability have received less attention than have the environmental and economic elements (Murphy, 2012 and references therein).

Various visual representations have been used to model the relationship between the three dimensions of sustainability (Mann, 2009), but two models, the Venn Diagram or interlocking circles (Figure 1) and the concentric circles diagram (Figure 1B), are most commonly used in the literature (Adams, 2006; Scott-Cato, 2009; Strachan, 2009). The interlocking circles model is often used to emphasize that the

Figure 1. Commonly used diagram models of sustainability in literature.



three dimensions are integrated and balanced. The concentric circles model, also known as the "Strong Sustainability" model, emphasizes the preservation of the integrity of all ecological systems, conveying the idea that the economy is a subset of society and both the economy and society are constrained by environmental limits (Scott-Cato, 2009).

In an effort to create a nuanced, dynamic, and multidimensional portrait of sustainability as the concept is used in the private and public sectors, Edwards (2006) analyzed the fundamental principles of organizations that identified themselves with sustainability. These principles ranged in scope (from local to international), sector (from business to government to coalition of stakeholders), and type (from values to standards for implementation). Amid the different principles, Edwards found similar key values, which he described as themes of sustainability: Stewardship, respect for limits, interdependence, economic restructuring, fair distribution (of resources), an intergenerational perspective, and nature as model and teacher. Nolet (2009) suggested that two additional themes, global citizenship and importance of place, should also be included. These two themes add a geographical perspective, from local to global, and a deeper appreciation for the interconnectedness of human society and the environment into the concept of sustainability. These themes collectively frame sustainability literacy as a complex and multidimensional construct.

SUSTAINABILITY EDUCATION

Although interpreted in different ways, the terms "Education for Sustainable Development (ESD)" and "Education for Sustainability (EFS)" are both commonly used to describe holistic and interdisciplinary approaches to developing the knowledge, skills, values, behaviors and lifestyles needed for a sustainable future. In a sustainable society, education plays a vital role in promoting community understanding, appreciation, connection, and responsibility. Sterling (2001) described three educational responses to sustainability in successive stages: education about sustainability, education for sustainability, and finally, education as sustainability. The first stage equated with *"learning as maintenance of the current paradigm."* The second stage focused on "learning for change" with critical and reflective thinking. The last stage described a transformative learning experience emphasizing a creative, reflexive, and participative process. To transform the way people "learn, reason, innovate, communicate, plan, predict, and organize" education requires pedagogies that support the development of knowledge and skills leading to behavioral change. For example, studies of real-world problems such as water and food shortages with place-based lessons and hands-on activities provide opportunities for systems thinking and an understanding of interconnectedness between individuals and collective physical, social, and economical communities. Forecasting, backcasting, and visioning exercises help develop transition strategies and evaluative techniques with long-term perspectives (Frisk & Larson, 2011).

Recent developments at the U.S. Department of Education, including the 2010 "Sustainability Education Summit: Citizenship and Pathways for a Green Economy" (U.S. Department of Education, 2011) and establishment of the Green Ribbon Schools program (U.S. Department of Education Green Ribbon Schools, 2014) signal national dialog about sustainability education. Church and Skelton (2010) studied 1,000 K-12 teachers from both public and private institutions across the US who had incorporated education for sustainability (EFS) into their classrooms. The survey revealed that teachers used EFS materials in a variety of ways, ranging from a single lesson relevant to core concepts in a curriculum to a semester-long series of lessons on sustainability. The most common barrier to bringing EFS into classrooms was the lack of time to learn new materials or to introduce additional ideas into the curriculum. Although progress is being made, sustainability-related instruction is sparsely represented in K-12 schools, in part because it had no place in science education standards issued nearly two decades ago (NRC, 1996). The recently released Next Generation Science Standards (NGSS, 2013) address sustainability through incorporation of "Earth and Human Activity" as a core idea and attention to previously neglected topics such as climate change and interactions among natural and human-designed systems. NGSS-aligned curriculum and assessments are still in the development, phase, but it is possible that explicit inclusion of concepts related to sustainability may create a more inviting environment for incorporation of EFS in the K-12 sector.

Although education for sustainability is gaining ground in the United States there is a dearth of research that explores teachers' and/or students' understanding of sustainability in the United States. Australia and the United Kingdom (UK) have included sustainability education in the primary and secondary level curricula, as well as in teacher education programs that train teachers how to adapt lessons to include sustainability. Several studies have been done in these countries to examine how practicing and preservice teachers and students understand sustainability. In a study completed in Australia, few teachers conveyed explicit knowledge of EFS even though they were incorporating aspects of it into their teaching, and with only intuitive understanding of EFS. Most teachers were unaware of the tensions implicit in sustainable development and did not mention social justice as part of EFS (Taylor, Nathan, & Coll, 2003). In general, teachers express a limited understanding of sustainability and often lack connections to all three dimensions (Spiropoulou *et al.*, 2007; Summers, Corney & Childs, 2004). Teachers often reveal that their lack of knowledge is their primary reason for not implementing sustainability-themed programs at their schools (Spiropoulou *et al.*, 2007) and while many hold positive views toward sustainability education, their lack of knowledge makes it challenging for them to teach the theoretical concepts of sustainability (Boon, 2011; Burmeister, Schimdt-Jacob & Eilks, 2013).

It is also important to examine students' perspectives, specifically how they make sense of sustainability. In a study of twenty-seven students (year 8, 12- to 13-year-olds) in the UK, Walshe (2008) reported that students needed a specific context (e.g. tourism or transportation) to better address the components of sustainability. Even with contextual assistance very few students demonstrated understanding of the interrelationships between the three dimensions of sustainability in concept map exercises. However, in the interview setting, students were more successful at conveying the interconnections.

METHODOLOGY

Theoretical Framework

When choosing a research paradigm to frame this study, the researchers subscribed to constructivism as described by Guba and Lincoln (1989), operating under the assertion that knowledge is a socially constructed reality. In this sense, the researchers worked with their participants to uncover how they make sense of their knowledge. Bodner (2006) rationalized that people develop concepts and models to make sense of their experiences and then continually test and modify these constructions in light of new experiences (Bodner as cited by Fergusen, 2007). Constructivism, as a framework, is particularly well aligned with the setting of this study, in which teachers were interviewed to examine how they made sense of the complex concept of sustainability while they attended a workshop on that very topic. Specifically, this study aimed to investigate how teachers made meaning of sustainability and constructed their understanding of sustainability in the framework of the three dimensions.

The research addressed the following questions: 1) How do pre-college in-service teachers describe sustainability? 2) How do teachers visually and orally relate the 3E's of sustainability to each other? 3) How do sustainability contexts presented in video clips affect how participants describe sustainability?

Research Setting

The study participants were attendees of the Bay Area Earth Environmental STEM Institute's (BAESI; www.baesi.org) three-day summer workshop on "Educating for Sustainability" held in July 2012. The workshop was part of an 18-month (January 2012 – June 2013) collaborative pilot project, the California Alliance for Sustainability (CASE), that united San Jose State University (SJSU) and Creative Change Educational Solutions, a national leader in sustainability education (www.creativechange.net), to investigate and address potential barriers to implementing education for sustainability (EFS) in San Francisco Bay Area classrooms. The summer workshop featured a blend of content knowledge about "umbrella" sustainability topics (climate change; sustainable communities; food systems; the ecological footprint; individual and collective actions that affect sustainability) and ready-to-use classroom activities. The workshop modeled the use of technology as a "hook" for introducing sustainability concepts though presentation and discussion of several short, humorous videos created by the Green Ninja Project (GNP; www.greenninja.org), a collaborative educational initiative at San José State University designed to inspire student interest in the science and solutions associated with our changing climate and related challenges to sustainability. Adventures of the Green Ninja – a superhero – are told in a youth-oriented and humorous way, but grounded in science and data. A "video teaching guide" accompanying each Green Ninja episode provides suggestions for using the film as an engagement piece for introducing investigations about climate change, energy and the environment.

Participants

Background information on the participants was collected from their workshop applications with their permission and was compiled by an external evaluator at the Santa Clara County Office of Education. The fifteen participants consisted of three male and twelve female in-service teachers from K-12 schools in the greater San Francisco Bay Area of Northern California. Fourteen teachers worked at public schools and one worked at a private school that served students of diverse ethnic backgrounds and low to middle socio-economic status. There were three high school (grades nine to twelve) teachers, ten middle school (grades six to eight) teachers, and two upper elementary school (grades three to five) teachers. These teachers taught a variety of subjects and exhibited a range of background knowledge relating to the concepts and pedagogy of Education for Sustainability. There were two social science teachers, seven science teachers, and six multiple-subject teachers who taught science and other core subjects (language arts, math, or social studies).

Data Collection

Semi-structured interviews were the main form of data collection. "*As a method of inquiry, interviewing is most consistent with people's ability to make meaning through language*" (Seidman, 1998). Interviews are inherently social encounters where interviewees and interviewers work together to construct meanings of the topic of the interview (Rapley, 2004). This study also used documents or diagrams produced by the participants during semi-structured interviews and the researcher's observations of the teachers within the workshop and during the interview to further uncover the participants' understanding. Triangulation of multiple sources of data helps to ensure the internal validity of the research (Merriam, 2009).

Individual interviews were conducted during the week of the "Educating for Sustainability" workshop. Due to time constraint, one teacher was interviewed before the start of the workshop. All other teachers were interviewed within seven days of the opening workshop presentation "Introduction to Sustainability." The workshop was a collaborative effort of three presenters from San José State University's departments of Meteorology and Climate Change, Geology, and Elementary Education. They used lectures, hands-on activities, and group discussions to address human interaction with Earth systems. They introduced common definitions of sustainability, the three dimensions of sustainability (3E's) and model diagrams were used to portray the dimensions (Figure 1).

Each interview was audio-recorded with the participant's consent and generally lasted approximately 30 minutes. The researcher who conducted the interviews used a list of questions (Table 1) as a general guide for in-depth discussions on the conceptual meaning of sustainability. This semi-structured format, with flexibly worded questions on the specific issues, allowed the researcher to respond to the emerging views of the participants and to their new ideas on the topic (Merriam, 2009).

Online Questionnaire

All of the workshop participants (19 total participants) completed an online questionnaire (Appendix A) before attending the workshop. The questionnaire contained seventeen questions, thirteen multiple-choice questions and four short-answer questions. The questionnaire was used to gain a better sense of the participants' background with respect to sustainability and solicited volunteers to participate in the individual interviews. The multiple-choice questions were adapted from similar surveys with permission

Table 1. Study outline and Semi-Structured Interview question samples

1. Definition of Sustainability a. Please describe what sustainability means to you. b. How do you define sustainability to your students?
2. The Three Dimensions of Sustainability a. What do you know about the three dimensions of sustainability? b. How do you relate the three dimensions (which one is more important or what roles do they play) in order to achieve sustainability? c. Which visual diagram (if mentioned by respondent) will you use to explain this concept to your students?
3. Videos "Sardines to Sanctuary" or "Tough Stuff"- Participants were shown one of two videos highlighting two dimensions of sustainability a. What concepts/ideas related to sustainability did you pick up from the video? b. Are there any missing sustainability-related concept/ideas? "Sustainability of Chocolate" All participants were shown this video which highlights all three dimensions of sustainability a. What concepts/ideas related to sustainability did you pick up from the video? b. Are there any missing sustainability-related concepts/ideas? c. Which video portrayed the idea of sustainability most completely? Why? d. What is the most important message about sustainability for your students to take away?

(OSPI, 2008; Green Education Foundation, 2011). These questions collected information on the respondents' previous EFS- related professional development trainings, their current teaching practices that incorporate sustainability-related concepts/topics, what they need to support sustainability education and perceived barriers to implementing sustainability. Short-answer questions asked respondents to describe the meaning of sustainability in their own words and to share their concerns about the environment. Responses to the short-answer questions served as a starter for discussion during individual interviews.

Interview Structure

The study consisted of three discernable sections (Table 1) and it was completed in one interview session lasting approximately thirty minutes. At the beginning of the interview participants were asked to provide their own definition of sustainability and to describe how they would define it for their students. The second part focused on examining the teachers' knowledge of the 3E's of sustainability - specifically, how they related to each other and the importance of each dimension in achieving sustainability. Because visual diagram models were used in the workshop to represent the 3E's of sustainability, if a respondent referred to any visual diagrams during the interview he/she was asked to explain how the diagram(s) represented his/her view and how he/she would use diagrams to teach the concept of the 3E's to students. In the final section, short videos portraying different real-life stories related to sustainability were shown to the participants to learn how a video context affected their ability to incorporate the 3E's of sustainability in discourse.

Three video clips showcasing exemplars of sustainability were chosen for the third section of the study based on their length (less than 3 minutes long), ease of online access (open source), and credibility of the production source (from reputable research/educational institutions in the San Francisco Bay Area). Links to the video clips are listed in Appendix B. In addition, the videos were selected based on the presence or absence of elements relevant to the 3E's of sustainability (Table 2).

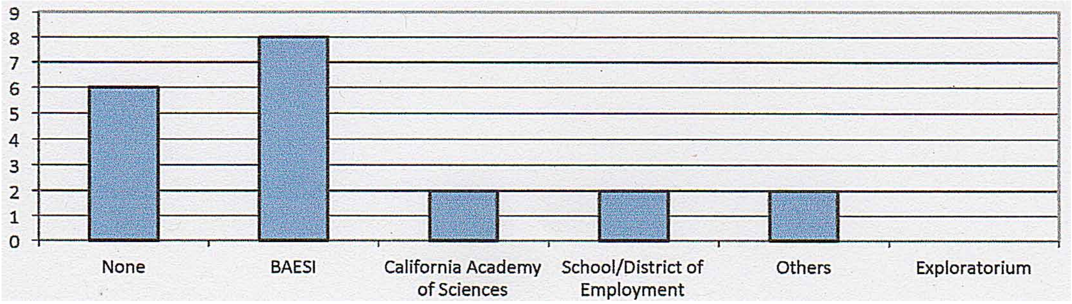
Table 2. Analysis of video clips, listed by title, with respect to whether the video emphasized each of the three dimensions of sustainability, noted with a checkmark

Sustainability Dimensions	Video Clips		
	Sardines to a Sanctuary	Tough Stuff	Sustainability of Chocolate
Environment	✓	-	✓
Economy	✓	✓	✓
Social Equity	-	✓	✓

- **Sardines to a Sanctuary:** This video talked about a historic multi-million dollar industry in Monterey, California that vanished due to overfishing. Although scientists later found that sardine populations followed natural cycles of increase and decline, human actions were still a major factor affecting the natural balance. This video portrayed an environmental crisis caused by exceeding the natural limits of the fishes' reproductive abilities for economic gain. It addressed two dimensions of sustainability, the environment and economy, with no direct reference to social equity.
- **Tough Stuff:** This video described how a social enterprise's products (portable solar panels and solar lights) changed villagers' lives in Madagascar and Kenya. These durable and affordable products gave the villagers access to electricity and improved their living conditions. Villagers also used the solar panel chargers to earn money, creating an economic opportunity for themselves. "Tough Stuff" contained many elements of economics and social equity but lacked obvious connections to the environment.
- **Sustainability of Chocolate:** This video traced the life story of chocolate as a consumer product from cultivation through production and transportation and ultimately consumption. It showed the importance of adopting a sustainable practice to ensure continuous supplies of chocolate, a multi-billion dollar industry worldwide. It discussed the environmental impacts of planting methods, contributions of science and indigenous wisdom, and positive impacts of socially responsible corporate policies such as "fair trade" on farmers' livelihood. This video integrated all three dimensions of sustainability into the story.

To begin this section of the interview, each participant was shown one of the two video clips highlighting two dimensions of sustainability. The two clips were randomly assigned to the participants so that half of the participants viewed the video "Tough Stuff" and the rest viewed the video "Sardines to Sanctuary." After watching the first video, the researcher asked participants to identify sustainability concepts or topics that they observed in the video. Following this question, the participants were asked if the video missed any elements of sustainability. Next, the participants viewed a second video, "Sustainability of Chocolate", which contained all three dimensions. Again, the participants were asked to first identify features of sustainability portrayed in the video followed by a question about whether the video lacked any features. The last interview question asked the participants to predict how their students might respond to the videos, by specifically asking them to describe the take away message.

Figure 2. Respondents' prior training on sustainability by institution (N=15)



RESULTS AND DISCUSSION

For ease of record keeping and the protection of participants' privacy, each respondent was issued a 2-letter code name. Any reference to a particular participant in this report uses the same code name for consistency and confidentiality.

Online Questionnaire

The online questionnaire (Appendix A) gave comprehensive insight into each participant's background experience and understanding of sustainability. For the purpose of this paper, only items most relevant to the study are discussed.

- **Prior education about sustainability and the institution(s) where training was received:** Out of fifteen participants, nine had received some form of training on sustainability. Local institutions that offer training were identified (Figure 2). BAESI, the institute sponsoring the workshop from which this study's participants were drawn was the institution where most respondents (8 out of 9) received prior training. None had attended any sessions on sustainability at the Exploratorium, a local science center that offers sustainability-themed teacher workshops. Respondents who selected "Other" listed "Solar Schoolhouse" and "Monterey Bay Aquarium" as institutions where they had received training.
- **Familiarity with international, national, and state policies/programs on ESD/ESF:** Data suggested that most teachers were unfamiliar with international and national policies and initiatives directly or indirectly connected to ESD/EFS themes (Table 3). State initiatives seemed more familiar to the participants perhaps due to advertisement and public election experience. The Next Generation Science Standards (2013) were most familiar to the teacher participants, but at the time of the study, the Standards had not yet been adopted by the State, which may account for the modest degree of familiarity reported.
- **Methods to teach sustainability concepts in classrooms:** The participants were asked to reflect on how they included sustainability in their curriculum. Results indicated that most (10) addressed sustainability topics in supplemental lessons/activities or they introduced it through a hook designed to connect their subject content to sustainability (Figure 3). A few respondents (3) had

Table 3. Respondents' familiarity with international, national, and state ESD/EFS policies and programs (N=15)

	Degree of Familiarity			
ESD/EFS Policies and Programs	**Know a lot**	**Know a little**	**Have heard of but know nothing**	**Have not heard of**
UN's Decade of Education for Sustainable Development (DESD)	0	4	2	9
California's Education and Environment Initiative (EEI)	2	8	3	2
US DOE's Green Ribbon Schools Program	0	3	6	6
Partnership for 21st Century Skills	0	5	3	7
Next Generation Science Standards	1	8	4	2

taught sustainability as a theme or unit. Other ways to address sustainability included integrating its concepts into lessons throughout the year or having students work on environmental projects. No respondents had taught sustainability as a course.

- **Barriers that prevented or limited participants from teaching sustainability-related topics/concepts:** Teachers reported that the lack of professional development and resources were the top barriers which limited their teaching of sustainability topics/concepts, followed closely by time and curriculum (Figure 4). "Lack of knowledge" was also a significant barrier reported by over half of the teachers. One teacher mentioned that there was a lack of freedom to veer from the prescribed curriculum, and this made it challenging to teach sustainability as the focal point of a lesson. It was not surprising to find that none reported "lack of personal interest" as a barrier since all these teachers willingly attended the EFS workshop and volunteered to participate in this study.

Interview

The constant comparative method of data analysis was employed to make sense of the data (Merriam, 2002). The participants' definitions of sustainability conveyed through interview, documents and observation were analyzed and compared to coding categories modeled from the work of Summers and Childs (2007). Next, the participants' definitions were reviewed and coded by researcher Chang and a researcher external to the study. Agreement rate between the two researchers was high and any discrepancies were

Figure 3. Respondents' methods of teaching EFS (N = 14)

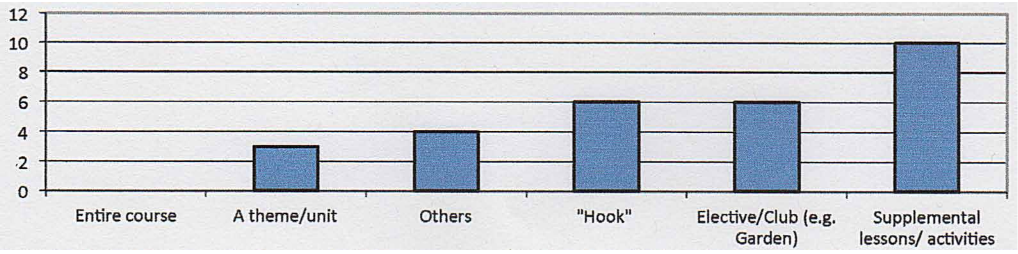
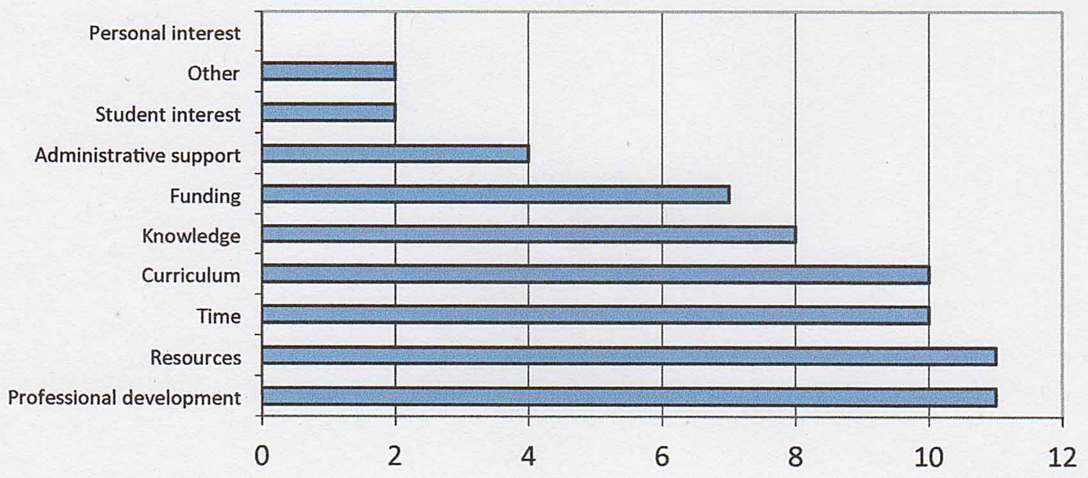


Figure 4. Barriers preventing teaching sustainability-related topics/concepts (N=15). Categories were listed in the questionnaire as "Lack of…"



reviewed and discussed until consensus was reached. With fifteen respondents, the frequency of occurrence for each feature ranged between one and fifteen. The coding process was non-repeating, meaning once a given feature was marked, further occurrences were not counted again. The overall frequency of occurrence of features by respondents was documented (Table 4).

Part 1 - Definition of Sustainability: At the beginning of the interview session participants were asked to briefly describe what sustainability meant to them and how they would explain it to students or others. For the analysis we used a slightly modified version of Summers & Childs' (2007) *a priori* codes to determine the frequency of occurrence of their eighteen features of sustainability (Table 4).

The findings indicate that for many teachers the purpose of sustainability is for conservation or management of resources and to achieve balance between human activities and natural systems. Conservation was the most frequently mentioned feature (14 of 15), expressed by teachers as "*use renewable resources*" and "*recycle and reuse*". Conservation in sustainability involves active management of resources, making a direct reference to the environment where the resources are found and an indirect reference to the economic dimension of sustainability through the use and management of these resources. The participants also emphasized "balance" as a purpose of sustainability. For example, teacher LB described the balance as replenishing natural resources in her description:

Using the resources we have in a way so that the future generation will have the same resources available to them. For example, using trees and planting new ones to replenish the supply.

Teacher LB also mentioned "future generations" in her description indicating the importance of time and providing an intergenerational perspective of sustainability. Most teachers (10 of 15) recognized the importance of a long-term time framework in their descriptions. This is an important concept addressed in the Brundtland Commission's definition of sustainable development (WCED, 1987) and was one definition of sustainability presented at the beginning of the workshop.

Table 4. Features of sustainability and frequency of occurrence in teacher's definitions using a modified version of Summer's et al's (2007) coding categories (n = 15)

Features of Sustainability		Frequency of Occurrence	
		Number of Participants (n=15)	Percentage
Purpose			
1	Conservation (Management)	14	(93%)
2	Preservation (Protection)	4	(27%)
3	Balance	6	(40%)
4	Improve environment	3	(20%)
5	Human success	2	(13%)
6	Meeting Needs	1	(7%)
7	Self-Sufficiency	2	(13%)
Time			
8	Current Generations	4	(27%)
9	Future Generations/Future	10	(67%)
Perspective			
10	3rd World Countries	1	(7%)
11	All lives	3	(20%)
12	Land, air, water	4	(27%)
13	Planet/Globe	8	(53%)
Dimensions of Sustainability (3E's)			
14	Environment	14	(93%)
15	Economy	14	(93%)
16	Social Equity	2	(13%)
Other			
17	Conflict	1	(7%)
18	Mentality	6	(40%)

Approximately half (8 of 15) of the respondents referenced a wide geographical perspective, stating that sustainability involved the entire planet (a global perspective). A few respondents included "all lives" (i.e. living things) (3 of 15), or land, air, and water (4 of 15) in their descriptions. This showed a consideration beyond a human-centered view on sustainability to include all Earth systems: the biosphere, geosphere, atmosphere, and hydrosphere. Some teachers (6 of 15) expressed sustainability as a way of thinking or a lifestyle that required awareness and conscience in people's actions.

The participants' descriptions of sustainability were thoroughly analyzed for their representation of the dimensions: Environment, economy and social equity. Most teachers (93%) focused on the environmental and economic dimensions in their description of sustainability. Only two respondents made reference to social equity. This low percentage of respondents who recognized the full scope of sustainability, especially the social dimension, was consistent with previous studies (Summer and Childs, 2004, 2007; Spiropoulou *et al.*, 2007; Burmeister *et al.*, 2013).

Part 2 - The Three Dimensions of Sustainability: The integration of the environment, economy, and society (equity), is frequently used to portray the multidimensional nature of sustainability. Hence the researcher felt that it was important to examine the extent to which these dimensions were recognized by the respondents in addition to counting the frequency with which each dimension of sustainability was mentioned during the interviews (Table 4; features 14 – 16). Teachers were specifically asked how they viewed or considered the relationships among the 3E's in order to achieve sustainability after they provided their initial definitions without clues from the researcher. Participants' responses were analyzed to learn the dimension they chose as most important. In many cases (13 of 15), without prompt from the researcher, participants gave references to the two visual diagram models of the 3E's presented in the workshop (Figure 1). Their preferences for a particular diagram and reason(s) for their choices were examined. Some respondents also drew diagrams which were included in the analysis to identify specific indiviual views about how the 3E's related to the concept of sustainability.

After the teachers gave their definitions, they were pointedly asked how they would relate the three dimensions (3E's) to each other to achieve sustainability. Teachers who were unfamiliar with the 3E's were provided with an oral explanation before continuing. The discussions on the relationship between 3E's of sustainability revealed that all teachers appreciated how they were connected. As teacher DF expressed:

…They are all related. I couldn't honestly think of anything in the economy that doesn't affect the environment... If you do want to have a sustainable lifestyle, not just for yourself, but for the rest of humanity, maybe not even the humanity, but the rest of the planet. Then you have to really take into account the social aspect, the economy, and the environment... If you are not just talking about personally and selfishly, you do need to pay attention to all 3 aspects because once you do something with one, you will affect the other two.... If you are trying to have a place that has shelter, air, water, and food source for a large group of people, what is the impact on the rest of the environment? And if you are trying to have less impact, how can you sort of use economy either within that group or throughout groups to maintain that balance? So you can't talk about one without talking about the other two, unless you are trying to destroy them essentially.

Teacher DF described how the 3E's were interconnected. He also believed that each of the 3E's were of equal importance in achieving sustainability; a view shared by five other teachers.

Several teachers (6 of 15) stressed the importance of one of the dimensions in their descriptions of interconnectedness. For example, the environment was often a focal point with the teachers stating that it should be a priority for consideration in achieving sustainability. Teacher JJ stated:

I would say the environment comes first for me… because when you protect the environment, it goes on, there will be equity, there will be economics.

The two social studies teachers believed that social equity should be emphasized to achieve sustainability because of selfish human nature. Teacher RM said:

It strikes me, people as human beings are very selfish… I would believe that if you put social equity first and you got that comprehension around the idea of social equity, then it might be easier to talk about economy and environment.

In discourse about the 3E's, most teachers (13 of 15) referred to the concentric circles and/or Venn diagram models (Figure 1) that were presented to them in the BAESI workshop. Through further discussion, the researcher found that the only teachers who did not reference the models had not been introduced to the diagram models before their interview. Ten teachers specifically used the same diagrams as presented to them in the workshop to emphasize their understanding of the 3E's. Two teachers referred to the Venn diagram as a model of a current situation, while the concentric circles diagram was the ultimate goal of sustainability. In general, teachers' interpretations of the two diagrams were similar to the meanings described by Scott-Cato (2009). Four (4) teachers drew original diagrams to express their understanding.

Several teachers (7 of 15) specifically used the concentric circles diagram (Figure 5) to represent relationships among the 3E's, stating that it showed the environment as all-encompassing yet with limits, influencing and influenced by the inner parts:

... all those things are contained within the environment... (EM);

... the environment has to be the biggest one, it is limited... (BW);

... ripple effects can go both ways... (DJ).

This interpretation of the diagram described both economy and society as constrained by environmental limits. Although in agreement with this idea, teacher MG shared another interpretation of the Concentric Circle diagram reflecting her belief that the economy led the world:

... I just picture the economy being the center of it. It's the reason why we do something... Why do we have economy in the middle? ...It's about money. Have you ever played a top? You know the very tip where everything spins, that's the economy... what everything stands on.

Figure 5. Concentric circles diagram by teacher BW

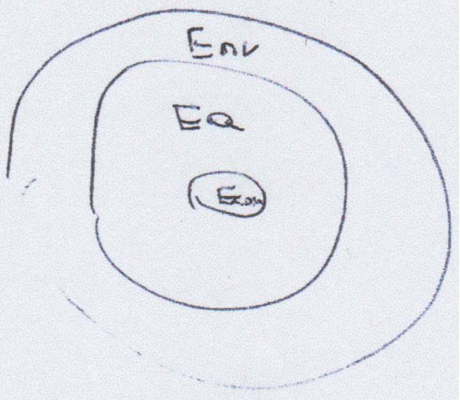
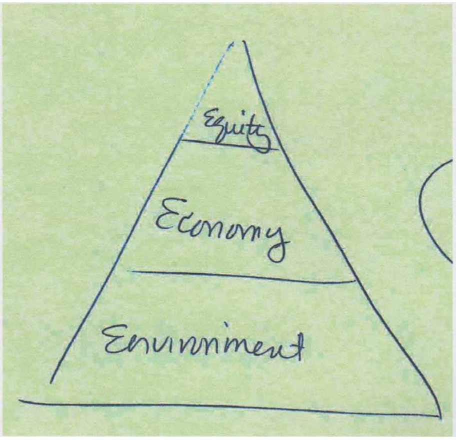


Figure 6. Triangle diagram made by teacher LH



Some teachers (3 of 7) indicated that they would use this diagram to teach their students. The other four teachers were less enthusiastic about the model and chose alternative ways to model the 3E's. Two teachers drew a pyramid or triangle diagram (Figure 6) because it better showed the environment's supporting role and its limits. Teacher LH expressed:

I guess it would be like a pyramid for me because this is the base, this is the limitation, we have this much, and build the others on top of those.

The other two teachers were unsure about using diagrams as a teaching tool, instead preferring hands-on activities to convey the ideas of limits and interconnectedness among the 3E's.

Only three teachers used the Venn diagram (Figure 7) to represent the relationship of the 3E's. The center of the diagram where the 3E's overlapped showed their interconnectedness and how the components must come together to achieve sustainability.

None of the teachers who taught elementary students supported using this diagram to teach. Teacher SL, preferred to have more labels to explain the meaning of the overlapping areas in the diagram where only two dimensions were involved. Teacher LB drew her own diagram (Figure 8) of sustainability and said:

I would have to talk to the kids about sustainability saying that there are these three things (dimensions) that we look at, then look to see how are those (two circles) related, how are those (other two circles) related, then how does it affect...

Fourth grade teacher DF was concerned with his young students' abilities to understand the Venn diagram. He preferred a web diagram that better described connections of the 3E's:

My kids are a lot younger. I got 3rd and 4th grades. The Venn diagram just sort of shows that they (the 3E's) are connected but I think it would need to be enhanced a little bit, with some examples showing how they would overlap. So with examples essentially.... So it might be through these particular diagrams but more like a web, like a food chain web that leads to how things are connected.

Figure 7. Venn diagram drawing by teacher SL

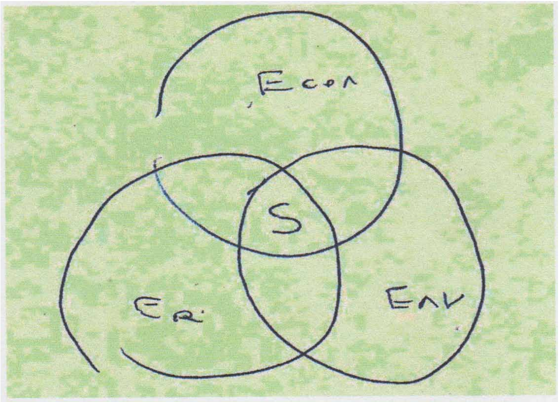
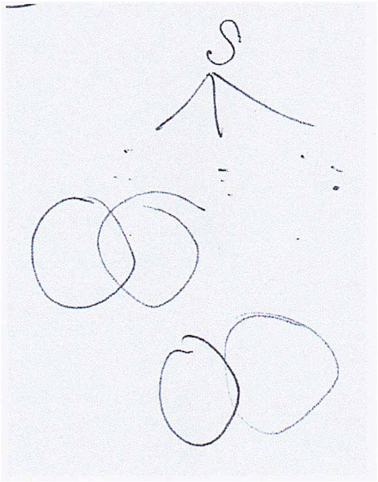


Figure 8. Branching diagram drawing by teacher LB. "S" at the vertice stands for sustainability and the three branches represent the 3E's of sustainability



Based on these descriptions, the interdependency between the dimensions is not well established and this has been viewed as a weakness of the Venn diagram model making it not well suited for teaching. (Scott-Cato; 2009) In this study, the Venn diagram was appealing to three teachers who indicated that they would use the diagram to teach because of its familiarity to themselves or their students. Teacher BB described her reasoning:

I naturally gravitate towards the Venn diagram because I understand that more. I have not used the other one.... I think if I were going to introduce those to my students, I would start with the Venn diagram because they understand that, because they've used that.

A few teachers were concerned that their students would not be able to understand diagrams. They felt scaffolding approaches might help the students understand the 3E's and interconnectedness, and they suggested explaining each dimension individually before making connections with examples. The two high school teachers felt that their students should understand visual representations. As a result, they could envision comparing and contrasting the Venn and concentric circles diagrams in their lessons.

Part 3 - Video Clips with Sustainability Contexts: Videos, as a teaching tool, can be quite powerful because they tell a story and are able to meaningfully portray abstract science concepts through human connection; however, learning from videos largely depends on how they are incorporated into other learning tasks (Karppinen, 2005). The dimensions of sustainability: environment, social equity and economy are difficult concepts to conceptualize, making them less accessible for learners to understand. Presenting stories portraying the dimensions and the interconnectedness could be beneficial to learners. In general, videos, although passive in nature, are useful as an instructional tool and have been used with success in predict-observe-explain cycles (Kearney 2004). Teachers tend to be comfortable using them and find them useful for motivating and exciting students to learn (Mayo, Sharma & Muller, 2009). In addition, videos have a great deal of range in how teachers

> may choose to use them, and the kinds of activities they choose to integrate with the video before during and after viewing the video. For example, they can be used as a hook to introduce concepts, as a form of concept development to enrich a lesson or they could also be used to assess students' understanding of sustainability. However, before teachers make use of videos in their practice, it would be useful to understand how teachers themselves take in information presented to them in a video context.

After determining teachers' views on the relationships among the 3E's of sustainability, this study focused on how videos portraying sustainability in a "real world" context affected teachers' description of sustainability and their incorporation of the 3E's. For this activity, each teacher watched two videos: "Sardines to a Sanctuary" or "Tough Stuff" and then "The Sustainability of Chocolate." After viewing the videos, discussions on sustainability grew richer as teachers referred to specific examples presented in the videos. In order to gauge how many features the teachers discussed with the video context, the same modified categories revised from Summer's & Child's (2007) categories were used to code their oral description of the videos (Table 5). The findings indicated that the frequency of occurrence of certain sustainability features in the teachers' explanations increased when context was provided. This is consistent with previous research that suggested that understanding the complex nature of sustainability could be greatly improved if it was presented with a context to provide meaning (Walsh 2008). We contend that if teachers have a better sense of sustainability from their analysis of videos, then they will likely draw on these examples when they teach their students or they may find useful ways to incorporate the videos into their own instructional practice.

Social equity was the sustainability feature that had the largest gain with more participants discussing its importance after viewing the video context. The videos "Tough Stuff" and "Sustainability of Chocolate" both conveyed the social aspect of sustainability effectively by showing how people's lives were affected. These two videos also noticeably helped more respondents view sustainability from a global perspective as more teachers referenced this feature in their discourse after viewing the videos. Other features like balance and preservation portrayed in the video "Sardines to Sanctuary" were more commonly referenced after the video context was presented.

All fifteen teachers identified elements related to all three dimensions of sustainability as portrayed in the "Sustainability of Chocolate" video. This was expected because the video provided examples of each dimension. Most of the teachers (6 out of 8) also noticed the absence of the environmental dimension when it was missing in the video "Tough Stuff". However, when the social equity dimension was missing in the "Sardines to a Sanctuary" video, only one teacher noticed that it was absent. It appeared that the strong attention to the environmental dimension helped teachers identify both its presence and absence in a scenario, while the less familiar social dimension was more easily overlooked. Teachers could readily identify the social dimension of sustainability when it was present, but its absence was usually unnoticed. Some specific findings from each video are detailed below.

Sardines to a Sanctuary

Seven teachers viewed this video, which referred to the environment and economy without a direct connection to social equity. All of the teachers noticed that the sardine population in Monterey Bay, California crashed because of the misuse of resources for economic gain, with the overfishing of sardines leading to the demise of a once plentiful fish population. As teacher MT described:

Table 5. Frequencies of occurrence of sustainability features following a priori coding (N=15). First set of data shows the frequency of occurrence from the definitions of sustainability only. Second set of data includes occurrences from discussions after viewing two videos.

Features of Sustainability		**Number of Participants (% total)**			
		Definition only		**After viewing videos**	
Purpose					
1	Conservation (Management)	14	(93%)	15	(100%)
2	Preservation (Protection)	4	(27%)	8	(53%)
3	Balance	6	(40%)	9	(60%)
4	Improve environment	3	(20%)	4	(27%)
5	Human success	2	(13%)	4	(27%)
6	Meeting Needs	1	(7%)	4	(27%)
7	Self-Sufficiency	2	(13%)	3	(20%)
Time					
8	Current Generations	4	(27%)	4	(27%)
9	Future Generations/Future	10	(67%)	10	(67%)
Perspective					
10	3rd World Countries	1	(7%)	2	(13%)
11	All lives	3	(20%)	4	(27%)
12	Land, air, water	4	(27%)	4	(27%)
13	Planet/Globe	8	(53%)	13	(87%)
Dimensions of Sustainability (3E's)					
14	Environment	14	(93%)	15	(100%)
15	Economy	14	(93%)	15	(100%)
16	Social Equity	2	(13%)	15	(100%)
Other					
17	Conflict	1	(7%)	3	(20%)
18	Mentality	6	(40%)	15	(100%)

... resource, the sardines, it appears that everyone assumed at that time, there was an infinite number... When they suddenly jump to this use for fertilizer, livestock feed, that was so much more profitable... the tipping point to make what may have been sustainable to no longer sustainable...

Some of the teachers noted that the story was geographically local, making it relevant to them and their students. Others noted that the decline in sardine populations could partly be caused by changes in natural cycles. When asked about concept(s) that were missing in the video, most wanted more details on current sardine populations, and laws and regulations on fishing limits, like those imposed on salmon. This video did not cover any issues related to the social dimension of sustainability, yet only one teacher (BW) noticed this missing component:

It didn't really talk about social equity at all. Like from the fact that there was a lot of jobs in those canneries. Then the canneries closed. It didn't really talk about there were a lot of people that lost their jobs.

Implications: How teachers choose to use videos in their instruction can be just as important as the instructional tool itself. An implication of this finding is that since the social equity dimension was easy to overlook, presenting a video in which it is missing could be a useful teaching practice. Teachers might use this video to purposefully ask students to predict how social equity would be affected in the scenario. Students could be asked to write a blog from the perspective of a person in the town where the video was filmed to describe how their lives would be affected by the decline in the sardine population. For example, a family in which one of the parents worked in a sardine cannery, how would overfishing affect them? How could it affect family grocery budgets? In this instance, the video has the potential to be used as an assessment tool to determine how students might reason from their studies of other examples to infer how social equity might be affected in this situation.

Tough Stuff

This video about the use of portable solar panels to provide affordable electricity to people in Madagascar and Kenya was shown to eight teachers. This video addressed the economic and social equity dimensions but lacked direct reference to the environment. All eight respondents appreciated the idea of improving the villagers' living conditions, increasing productivity, and meeting their needs with technology. As teacher SL reflected:

...They are solving the problem these people have... to charge their mobile phone then they have to ruin their day of work. Also they are solving the problem of getting fuel to light their houses with these lights and solar panels... It's solved that social thing, using a renewable resource.

Many also wondered if the villagers were given opportunities to learn and contribute to the production process instead of simply being passive recipients or dependents on foreign aids. Every respondent noticed elements of social equity and economy in this video. Most (6 out of 8) questioned the lack of reference to the environmental dimension of sustainability. Teacher JJ expressed:

I felt what's missing is the education. What I saw was just they were exposed to technology... some stuff like solar panels. They did not teach them how to do something about it... teach them to be self-sufficient about it... This video, for me, discussed on economics. I didn't hear how they protect the environment...

Only two respondents were oblivious to the fact that the environmental dimension was missing in the video.

Implication: Since most of the teachers recognized that the environmental dimension was missing, they might feel that their students would notice this too. As a result, the teachers might be inclined to use the video in their lessons as a hook to have their students investigate the environmental ramifications of using portable solar panels. The video, by not addressing the environmental dimension, presents an opportunity for students to get involved to help uncover how solar energy affects the environment or perhaps it could lead to a lab where students consider how to design solar cells and through the design process learn how solar energy affects the environment.

Sustainability of Chocolate

All fifteen teachers watched "Sustainability of Chocolate" after viewing either "Sardines to Sanctuary" or "Tough Stuff." Everyone commented that this video conveyed a complete idea of sustainability with the 3E's. Teacher MT explained:

The idea of having to look at sustainability in a system's thinking where there are so many other things interconnected there, not only the consumption, but the method of production. Then it focused quite a bit on the whole economics and social equity...

Fair Trade, a feature portrayed in the video, was most frequently mentioned by the respondents (11 of 15). Two teachers who taught both science and language arts were especially excited about this topic because they felt it would allow them to connect sustainability between the two subjects. About one third of respondents (5) noticed that the monoculture of cacao plants made it unsustainable due to its farming practice. They also noted the wisdom in learning how wild cacao plants grew in nature as a farming model to adopt for a healthy environment and a lasting supply. Some teachers (6) also commented that video would have personal relevance to themselves and/or their students due to their affinity for chocolate.

Implication: This video was the ideal model for the teacher because it connected to all three dimensions of sustainability. In addition, it provided a great context for exploring more deeply how environment, social equity and economy were related to each other. A good activity, involving this video, might be for teachers to ask their students how the dimensions portrayed in the video related? How would you construct a diagram to show the relationship between the dimensions and how would you defend it? Upon doing this, the students could be asked to compare and contrast their diagram to either the concentric circles diagram or the Venn diagram or to each other. The video serves as the model from which to understand the context and more deeply explore the relationship between the dimensions. In addition, the teacher would gain valuable insight into how students use diagrams to convey their understanding.

LIMITATIONS

This self-selected group of fifteen teachers was very motivated to learn and teach sustainability, evidenced by their willingness to attend workshops and to incorporate sustainability concepts into their curriculum despite their lack of formal training. Therefore, their knowledge about sustainability and experience with EFS were expected to be higher than a teacher with less vested interest in the subject matter. Consequently, results of this group's understanding of sustainability are not likely generalizable to the larger pre-college in-service teacher population due to the nature of the sample population.

Another weakness of the study is that the participants were asked about the 3E's and they were reminded of these levels prior to watching the videos. As a result, this may have motivated the participants to look for the presence of the 3E's in the videos. However, it is interesting that in spite of this nudge, most of the participants who watched "Sardines to Sanctuary" did not notice that social equity was missing.

One final limitation of the study was that because most interviews were conducted during the timeframe of the workshop on sustainability, it was highly probable that the workshop had some effect on the respondents' understanding of this subject. The influence of the workshop contents was evident when teachers recalled concepts that they had recently learned in the workshop. For example, when talking about the 3E's of sustainability, most teachers referred to the two diagram models of sustainability presented in the workshop. However, even though the participants were learning about sustainability during the workshop, they often showed uncertainty in their explanations.

CONCLUSION

This study reflects that teachers have difficulty defining sustainability in terms of all three dimensions when asked to describe sustainability from their recollection of experience and understanding of the construct. Specifically, most participants were able to connect to the environmental and economic dimensions, but were unable to demonstrate awareness of social equity in their descriptions. However, when first reminded of the three dimensions of sustainability and then presented with video clips or short movies portraying models of sustainability we found that the teachers' ability to describe sustainability was enhanced for all the dimensions explicitly portrayed; however if the environmental dimension was not specifically portrayed the teachers were still likely to mention it. This was not the case when the social equity dimension was not portrayed. In this instance it largely went unnoticed that it was missing.

How do the Participants Describe Sustainability?

The results of this study indicate that when in-service teachers enrolled in an Educating for Sustainability workshop were asked to describe their understanding of sustainability, they most frequently described the purpose of sustainability as a form of conservation, such as preventing waste and reducing pollution. Many also described the purpose of sustainability as achieving balance between human activities and the need to preserve the ecosystems upon which our well-being depends, specifically including the idea of the replenishment of resources. In terms of the three dimensions frequently used to describe sustainability, most of the teachers were able to describe the environmental and economic dimensions of sustainability, but very few recalled the social equity dimension. Many had a sense of how time was associated with sustainability and discussed the importance of the future and future generations. In addition, more than half of the participants connected with a global perspective when they discussed their understanding of sustainability. In general, the participants of this study had a basic understanding of sustainability.

How do the Teachers Visually and Orally Relate the 3E's of Sustainability?

On their own, the teachers participating in this study, as mentioned, had difficulty relating to all three dimensions of sustainability often forgetting about social equity. When the teachers were asked how the 3E's related to each other, most needed assistance to recall them and they could not fully integrate the environmental, economic and social dimensions into their description of sustainability. However after the teachers were reminded of the 3E's, every teacher was able to describe their connections. In addition, many of the participants were able to recall diagrams presented to them in a workshop, but most of the elementary and middle school teachers did not think these models would be useful for their students. In some cases, the teachers adapted their own diagrams to explain how they would present connections between the sustainability dimensions and a few teachers suggested that they would rather employ activities to help the students construct their understanding.

How do Sustainability Contexts Presented in Video Clips Affect how Participants Describe Sustainability?

When video clips modeled the dimensions of sustainability through real life contexts, teachers made noticeable gains in their ability to discuss features of sustainability. They were better able to describe the following features: purpose of sustainability, how time was involved, global and cultural perspectives, the dimensions of sustainability and features such as personal conflict and mentalities. Even though the video context assisted the participants to more successfully identify the many features of sustainability, when a dimension that the participants had difficulty recalling on their own was missing from the video, the participants did not notice that it was absent. However, when a dimension that the participants strongly recalled was absent in a video, nearly all noticed its absence. The lack of concern for social equity is consistent with previous studies showing a similar lack of concern. It also strengthens the concerns raised by other experts in the field and confirms the need to address environmental and societal challenges of the 21st century at all levels of education (Sterling, 2001; Nolet, 2009; USDOE, 2011; Frisk & Larson, 2011).

REFERENCES

Adams, W. (2006). *The Future of Sustainability: Re-thinking Environment and Development in the Twenty-first Century*. The World Conservation Union. Report of the IUCN Renowned Thinkers Meeting.

BAESI. (2011). *Education for Sustainability Teacher Survey*. San Jose, CA: Bay Area Earth Science Institute.

Bodner, G. M. (2006). The role of theoretical frameworks in chemistry/science education. In *Theoretical frameworks fo research in chemistry/science education* (pp. 2–26). Upper Saddle River, NJ: Prentice Hall.

Boon, H. J. (2011). Beliefs and Education for Sustainability in Rural and Regional Australia. *Education in Rural Austratlia, 21*(2).

Boström, M. (2012). A missing pillar? Challenges in theorizing and practicing social sustainability: introduction to the special issue. *Sustainability: Science, Practice, & Policy*, *8*(1), 3–14.

Burmeister, M., Schmidt-Jacob, S., & Eilks, I. (2013). German chemistry teachers' understanding of sustainability and education for sustainable developmet - An interview case study. *Chemistry Education Research and Practice*. doi:10.1039/c2rp20137b

Church, W. & Skelton, L. (2010, May). Sustainability Education in K-12 Classrooms. *Journal of Sustainability Education, 1*.

Edwards, A. (2006). *The sustainability revolution*. Gabriola Island, Canada: New Society.

EPA Environmental Protection Agency. *What is sustainability? What is EPA doing? How can I help?* Retrieved February 12, 2015, from http://www.epa.gov/sustainability/basicinfo.htm

Feinstein, N. (2009). *Education for sustainable development in the United Stated of America*. University of Wisconsi-Madison School of Education.

Feinstein, N. W., & Kirchgasler, K. L. (2015). Sustainability in Science Education? How the Next Generation Science Standards Approach Sustainability, and Why It Matters. *Science Education*, *99*(1), 121–144. doi:10.1002/sce.21137

Ferguson, R. (2007). Constructivism and Social Constructivism. In G. M. Bodner & M. Orgill (Eds.), *Theoretical Frameworks for Research in Chemistry/Science Education* (pp. 28–49). Upper Saddle River, NJ: Pearson Prentice Hall.

Frisk, E. & Larson, K. L. (2011, March). Educating for sustainability: Competencies & practices for transformative action. *Journal of Sustainability Education, 2*.

Green Education Foundation. (2011). *Teacher Survey*. Retrieved November 11, 2011, from Green Education Foundation: www.greeneducationfoundation.org

Guba, E., & Lincoln, Y. (1989). *Fourth generation evaluation*. Newbury Park, CA: Sage.

Karppinen, P. (2005). Meaningful learning with digital and online videos: Theoretical perspectives. *AACE Journal*, *13*(3), 233–250.

Kearney, M. (2004). Classroom use of multimedia-supported predict-observe-explain tasks in a social constructivist-learning environment. *Research in Science Education*, *34*(1), 427–453. doi:10.1007/s11165-004-8795-y

Little II, D. L. (2014). Defining Sustainability in Meaningful Ways for Educators. *Journal of Sustainability Education, 7*.

Lozano, R. (2008). Envisioning sustainability three-dimensionally. *Journal of Cleaner Production*, *16*(17), 1838–1846. doi:10.1016/j.jclepro.2008.02.008

Mann, S. (2009, March 15). *Visualizing Sustainability*. Retrieved February 27, 2012, from WordPress Computing for Sustainability: http://computingforsustainability.wordpress.com/2009/03/15/visualising-sustainability

Mayo, A., Sharma, M. D., & Muller, D. A. (2009). Qualitative differences between learning environements using video in small groups and whole class discussions: A preliminary study in physics. *Research in Science Education*, *39*(4), 477–493. doi:10.1007/s11165-008-9090-0

Merriam, S. B. (2002). Introduction to Qualitative Research. In S. B. Merriam (Ed.), *Qualitative Research in Practice: Examples for Discussion and Analysis* (pp. 3–17). San Francisco: Jossey-Bass.

Merriam, S. B. (2009). *Qualitative Research: A Guide to Design and Implementation*. San Francisco, CA: Jossey-Bass.

Monterey Bay Aquarium. (n.d.). *Sardines to a Sanctuary* [Motion Picture]. Retrieved April 1 2012, from http://www.montereybayaquarium.org/videos/Video.aspx?enc=0ZZ+8rD1FkYlVUC+FOQbAQ

Murphy, K. (2012). The social pillar of sustainable development: a literature review and framework for policy analysis. *Sustainability: Science, Practice, &. Policy*, *8*(1), 15–29.

NGSS The Next Generation Science Standards. (2013, June). Retrieved August 2013, from Next Generation Science Standards: http://www.nextgenscience.org/next-generation-science-standards

Nolet, V. (2009). Febrary). Preparing Sustainability-Literate Teachers. *Teachers College Record*, *111*(2), 409–442.

NRC (National Research Council). (1996). *National Science Education Standards*. NRC.

OSPI. (2008). *Report on Washington State K-12 Environmental Education and Education for Sustainability 2008 Teacher Survey*. Washington Superintendent of Public Instruction. Washington Superintendent of Public Instruction.

Rapley, T. (2004). Interviews. In C. Seale, G. Gobo, J. F. Gubrium, & D. Silverman (Eds.), *Qualitative Research Practice* (pp. 15–33). Thousand Oaks, CA: Sage Publications Ltd. doi:10.4135/9781848608191.d5

Scott-Cato, M. (2009). *Green Economics: An Introduction to Theory, Policy and Practice*. London: Earthscan.

Spiropoulou, D. T. A., Kontaxaki, S., & Bouras, S. (2007). Primary teachers' literacy and attitudes on education for sustainable development. *Journal of Science Education and Technology*, *16*(5), 443–450. doi:10.1007/s10956-007-9061-7

Sterling, S. (2001). *Sustainable Education: Re-visioning Learning and Change.* Schumacker Briefings No. 6. Green Books Ltd.

Strachan, G. (2009). Systems Thinking. In A. Stibbe (Ed.), *The Handbook of Sustainability Literacy* (pp. 84–88). Green Books Ltd.

Summers, M., & Childs, A. (2007, November). Student science teachers' conceptions of sustainable development: An empirical study of three postgraduate training cohorts. *Research in Science & Technological Education*, *25*(3), 307–327. doi:10.1080/02635140701535067

Summers, M., Corney, G., & Childs, A. (2004). Student teachers' conceptions of sustainable development: The starting points of geographers and scientists. *Educational Research*, *46*(2), 163–182. doi:10.1080/0013188042000222449

Sustainability of Chocolate: The cacao plant is in trouble! (2012, January). [Motion Picture]. California Academy of Sciences. Retrieved 2012, April from http://www.calacademy.org/sciencetoday/the-sustainability-of-chocolate/

Taylor, N., Nathan, S., & Coll, R. K. (2003). Education for sustainability in regional New South Wales, Australia: An exploratory study of som teachers' perceptions. *International Research in Geographical and Environmental Education*, *12*(4), 291–311. doi:10.1080/10382040308667543

The Tech Museum of Innovation. (n.d.). *Tough Stuff* [Motion Picture]. Retrieved February 13, 2015, from http://thetechawards.thetech.org/the-laureates/stories/1495

United Nations. (2002). *Report of the World Summit on Sustainable Development.* New York: United Nations. Retrieved April 2013, from http://daccess-dds-ny.un.org/doc/UNDOC/GEN/N02/636/93/PDF/N0263693.pdf?OpenElement

United Nations Educational, Scientific and Cultural Organization (UNESCO). (2004). *United Nations decade of education for sustainable development: Draft international implementation scheme*. New York: United Nations Education, Scientific, and Cultural Organization.

United Nations Educational, Scientific and Cultural Organization (UNESCO). (2012). *Education for Sustainable Development Source Book: Learning and Training Tools No. 4*. Paris: UNESCO Education Sector.

U.S. Department of Education. (2011). *Proceedings Report From the Sustainability Education Summit.* Retrieved February 13, 2015, from http://www2ed.gov/about/reports/strat/sustainability/summit-2010.doc

U.S. Department of Education Green Ribbon Schools. (2014). Retrieved February 13, 2015, from http://www2.ed.gov/programs/green-ribbon-schools/index.html

Walshe, N. (2008, October). Understanding students' conceptions of sustainability. *Environmental Education Research*, *14*(5), 537–558. doi:10.1080/13504620802345958

Wheeler, K. A., & Byrne, J. M. (2003). K-12 Sustainability Education: Its Status and Where Higher Education Should Intervene. *Planning for Higher Education*, *31*(3), 23–29.

World Commission on Environment and Development (WCED). (1987). *Our Common Future*. Geneva: United Nations.

APPENDIX 1: ONLINE QUESTIONNAIRE

Questions #6, #8, #9, #11 ~ #15 were adapted from Washington State K-12 Environmental Education and Education for Sustainability 2008 Teacher Survey (OSPI, 2008), questions #3 ~ #5, #7, #16 were adapted from BAESI's Education for Sustainability Teacher Survey (2011); Some answer choices in questions #8, #12 ~ #14 were adapted from Green Education Foundation's Teacher Survey (2011).

1. Please state your name and email. Information is for reference only.
2. Please briefly describe what "sustainability" means to you.
3. Have you attended any conferences, workshops, or classes which address topics or concepts on *sustainability* and/or *Education for Sustainability (EFS)* offered by these institutions? Please check all that apply.
   - I have not attended any
   - BAESI workshops
   - Sessions at the Exploratorium
   - Sessions at the California Academy of Sciences
   - School or district sponsored trainings
   - Others (please specify)
4. How much do you know about the following: (choices are "I know a lot about it", "I know a little about it", "I have hear d of it but know nothing about it", "I have not heard of it")
   - UN's Decade of Education for Sustainable Development
   - Partnership for 21st Century Skills
   - US Department of Education's Green Ribbon Schools Program
   - Next Generation Science Standards
   - California's Education and Environment Initiative (EEI)
5. What are your own interests and concerns about the environment?
6. What subject area(s) do you believe to be most suitable for Education for Sustainability? Please check all that apply.
   - Science
   - Social Studies
   - Math
   - Language Arts/English
   - Health and Fitness
   - Arts
   - Career and Technical Education
   - Others (please specify)
7. Do you address any sustainability topics/concepts in your classroom?
   - Yes (continues to #8)
   - No (skips to #12)
   - Not sure (skips to #8)
8. How do you teach sustainability topics/concepts? Check all that apply.
   - An entire course on sustainability
   - A theme or unit on sustainability

   - Occasional lessons or activities used as "hooks" to engage students
   - Supplemental lessons/activities in a unit or subject
   - As an elective or club activity (Garden Club, Green Team)
   - Other (please specify)

9. What resources and strategies are used to address sustainability topics/concepts? Check all that apply.
   - Textbook(s)
   - Internet (web quests, online games, etc.)
   - Supplemental readings
   - Service learning
   - Video/films
   - Science resource teachers (in school)
   - Labs/activities
   - Specialists (e.g. guest speakers)
   - Research assignments
   - Part of a special school or department event (e.g. Earth Day)
   - Writing assignments
   - Part of a school club (Garden Club, Green Team)
   - Field trips
   - Other (please specify)
10. On a scale of 0-5, 0 being not at all and 5 being completely, how successful do you believe YOUR sustainability lessons help your students understand these themes?
    - Environmental Stewardship
    - Respect for limits
    - Systems thinking and interdependence
    - Sustainable economics
    - Social justice and fair distribution
    - Intergenerational perspective
    - Nature as model
    - Global citizenship
    - Importance of local place (bioregion)
11. On a scale of 0-5, 0 being not at all to 5 being a lot, how much do you believe the students benefit from the sustainability-related lessons/activities?
    - Engagement and motivation
    - Meeting standards in core content areas (e.g. math, science, reading/writing)
    - Academic achievement (e.g. grades, test scores)
    - Building essential skills (e.g. critical thinking, system thinking, collaboration, communication, problem-solving)
    - Fostering positive and productive social behaviors (equity, justice, inclusivity, and respect for all)
    - Connecting students to their community and inspire active citizenship
    - Preparing students for challenges of the 21st Century
    - Other (please specify)

12. What barriers prevent or limit your teaching of sustainability-related topics/concepts? Please check all that apply.
    - Lack of knowledge
    - Lack of personal interest
    - Lack of professional development
    - Lack of time
    - Lack of resources (people, materials, etc.)
    - Lack of curriculum
    - Lack of funding
    - Lack of student interests
    - Lack of administrative or other teachers' support
    - Other (please specify)
13. Which of the following topics/concepts do you currently address in your lessons? Please check all that apply.
    - Climate change / global warming
    - Energy: conservation and alternative/renewable energy
    - Ecological footprint (and/or water, carbon)
    - Water resources and conservation
    - Carbon cycle
    - Pollution (air, water, land) and prevention
    - Life cycle analysis
    - Resource consumption, consumerism, and conservation
    - Carrying capacity
    - Recycling and waste management
    - Population Growth
    - Sustainable farming, fishery, and/or forestry
    - Biodiversity
    - Environmental justice, laws, and regulations
    - Quality of life and social equity
    - Other (please specify)
14. What materials or information would you like to have to help you teach sustainability topics/concepts in your subject area? Please check all that apply
    - Printed textbooks
    - Online textbooks
    - Other print materials (supplemental texts, books, magazines)
    - Videos/Films
    - Websites
    - Community resources (guest lecturers, non-profits organizations)
    - Other (please specify)
15. Which of the following programs are currently implemented (in class, in school, at home)? Check all that apply.
    - Recycling
    - Composting

   - Vermicomposting
   - Garden
   - Energy efficiency
   - Water conservation
   - Other (please list)

16. Please provide any additional comments or suggestions regarding this survey or Education for Sustainability.
17. For K-12 teachers only. Are you willing to participate in a 20-minute interview during the workshop? Participation is voluntary and optional.

APPENDIX 2: LINKS TO VIDEO CLIPS

- Sardines to a Sanctuary by Monterey Bay Aquarium
  http://www.montereybayaquarium.org/videos/Video.aspx?enc=0ZZ+8rD1FkYlVUC+FOQbAQ
- Toughstuff (Renewable Electricity) by The Tech Museum
  http://www.youtube.com/watch?feature=player_embedded&v=4dcK0ZyMjA8
- Sustainability of Chocolate by California Academy of Science
  http://www.calacademy.org/sciencetoday/the-sustainability-of-chocolate/

Chapter 11

Coupling Geospatial and Computer Modeling Technologies to Engage High School Students in Learning Urban Ecology

Dennis J. DeBay
University of Colorado – Denver, USA

Paul E. Madden
Boston College, USA

Amie Patchen
Boston College, USA

Yang Xu
Boston College, USA

Anne C. Vera Cruz
Boston College, USA

Meredith Houle
San Diego State University, USA

Michael Barnett
Boston College, USA

ABSTRACT

This chapter is a description of the Urban Tree Project where high school students were engaged in the use of Geographic Information System (GIS) technologies to determine the economic and ecological value of trees in their neighborhood. Students collected data on tree locations and conditions and then used CITYgreen to evaluate the economic and ecological value of their trees. Urban high school youth had the opportunity to explore urban ecology in their neighborhoods. Pre–post interview and written assessments were conducted across a wide sample of school contexts. The goal of these assessments was to explore the students' beliefs and understanding regarding the ecosystem services that trees and greenspace provide to a city. The results were mixed as students' understanding measured by the written assessments increased significantly. However, upon further probing, students often showed difficulty in drawing coherent concepts and ideas that depicted a robust understanding of urban ecological principles regarding green space and the services that trees provide.

DOI: 10.4018/978-1-4666-9616-7.ch011

INTRODUCTION

Recently the President's Council of Advisors on Science and Technology noted that information and computation technology can be a powerful driving force for innovation in education by improving the quality of instructional materials available to teachers and students (National Science Board, 2014). Yet, research has consistently found that information technology is underutilized in classrooms, particularly in high poverty urban areas (National Telecommunications and Information Administration, 2000). For years, researchers have documented that students in low income areas often use technologies for repetitive activities whereas students in higher-income areas often use technologies for higher-order thinking, problem solving, and other intellectually challenging activities (National Telecommunications and Information Administration, 2000). Further, information technology in such classrooms is often used independently of content, which limits the understanding that students can develop regarding the use of information technologies (Presidents Council of Advisors on Science and Technology, 2012). Nevertheless, educators have recognized the potential of geospatial technologies to motivate students to learn because geospatial technologies can provide opportunities for authentic scientific inquiry using the very tools that scientists use to analyze and manipulate data (National Research Council, 2006). This recognition is supported by improvements in technology that mean using geospatial technologies to explore and analyze our world is no longer isolated to a few very skilled scientists and researchers. Rather, such technologies are now available to nearly everyone (Barnett, MaKinster, Trautmann, Houle, & Mark, 2012). Over the past decade, consumer demand for the opportunity to manipulate and display geospatial information using Global Positioning Systems (GPS) and GIS has skyrocketed (Folger, 2008). For example, the integration of GPS data with digital maps has led to handheld and dashboard navigation devices used daily by millions of people worldwide. The release of Google Earth in 2005 made it possible for people from all walks of life to manipulate digital maps and geospatial data (Folger, 2008). The ability to swiftly and dynamically represent Earth's geography and scientific, social, political, economic, and environmental issues from a variety of perspectives creates powerful opportunities for teachers and students. In fact, geospatial tools expand the scope of topics that students can explore, promote interdisciplinary learning, and change the way that students learn to reason about and interpret data (Ramamurthy, 2006).

Building on these perspectives, geospatial technologies have significant potential to engage students in locally relevant, interdisciplinary study of phenomena with direct impact in the classroom (Barnett et al., 2013). For example, students can use geospatial technologies not only to map data and explore digital representations of Earth's surface, but also to visually explore relationships between various types of environmental and social data. By overlaying different data layers, students can identify areas of environmental concern in their own communities, such as steep slopes vulnerable to erosion, or areas of greatest benefit, such as habitat for a threatened or endangered species. Students also can examine relationships between biological and social variables. For example, in urban areas, students can consider comparing the health of trees, shrubs, and other vegetation with neighborhood income levels. Such relationships can be explored not only visually, but also by using the analytic capabilities of GIS. ”Queries” enable a user to filter a specific data set or create a new data layer based on the intersection of two or more layers. Such queries enable students to identify hidden patterns or difficult-to-see correlations in their data. In essence, geospatial technologies provide an ideal tool for students to use when visualizing data, posing their investigation, and addressing specific questions. Coupled with this increased use of geospatial technologies, new technologies have enabled students to gain access to a wide array of information, educational, and entertainment media. For instance, Jenkins (2006) argues that youth are no longer spectators, or even consumers, of information; rather, they are active participants in contributing and shaping information through the use of information technology tools and resources. As a result, students are immersed in a cultural context that is often at odds with typical classroom experiences, where students are expected to be consumers, rather than producers of knowledge. With the premise of engaging students as creators of knowledge our project team has been developing, through support from the National Science Foundation, a Geographic Information System technology-enhanced curriculum project to support students in learning about the impacts of urban forests on their city's climate, environment, energy use and how those factors impact climate change. It is the focus of this chapter to describe the program and how participation in the program has impacted student-learning outcomes.

BACKGROUND

About the Program: Why Use GIS to Explore Trees and Sustainability

Urbanization trends of the past century have shown a dramatic increase in the magnitude of cities. More than 300 cities have more than 1 million citizens, and 16 "megacities" have populations exceeding 10 million. In light of such pressures on population, urban natural resources, such as urban forests, watersheds, and wildlife are critical to maintaining cities and to providing economic, social, and public health benefits for metropolitan area residents worldwide (Pickett et al., 2008). At the forefront of ensuring the maintenance of urban systems are the young people who are and will be living in cities. All too often, unfortunately, urban students are not afforded the learning opportunities needed to understand and appreciate the ecological influence of their city, nor do they have the scientific skills to understand how their actions impact their urban ecosystem, how they can improve and change their city's ecosystem for the better, and how a healthy urban ecosystem impacts their own lives (Rees & Wackernagel, 2008). In fact, to date, teaching of ecology in high school classrooms has primarily focused on the study of areas where there has been relatively minimal human intervention. For example, in their 2004 review of environmental science high school textbooks, the Environmental Literacy Council (2004) found that very few books critically examined urban ecosystems, the impact of urbanization on the environment, and the role that humans have had in changing, creating, and impacting urban ecosystems.

Geospatial technologies such as GIS have emerged over the last fifteen years as one of the key tools used by environmental scientists (National Research Council, 2006). However, a disconnect exists between the research conducted by professional environmental scientists and how environmental science is taught in typical public school classrooms. Few students work with tools regularly used by scientists or pursue authentic inquiries using current scientific data, regional or global information, and available research tools (National Research Council, 2006). However, recently there has been a dramatic increase in the availability of user-friendly geospatial technologies for educators (such as MyWorld, Google Earth, and ArcExplorer) that has increased the potential for use of GIS technologies in schools. Our project team has been developing curriculum materials for use in urban schools that leverage ArcView, the premiere GIS software package and CITYGreen, an extension for ArcView, which allows students to evaluate the economic and ecological value of urban street trees and green space.

Context of Study

The Urban Tree Project is a two to three week project that was implemented in a high school environmental science, urban ecology, or environmental technology course. The project is built upon three ideas: First, students do not often understand or appreciate the ecological services that trees provide beyond simple removal of carbon dioxide from the atmosphere and the production of oxygen. Second, this project capitalizes upon the increased recognition that city street trees have significant positive ecological impacts and have a significant role to play in the fight against climate change (Donovan & Butry, 2009). Third, GIS have become indispensable tools for geoscientific exploration, commerce, and for decision making in environmental and social sciences related issues (National Research Council, 2006). Regardless of the application, it is possible to input geographically related data such that students can visualize data of interest or combine data to produce additional value-added information that might help answer a specific ecological problem. It is through this problem-solving process that students were engaged in the same practices as urban ecologists and urban planners.

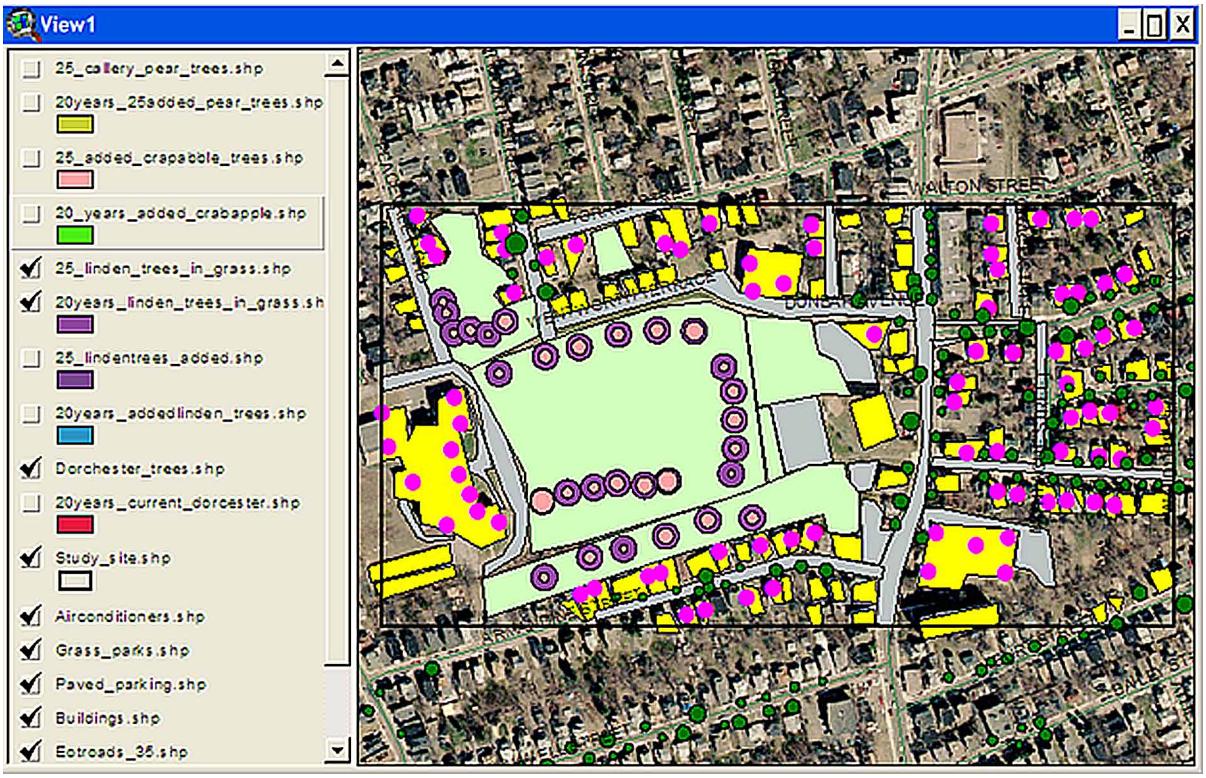
The Urban Tree Project was conducted using GIS technologies and CITYgreen, a software package develop by American Forests that works in conjunction with the GIS software package, ArcView. CITYgreen allows students to link each tree's location, through the use and labeling of satellite images, to a database of geographic and health information. This process enables students to conduct analyses regarding the economic and ecological benefits of urban trees. Subsequently, students collected data on tree location and condition in the field and used CITYgreen to evaluate the economic value of street trees using constructs such as storm water runoff, energy savings, and air pollution removal. The students also evaluated the impact of street trees on air quality and the rate of carbon sequestration to determine how much carbon is stored in their urban street tree sample. However, what is perhaps most powerful about this project is that students, through baseline data that they collected (or data from an existing street inventory for their neighborhood), asked "what if" questions regarding the impact of tree cover on air quality, the impact of trees on the collection of storm water runoff, and generally, the economic and ecological impact of trees and greenspace on their study site.

These questions led to timely, relevant, and authentic applications. One prime example was related to Boston's Big Dig where the city diverted major above-ground interstates into underground tunnels and reclaimed the roadways for greenspace. As a result, the city of Boston has been striving to plant 100,000 trees to increase the city's tree canopy from 26% to 35% (see http://www.bostonglobe.com/news/science/2012/07/07/boston-struggles-meet-pledge-planting-trees/3erBLCsecs4ILshlzNvloJ/story.html). Through the use of the ArcView and CITYgreen, students wrote a letter to the mayor of the city to request that trees be planted in particular areas, while justifying their reasoning with a dollar figure. Students were able to generate findings that were not only personally relevant, but also useful to policy makers and the general public (See Figure 1, 2 and 3 for examples of student work).

Pedagogical and Scientific Framework

Urban ecology is an important frontier for educators because the core skills and concepts integral to urban ecosystem education are well established in national and state science education standards (Hollweg, Pea, & Berkowitz, 2003). The field allows space for an integrated curriculum that combines the power of science *as a way of knowing* with the direct impact of active learning about and in service to the local community (Berkowitz, Nilon, & Hollweg, 2003). By developing science curricula around urban ecology

Figure 1. Students' GIS map of planting trees around their school in grassy areas and then evaluating their ecological and economic impact in 20 years. Students are able to "re-draw" their urban neighborhood and evaluate the impact of their tree planting locations on the environment. Note that in this project students have several layers (left side of the image) in which they have tested and evaluated various scenarios including whether Linden, Pear, or Crabapple trees are best to plant and they have also investigated where would be good locations to plant the trees

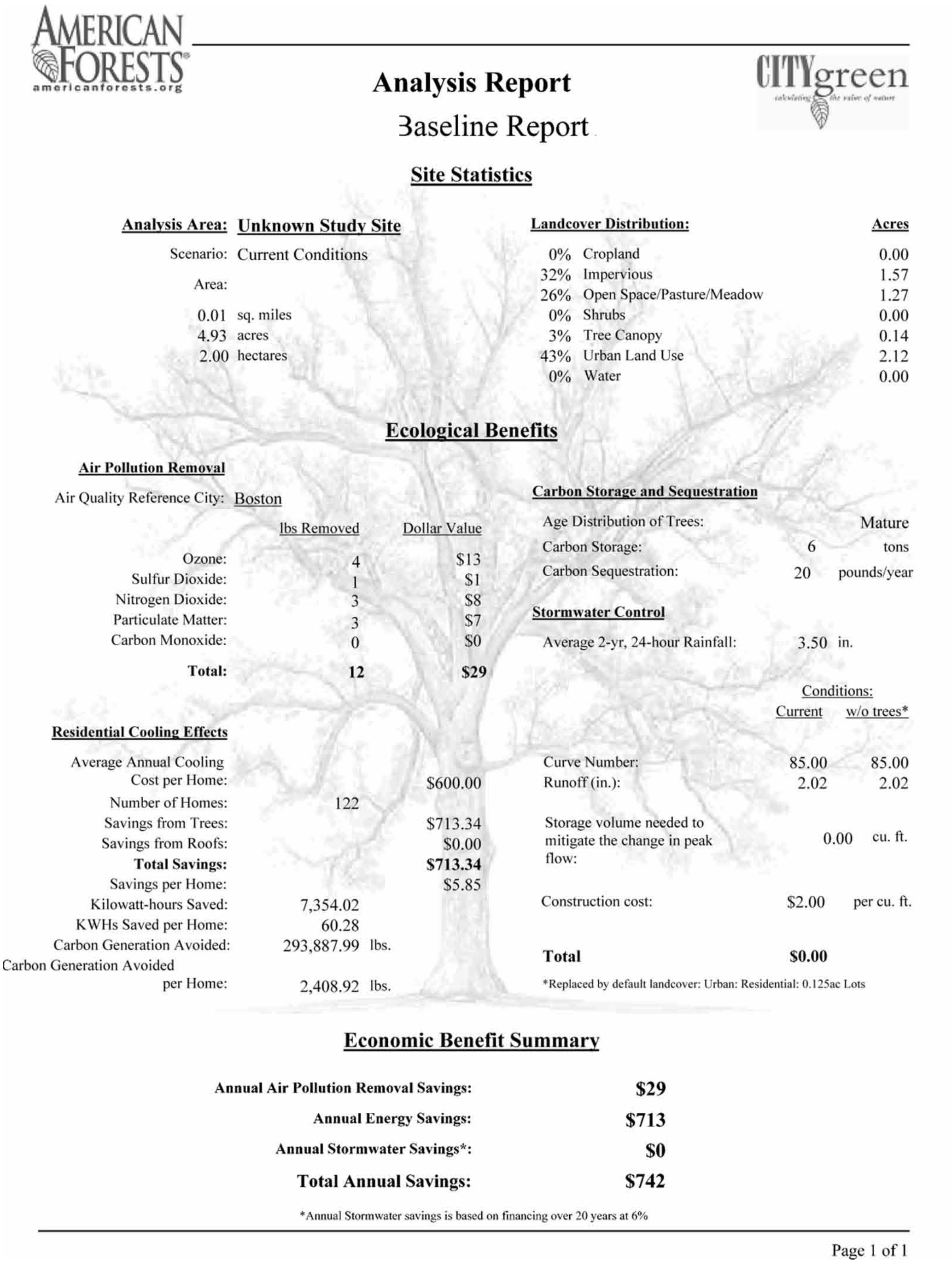


☐ 25_callery_pear_trees.shp
☐ 20years_25added_pear_trees.shp 🟨
☐ 25_added_crapabble_trees.shp 🟥
☐ 20_years_added_crabapple.shp 🟩
☑ 25_linden_trees_in_grass.shp
☑ 20years_linden_trees_in_grass.sh 🟪
☐ 25_lindentrees_added.shp 🟪
☐ 20years_addedlinden_trees.shp 🟦
☑ Dorchester_trees.shp
☐ 20years_current_dorcester.shp 🟥
☑ Study_site.shp ☐
☑ Airconditioners.shp
☑ Grass_parks.shp
☑ Paved_parking.shp
☑ Buildings.shp
☑ Eotroads_35.shp

constructs, students were immersed in relevant local and inquiry-oriented learning environments. This curricular strategy emphasizes both process and content, moving away from the "survey of the sciences" and "skill and drill" approach often found in traditional classrooms and textbooks, which, all too often, saps the excitement and curiosity from many urban students (Tidball & Krasny, 2010).

Urban ecologists engage in a variety of practices to understand urban ecosystems. Their specific research approach considers that bio-geophysical systems are tightly linked to the socioeconomic aspects of human life. Ecological systems are dynamic and shaped by forces that occur over long periods of time (presses) such as climate change, and short-term impacts (pulses) such as cataclysmic storms, tornadoes, or fire. Cities are studied as coupled human-natural systems. Given their holistic paradigm, urban ecologists tend to take a central role in trying to keep urban ecological systems sustainable through understanding the deep interconnectedness between humans and the natural environment (Alberti, 2008). Unlike traditional ecology which often attempts to understand an ecological system devoid of human interference and impact, urban ecology as a discipline embraces humans as a keystone species and tries to understand the impact that the human-built system is having on the environment and how these anthropogenic changes feed back on the forces and drivers that shape urban ecosystems. Thus,

Figure 2. A student generated report. This figure shows the impact of planting 25 trees and their ecological and economic impact on the neighborhood in 20 years. Students are expected to understand the science and be able to interpret the above report. Then, using this report, students can justify or argue for or against planting trees in particular locations in their neighborhood



AMERICAN FORESTS®
americanforests.org

CITYgreen
calculating the value of nature

Analysis Report

Baseline Report

Site Statistics

Analysis Area: Unknown Study Site

Scenario:	Current Conditions
Area:	
0.01	sq. miles
4.93	acres
2.00	hectares

Landcover Distribution:		Acres
0%	Cropland	0.00
32%	Impervious	1.57
26%	Open Space/Pasture/Meadow	1.27
0%	Shrubs	0.00
3%	Tree Canopy	0.14
43%	Urban Land Use	2.12
0%	Water	0.00

Ecological Benefits

Air Pollution Removal

Air Quality Reference City: Boston

	lbs Removed	Dollar Value
Ozone:	4	$13
Sulfur Dioxide:	1	$1
Nitrogen Dioxide:	3	$8
Particulate Matter:	3	$7
Carbon Monoxide:	0	$0
Total:	**12**	**$29**

Residential Cooling Effects

Average Annual Cooling Cost per Home:		$600.00
Number of Homes:	122	
Savings from Trees:		$713.34
Savings from Roofs:		$0.00
Total Savings:		**$713.34**
Savings per Home:		$5.85
Kilowatt-hours Saved:	7,354.02	
KWHs Saved per Home:	60.28	
Carbon Generation Avoided:	293,887.99 lbs.	
Carbon Generation Avoided per Home:	2,408.92 lbs.	

Carbon Storage and Sequestration

Age Distribution of Trees:		Mature
Carbon Storage:	6	tons
Carbon Sequestration:	20	pounds/year

Stormwater Control

Average 2-yr, 24-hour Rainfall: 3.50 in.

	Conditions: Current	Conditions: w/o trees*
Curve Number:	85.00	85.00
Runoff (in.):	2.02	2.02
Storage volume needed to mitigate the change in peak flow:	0.00 cu. ft.	
Construction cost:	$2.00 per cu. ft.	
Total	**$0.00**	

*Replaced by default landcover: Urban: Residential: 0.125ac Lots

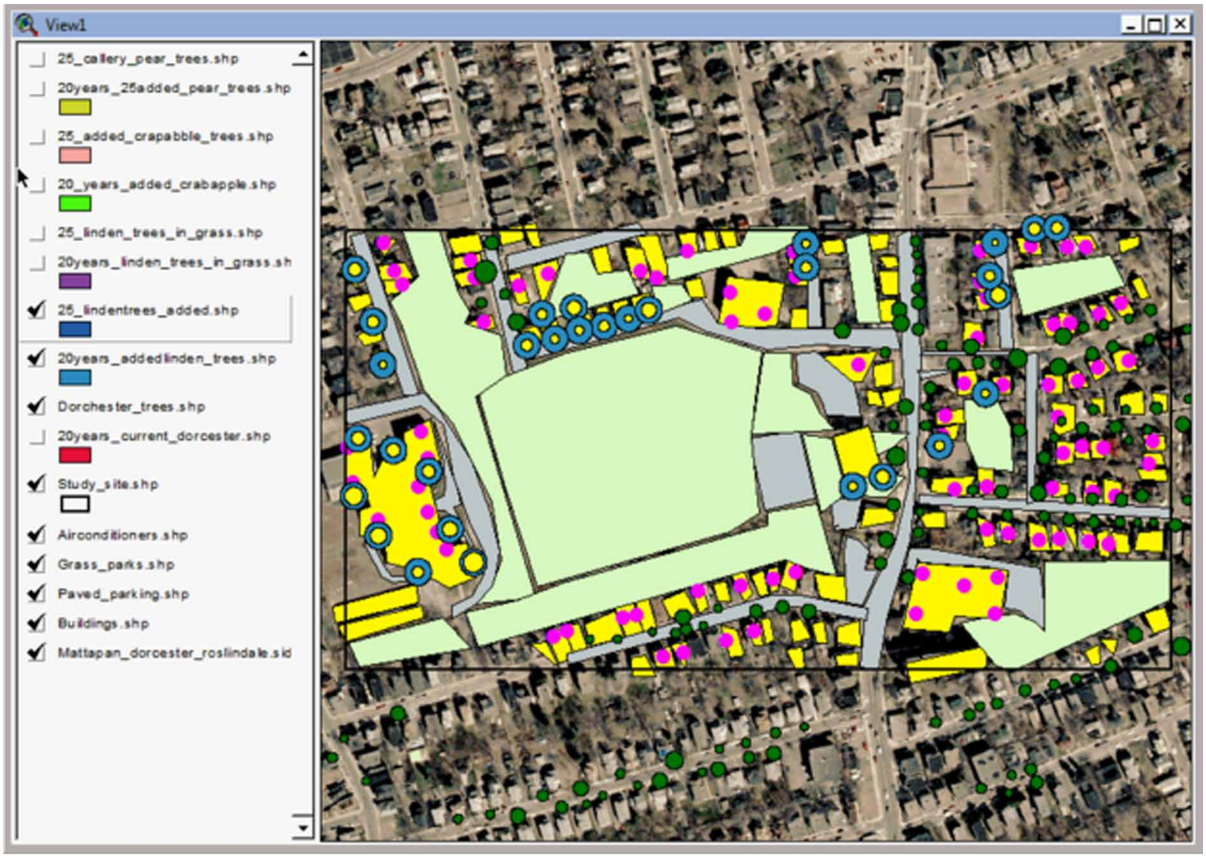
Economic Benefit Summary

Annual Air Pollution Removal Savings:	**$29**
Annual Energy Savings:	**$713**
Annual Stormwater Savings*:	**$0**
Total Annual Savings:	**$742**

*Annual Stormwater savings is based on financing over 20 years at 6%

Page 1 of 1

Figure 3. The yellow circles inside the blue circles represent the initial virtual planting of 25 four inch diameter American Linden trees. The blue circles show the growth of those trees after 20 years



an urban ecologist collects data with the goal of understanding how to solve complex urban problems, both social and natural, by developing land use plans, wildlife management strategies, and ecosystem service protections that function to simultaneously accommodate human needs and ease the burden on the natural places people use (for a review of the discipline, see Marzluf, 2008).

One approach urban ecologists commonly take is the development of data-driven models which allow them to visualize potential future scenarios, compare alternative scenarios, and describe implications of potential changes in the urban environment for both humans and the natural world. These findings are then communicated to stakeholders so that policy makers can make informed decisions about future development. In short, urban ecologists live at the intersection of social science, policy, and scientific research and through their expertise and interdisciplinary collaborations are well positioned to understand the unique problems facing urban areas today. As such, the field of urban ecology is nuanced and consists of multiple layers which make the use of geospatial technologies a critical tool to identify relationships and patterns between the various components of urban ecosystems. It is our hope that, through meaningful field study science projects, teachers will be able to use geospatial technologies to engage students in the practices of urban ecology.

Participants and Data Collection

Our research took place in three major locations with a total of 680 students. The first project was implemented in four inner city high schools (N = 215) whose population is mostly (94%) from students who are considered to be from underrepresented populations in science. The study was also conducted in an urban-suburban high school (N=385) whose population was quite diverse with 40% Caucasian, 30% Hispanic, 15% African-American, 10% Asian, and 5% a mixture of other cultures. The last location was an affluent suburban school whose population was predominately Caucasian (N=70, 88% Caucasian, 10% Asian-American, 2% other). Each of the implementations occurred in an environmental science classroom. For the purposes of this chapter, we are choosing to focus on the urban classrooms because we were able to collect pre-post interview data in those contexts. Further, during our quantitative analysis, we found that the program has the largest impact on students in the urban settings (which are explored below).

A mixed methods strategy was used for data collection in this research (Tashakkori & Teddlie, 1998). A pre-post content exam was administered that consisted of multiple choice items that were derived from standardized exam questions. Open-ended questions were also selected with the intention to probe student understandings more deeply. A subset of students at one of the urban schools, Chandler High (predominately African-American) were also randomly selected (N=30) and administered a pre-post semi-structured content interview to explore students' depth of understanding, their knowledge of GIS and their perceptions of their urban environment.

Data Analysis

Data analysis consisted of conducting a paired t-test analysis on the written survey and the development of a rubric for the students' open ended questions and interview responses (see Table 1 for example questions). The content exam reliability was found to be $\alpha = 0.75$. We assessed student understanding as measured by the open-ended exam responses by reading the student responses and scoring the student responses by a rubric. The rubric is based upon the categorization scheme used by a number of researchers (Keating, Barnett, Barab, & Hay, 2002). Both the pre and post-open-ended responses were scored using a rubric adapted to the question of interest. Two raters scored the open-ended exam responses and reached an inter-rater agreement of 0.82 (please see Appendix B for a full list of assessment questions).

In order to analyze the interview data, an inductive approach was used. The inductive approach is used to aid an understanding of meaning of the data through the development of summarizing themes from

Table 1. Example Content-focused questions for the Urban Tree Assessment

1. What is the trunk of a tree mostly made out of?
2.
    a. Water
    b. Soil and other nutrients
    c. Carbon
    d. A combination of soil and water
3. If you wanted to have the greatest impact on carbon dioxide emissions where would be the best location to plant a tree?
4.
    a. By itself in the middle of a park
    b. In a forested region
    c. In an urban residential area near a house
    d. d. In an urban area near a parking lot

the original interview data (M.B. Miles & A.M. Huberman, 1994). Recorded interviews were analyzed and transcripts of important information were listed by the research team. The transcripts were read individually several times and then the research team met to identify themes and categories. Together the research team identified commonalities across the interviews following a discussion amongst the entire research team. These discussions served both as a way to ensure reliability across the codes as they were developed and served as a way to identify confirming and disconfirming evidence regarding the emerging coding structure (Matthew B. Miles & A. Michael Huberman, 1994). Following an interpretative framework (Kelly & Lesh, 2000) to evaluate the codes the research team distilled the larger set of codes into a set of overarching codes. Upon identifying the final set of codes pairs of researchers were then assigned to write "mini-cases" around each of the themes. These mini-cases were then shared with other members of the research team to re-read to ensure that the data presented was not only consistent but also provided another opportunity to identify disconfirming evidence based upon the other mini-cases. This detailed and in-depth approach ensured high reliability within and across the themes that are presented in this chapter (Please see Appendix A for a full list of interview questions).

Below we present our quantitative findings with a focus on the urban schools and how the participation in the program impacted different groups (i.e. gender). In addition, our qualitative analysis led us to develop four themes: (1) ecosystem services provided by greenspace and trees, (2) personal awareness of greenspace, (3) student social perception of cities not connected to ecology, and (4) student understanding of ecological footprint. Each of these themes are explored in detail below.

RESULTS AND DISCUSSION

Quantitative Results

Pre-Post Results

During the research study, a total of 680 students were studied from seven different schools. Of the students in the seven schools, 470 students were in urban schools, 55 in suburban schools and 155 students were in schools that were a mix of urban and suburban (we classified the suburban schools as those with less than 10% free and reduced lunch and whose student body was mostly Caucasian). Comparing students by ethnicity 295 were African-American, 188 Hispanic, 93 White, 61 Asian, 2 Native American and 41 that fit into the other category (as self-reported by the students). All 680 students were given a pre-test and post-test to explore their understanding of the ecological impact of trees in their neighborhoods. Exploring the mean differences of the pre and post-tests, it was noted that there was a significant increase from the beginning of the Urban Tree Project to the end ($\mu_{pre} = 8.05$, $\mu_{post} = 17.46$, $SD_{pre} = 3.13$, $SD_{post} = 7.76$, $t = -61.067$, $p < 0.05$ and $Cohen's\ d = 1.59$) but some of the schools had greater increases in their pre to post scores than others (Table 2). In particular, Chandler High School showed larger increases compared to their peer schools (other highly diverse urban schools). It was also interesting to note that the most significant differences were not on the multiple choice pre-test and post-test comparisons, but the open response questions (see Table 1). This was particularly surprising because for many students, open-ended questions cause the most discomfort due to the difficulties associated with their comfort level with expressing their ideas in writing, scientific writing, or lack of practice in answering this type of question. Although all of the schools showed significant increases in scores from the pre-test to the

Table 2. Mean Scores by School

School	Pre-test Multiple Choice	Post-test Multiple Choice	t-test Multiple Choice	Pre –test Open Response	Post -test Open Response	t-test Open Response	Pre -test Total	Post -test Total	t-test Total
Chandler	1.83	7.06	-16.19	4.37	12.17	-24.40	6.20	19.23	-54.12*
Mt. Vista	6.47	17.16	-19.241	6.95	14.11	-11.96	13.68	31.26	-34.93*
Oneonta	2.09	7.13	-16.21	4.48	12.78	-19.60	6.57	19.91	-27.73*
Bellville	7.89	19.47	-23.25	7.53	14.92	-16.84	15.42	34.39	-62.27*
Waterville	4.72	10.73	-34.53	4.01	13.09	- 57.88	8.72	23.82	-106.07*
Tech High	2.93	3.10	-1.14	4.17	9.71	-41.80	7.10	12.81	-24.22*
Appleton Ridge	2.10	2.64	-2.119	5.10	9.63	-20.345	7.20	12.28	-11.487*

* significant with $p < 0.01$

post-test overall, expanding the data shows that one of the schools (Tech High) did not have statistically significant differences in the multiple choice questions ($\mu_{pre} = 2.93, \mu_{post} = 3.10, SD_{pre} = 2.29, SD_{post} = 5.77$, $t = -1.14$, $p < 0.05$ and *Cohen's d* = 0.08).

Gender Comparisons

When examining the gender effect of 334 female and 346 male students, we considered the pre-test and post-test scores for all schools. The results of a t-test do not yield significance on gender effects. The female scores ($\hat{\mu}_{pre} = 8.57, \hat{\mu}_{post} = 17.93, SD_{pre} = 3.50$, $SD_{post} = 8.74$, $t = -26.07, p < .05$, and *Cohen's d*= -1.41) were similar to the male scores ($\hat{\mu}_{pre} = 7.54, \hat{\mu}_{post} = 17.01, SD_{pre} = 2.64$, $SD_{post} = 6.65$, $t = -31.76, p < .05$, and *Cohen's d*= -1.87) for both the pre and post tests. When comparing the post-test between female and male students there was not a significant change in mean scores scores ($\hat{\mu}_{female} = 11.07, \hat{\mu}_{male} = 11.13, SD_{female} = 6.55$, $SD_{male} = 5.55$, $t = -0.34, p = 0.74$, and *Cohen's d*= -0.02). As a result, gender was not a factor that is explored further in this chapter.

Ethnicity Comparisons

In table 3, we show the disaggregated results by ethnicity across school sites. Across all sites, Black and Hispanic students had smaller changes between the pre- and post- tests than White, Asian, and Native American students. However, the difference in change between ethnicities was not significant. It is interesting to note the counter narrative presented by Chandler High School, as it is an urban school whose students are mostly Black with one of the largest changes pre-post. Overall, Black students had the smallest change pre-post by ethnicity, and urban schools overall had the smallest change pre-post by school type. It was also evident that the Suburban schools had overall bigger changes pre-post than urban schools. This was due in part because the suburban schools had covered many of the concepts in the urban tree project before and as such it was likely easier for the students to put together the many concepts and ideas than it was for students who were being introduced to the concepts for the first time.

With that said, we will focus on one school, Chandler High School, for the qualitative analysis. Chandler, an urban high school, had a total of 35 students in one environmental science class and was

Table 3. Written scores disaggregated by Race

Race	Pre-test Multiple Choice	Post Test Multiple Choice	t-test Multiple Choice	Pre-test Open Response	Post Test Open Response	t-test Open Response	Pre-test Total Score	Post Test Total Score	t-test Total Score
Black	2.88	4.11	-6.098	4.49	10.23	-37.803*	7.37	14.34	-22.478*
Asian	3.66	9.49	-19.484	4.28	12.52	-34.318*	7.93	22.02	-50.149*
White	5.62	13.96	-22.414	5.49	13.82	-31.367*	11.12	27.77	-65.635*
Hispanic	2.78	3.74	-4.123	4.41	10.18	-30.641*	7.19	13.93	-18.583*
Native American	6	13.5	-5	4.5	15	-7	10.5	28.5	**
Other	5.78	12.32	-18.003	4.17	13.1	-26.887*	9.95	25.41	-48.286*

* significant with $p < 0.01$

**The *t* cannot be computed because the standard error of the difference is 0

taught by an experienced teacher. The students in this class showed a higher difference in scores and a more significant difference from pre-test to post-test ($\mu_{pre} = 6.20$, $\mu_{post} = 19.23$, $SD_{pre} = 1.98$, $SD_{post} = 2.78$, $t = -54.117$, $p < 0.05$ and *Cohen's* $d = 0.31$) when compared to the other schools. Further, Chandler was one of the few schools that we were able to interview the students before and after the program implementation.

Qualitative Findings

The quantitative results provided us with evidence that the program was effective with regards to supporting students to develop sufficient understandings to do well on an assessment that was purposively designed to be aligned with the Urban Tree Project. However, we also wished to better understand if students were able to apply and extend their understanding to novel problems and situations. To that end, we conducted pre-post interviews to try to determine the depth of student understanding regarding urban ecological principles and to better understand their perceptions regarding the role and impact of green space and cities. Below, we present the four themes that emerged through our analysis of the semi-structured pre-post interviews.

Theme 1: Ecosystem Services Provided by Greenspace and Trees

In pre-interviews, the most commonly cited ecosystem service provided by trees was increased oxygen to the environment. Two students, Ajay and Antoine, identified this ecosystem service as part of their matter of fact list of the benefits that trees provide. Similarly, one student, Javier, connected this service's impact with humans, stating that trees "give off a lot of oxygen just for us to breath as people". Two additional students, Angela and Javier, without explicitly mentioning oxygen, also connected the role of trees to breathing. Angela also added that "without them we wouldn't be able to have fresh air." Both students reiterated this connection during their post-interviews where they also referenced a potential connection between location, tree quantity, and air quality but with a continued focus on the fact that trees are good because they help humans breathe.

In many instances, the students would call upon their personal experiences and beliefs regarding their interactions and observations with trees in the city. For example, one student, Angela, claimed, "if you come to [our city] and feel the air, and then you go somewhere totally different like Rhode Island or Vermont where there's more trees...you [will] feel the difference of how the air is". Another student, Jack, also claimed that even though he did not have asthma he could feel the difference while playing basketball. He stated that when he plays in an area with "a big garden and trees all over the place" that it is "easier" than usual - "it's just I breathe, easy".

In post-interviews, Deahadre and Danielle discussed the ecosystem service that trees provide by absorbing carbon dioxide from the atmosphere. Danielle was the only student to explicitly connect this service with that of providing oxygen when she stated that trees "provide us with oxygen and they take in the carbon dioxide that we put out there." Deahadre on the other hand connected this service with the reduction of carbon emissions by stating that trees "collect the carbon from the exhaust." Related to Deahadre's response, in pre- and post-interviews Jon alluded to the benefit of this service when he claimed that this service "reduces some of the pollution but not enough." This was replicated by another student who suggested that "fewer trees means it isn't as clean as it should be". Two other students echoed this idea that more trees are better for our health and that there are not enough trees to affect our health in cities.

Overall, the most cited ecosystem service mentioned in post-interviews was not related to any aspect of the oxygen–carbon dioxide cycle, but rather trees' ability to regulate temperature and/or provide shade. Interestingly, in the pre-interviews only one student mentioned trees' ability to provide shade. In the post-interviews five students discussed tree placement in relation to both shade and temperature regulation. Ajay, Jon, and Chanel were specific about their ground placement and shade. Specifically, Ajay claimed that people should generally "plant them towards the back of your house," while Chanel claimed that she would plant trees in the front of her house, and Joseph proposed that one should plant the tree "where the sun faces." Another student believed that the more trees you have the "cooler it is," but was not clear about the placement's effect. Cherise and Joseph went further in claiming a relationship between the increased shade provided by trees with "using less air conditioning in your house because it's cooler." Jack also discussed trees' ability to regulate temperature, but this time from the top of a building. He stated: "I know that without AC [air conditioning] it gets really, really hot everywhere, so if you plant trees and plants on top of the building, it can absorb all the energy, all the heat. We won't be as hot." These findings are interesting in that the students explored the concept of an urban heat island and the value of trees reducing the temperature (which in turn reduces pollution). However, when probed more deeply during the interviews, students were unable to create or explain the more complicated ecological systems services that trees provide or how trees and greenspace impact the ecological health of the city in a variety of ways. Instead, most students would focus on a single ecosystem service or a single idea (usually drawn from their personal experiences).

Theme 2: Personal Awareness of Greenspace

One of the major goals of environmental science education is to support students' awareness of the social, ecological, and economic values of greenspace in their communities. In particular, we were interested in exploring if curriculum that relied heavily on the use of geospatial computational tools would help students develop better awareness of greenspace through their participation. After comparing the pre-post interview results, we found that students seemed to be more aware of the green spaces around them, and the impact greenspace had on the environment, in post-interviews than they were in pre-interviews. This was particularly evident in the way students discussed the environmental health of their neighborhoods. In the pre interviews, students focused primarily on pollution to assess neighborhood health. For example, two students, Ajay and Andy, highlighted the trash and pollution they had noticed in their neighborhoods:

Ajay: *Because there's so much like trash on the street… there's tons of buses that go by my house and in the area. There's like only two trash cans on my whole street.*

Andy: *it looks kinda healthy but some things are kinda not the way I think they should look. Like there's a yard next to my house and it's nothing, it's just a bunch of broken down trees and some people throw trash in there sometimes, I've seen a lot of garbage in there.*

Only one student, Chad, explicitly connected greenspace to environmental health in the pre interviews. In his response he contrasted the pollution in his neighborhood with the comparatively greener, and healthier, suburbs:

Chad: *In the city, in some certain towns, like [neighborhood], they're just really bad [because of] the factories that they had, the buses, the gases they release, just builds up and makes it the way it is…I've honestly never been to a good area. Out of the city I have, in the suburbs like Bridgewater or Trevor or places like that, they're cleaner, you could know because there's a lot of trees. I mean maybe in the city there's places where there are a lot of trees, there's parks, maybe that's where the city is healthy.*

In all of these comments, however, the students appeared to pay more attention to the pollution in their neighborhoods than the presence or absence of greenspace.

In contrast, the post-interviews showed that most of the students noted the presence or lack of trees in their neighborhoods and what that meant in terms of community health. For example, for Ajay and Andy, the two students above, the presence of trees became a criterion by which they judged the health of their neighborhoods:

Ajay: *her neighborhood is not healthy "because it's lots of trash on the floor, there's lots of old abandoned buildings and lots of garbage in them. There's not a lot of trees. There is a big open field but like, it's basically dead, it's just dirt."*

Andy: *"Yeah, but I think it probably needs a little more trees, there's not that much trees. But behind my house there's a park, for Donald High, so that's probably a good thing."*

The focus on trees was consistent throughout the post interviews. For example, two other emphasized trees in describing the health of their neighborhoods:

Dany: *Well there's a couple of parks and there's a big park around and in that sense it's healthy, but it's actually not that clean around so I guess there is a lot of pollution.*

Angela: *City is not health "because we barely see trees, plants, stuff like that.*

The increased mentions of trees and parks in students' post-interviews indicated that the students became more conscious of the greenspace around them. Additionally, the students' comments on greenspace in post-interviews seemed to suggest trees and parks became an additional dimension in their judgments. Although they did not specifically mention why greenspace made their neighborhoods healthy, they did begin to recognize the presence, or absence, of greenspace, and the positive effects of greenspace on people's health.

Theme 3: Student's Social Perception of City Not Connected to Ecology

A challenge for many urban ecological educators is designing experiences that support students in understanding the ecological dynamics regarding how different types of living environments (i.e. suburban vs. urban) impact the larger environment. During the interview, the students were asked if they preferred to live in the suburbs or the city and why. Though the question was raised to find out if students gave weight to the ecological impact of living in suburban and urban areas, students provided social reasons to justify their choice. These reasons were not necessarily linked to the curriculum but instead reflected students' personal experience and preference.

Six of the students stated that they would remain in urban areas because they are used to that location. One student stated:

Because that's where I lived my whole life, and it would probably feel awkward to live somewhere more quiet, and you have to do more work when there's something so close together, you have to go real far when you live in the suburb.

As exemplified by this student, when asked about preferences on urban or suburban areas, students raised personal routines and experiences as reasons aside from ecological factors they have learned from the curriculum. However, three students stated that they would move to the suburban area because of good personal experiences (ex. Some family members currently or previously lived there) or bad ones (ex. Violence).

Students' social perception of how cities are designed also influenced students' preference. Three students mentioned that access to public transportation, supermarkets, services, and malls is easier in the city compared to suburban areas. Nevertheless, one student noted that the quality of urban resources is not the same:

In the city, you don't have a lot of access to healthy markets. There are a lot of corner stores and they sell unhealthy food that leads to obesity. In suburban areas you are more likely to have healthy markets around your house to get some fresh fruits and vegetables. In the city you don't have that, you have to drive out to get to that, it's not really close to the house and there's not that much many stores, there's like three or four.

Though student opinions differed, their perception of how cities and suburban areas are designed influenced their thinking processes.

Aside from student's personal experiences and perceptions of urban living, students also mentioned human diversity as a reason for living in urban areas. Two students felt strongly about being surrounded by diverse cultures and populations. For example, one student stated:

I will definitely stay in the city, even though it may not be healthy to live there. More people and the city is diverse. I like diversity. I am from a different country. I like diversity. I don't want to be in a place where everyone is the same--that's not healthy for me. I'm from Kurdistan Turkey. I'm Middle-Eastern. I've been here for eight years.

Thus, personal identities and culture was a factor in student preference. Though these were not necessarily discussed in the curriculum, how students viewed themselves in relation to the people around them mattered in their decision-making.

Finally, the students' perception of urban or suburban living was also a factor in their preference. Of the eight students who stated their preference for living in an urban area, three students mentioned that living in urban areas was more exciting than suburban areas. They liked having easy access to people and places. One student stated, "It's just like living in the suburbs you're just there. There's no real excitement." On the other hand, students who preferred suburban areas stated that it's "more peaceful and relaxed" and that suburban areas were "quieter, less problems." Therefore, students' conceptions of life experiences in urban and suburban areas also shaped their preference.

Some of the reasons students conveyed to justify their preference were well outside the boundaries of the curriculum. This suggests that despite learning about ecological impacts of urban and suburban areas—as depicted by the pre- and post-test quantitative results—students were nonetheless significantly influenced by their personal and social perceptions and experiences.

Theme 4: Student Understanding of Ecological Footprint

An important idea in urban ecology is for students to struggle with the concept of urban ecological footprint. The idea of urban ecological footprint is a complicated and multifaceted construct that embeds sustainability, social and economic aspects, biodiversity, and land-use influences on resources use. However, through the use of CITYgreen, students could explore at a neighborhood micro level regarding how land-use can influence the ecological impacts of the built environment. In this way, the Urban Tree project aimed to expose students to tradeoffs between non-urban living, which roughly tends towards more resource use per person and more greenspace, and urban living, which tends towards less greenspace and less resource use per person, and how different land-use patterns impact the environment. The curriculum aimed to help students consider that urban and non-urban areas impact the environment in complex ways, and one is not uniformly better or worse than the other. However, these concepts were not very well internalized by the students as their explanations remained consistent from pre-to-post interviews. Specifically, most students in the pre and post interviews noted that suburban areas were better for the environment than urban environments because there were fewer people. This understanding was based on the idea that because urban areas have more people living in the same amount of space, they produce more pollution than non-urban areas, which is worse for the environment. While it is true that there is a lower-population density in suburban areas that in urban areas, other aspects of the ecological footprint mean that higher density areas often have a lower ecological impact than suburban areas. An understanding of this complexity was not evident in students' responses.

In the pre-interviews when asked whether urban or non-urban living was more harmful for the environment, two students discussed the pollution produced in the two contexts:

Yeah, a single family [house] isn't as big, it wouldn't take up as much of the environment as [an apartment] complex would, and there's a lot of pollution capital from a complex because there's more than one person affecting that area

In my opinion I'd say city [is more damaging for the environment] because there [in the suburbs] they got a lot more grass and a lot more trees and here [in the city] there is a lot more pollution from cars, [in the suburbs] there's a lot more grass, clean air.

These quotes show an initial understanding of pollution and greenspace as important environmental factors. However, the focus in both is on the environmental impact per area rather than per person. While the second student pointed to the greenspace in non-urban areas as good for the environment, he did not consider that the spread of non-urban areas and comparative lack of public transit means that individuals in non-urban areas are more likely to own a car, drive farther distances, consume more fuel, and consequently produce more pollution per person than individuals in urban areas. Similarly, while the first student rightly suggested that an apartment complex would produce more pollution than one single family home, he did not consider the per person impact if everyone in the apartment complex lived in separate single family homes.

However, when the above students were asked the same question during the post-interview, their responses proved to be consistent with their pre-interviews as noted in the quote from the first student above:

Apartments [are more damaging] because overall it's more people living in one building so it's more energy being used.

This understanding was further echoed by other students in the post-interviews:

Probably a complex [is more damaging for the environment] because [you have] the house and you have a big yard, have a lot of green and helping the environment and have a lot of trees

In these quotes students considered resource consumption, waste and pollution production, and the positive contributions of greenspace in assessing whether urban or non-urban living was more damaging for the environment. However, they did not appear to consider the environmental impact of having the same number of people live in either an apartment complex or suburban homes. As in the pre-interviews, the students focused on the impact per area, and did not consider the ecological footprint per person.

Only one of the students interviewed considered environmental trade-offs and per person environmental impact of urban versus non-urban living:

They [urban areas] are damaging but at the same time I know that even in the suburbs I know that there is damage because everybody in the suburbs has a car. In the city people take public transportation which you know like let's say 40 people riding one bus that's 40 people but and like every house hold every person has a car that's like 1 person per car so and then they have bigger houses...use more fuel.

In contrast to the other students, this student discussed per person use of resources. The consideration of public versus individual transport, differences in size of living accommodations, and associated fuel consumption shows a deeper understanding of resource consumption and environmental impact than was expressed by the other students. With the exception of this student, an understanding of per person environmental impact and ecological footprint was missing from their responses, and appeared to be a challenging concept for the students.

SOLUTIONS AND RECOMMENDATIONS

Several research and development studies have found that GIS tools have the potential to provide students in all grades with a rich, inviting, and challenging problem-solving environment (Akerson & Dickinson, 2003; Baker & White, 2003; Carlson, 2007; Kerski, 2007; National Research Council, 2006; Stubbs et al., 2007). In fact, many educators have been successful with using these technologies in K-12 classrooms; however, little work has been reported on integrating geospatial technologies when coupled with ecological fieldwork and computer simulation tools like CITYgreen. We have found that embedding technologies as a central part of an environmental science course can be helpful in engaging students in thinking about urban ecology concepts and the value of greenspace, particularly for urban students, as evidenced by the performance on the written exams. However, we found that the students, despite performing well on the written exam, still struggled to understand the relationships between ideas and concepts that would lead to a deeper understanding of urban ecology and to connect the work they did using the geospatial computational modeling software to their own knowledge and experiences. We speculate that part of the reason for these results is that the written exam was written as an experience-near exam that was highly correlated to what the students were learning as a part of the project. On the other hand, the interviews were administered in order to gain an experience-distant assessment that tried to probe the depth and robustness of student ideas. This finding is similar to Ruiz-Primo and colleague's work (2002) in which they found that students performed better on experience near assessments as opposed to experience-distant assessments. As a result, both of these types of assessments provided valuable information regarding student learning and how the technology either supported or impeded learning. For example, our findings, particularly the qualitative interview findings, reveal that there are many challenges that remain in how to leverage the pedagogical potential of geospatial computational modeling in urban classrooms. Our findings suggest that a complementary approach in which emerging technologies and hands-on activities (particularly data collection) are integrated, with each activity informing the other, could be a very powerful technique for supporting student scientific understanding (as measured by the written exam), keeping in mind that it may be difficult for students to be apply that knowledge. One may consider this suggestion as a common sense approach, however— as found by a recent National Science Foundation workshop and the recent report on the research agenda for cyber-infrastructure development— there needs to be significant work that investigates how emerging visualization technologies can be leveraged to support "real life" scientific investigations and vice versa (Computing Research Association, 2006; NSF Task Force on Cyberlearning, 2008) and how to scaffold student learning in a way that the technology allows students to create connections between complex phenomena.

FUTURE DIRECTIONS FOR TEACHERS

Current state and national environmental science education reform policies and practices emphasize the importance of students understanding how to care for and about their environment. Implicit in these initiatives is the assumption that students need to be engaged in real-world scientific experiences that engage and support them in learning about the process of science and how to become caretakers for their environment. Several research and development studies have found that GIS has the potential to provide students in all grades with a rich, inviting, and challenging problem-solving environment (see Barnett, Makinster, Trautman, Houle, & Mark, 2012 for a review). The complexity of the technology, however, has hindered widespread acceptance and limited the use of GIS technology with students (NRC, 2006). The work presented here aimed to mitigate this inherent complexity by explicitly connecting the use of the technology with real-world experiences. The program included a hands-on set of experiences such as identifying trees, determining the health of trees, and collecting temperature data around the school, that served as the foundation upon which the use the geospatial technology was based (for a detailed description regarding implementation see Barnett, et al., 2010). Without the connection between the real-world data collection and the geospatial modeling technology the latter is reduced to the use of a complicated software product to produce results that have little relevance to the local context. Explicitly tying the real-world data collection to the geospatial modeling technology helps students understand the connections between the activities and the technology, and how the technology supports and extends the analysis of the collected data. This enriches both the use of the technology as a learning tool and students' opportunities to engage in real-world, locally relevant, environmental problem-solving.

ACKNOWLEDGMENT

This work is supported in part through a National Science Foundation Information Technology Experiences for Students and Teachers (ITEST) program (Grant # 0525040); Hewlett Packard Foundation – Teaching with Technology Program (Grant# 189660).

REFERENCES

Akerson, V. L., & Dickinson, L. E. (2003). Using GIS Technology To Support K-8 Scientific Inquiry Teaching and Learning. *Science Educator*, *12*(1), 41–47.

Alberti, M. (2008). *Advances in Urban Ecology: Integrating humans and Ecological Processes in Urban Ecosystems*. New York: Springer. doi:10.1007/978-0-387-75510-6

Baker, T. R., & White, S. H. (2003). The effects of GIS on students' attitudes, self-efficacy, and achievement in middle school science classrooms. *The Journal of Geography*, *102*(6), 243–254. doi:10.1080/00221340308978556

Barnett, M., Houle, M., Hirsch, L., Minner, D., Strauss, E., Mark, S., & Hoffman, E. (2013). Participatory professional development: Geospatially enhanced urban ecological field studies. In J. Makinster, N. Trautmann, & M. Barnett (Eds.), *Teaching Science and Investigating Environmental Issues with Geospatial Technology: Designing Effective Professional Development for Teachers* (pp. 13–33). New York, NY: Springer.

Barnett, M., MaKinster, J., Trautmann, N., Houle, M., & Mark, S. (2012). Geospatial technologies: The present and future roles of emerging technologies in environmental education. In R. Stevenson, M. Brody, J. Dillon, & A. Walls (Eds.), International Handbook of Research on Environmental Education (pp. 327-344). Washington, DC: American Educational Research Association.

Berkowitz, A., Nilon, C., & Hollweg, K. (Eds.). (2003). *Understanding urban ecosystems: A new frontier for science and education*. New York: Springer.

Carlson, T. (2007). A Field-Based Learning Experience for Introductory Level GIS Students. *The Journal of Geography*, *106*(5), 193–198. doi:10.1080/00221340701697636

Computing Research Association. (2006). *Cyberinfrastructure for Education and Learning for the Future: A vision and research agenda*. Author.

Donovan, G. H., & Butry, D. T. (2009). The value of shade: Estimating the effect of urban trees on summertime electricity use. *Energy and Building*, *41*(6), 662–668. doi:10.1016/j.enbuild.2009.01.002

Environmental Literacy Council. (2004). Retrieved February, 22, 2006, from http://www.enviroliteracy.org/article.php/1126.html

Folger, P. (2008). *Geospatial information and geographic information systems (GIS): Current issues and future challenges*. Washington, DC: Congressional Report Service for Congress.

Hollweg, K., Pea, C. H., & Berkowitz, A. R. (2003). Why is understanding urban ecosystsm an important forntier for education and educators? In A. R. Berkowitz, C. H. Nilon, & K. Hollweg (Eds.), *Understanding urban ecosystems: A new frontier for science and education* (pp. 19–38). New York: Springer. doi:10.1007/0-387-22615-X_2

Keating, T., Barnett, M., Barab, S. A., & Hay, K. E. (2002). Developing conceptual understanding of scientific concepts through building three-dimensional computational models. *Journal of Science Education and Technology*, *11*(3), 261–275. doi:10.1023/A:1016024619689

Kelly, A. E., & Lesh, R. A. (Eds.). (2000). Handbook of Research Design in Mathematics and Science Education. Mahwah, NJ: Lawrence Erlbaum Associates.

Kerski, J. J. (2007). *The Implementation and Effectiveness of Geographic Information Systems Technology and Methods in Secondary Education*. Retrieved from http://gis.esri.com/library/userconf/proc01/professional/papers/pap191/p191.htm

Marzluf, J. (2008). *Urban Ecology: An International Perspective on the Interaction Between Humans and Nature*. New York: Springer. doi:10.1007/978-0-387-73412-5

Miles, M. B., & Huberman, A. M. (1994). *An Expanded Sourcebook: Qualitative Data Analysis* (2nd ed.). Thousand Oaks, CA: Sage.

Miles, M. B., & Huberman, A. M. (1994). *Qualitative data analysis: An expanded sourcebook* (2nd ed.). Thousand Oaks, CA: Sage.

National Research Council. (2006). *Learning to think spatially: GIS as a support system in the K-12 curriculum*. Washington, DC: National Academies Press.

National Science Board. (2014). *Science and engineering indicators, 2014: A broad base of quantitative information on the U.S. and international science and engineering enterprise*. Washington, DC: Author.

National Telecommunications and Information Administration. (2000). *Falling through the net: Toward digital inclusion*. Washington, DC: Author.

NSF Task Force on Cyberlearning. (2008). *Fostering Learning in the Networked World: Learning Opportunity and Challege, a 21st century agenda for the National Science Foundation*. Arlington, VA: National Science Foundation.

Pickett, S. T. A., Cadenasso, M. L., Grove, J. M., Nilon, C. H., Pouyat, R. V., Zipperer, W. C., & Costanza, R. (2008). Urban Ecological Systems: Linking Terrestrial Ecological, Physical, and Socioeconomic Components of Metropolitan Areas. In J. Marzluff, E. Shulenberger, W. Endlicher, M. Alberti, G. Bradley, C. Ryan, & C. ZumBrunnen et al. (Eds.), *Urban Ecology* (pp. 99–122). Springer, US. doi:10.1007/978-0-387-73412-5_7

Presidents Council of Advisors on Science and Technology. (2012). Engage to Excel: Producing one million additional college graduates with degrees in science, technology, engineering, and mathematics. Washington, DC: Author.

Ramamurthy, M. K. (2006). A new generation of cyberinfrastructure and data services for earth system science education and research. *Advances in Geosciences*, *8*, 69–78. doi:10.5194/adgeo-8-69-2006

Rees, W., & Wackernagel, M. (2008). Urban Ecological Footprints: Why Cities Cannot be Sustainable—and Why They are a Key to Sustainability. In J. Marzluff, E. Shulenberger, W. Endlicher, M. Alberti, G. Bradley, C. Ryan, & C. ZumBrunnen et al. (Eds.), *Urban Ecology* (pp. 537–555). Springer, US. doi:10.1007/978-0-387-73412-5_35

Ruiz-Primo, M. A., Shavelson, R. J., Hamilton, L., & Klein, S. (2002). On the evaluation ofsystemic education reform: Searching for instructional sensitivity. *Journal of Research in Science Teaching*, *39*(5), 369–393. doi:10.1002/tea.10027

Stubbs, H. S., Fowler, K., Ball, J., Singh, N., Whitaker, D., & Hawley, B. (2007). Educational Environmental Projects, using Technology Applications, For Middle School Students in Formal and Non-Formal Settings. *Meredian: A Middle School Computer Technologies Journal*. Retrieved from http://www.ncsu.edu/meridian/sum2003/gis/3.html

Tashakkori, A., & Teddlie, C. (1998). *Mixed methodology: Combing qualitative and quantitative approaches* (Vol. 46). Thousand Oaks, CA: Sage.

Tidball, K., & Krasny, M. E. (2010). Urban environmental education from a social-ecological perspective: Conceptual Framework for Civic Ecology Education. *Cities and the Environment, 2*(1).

APPENDIX 1: INTERVIEW QUESTIONS

Introduction/Background

1. First we just need some basic information.
    a. What is your name?
    b. What grade are you in?
    c. What science classes are you taking right now?

About Cities/lifestyle

2. Do you think your city or your neighborhood that you live is healthy from an environmental perspective? Why or why not?
3. How many acres of land (in acres and an acre is about a football field) do you think it takes to support your lifestyle (the way you live and consume now)?
4. Imagine someone told you that large cities are the primary cause of the worst ecological damage that humans have caused to the Earth. Would you agree or disagree? Why?
    a. Imagine you were looking at a map of the world. And you saw Boston.
    b. How much land (in acres) do you think is needed to support the city of Boston?
5. Which do you think is less damaging to the environment (1) Living in a large apartment complex, (2) living in a house in the suburbs with a large yard. Why?
6. If you had your option of where you would want to live where would that be? Would you choose to live in a high density urban area like a city or would you choose to live in an area where there were single houses with yards?

Curriculum and Content

7. What do you think is the impact of trees that live in the city on the environment?
8. Now when you look at a tree you see that is really big.
    a. Do you know what a tree is made of?
    b. Why do you say is tree made of (what the student says here)?
9. Imagine someone asked you to develop a research question for figuring out the impact of trees on a region. Can you describe for me what information you would need to develop a research question?
10. Imagine that someone from Grow Boston Greener and they are trying to figure out where to plant a set of trees in the city. Can you describe for me some of the issues that Grow Boston Greener would need to worry about where to plant their trees in the city?
11. Imagine you had the opportunity to plant trees around your school or house. Where would you plant them and why?
    a. What kind of trees would you plant and why?
12. You have probably heard of the idea of global warming?
    a. Can you describe for me what global warming is?
    b. What is causing global warming?
    c. What is the impact of city trees (trees on the sidewalk) on global warming? Anything?

13. You have probably heard about Ozone before?
    a. Can you tell me what Ozone is?
        i. Can you tell me where Ozone is located in the atmosphere? What is the purpose of it?
    b. Does Ozone affect global warming? How and in what ways?
    c. Does Ozone affect our health? Why?

APPENDIX 2: ASSESSMENT

Part II

1. The primary cause for the Earth's greenhouse effect is:
    a. Water vapor in the atmosphere
    b. An increasingly hot Sun
    c. Increasing Carbon Dioxide in the atmosphere
    d. Decreasing ozone levels in the atmosphere
2. Ozone, a gaseous molecule, near the ground can lead to several detrimental health effects. Which of the following is true about the formation of ground level ozone?
    a. Ground level ozone formation is inversely related to temperature
    b. Ground level ozone formation increases rapidly as temperature increases
    c. Ground level ozone formation is dependent upon the water vapor in the air
    d. None of the above
3. If you were the mayor of the city of Boston and you want to help reduce the urban heat island effect in your city what would you recommend (choose what would probably work the best)?
    a. Paint all the rooftops white
    b. Plant more trees
    c. Create more green spaces (e.g. parks)
    d. All of the above
4. Trees may be valuable in saving a city money in terms of sewer costs due to heavy rainfall because
    a. Trees decrease the temperature of the city which prevents rainfall
    b. Trees increase the amount of time a sewage system has to absorb water runoff
    c. Trees speed up the flow of water into the sewage system
    d. Trees' leaves prevents most of the rainfall from ever reaching the ground
5. Which type of tree do you think would absorb the most Carbon Dioxide in one year?
    a. An old tree with a very large crown
    b. A young slow growing tree
    c. A young fast growing tree
    d. An old tree with a many braches
6. What is the trunk of a tree mostly made out of?
    a. Water
    b. Soil and other nutrients
    c. Carbon
    d. A combination of soil and water

7. When you indentify a tree which of the following would you probably not look at?
   a. Leaf shape
   b. Seed shape
   c. Crown size
   d. Bark
8. If you wanted to have the greatest impact on carbon dioxide emissions where would be the best location to plant a tree?
   a. By itself in the middle of a park
   b. In a forested region
   c. In an urban residential area near a house
   d. In an urban area near a parking lot
9. Carbon sequestration is
   a. The production of carbon dioxide by cars
   b. The amount of carbon that is produced by burning one tree
   c. The amount carbon dioxide that is in the Earth's atmosphere
   d. The removal and storage of carbon from the Earth's atmosphere
10. If you were given the opportunity to plant a ***maple tree*** near your house or school and you wanted to maximize the energy benefits where would you plant the tree?
    a. On the western side of the house
    b. Very close to house and on the northern side of the house
    c. On the southern side of the house
    d. On the eastern side of the house
11. An instrument that measures that is used to measure the height of a tree is:
    a. Gauge
    b. Clinometer
    c. Caliper
    d. Spectrometer

Part II: Short Answer and Essay Questions

Below you will find four questions that require you to write a response. Do not worry if you cannot answer the question completely and if you are not sure please write down what you think. Again, you responses will not count toward your grade.

12. Our city is planning to increase its tree canopy from 26% to 35% within the next ten years. Describe at least two potential benefits of increasing the tree canopy to the citizens of our city?
13. Below is a picture of a local high school area in your city. The red areas represent houses. The blue areas represent parking lots. The pink dots are air conditioning units and the green circles are trees. Now imagine that you had funds to plant 15 new trees and you wanted to maximize the health and economic benefits of those trees where would you plant them? Mark where you would plant them with an X and explain why you would plant them there?

14. You have been asked to make a presentation about Geographic Information Systems. How would you explain what a Geographic Information System is to someone? You can do this by either describing your idea in words or by drawing and labeling a picture.
15. Recently your city reported that the street trees in the city were worth nearly $50 million dollars? How do you think the city foresters determined that the trees were worth that amount of money?

Chapter 12

Using Technology to Rethink the Intersection of Statistics Education and Social Justice

Lisa L. Poling
Appalachian State University, USA

Nirmala Naresh
Miami University, USA

Tracy J. Goodson-Espy
Appalachian State University, USA

ABSTRACT

A critical consumer is able to ask questions and discern information about data—its collection and analysis, and is able to judge whether conclusions are warranted (GAISE, 2007; Best, 2001). Promoting statistical knowledge by exploring social issues that create disparities helps individuals foster initiative for positive change and engage in equitable practices (Moses & Cobb, 2001; Gutstein, 2006). This chapter explains investigations suitable for use with pre-service/in-service teachers and middle school or high school students. Investigations were structured to help participants: 1) Engage in statistical problem solving using real data; 2) Focus on the process of statistical investigation (Rossman & Chance, 2012); and 3) Consider statistics as a means of promoting social change. A description of investigations and sample artifacts are included.

INTRODUCTION

Will saving the poor children of the world from dying of disease lead to overpopulation? This stunning question was recently posed by Hans Rosling of the Gapminder Foundation (http://gapminder.org/videos/will-saving-poor-children-lead-to-overpopulation/). Rosling was obviously not suggesting that this is the case; rather he was drawing awareness to the fact that sometimes erroneous beliefs may, consciously or unconsciously, influence people's actions or their failure to act. Beliefs and opinions concerning such

DOI: 10.4018/978-1-4666-9616-7.ch012

questions are critical, as some individuals serve in positions of power and are able to make decisions that can impact world problems, such as funding aid to poorer countries. Others will influence policy-makers by their votes and by voicing public opinion, or through engagement with private corporations or foundations. Beliefs motivate individuals to spur action or may cause serious societal harm. The following sections describe this chapter's theoretical foundations, including the use of critical statistics pedagogy to promote social justice, the role of specialized technologies in statistical explorations, and an explanation of how this work is framed in connection to the development of technological pedagogical content knowledge (TPACK). Investigations suitable for use with middle school or high school students or with pre-service/in-service teachers are illustrated and some samples of student work are shared.

Background

Critical statistics acknowledges the political nature of knowledge and how data can be construed and misrepresented when used in a public arena. Understanding how statistical knowledge is valued and who is making decisions helps individuals better understand social realities and how power struggles are enacted and sustained. Garfield and Ben-Zvi (2008) note that in the realm of statistics, "context provides meaning for the numbers, and data cannot be meaningfully analyzed without paying careful consideration to their context" (p. 8). Critical consumers of data are able to think and reason about statistics and use statistical tools to better explore and understand issues that are significant to their immediate community and the broader world.

Critical Statistics Pedagogy to Promote Social Justice

The mathematics education community acknowledges that the study of mathematical knowledge has a value dimension and that such study is a social and cultural phenomenon (Bishop, 1988). This is apparent in the morality of the question posed by Rosling in this chapter's introduction. Critical pedagogy, the umbrella under which critical statistics falls, is an "attempt to be discerning and attentive to those places and practices in which social agency has been denied and produced" (Giroux, 2011, p. 3). Critical pedagogy brings attention to oppression and allows individuals to become agents of change that promote social change over time (Frankenstein, 1987). Skovsmose (1985) states that when implementing critical education pedagogy two criteria, subjective and objective, need to be used when selecting problems for the classroom. First, the subjective, requires that the problem appears relevant to the students and within the realm of their conceptual understanding. The second, the objective, requires using an existing social issue to help students build deeper understanding. Thus, the activities that are described in this chapter focus on teaching students to pose questions pertaining to real-world problems and to use actual data from reliable sources to hypothesize mathematically-grounded answers to their inquiries and to consider the ethical nature of their observations or proposed solutions.

Frankenstein (1995) explains critical statistics as asking students to, think "critically by examining its [statistics] underlying interests and methods of collection, description and inference, and by considering historical, philosophical, and other theoretical insights along with statistical knowledge" (p. 192) to build the capacity to enter into meaningful conversations. Skovsmose (2011) furthered the idea of critical mathematics *(statistics)* by discussing the notions of *situation, students' foreground, landscapes of investigation, critical conceptions, mathematics in action* and *mathemacy*. He referred to *situation* as the wide diversity of settings one encounters when engaging in teaching and learning mathematics internationally and how these instructional settings are impacted by social, cultural, political and economic contexts. Students' *foreground* pertains to how students construct mathematical meanings based on both their local situation and also their ability to visualize and experience different mathematical learning possibilities. *Landscapes of investigation* include educational possibilities for students that may fall beyond the context of school mathematics. *Critical conceptions* of mathematics and *mathematics in action* require one to consider how mathematics is used to create our technological, environmental, social, and economical worlds. *Mathemacy* is therefore defined as "mathematics education for critical citizenship" (p. 3).

Taking into account Skovsmose and Frankenstein's work, critical statistics education provides a context that allows individuals to pose meaningful inquiries and to draw conclusions based on thoughtful analysis of data. Statistics education, when implemented using critical education pedagogy, allows individuals to work toward quantitative literacy and, in turn, develop into more critical consumers of knowledge. In this way, the consolidation of statistics and social justice provides a platform to initiate meaningful conversations about issues that impact our world and prepare individuals for active citizenship.

The Use of Technology to Promote Statistics Education

A balanced focus on content, pedagogy, and technology is the key to emphasizing meaning in statistics education (Chance, Ben-Zvi, Garfield, & Medina, 2007). Technology has greatly revolutionized the field of statistics education and has made statistics more accessible to students. Effective use of technology enables learners to focus more on data interpretations and conclusions than on data displays and analysis. Thus, there is a significant push for strategic use of technological tools to maximize the potential for the teaching and learning of statistics in K-16 education. Students must be able to use technological tools efficiently and strategically, in tandem with data, to better understand the "possibilities and dangers, [and] the morality supporting the use of technology" (D'Ambrosio, 2007, p. 29). Technology in statistics education allows individuals, both novices and critical consumers, to make decisions that are grounded in facts and logic.

Technology, for the purposes of this paper, is defined as, "any systematized practical knowledge, based on experimentation and/or scientific theory, which enhances the capacity of society to produce goods and services, and which is embodied in productive skills, organization or machinery" (Saettler, 1990, p. 4). Many technological aids are widely available for use in mathematics courses. These include statistical software, educational software, spreadsheets, graphing calculators, stand-alone applications, and multimedia materials (Chance, Ben-Zvi, Garfield, Medina, 2007). This chapter points to tools that are aimed at supporting student growth and those that are judged as most helpful in attending to the key learning goal – generating and fostering critical reflection on the use of statistics to explore social justice issues. Tools such as *Gapminder*, *Population Connection*, *Population Pyramid*, *Census @ School Project*, *Radical Math*, the Journal of Statistics Education Data Archive, or information made available via the Statistics Education Web, allow individuals to see and use data sets that enable students to formulate questions and analyze and interpret the answers to their inquiries. These tools also allow prospective teachers to generate statistical questions across various contexts and engage in statistical problem solving. Below, a brief overview is provided of some of the tools referenced in the activities shown in a following section.

Gapminder

Gapminder (http://www.Gapminder.org) is a powerful tool that integrates data sets in a user-friendly interface that allows individuals to establish self-selected parameters based on specific questions. In conjunction with the Ignorance Project (http://www.gapminder.org/ignorance/), new teaching materials are developed in response to knowledge gaps identified through surveys in which respondents answer questions about key-aspects of global development. Questions that may be explored through Gapminder, include statistics related to the environment, the economy, or health, as in Rosling's question posed in this chapter's introduction. The developers of Gapminder understand that sometimes facts are counterintuitive to preconceived notions. Therefore, Gapminder's developers realized that solid explanations based on hard data are often required. All of the data sets used in the Gapminder program come from well-established databases such as International Labour Organization, World Bank, UNICEF, and the Food and Agriculture Organization. Gapminder allows users to explore data sets while alleviating the burden of computing statistical information. An investigation using this tool is explored in a following section.

Population Connection America's Voice for Population Stabilization

Originally introduced as Zero Population Growth (ZPG), Population Connections' (http://www.populationconnection.org/site/PageServer) quest is to raise awareness regarding the effects of population growth. Population Connection allows individuals to look at various data sets for a multitude of countries. Items such as population growth rate, youth dependency, elderly dependency, infant mortality rate, and life expectancy are reported for each respective country, allowing students to compare and contrast countries and begin to ask questions about why differentiations exist among nations.

Population Pyramid

The Population Pyramid (http://populationpyramid.net/) creates a graph that shows the age-sex distribution of a given population. Gender is shown on the left/right sides, age on the y-axis, and the percentage of population on the x-axis. A population pyramid, based solely on specific demographics, displays percentages of the people who align with that category. Trends can be explored using the data provided in a population pyramid. For example when looking solely at overall population, a representation that is more rectangular depicts a population that is growing at a slower rate. In these societies, newer generations are growing at a rate similar to older generations. Whereas, a graph that is more triangular indicates a faster growing population because newer generations are growing at a rate faster than older generations and the opportunity for an increase in population exists. An investigation involving this tool is also shown in a following section.

Census @ School Project

This project is available on the American Statistical Association's website, http://www.amstat.org/censusatschool/. Data collected from students in grades 4-12 from various countries are available from this data source. Teachers can engage their students in four-step statistical problem solving by encouraging them to develop a research question, analyze data, and interpret data to address this research question. An example using this tool is shown later in this chapter.

Radical Math

Radical Math (http://www.radicalmath.org/) began in 2006 and is comprised of over 700 lessons that integrate issues of social and economic justice into current mathematical strands. In conjunction with lesson plans, this site provides articles, data sets, book suggestions, and links to other websites that promote similar social philosophies.

Journal of Statistics Education Data Archive

The *Journal of Statistics Education* data archive, (http://www.amstat.org/publications/jse/jse_data_archive.htm) is slightly different than the previous referenced resources in that established activities are contributed and peer-reviewed before inclusion in the archive. Each activity includes the data set used for the exploration as well as an article that describes the activity and the models created by the data sets.

Statistics Education Web (STEW)

STEW (http://www.amstat.org/education/STEW/) is an on-line collection of peer-reviewed statistics resources for K-12 educators. STEW lesson plans outline the statistical concepts being acquired (e.g., comparing distributions), grade levels addressed, and the corresponding standards that are met through the exploration.

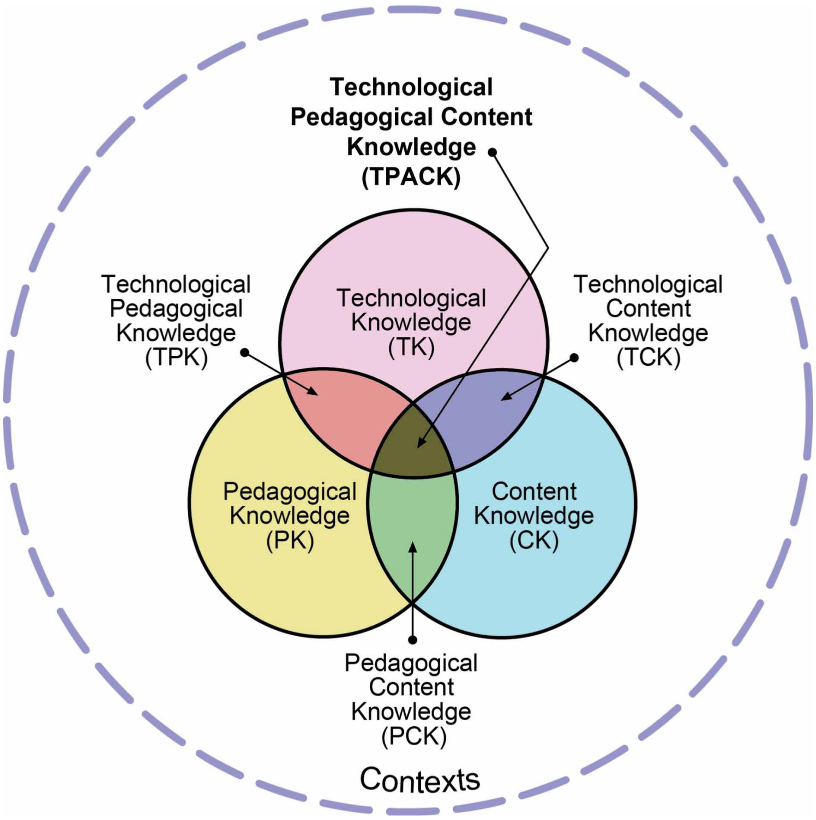
Other technology sources that can be used to promote statistical thinking include resources such as Technology, Entertainment and Design Talks (TED) (http://www.ted.com/), YouTube videos (https://www.youtube.com/), and the website Teaching Tolerance (http://www.tolerance.org/). Although each of these resources does not promote statistics education specifically, they offer starting points for critical analysis involving statistics. One example of a TED talk that promotes statistical reasoning is presented by Hans Rosling (2007) titled, *Debunking myths about the third world* (http://gapminder.org/videos/hans-rosling-ted-2006-debunking-myths-about-the-third-word/). In a subsequent section, a lesson initiated by this TED Talk is described in further detail. These are some resources that are helpful in supporting the tenets of social justice and promoting the engagement of active citizenry through the use of statistics. The following section explores how the activities described in this chapter relate to the development of technological pedagogical content knowledge when used with pre-service and in-service teachers.

Connections to Technological Pedagogical Content Knowledge (TPACK)

Shulman (1986, 1987) introduced a construct known as pedagogical content knowledge (PCK) described as a teacher's ability to integrate domain knowledge from a content area with fitting pedagogical approaches so that learners can successfully comprehend instruction. Koehler & Mishra (2005) claimed that PCK was inclusive of the appropriate use of technologies in teaching. In 2007, the acronym was modified to TPACK (Thompson & Mishra, 2007) to refer to Technology, Pedagogy, and Content Knowledge and was referred to as the "Total PACKage" for effectively teaching with technology (Voogt, Fisser, Pareja, Roblin, Tondeur, & van Braak, 2013, p. 109). See Figure 1.

In the outer circle of the TPACK image, one notes the label, *Context.* The activities that are illustrated in the following section of this chapter are directed at helping participants (middle school or high school students or pre-service or in-service 6-12 teachers) learn about statistics content within the broader

Figure 1. TPACK Image, Reproduced by permission of the publisher, © 2012 by tpack.org



context of learning about social justice issues. For pre-service or in-service 6-12 teachers, these activities can be expanded to explore instructional pedagogy and appropriate uses of technology for teaching statistical ideas. This follows Koh and Divaharan's (2011) model for supporting the development of teachers' TPACK via information and communication technology (ICT) emphasizing that teachers must experience the utility of a tool for themselves; they must accept that the tool can be used effectively for instruction; they must see exemplars of its use; and they must be allowed to apply and expand upon exemplars. Teachers must therefore, not only develop knowledge in each of the areas represented in the TPACK model (Figure 1), but they must also develop a sense of efficacy in their abilities to apply this knowledge.

This approach to helping teachers learn how to convey statistical concepts within a social justice context using technology is also consistent with the outlined five dimensions of meaningful ICT-supported constructivist learning defined by Jonassen, Howland, Marra, & Crismond (2008):

1. Learners must be active, manipulating objects in the learning environment and observing and analyzing the results of that activity.
2. It [learning] is constructive in that teachers must ask students to reflect on and articulate their understandings.

3. Students must be engaged in authentic tasks based on real-world problems.
4. Students must set their own learning goals and plan their own problem-solving processes.
5. Learning is a social process that involves collaborative problem-solving within a classroom community (p.7)

The learning activities described below are consistent with these dimensions.

STATISTICAL INVESTIGATIONS TO PROMOTE SOCIAL JUSTICE

Below, three instructional activities are described that were used with three related projects at the authors' institutions and their resulting artifacts. These activities may be used with students in grades 6-12 or with pre-service and in-service teachers. Investigations were structured to help participants: 1) Engage in statistical problem solving using real data; 2) Focus on the process of statistical investigation; and 3) Consider statistics as a means of promoting change. The *Guidelines for Assessment and Instruction in Statistics Education* (GAISE, 2007) and the *Common Core State Standards for Mathematics* (CCSS-M, 2010) were consulted in deriving the investigations' goals. Two key resources, *Rethinking Mathematics* (Gutstein & Peterson, 2013) and *Workshop Statistics: Discovery with Data* (Rossman & Chance, 2012) served as the foundation for these investigations. The first example activity is entitled, *Census @ School,* from the American Statistical Association (http://www.amstat.org/censusatschool/) and demonstrates how classroom generated census data can be used to model the 4-step statistical problem-solving process.

Example 1 Investigation: Census @ School Project

The goal of this project is to introduce students to the 4-step statistical problem-solving process (GAISE, 2007):

1. Formulate Questions
   - Clarify the problem at hand
   - Formulate one (or more) questions that can be answered with data
2. Collect Data
   - Design a plan to collect appropriate data
   - Employ the plan to collect the data
3. Analyze Data
   - Select appropriate graphical and numerical methods
   - Use the methods to analyze the data
4. Interpret results
   - Interpret the analysis (in context)
   - Relate the interpretation to the original question (p.11)

Census @ School is an international classroom project that engages students in statistical problem-solving. Students complete an online survey, analyze their class census results, and compare their class with random samples of students in the United States and other countries. There are two parts to this project.

Census @ School Project

Phase 1 (Individual work):

- ◦ Each student will complete an online survey. Take the survey at http://www.amstat.org/censusatschool/students.cfm
- ◦ Click the Online Survey link; (Teaching note: The teacher must register and log-in in order to get a class ID and password)
- ◦ Complete the survey.

Phase 2 (Group work):

Teaching note: The teacher can download their own class data from the Census @ School site as well as comparison data from other classes that can be used to answer some of the following questions. A sample of such an analysis is shown below.

- Within your groups, analyze the two data sets to make representations, and data-warranted conclusions and inferences.
- First choose a theme for your investigation (e.g. food preferences, past times, social media, environmental concerns etc.,)
- Identify and choose 10-12 data entries that will help your investigations. Make sure you choose multiple data types (e.g., categorical /ordinal / numerical…)
- Create multiple representations that include the following.
    1. A comparison bar graph (multiple bar graph)
    2. Pie charts
    3. Multiple histograms
    4. Multiple frequency histograms
    5. Back-to-back stem-and-leaf plot
    6. Back-back Box-and-whisker plot
    7. Provide descriptive measures such as the mean, median, mode, quartiles, range for appropriate data.

Analyze and interpret the representations and write a story (not exceeding 2 pages) that summarizes key findings from your data analysis. Pay attention to the specifics - describing clusters of data and deviations/outliers in data. Other guiding questions: What did you find interesting? What surprised you? What patterns and trends did you notice? What reasons do you attribute to those patterns and trends?

Example Inquiry and Data Generated for Investigation 1

Step 1: Inquiry. Are there regional differences in texting and social media use among high school seniors in North Carolina, Ohio, and Massachusetts as demonstrated by data collected in 2014?

Step 2: Collect Data from Census @ School (Table 1).

Step 3: Analyze data (see Table 2 for a data analysis sample).

Table 1. Step 2-Sample data (25 students) randomly generated from the Census @ School website

State	Main Means of Communication With Friends	Text Messages Sent Yesterday	Social Websites Hours per week	Texting Messaging Hours per week	Computer Use Hours per week
MA	Text messaging	2	2	1	20
MA	Cell phone	200	14	2	5
MA	In person	200	1	5	5
MA	In person	100	2	21	20
MA	Text messaging	200	5	7	15
MA	Text messaging	25	2	1	3
MA	Text messaging	75	2	2	6
MA	In person	250	20	50	30
MA	Text messaging	150	8	25	15
MA	In person	20	4	5	7
MA	In person	25	2	3	2
NC	Text messaging	5	28	5	35
NC	Text messaging	7	4	3	30
NC	Text messaging	600	50	80	10
NC	Text messaging	150	7	16	14
NC	In person	200	2	8	3
NC	Text messaging	1900	40	168	168
NC	Text messaging	50	5	20	15
NC	Text messaging	300	90	125	10
NC	Text messaging	175	35	45	10
OH	Text messaging	50	1	3	4
OH	Text messaging	180	12	9	7
OH	In person	20	1	1	6
OH	Text messaging	100	10	20	40
OH	Text messaging	50	12	20	0

Table 2. Sample Data Analysis

Region	Avg. # of Text Messages Sent Yesterday	Avg. Social Websites Hours	Avg. Texting Messaging Hours	Avg. # of Computer Use Hours
MA	113	6	11	12
NC	373	29	52	33
OH	80	7	11	11

When students download a random set of data such as this to explore their inquiry, several issues should be examined. First, this set of data for a random sample of 25 students does not show an equal number of students from each state. How does that impact the analysis? Should one instead perhaps randomly generate a set of fifty responses and accept the first 8 student responses from each state so that one has an equal number of respondents from each location? Second, one needs to clean the data in order to make sure what is being analyzed is reliable. Are there outliers in the data? For example, in the original set of data shown in Table 1; one of the respondents from North Carolina reported sending 600 text messages in a day while another reported sending 1900 messages. Are these data reliable? This is doubtful. Such outliers can heavily impact the averages shown in Table 2. By improving the sample as described above to include the first eight students from each state and by scrubbing outliers from the data, one may see the following, more reasonable averages in Table 3.

Step 4: Interpret results.

Examining Table 3, one may note that it appears that high school seniors in North Carolina spend more time on social media websites than their peers in Ohio and Massachusetts. This result is also supported by noting that these students reported spending more time on computers. It also appears that students in Massachusetts send more text messages than the students in the other two states. Students may also analyze and interpret these data through using a variety of representations such as pie charts. The point is that the students must examine the validity of the data and make decisions about how to analyze and represent that data in order to propose answers to their original inquiry.

Other examples of activities using Census @ School can be found at http://amstat.org/censusatschool/resources.cfm. The following activity explores how online population tools can be used to help students investigate and visualize inquiries pertaining to world populations.

Example 2 Investigation: Population Pyramid Project

The geographical setting for the first project was a large mid-western university in the United States. The study setting was a mathematics capstone course offered to in-service elementary and middle school teachers. This course, which the students took toward the end of their program was designed to foster critical thinking, solving complex problems, engaging with other learners, and communicating mathematical ideas. Sixteen prospective teachers enrolled in this course and participated in a series of activities intended to promote statistical thinking. This activity was conducted with the pre-service teachers as a model of an activity they could complete with their own future students.

Table 3. Improved Sample Data Analysis

Region	Avg. # of Text Messages Sent Yesterday	Avg. Social Websites Hours	Avg. Texting Messaging Hours	Avg. # of Computer Use Hours
MA	130	4	5	10
NC	103	20	10	27
OH	69	7	7	9

Population Statistics to Promote Critical Statistics Thinking

The class used world population data to discuss the potential for a critical analysis and interpretation of statistics. First, the class watched a You-tube video, *The World is a Village*, that gave a preview of the world population statistics, condensed to fit a village with 100 citizens (http://youtube.com/watch?v=i4639vev1Rw). Next, the instructor presented an activity, *Food for Thought*, from the Population Connection web source (www.Populationconnection.org) and simulated the world population of different continents and highlighted socially relevant statistics on wealth, health, sanitation, and pollution. The class also used world population statistics to probe students' current thinking about different countries. Next, an activity called the Power of the Pyramids was employed (https://www.populationeducation.org/sites/default/files/power-of-pyramids.pdf). Participants constructed and interpreted population pyramids, discussed similarities and differences in population growth rates. To further encourage them to engage in statistical problem solving, the following activity was assigned.

Population Pyramid Investigation

Go to http://populationpyramid.net/.

1. Choose any two continents - Within these continents choose four countries (two from each continent) and generate their population pyramids. Provide a brief rationale for your choice of the continents and the countries. (*Teaching note: For example, students could choose Europe and South America as the two continents. Within these continents, they could choose to display the population pyramids of France, Italy, Belize, and Guatemala.)*
2. Describe commonalities and differences that you noticed between the population pyramids of the countries within a continent. How would you explain these findings?
3. (*Example data-related question)* If you were a marketing agent for a company in Europe, what product would you try to sell and why? Would your product sell equally as well as in South America? Why or why not? *(Teaching note: Pose two data analysis questions that would enable students become critical and caring consumers of data represented in the population pyramids such as the one above. Craft potential responses ahead of time to your questions so you can help scaffold student learning.)*
4. By looking at four graphs, which graphs look most like pyramids? What does this reveal about these countries population growth rates?

Example Student Response to Investigation 2

Response to Question 1

Figures 2 and 3 illustrate population pyramids of 4 countries from 2 continents.

Figure 2. Population pyramids for France and Italy

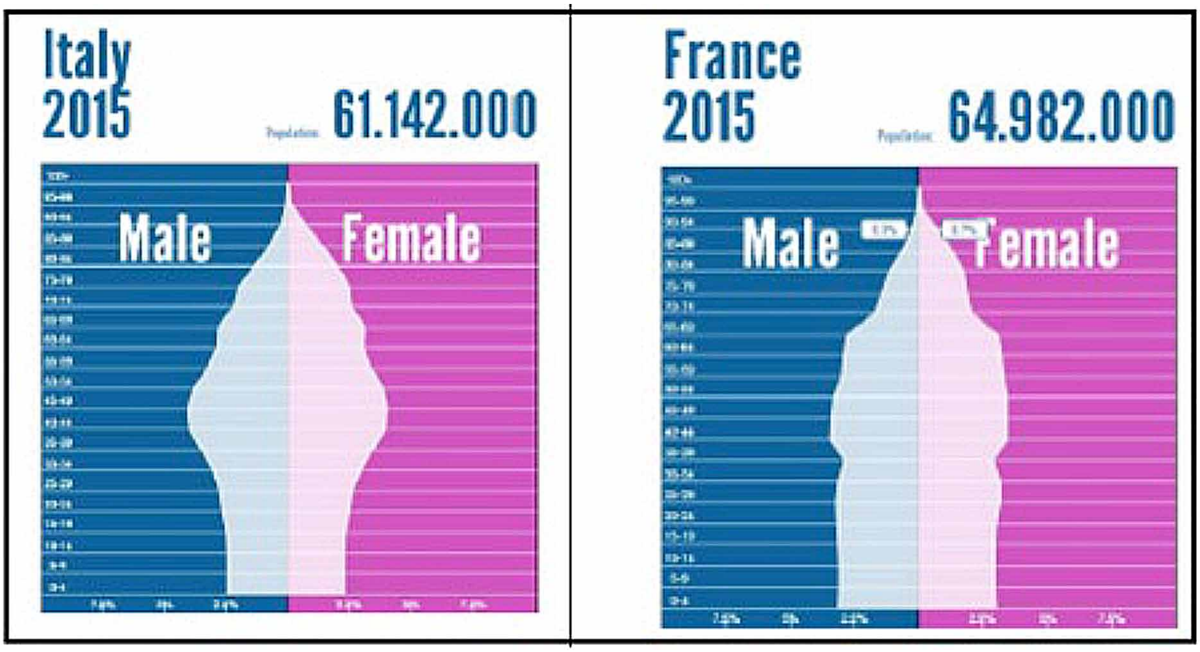
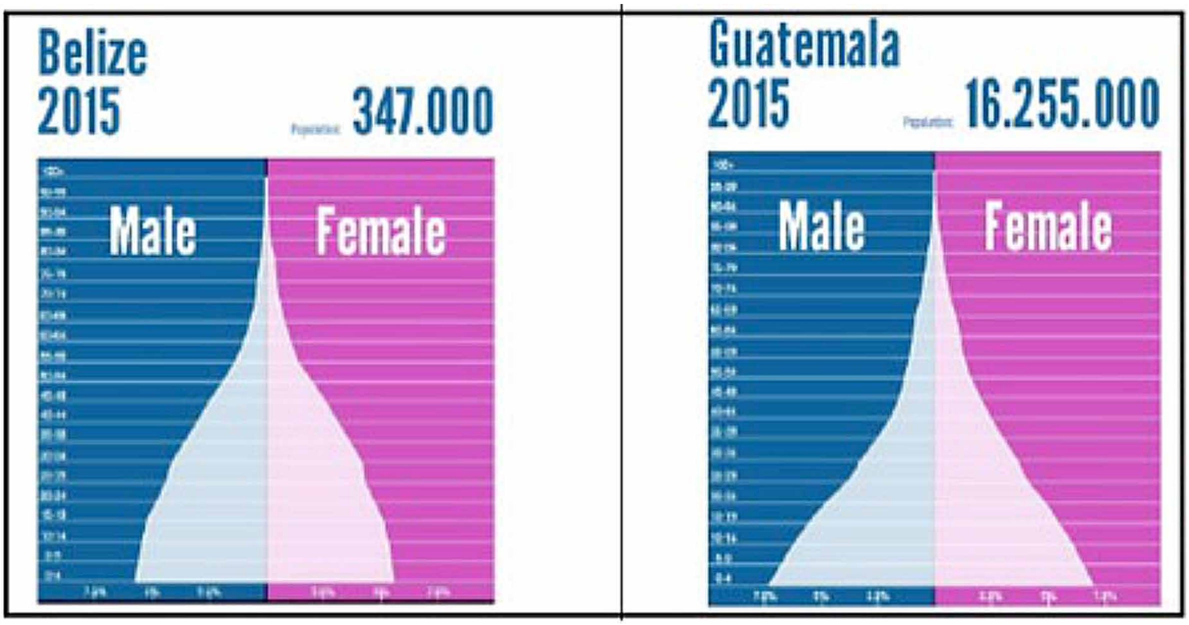


Figure 3. Population pyramids for Belize and Guatemala



Response to Question 2

France and Italy

Commonalities:

- France and Italy both have a small percentage of young children.
- France and Italy both have a small percentage of elderly generation.
- Both graphs are an "arrow head" shape, almost symmetric.
- The largest percentage of the population is the age group mid 30's to mid 50's
  - Both graphs show a similarly between the age group of 75-79 and 0-4 range.
  - Both countries, overall, have similar total population in 2015 shown when looking at the number given and the linear graphs.

Differences:

- Italy has a steady slope that remained approximately the same throughout the time periods.
- France did have a moderate change in slope, over the time periods.
- France increased in populations, over time, compared to Italy who stayed consistent.

Belize and Guatemala

Commonalities:

- Both countries have similar percentages of the population in the age rand from 55-99.
- Both countries have a much larger percentage of the population in the infants range than any other age which gives the graph a similar appearance.
- Both countries have a similar spread or "look" to them, a pyramid.
- Both countries have a small population in the 1900's and have an increasing slope after that time.

Differences:

- Guatemala has a larger percentage of the population in the 0-4 range.
- There is a major difference in percentages of the population in the age ranges from 20-49.
- In 2015, the both countries' overall population differs by a larger percentage.

Findings were explained by the comparing of linear graphs and the pyramid graphs between the two countries. Many aspects were acknowledged such as slope, age ranges, growth over time, and overall populations.

Response to Question 3

If I were a marketing agent for a company in Europe, I would try to sell health insurance because the largest percentage of both populations is ranging in age from 30-60. This is the prime age for persons searching for health insurance. I do not think that health insurance would be marketable in terms of the appropriate age range of 30-60 because these countries lack in that age range. Most of South America's age range in in the younger categories. Although this might be the case, I could try to promote health insurance in South America due to their low percentages in middle aged to elderly population.

Response to Question 4

Guatemala and Belize both are shaped like pyramids. This reveals that as the population increases in age, the population becomes more disparate. This suggests that the younger generation is reproducing at a faster rate than older generations had in the past.

The final example activity shows how the online tool Gapminder can be used to investigate a wider range of student questions.

Example 3 Investigation: Gapminder Exploration

In the final project, artifacts produced by pre-service secondary teachers from a university in the south-eastern Appalachian regions of the U.S. were examined as they explored an activity designed to be used with high school mathematics students. Nineteen pre-service teachers were enrolled in a mathematics methods course their final semester before student teaching. They were asked to complete a series of activities built around Gapminder software. An exploration of the Gapminder tool and analyses of related graphs enables participants to uncover, understand and question their perceptions about various nations and the issues facing the world. Prior to the Gapminder content explorations, the class watched the TED talk presented by Hans Rosling (2007) entitled, *Debunking Myths about the Third World*. They were then introduced to the Gapminder sorting game: http://gapminder.org/GapminderMedia/GapPDFs/GapminderSort/GapminderSort.pdf. This activity was designed to help students further probe their beliefs and perceptions of the developed and the developing nations of the world. As a next step, participants were asked to explore Gapminder World Graph and understand features of the graph. In particular, they were asked to attend to, and understand, the available options for choosing scales (linear or logarithmic), indicators (e.g., life expectancy, infant mortality) and categorizations (e.g., income, religion) to generate graphical displays. Once the pre-service teachers had developed some facility in using the Gapminder tool, they were asked to complete the following investigation:

Gapminder Explorations

1. Identify a research question:
    a. Propose a research question that focuses on a global issue that could be addressed by analyzing data depicted in the Gapminder graph.
    b. Explain why you chose this question - In particular, describe your interest in exploring this topic.
2. Explore:
    a. Use the Gapminder software to address your research question.
    b. Describe how you analyzed the data using the Gapminder software. Include all evidence that was used to arrive at this response.
    c. Interpret the graphs and tell the story.
    d. Discuss plausible reasons that will explain the trends that you noted in your graph.

3. Reflect: In light of the presented data and its analysis, reflect on your research question.
    a. Suggest possible actions that could be initiated by various agencies (a world organization, governments, social activists, individuals, etc.,) to address the global issue.
    b. As a citizen of the world, how do the findings this concern you? What can you do about it?
    c. Discuss ways in which prospective teachers can engage students in a deeper analysis of global / local issues using the lens of statistics and through the use of the Gapminder software.

As an example of inquiry-based learning, Table 4 describes the research questions posed by some of the pre-service teachers and their reasons for exploring these questions. The Gapminder tool invites students to pose probing questions and supports them in engaging in a more thoughtful, and less superficial, analysis of data.

Table 4. Participant-created research questions and their reasons for selecting these questions

Research Question	My Reason for Choosing This Question…
How has the childbirth per woman in the United States and China changed since 1800?	"Because I have always heard about how China has a one child limit to limit its population size. I also wanted to see how the United States childbirth per woman compared to China."
What is the average age that women across the world get married for the first time?	"Because I got married this year. I was twenty-two years old when I got married. Often, people gave me odd looks because I was getting married at my age; but the odd looks may have also been because I look a lot younger than I am. I was curious as to what age most women in the United States and other countries are getting married."
Do sanitation conditions affect life expectancy? Are they correlated?	"Because I think there is a good possibility that sanitation conditions could be correlated with the life expectancy of individuals living in countries around the world. My conjecture is that the poorer the sanitation conditions are, the lower the life expectancy, and that maybe the more developed countries might have better sanitation conditions."
Create a "weighted" best fit line for the graph of life-expectancy vs. income-per person. In other words, not all points should count in the same way when determining your best fit line. The line should be (typically) closer to points with more population.	"Because a best fit line would describe in a general way how life-expectancy and income are related throughout the world; but it would be inaccurate to consider each country as having the same impact on the trend. For example, Luxembourg is one of the richest (per-person) countries in the world, but there aren't very many people there. This would make a good mathematical research question because students could come up with their own ways of assigning weights and argue about which is better and why."
Does the amount of nuclear energy produced affect the child mortality rate?	"Because I wrote a paper in high school about chemical and nuclear engineering and the affects it had on people in the past so I wanted to see what new data there was since I hadn't researched it in 6 years."
How do different countries differ in 8th grade achievement scores over time versus the amount of residential energy used kilowatt per hour? The countries I choose were South Korea, Japan, United States, Sweden, Kuwait, and El Salvador.	"To see were mathematics achievement scores are affected by how much residential electricity is used."
What is the child mortality rate for children 0-5 years old per 1,000 born between 1800 to present day of the U.S., Austria, and China?	"To see the contrast between different countries child mortality rate. I wanted to research the reason these 3 countries peaked and fell at certain times."
How does the corruption affect the economic status of the individuals in a country? Countries chosen to explore are Mexico, United States, Austria, and Uganda.	"Because when exploring Gap Minder, my interest was piqued when Mexico was ranked so much higher than my preconceived notion. Their wealth in income is at a similar level to many Eastern European countries, even though with recent news I thought that their crime would have affected their health and their incomes drastically. The other countries are there to provide a variance of different economic status countries and how corruption has played a role with their growth as well."

continued on following page

Table 4. Continued

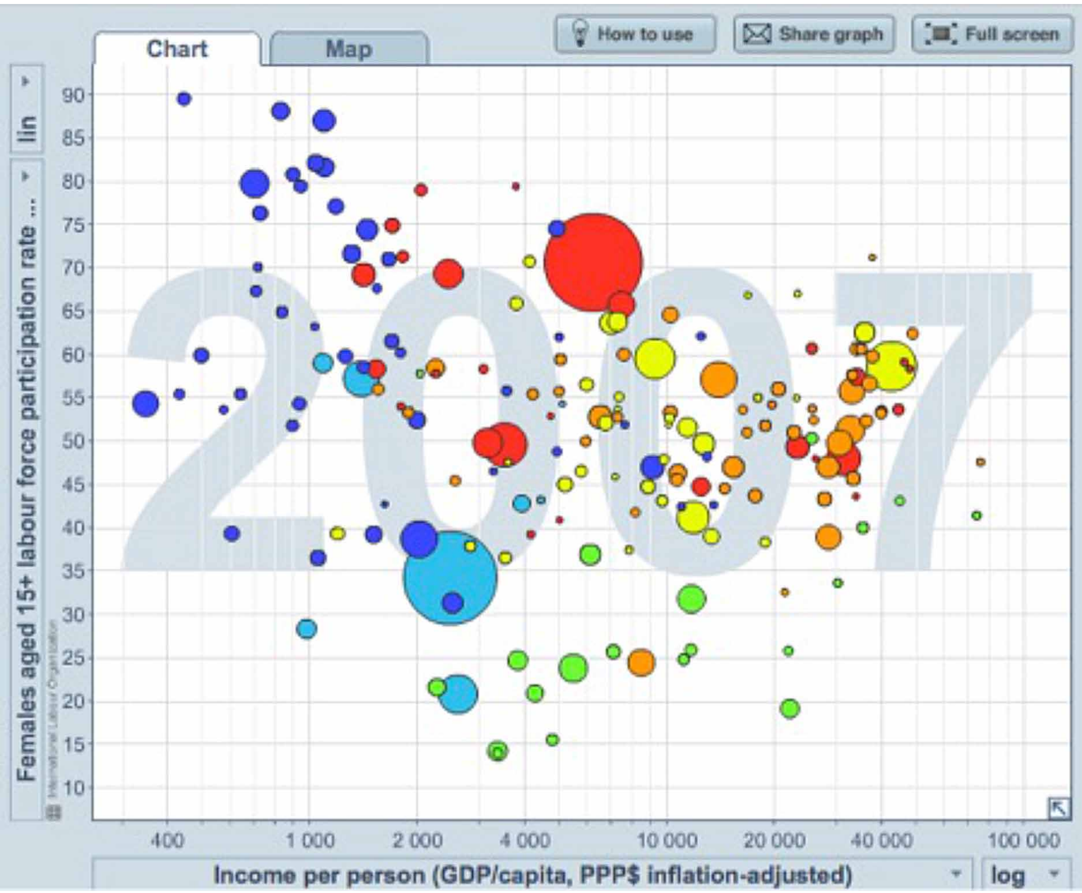
Research Question	My Reason for Choosing This Question…
How does education for women affect the child mortality rate for a country?	"Because I think that women being in school would positively impact the child mortality rate of a country. Women should be educated in order to give care to their child and take care of themselves."
What country has the highest total adult literacy rate? What country has the lowest? What about adult literacy rate by gender? What do you notice about the literacy rate among the genders in the highest and lowest countries?	"Because I thought it would be interesting to compare the two variables. We all expect the "developed" countries to have a high literacy rate, which they do, but we also expect there to be no differences in the genders. However, it appears that there is some degree of variation between male and female literacy rates."
How has the literacy rate changed over time for Mali, Haiti, and China?	"Because is very important to explore literacy rate. This has to deal with how many people are educated in each of these countries. I enjoy reading in my free time, so it is hard to believe that some countries have such a low literacy rate. I feel that this affects development of the country as well, because if people cannot read then they cannot accomplish much."
How does sugar consumption affect blood pressure in men among different countries?	"Because I am very interested in health science and health promotion and I want to peruse a career in preventative healthcare, particularly involving diet and exercise."
Does math achievement in eighth grade affect the percentage of total adults literate?	"Because I found this idea interesting because so few people look at the correlation between Math literacy and English literacy."

Below an example student response for Investigation 3, Gapminder Exploration is shown.

Example Student Response for Investigation 3

1. Identify a research question:
   a. What is the relationship between females aged 15+ that participate in the labor force and income per person? (Figure 4).
   b. "I chose this question because I have always been interested in female equality especially in the labor force. Statistically, women get paid lower wages than men in the same job and men are also more likely to move up in a company or get a raise as opposed to women. I would like to see if countries where people make more money have more female workers than countries where people make less money."
2. Explore:
   a. "When first analyzing this data, I did not pick certain countries to focus on. I wanted to get a good feel for this data by analyzing certain countries at both ends of each data. I wanted to look at some of the poorest countries and then some of the richest and compare their percentage of females in the labor force. Next, I did the opposite. I wanted to compare the countries that had the largest perfect of females in the labor force with the countries that had the smallest perfect of females in the labor force. From here, I picked a few countries to focus on including the United States, Burundi, Qatar, United Kingdom, and Vietnam."
   b. "The graph I obtained from looking at these five countries ended up looking like Figure 5."
   c. "This graph is not what I expected to see at all. I am not by any means someone that knows a lot about these issues but when thinking about these issues, I expected the richer countries to be the more developed countries and as a result have more females working in the labor force. I also always thought more developed countries like the United States and the United Kingdom to have more females in the labor force because women essentially have more rights

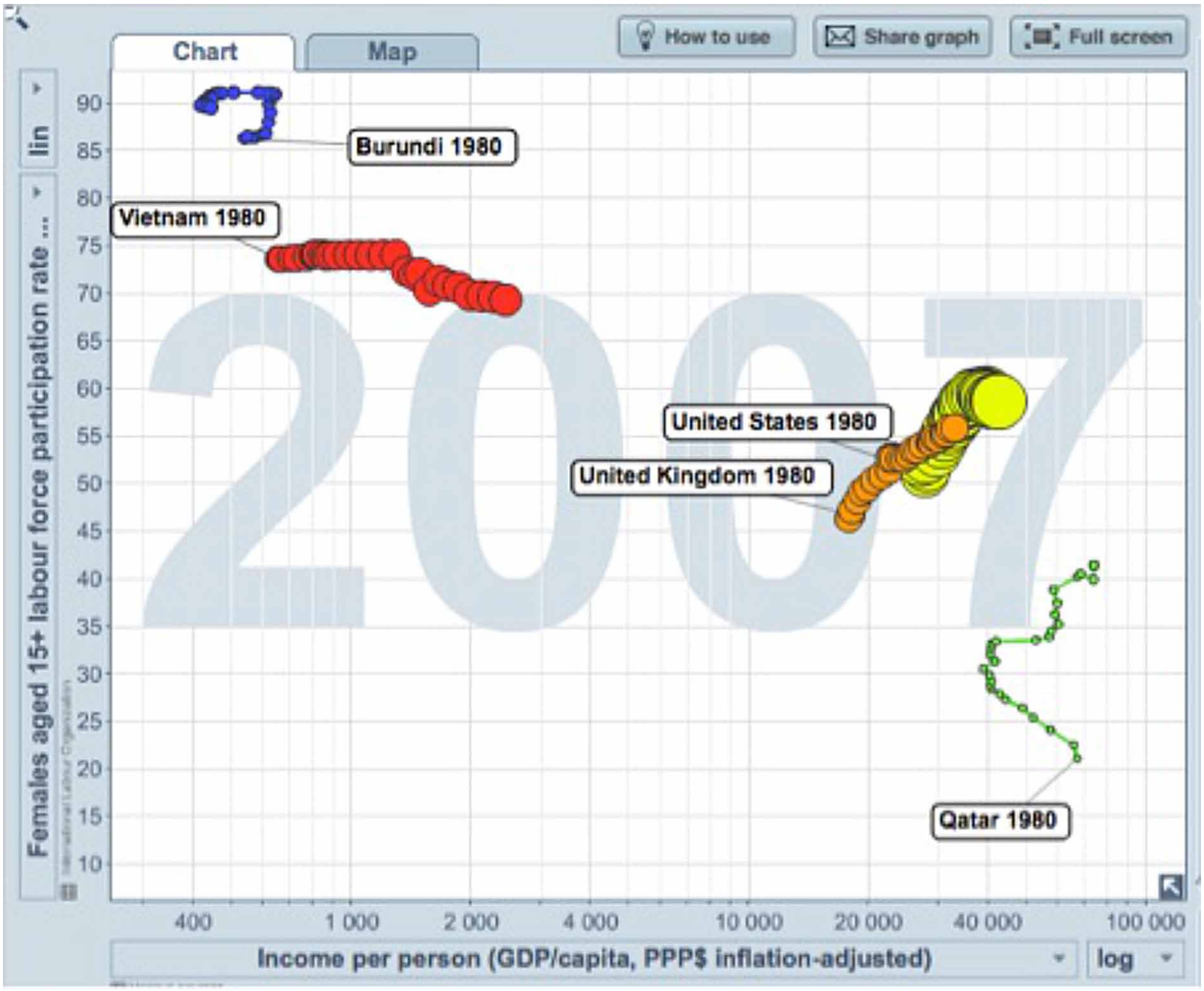
Figure 4. Females aged 15+ labor force participation rate vs. income per person (GDP/capita, PPP$ inflation adjusted)



here and are able to actually obtain a job. Only 56% of women in the United Kingdom work in the labor force and only 59% percent of women in the United States do so. However, two extremely poor countries, Vietnam and Burundi, have a much highest percentage of women in the labor force. 90% of women in Burundi work in the labor force but their income per person is only $446.00. Also, 69% of women in Vietnam work in the labor force where their income per person is $2,545.00. While their income is a lot more than Burundi, it isn't close to the United States $42,764.00 per person. Yet, both Burundi and Vietnam have a much highest percentage of females working in the labor force than the United States. The most surprising thing I noticed about this data is in relation to the country of Qatar. When I think about Qatar, I think about it being in Africa and thus being a poor third-world country. However, from this data, the income per person is $74,095.00, which is more than people in both the United States and the United Kingdom. Being one of the richest countries, their percentage of females in the labor force is only 41%."

d. "The jump in females in the labor force of Qatar came because in the 1990's Qatar's women made significant legal and social advancements. As a result of these advancements, Qatari women have been able to obtain many career opportunities. Also, Qatar is also not a third-

Figure 5. Females aged 15+ labor force participation rate vs. income per person (GDP/capita, PPP$ inflation adjusted) for selected countries, Burundi, Qatar, United Kingdom, United States, Vietnam



world country like I previously thought. It is actually the wealthiest country in the world. In regards to women in Burundi, the 90% of women in the labor force comes from women working in agriculture. The people of Burundi believe that a woman's fertility is transferred to the seeds they plant so this is why Burundi has such a high percentage of women working. However, women do not really work in actual businesses or for the government. The growth of income per person in Vietnam is because since 1997, Vietnam has shifted toward a more market-oriented economy, which has allowed them to grow financially. As far as the percentage of females working in the labor force in the United States being barely over half, it should be pointed out that the United States is one of the only industrialized countries that does not mandate some sort of paid parental leave. Therefore, many women choose to be stay-at-home moms and not work."

3. Reflect:
    a. "In order to combat the issue in the United States, the government could mandate paid parental leave for all women workers in the labor force. Several industrialized countries provide up to a year of paid parental leave for both mothers and fathers – something the United States has never seen. As far as Burundi goes, the government needs to allow women to enter work forces other than agriculture. This may help to increase the countries income per person because more people are working in those areas and women could contribute new ideas to help these places as well. It would also move the Burundi women's status in the country and gain them more rights."
    b. "These findings concern me because I am a woman that works in the labor force in the United States. I am not guaranteed much paid parental leave if I were to have children as opposed to other industrialized countries. Women have fought for equal rights for as long as I can remember and women in the United States are not able to utilize this because they want to be able to spend time with their children and combat the aftermath of having a child, yet our government does not allow for this. In order to change this, I must vote for the people that are pushing for women's right and continually remain a women's rights activist."
    c. "Gapminder is a good source for all teachers because it contains statistics that cover all kinds of subjects. Many students do not have a clear understanding of certain countries and tend to group them together without a real knowledge of them. This will allow students to get a better grasp on countries they don't really know about and compare them to better-known countries they know or think they know about."

The above example is a representative analysis of the ones written by the pre-service teachers for their questions posed in Table 4.

SOLUTIONS AND RECOMMENDATIONS

Seeking to help students become critical consumers and responsible citizens, using technology in tandem with statistics will help them form, maintain, or reject opinions concerning critical questions. In the teacher education context, this highlights the need to pose questions that will lead both prospective and in-service teachers to investigate social issues with a critical eye, so that inequities may become apparent and ideas for change discussed. Teachers who have learned to enact such investigations are better able to foster such thinking in their students in grades 6-12. "Teaching Statistics for Social Justice" (TSSJ) is one plausible model to help individuals gain statistical competency and critical awareness necessary to become agents of change attaining:

> *a critical perspective that incorporates and facilitates awareness of issues of social justice and prepares students not only to be competitive workers in the economy but also engaged participants in a democracy, able to be critically reflective about the role statistics has played and can play in our society. In other words, statistics must be seen not merely as useful (for working, shopping, etc.) but also as a tool to help effect social change in the world. (Lesser, 2007, p. 3)*

In a TSSJ model, educators must provide learners with opportunities to recognize that their world is active, complicated, and can be transformed based upon action.

The use of technology to teach statistics presents both challenges and opportunities for the advancement of critical statistics education. In order to realize the goals for critical statistics education, it is necessary to develop learning goals that support a seamless integration of technology and critical analysis of data, re-envision the assessment strategies that are compatible with the learning goals, choose technological tools that are most helpful in realizing their learning goals, and build in sufficient time and space for learners to comprehend the technology and then apply it to the situation in hand (Gaise, 2007; Chance, Ben-Zvi, Garfield, & Medina, 2007). Stand-alone applications (e.g., Gapminder) and multimedia materials (e.g., Population Pyramids) provided the much needed data and representations that were crucial for a critical analysis of data. This interpretation provided a global lens for individuals to view their world, defining the world through careful consideration, not ignorant acceptance. Modeling how to be critical consumers of knowledge and utilizing tools, such as the technology resources presented previously, allows all individuals to ask critical questions and interpret results that forego bias.

FUTURE RESEARCH DIRECTIONS

A consequence of implementing a critical statistics pedagogy is empowerment. The use of technology in statistical reasoning allows for statistical information to be scrutinized without requiring an extensive understanding of formal statistics; therefore statistical reasoning can take the forefront, while statistical computation remains ancillary. As the literature base for critical statistics education continues to develop, it becomes essential that educators, as well as students, engage themselves with the composition of critical questions that involve their communities as well as the world. Statistics education related to social justice becomes the context in which the ultimate goal is agency. Knowledge leads to action and action changes the world.

CONCLUSION

We conclude by returning to Hans Rosling's initial question, *Will saving the poor children of the world from dying of disease lead to overpopulation?* Obviously, there are serious moral implications of this question that would lead us to answer that we should save such children from disease even if overpopulation did result. However, by a careful analysis of the data, Rosling persuasively demonstrates that, "it is the other way around" (http://www.gapminder.org/videos/will-saving-poor-children-lead-to-overpopulation/) as he shows that, by saving children from dying of preventable diseases, we actually encourage smaller families as parents do not anticipate routinely losing children to disease. By making it possible for parents to choose to have smaller families, we in turn, reduce overall population growth. By using Gapminder, real-world data, and other technological tools for carefully analyzing that data, we may invite our students to broaden the types of questions that they can explore for themselves and change their view of the world, and their actions on their beliefs, as a result.

REFERENCES

Best, J. (2001). *Damned Lies and Statistics*. Berkeley, CA: University of California Press.

Bishop, A. J. (1988). Mathematics education in its cultural context. *Educational Studies in Mathematics*, *19*(2), 179–191. doi:10.1007/BF00751231

Chance, B., Ben-Zvi, D., Garfield, J., & Medina, E. (2007). The role of technology in improving student learning of statistics. *Technology Innovations in Statistics Education Journal, 1*(1). Retrieved from http://escholarship.org/uc/item/8sd2t4rr

D'Ambrosio, U. (2007). Peace, social justice and ethnomathematics. *The Montana Mathematics Enthusiast. Monograph*, *1*, 25–34.

Frankenstein, M. (1987). Critical mathematics education: An application of Paulo Freire's epistemology. In I. Shor (Ed.), *Freire for the classroom: A sourcebook for liberatory teaching* (pp. 180–210). Portsmount, NH: Boyton/Cook.

Frankenstein, M. (1990). Incorporating race, gender, and class issues into a critical mathematical literacy curriculum. *The Journal of Negro Education*, *59*(3), 336–359. doi:10.2307/2295568

Frankenstein, M. (1995). Equity in mathematics education: Class in the world outside the class. In W. G. Secada, E. Fennema, & L. B. Adajian (Eds.), *New direction for equity in mathematics education* (pp. 165–190). Cambridge, UK: Cambridge University Press.

Garfield, J. B., & Ben-Zvi, D. (2008). Learning to Reason about Data. In J. B. Garfield & D. Ben-Zvi (Eds.), *Developing students' statistical reasoning* (pp. 123–142). New York, NY: Springer Publishers. doi:10.1007/978-1-4020-8383-9_6

Garrett, R. K., & Weeks, B. E. (2013). *The promise and peril of real-time corrections to political misperceptions. In Proceedings of the 2013 conference on computer supported cooperative work (CSCW '13)* (pp. 1047–1058). New York, NY: ACM. DOI: doi:10.1145/2441776.2441895

Giroux, H. A. (2011). *On Critical Pedagogy*. New York, NY: Continuum International Publishing Group.

Guidelines for Assessment and Instruction in Statistics Education (GAISE) Report. (2007). A Curriculum Framework for PreK-12 Statistics Education. Alexandria, VA: American Statistical Association (ASA).

Gutstein, E. (2006). *Reading and writing the world with mathematics: Toward a pedagogy for social justice*. New York: Routledge, Taylor & Francis Group.

Gutstein, E., & Petersen, B. (2013). *Rethinking Mathematics*. Milwaukee, WI: Rethinking Schools.

Jonassen, D., Howland, J., Marra, R., & Crismond, D. (2008). *Meaningful learning with technology* (3rd ed.). Upper Saddle River, NJ: Pearson.

Koehler, M., & Mishra, P. (2005). What happens when teachers design educational technology? The development of technological pedagogical content knowledge. *Journal of Educational Computing Research*, *32*(2), 131–152. doi:10.2190/0EW7-01WB-BKHL-QDYV

Koh, J., & Divaharan, S. (2011). Developing pre-service teachers' technology integration expertise through the TPACK-developing instructional model. *Journal of Educational Computing Research*, *44*(1), 35–58. doi:10.2190/EC.44.1.c

Lesser, L. M. (2007). Critical values and transforming data: Teaching statistics with social justice. *Journal of Statistics Education*, *15*(1).

Moses, R., & Cobb, C. E. Jr. (2001). *Radical equations: Math literacy and civil rights*. Boston, MA: Beacon Press.

National Governors Association Center for Best Practices, Council of Chief State School Officers. (2010). *Common Core State Standards for Mathematics*. Washington, DC: Author.

Rossman, A. J., & Chance, B. L. (2012). *Workshop Statistics: Discovery with Data* (4th ed.). John Wiley Publications.

Saettler, P. (1990). The Evolution of American Educational Technology. Englewood, CO: Libraries Unlimited, Inc.

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher*, *15*(2), 4–14. doi:10.3102/0013189X015002004

Shulman, L. S. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review*, *57*(1), 1–22. doi:10.17763/haer.57.1.j463w79r56455411

Skovsmose, O. (1985). Mathematical education versus critical education. *Educational Studies in Mathematics*, *16*(4), 337–354. doi:10.1007/BF00417191

Skovsmose, O. (2011). *An Invitation to Critical Mathematics Education*. Sense Publishers. doi:10.1007/978-94-6091-442-3

Thompson, A., & Mishra, P. (2007). Breaking news: TPCK becomes TPACK! *Journal of Computing in Teacher Education*, *24*, 38–39.

Voogt, J., Fisser, P., Pareja Roblin, N., Tondeur, J., & van Braak, J. (2013). Technological pedagogical content knowledge: A review of the literature. *Journal of Computer Assisted Learning*, *29*(2), 109–121. doi:10.1111/j.1365-2729.2012.00487.x

Chapter 13

Using Authentic Earth Data in the K-12 Classroom

Meghan E. Marrero
Mercy College, USA

Amanda M. Gunning
Mercy College, USA

Karen Woodruff
U.S. Satellite Laboratory, USA

ABSTRACT

Our planet is under intense observation—by satellites, seismometers, buoys, radar, and more. These instruments generate authentic data sets that are freely accessible online, and thus available for K-12 students and teachers to use in STEM classrooms. This chapter examines how teachers engaged in the NASA Endeavor program, a STEM teacher professional development initiative, use authentic online data in their classrooms and the effects of these activities on teaching and learning. Endeavor teachers use data in many ways, including through curriculum programs developed to scaffold earth data sets for use by students. Through qualitative analysis of teacher interviews, teacher course work, student work, and other relevant data, the researchers discovered that employing authentic online data in Endeavor teachers' classrooms helped students to construct explanations based on evidence and make real world connections to science content.

INTRODUCTION

Authentic data integrated into K-12 instruction, provides meaningful, engaging, and long-lasting connections for students. The myriad data available through scientific research addresses current research-based standards and best practices in education and it is publicly available to educators (all citizens) as a valuable teaching tool. As you read this, nearly every earth environment is being monitored. Satellites are observing changes in vegetation; monitoring the albedo of land, sea, and ice; and following the paths

DOI: 10.4018/978-1-4666-9616-7.ch013

of caribou, eagles, sea turtles, and whales. Buoys atop the sea's surface measure atmospheric and oceanic parameters including air and water temperature, wind speed, and changes in water column heights that might indicate a tsunami. On the ocean floor, seismographs detect nearly imperceptible tremors, and hydrophones listen for sonar waves and whale songs.

Today's technological innovations mean that these and many other examples of earth observations become robust data sets, which can be used in K-12 classrooms. Many of the data collected by these and other instruments are accessible through online portals, making them available for teaching and learning. Students are able to look for patterns in earthquake and volcano data to learn about plate tectonics, or watch how chlorophyll in the ocean varies with the seasons as they study photosynthesis and food webs.

The teachers featured in the following chapter demonstrate successful integration of authentic data with varied student groups and share evidence of students constructing explanations and making real-world connections through data analysis activities. Findings suggest that with sustained, quality professional development the use of authentic data can reach more classrooms and achieve notable results with student understanding of STEM topics.

BACKGROUND

The Science and Engineering Practices of the Next Generation Science Standards (NGSS) underscore the importance of helping students to think scientifically, such as through the practice *Analyzing and Interpreting Data* (NGSS Lead States, 2013). When students use practices such as data analysis, they often demonstrate deeper understanding of concepts, more motivation and engagement, and higher grades in science (Minner, Levy, & Century, 2010) Technological tools that include opportunity for visualizing data can help students to make connections between their local communities and global issues (Marrero & Schuster, 2010).

In this chapter, we describe three K-12 programs in which students successfully analyze and interpret earth data as they learn standards-based science content, and examine the perspectives of teachers and students using the programs. These programs are now all courses within the NASA Endeavor program, in which teachers from across the United States and from around the world complete a course sequence in STEM education (www.us-satellite.net/endeavor). We then describe a case study in which we examined examples of the ways in which these data are affecting teaching and learning. Finally, we share some examples of ways in which teachers can use freely available sources of earth data with their own students.

While our discussion focuses primarily on Earth System Science, we hope that the ideas will challenge and encourage pre- and in-service teachers to use the myriad sources of authentic data that can be easily accessed online, and incorporate these data as an effective tool for science instruction.

Authentic Data in the Classroom

In science classrooms, we encourage students to collect data as much as possible. Students as young as preschool observe each day's weather, creating a calendar of suns and clouds that illustrates their monthly data. Elementary school students grow and observe plants and the life cycle of animals such as butterflies and chicks, take data on simple machines or observations of phase changes. In middle and high school, our students conduct experiments in which they collect varied data during each laboratory or hands-on experiment. They might measure temperature changes to compare the specific heat of different liquids; measure distance and time for motion of a classmate or a toy car to determine velocity; or compare their pulse rates before and after exercise when learning about the circulatory system.

Collecting, analyzing, and interpreting data clearly are extremely important practices in which our students of all ages should, and often do, engage. Thanks to modern technological capabilities, there are also many types of data accessible online, which now allow students to analyze and interpret data that will expand their thinking far beyond their classroom, science lab, or local community. Using online data in the classroom is a powerful tool that can take students to far-away places and paint a picture of change during a period of time, all within one class meeting. Studies of real-time data (RTD) use in science teaching illustrate how it can make a lesson relevant to the real-world and students' lives, while providing an engaging learning context (Adams & Matsumoto, 2009; McKay & McGrath, 2007; Ucar & Trundle, 2011).

When we think about data, we often picture rows of numbers, complicated tables, or statistical findings. Visualization of data is a process of making numbers graphical, making the numbers more meaningful. When students are able to form a visual representation in their mind of something difficult to observe in the classroom, for example, a series of events or microscopic objects, we call this a visualization (Cheng & Gilbert, 2014). These types of mental models are important for science teaching and learning (Gilbert, 2004). Teachers can incorporate visualizations of data in many different ways, including using pie charts, line graphs, or histograms. Another approach is assigning numbers to colors, like on a temperature map where warms are shown in red, and cool temperatures in blue or purple. Programs such as Google Earth™ allow users to "fly through" many different data layers, including visible satellite imagery, seafloor features, watershed changes, and species distributions. Using the varied online tools to explore authentic data makes the content more accessible and engaging for students.

The use of genuine online data creates a more exciting and meaningful scientific practice for students. In their study of improving pre-service teachers' understandings of tides, Ucar and Trundle (2011) found that the use of online data for inquiry-based instruction was a more effective model for developing scientific understanding of tides than both traditional teaching methods and traditional methods paired with computer simulations. Using online data allowed students in the study to explore data from a longer timeframe and wider geographical scope than live, in-person data collection from observing the ocean directly would allow. This is one example of how access to online data can open up a new world of scientific understanding. Authentic data provides an important context for inquiry explorations and another avenue for students to experience science practices in general. Adams (2011) reports how using RTD for student inquiry work facilitates the illustration of the nature of science in the classroom. In her study, students analyzed several data sets from local bodies of water to compare varied factors and developed their own reasoning to explain physical phenomena. This creek-study activity fostered a "deeper understanding" of tidal and freshwater creeks and "a sense of ownership and pride" for their local aquatic ecosystem (Adams, 2011, p. 37). The use of authentic data in this unit illustrates how using online resources in the classroom can bring even local contexts closer and foster a deeper understanding of the way scientists work.

While real data is an excellent way to help students explore and experience scientific practices, it is also an opportunity for students to develop and practice their own problem-solving skills. Using authentic data to frame real-world problems presents authentic situations that are not as clear-cut as many textbook problems. These data also provide the tools to help students consider possible solutions. McKay and McGrath (2007) investigated how students used real-time weather, wind and wave-height data to solve problems involving hypothetical situations related to planes and boats. Students utilized their physical science and math content knowledge with the RTD to determine speeds, accelerations and times of travel for the vessels. Students who participated in the program showed sustained higher levels of achievement in science. We see in many contexts, across grade levels and content areas, that the use of RTD not only is an engaging instructional method for students, but also one that promotes increased achievement and interest. Utilizing real data in the classroom also provides an authentic application of science standards and allows students to become deeply engaged with the content (Adams, 2011).

One of the goals of science education has been to make science instruction more authentic; students should be using practices like scientists (Edelson, 1998; Hawkins & Pea, 1987; NGSS Lead States, 2013). Implementation of K-12 classroom activities including authentic data is crucial to the success of science education reform (Doering & Veletsianos, 2007; Lee & Butler, 2003) as it provides students entrée to research in which scientists actually engage and fosters skills central to scientific literacy (Chin & Malhotra, 2002). Modern science education is founded on critical thinking, problem solving, inquiry-based activities and scientific reasoning; principles that the authors believe are enhanced by use of authentic data in the K-12 classroom. The NGSS place a significant focus on *Analyzing and Interpreting Data* as part of the science and engineering practices, one of three cornerstones of the standards (NGSS Lead States, 2013). Using authentic data should be contextual, however, giving students perspective as to why the data are important. The NGSS note, for instance, note that the Science and Engineering Practices, ". . . are designed to be taught in context—not in a vacuum" (NGSS Lead States, 2013, Executive Summary, p. 1). For instance, if students are studying plate tectonics, they can use real-time earthquake or volcano data to help support understandings of seafloor spreading, hot spots, and subduction zones. Tracking animal movements in response to seasons can help students to better understand phytoplankton blooms and food webs.

Authentic scientific inquiry, identified as 'practices' in current standards, refers to research that scientists conduct in the 'real world' and depends largely on access to real scientific data. Science education researchers posit that all citizens need to be able to engage in scientific reasoning to make informed everyday decisions (Chinn and Malhotra, 2002). To that end, teachers and students require access to authentic data in classrooms and teachers need support to implement activities that foster the skills central to scientific reasoning. With increasing access to technology in schools, students have greater potential to engage with authentic data than ever before (Gray, Thomas, & Lewis, 2010). Technology is a valuable tool for access and direct interaction with authentic data and communication between researcher and classrooms. For example, geospatial technologies, like Google Earth, can be used as a pedagogical tool for teaching content. In a peer collaboration model, use of technology was effective with middle school students learning the geography of their region and researchers found that interaction with geospatial technologies assisted students in developing a sense of place and an understanding of the nature of science through sharing of data (Doering and Veletsianos, 2007). By using practices such as analyzing data, students demonstrate higher achievement, deeper conceptual understanding, and improved motivation in school (Minner, et al., 2010).

Chinn and Malhotra (2002) conducted an analysis of inquiry activities in both textbooks as well as those developed by researchers in education and concluded that there is a direct need to design improved inquiry tasks that incorporate more of the features of authentic science, i.e., data analysis. Student data use allows them to gain deeper understandings of science content and the nature of science (Adams, 2011). Bell, Fowler and Stein (2003) encourage partnerships between scientists and educators at all levels so that students have greater access to monitoring activities, given evidence from their research that authentic data can enhance understanding of important science concepts. When searching for engaging contexts for teaching science, educators can look to the environment around them (Bell, Fowler, & Stein, 2003; Bodzin, 2008; Bodzin & Shive, 2004). Bodzin (2011) demonstrated successful support of teachers in local districts using data in inquiry-based watershed lessons in which students collect their own data on freshwater ecosystem and access scientific data from various sources. Classes of fourth grade students given the opportunity for "real-life experience" and an "authentic investigation" (p. 55) into a pond ecosystem developed a personal connection to the science concepts.

Successful Examples of Using Authentic Earth Data in the Classroom

Below are descriptions of three curricula in which students use technological tools to access and analyze earth data in order to meet science standards. Teacher training for these curricula is now a part of the NASA Endeavor program (www.us-satellite.net/endeavor). These curricula are examples of how authentic data are being used in the classroom. The current study (see "Main Focus" section) examined the perspectives and work of teachers and students using these curricula in their classrooms.

Project 3D-VIEW

Project 3D-VIEW [Virtual Interactive Environmental Worlds] (www.3dview.org) is a 5th and 6th grade curriculum in which students use 3D visualization and hands-on activities to learn Earth Systems Science content. There are five units, Lithosphere, Atmosphere, Biosphere, Hydrosphere, and Earth Systems, each of which leads students through a thematic exploration of science, relying heavily on authentic earth data. For instance in the lithosphere unit, students observe earthquake epicenter locations all around the world, looking for patterns and evidence of plate tectonics. In the biosphere unit, they use NASA vegetation imagery to compare the productivity of different biomes. Different levels of productivity correspond to different colors, keyed on an accompanying color bar, which students then interpret as they learn about biomes. Students learn, for instance, that the desert is much less productive than the grasslands, but also that the tundra's productivity has stark seasonal variations, with summer resulting in an explosion of grasses, flowers, and other flora.

Evaluation results of the original program 3D-VIEW program, which was funded by NASA, revealed that students performed strongly on science content questions, and demonstrated increased engagement in science and a belief that they understood science better. Fifth and sixth grade 3D-VIEW students outperformed a reference group of 8th grade students, 66.67% of the time (n=864) (Wilson, 2009) . The researchers also collected qualitative data, i.e., through teacher and student interviews and classroom observations, and found that when students discussed their learning in the program, they often referred to concepts they learned using authentic data. For instance, a group of students in Georgia discussed productivity and referred to the vegetation imagery activity described above when they talked about biomes (Marrero, Schuster, & Bickerstaff, 2013) .

ACES

The ACES [Animals in Curriculum-based Ecosystem Studies] (www.signalsofspring.net/aces) program brings ocean literacy and marine conservation concepts to life through tracking online the movements of marine animals (e.g., polar bears, whales, sharks, seabirds) with respect to earth data (e.g., bathymetry, chlorophyll, sea surface temperature, sea ice). For instance, a student might follow the movements of a polar bear in the spring and summer, as the Arctic sea ice retreats further and further north. As students analyze and interpret these authentic data, they discover conservation-related issues, e.g., global climate change and biomagnification of pollutants. The crux of ACES is that students are using authentic animal tracking data (animals are tracked using satellite tags) and diverse earth data sets. Students work in teams and examine an animal's movements from different perspectives, e.g., with respect to seafloor features or phytoplankton availability.

In a previous study, ACES students demonstrated the ability to draw upon standards-based concepts they learned in the program and apply them to novel situations. For instance, ACES students learned about marine pollution and sustainable fishing, but demonstrated scientifically-based decision-making abilities when given a scenario of proposed construction of a wave power plant. In focus groups, middle school students discussed how studying their marine animals and learning about the relevant conservation issues affected their personal decision-making, and that upon their families. e.g., related to plastic use and seafood choice. In other words, these students relied on their scientific understandings to support their decisions (Marrero & Mensah, 2011)

SPRINTT

In the SPRINTT [Student Polar Research for IPY with International and National Teacher Training] program, students conduct research studies about aspects of global climate change (http://www.us-satellite.net/sprintt/). Using a database-driven online research tool, students work through a scientific inquiry process: collecting background information, forming a hypothesis, analyzing and interpreting data, and reporting results and further questions. The design of the online tool scaffolds the process for elementary, middle and high school students, allowing them to conduct the research at the most appropriate level for them. Students study topics including:

- Walrus: How will changes in sea ice affect walrus populations?
- Treeline: Movement of the Arctic Treeline
- Greenland: Is the Greenland ice sheet growing or shrinking, thickening or thinning?
- Paleoclimatology: What can ancient atmospheres on earth tell us about earth's future atmosphere?

As they work through researching their topics, students access, analyze, and interpret authentic earth data. The SPRINTT online investigations are designed to lead students through the process of analyzing different data sets as they relate to a central question, and then using the data to support their answers to questions. For instance, for the Greenland study, students progress through a series of data sets, in which they analyze evidence of glacial retreat and build knowledge of the dynamic nature of earth's cryosphere. Activities integrate fundamental science concepts (i.e. properties of water, gravity, temperature, albedo, and plate tectonics) and math concepts (i.e. distance, area, measurement) so that students achieve deeper understanding of the content. Utilizing satellite data of melt zones, elevation maps, and photographic evidence of change over time, students use critical thinking skills to justify whether the evidence supports or refutes their original hypotheses.

Research results show that students engaged in SPRINTT were highly successful at using scientific practices. A random sample (n=89) of 852 completed student research papers were analyzed using the program rubric, which focuses on practices such as developing hypotheses, collecting evidence to support or refute the hypothesis, analyzing and interpreting data, supporting ideas with evidence, and communicated results. According to the study, "In these research papers, students demonstrated they developed sufficient understanding of the content to draw evidence-based conclusions about a pivotal issue or an important question" (Marrero, Davey, Davis, & Schuster, 2011, p. 106).

TEACHING AND LEARNING WITH AUTHENTIC DATA

This research study is a qualitative case study of teachers and students utilizing the three programs described above. Case studies result in a rich description of themes emerging from the data source and seek to bring together research participants into a "bounded system" for the sake of better understanding their experiences and perspectives (Merriam, 1998). In this case, the bounded system included teachers and students working with the three curriculum programs described above: Project 3D-VIEW, ACES, and SPRINTT. The teachers were all members of the NASA Endeavor program and received professional development in the programs through their fellowship coursework. We analyzed both teacher and student work, student presentations, and transcripts of interviews with teachers. Utilizing qualitative methodologies allowed us to explore the participants' views in their own words and better understand the ways in which authentic data are being used for teaching and learning.

Theoretical Framework

The main theoretical framework for this study was social constructivism. Within the NASA Endeavor program, teachers build knowledge based on their own experiences and those shared with other learners, in this case, the other Endeavor teachers. The idea of social constructivism is that knowledge is constructed as a group through interaction and collaborative knowledge building. In social constructivism, "... the process of constructing meaning always is embedded in a particular social setting of which the individual is a part" (Duit & Treagust, 1998, p. 8).The teachers in this case study developed their ideas about using data in the classroom through interactions with colleagues, NASA scientists, and teacher educators. Richardson (1997) explains that in teacher education, "It is within this interaction that cultural meanings are shared within the group, and then internalized by the individual" (p. 8).

Each of the curriculum programs is also built upon this idea of social constructivism (Duit & Treagust, 1998). In this framework, learners build new knowledge by intertwining new ideas with their own experiences, and experiences they share with others. As Palinscar (2005) describes, "learning and understanding are regarded as inherently social; and cultural activities and tools (ranging from symbol systems to artifacts to language) are regarded as integral to conceptual development" (p. 348). For instance, in the ACES program, students are constantly asked to reflect on their experiences with the ocean and freshwater resources, to ask new questions and to reflect on findings of data-based activities, such as the animal tracking. In SPRINTT, students work in teams to study climate change issues, discussing findings and generating a shared scientific paper that reflects their findings. They are encouraged to share their ideas with their teacher and other students, such as through an online symposium (see data collection, below). Crotty (1998) notes that the case study methodology is well-aligned with the constructivist theoretical framework as it "will put all understandings, scientific and non-scientific alike, on the very same footing" (p. 16).

Setting and Participants

We studied diverse teachers in the NASA Endeavor STEM Teaching Program, the STEM professional development arm of U.S. Satellite Laboratory. K-12 teachers, curriculum supervisors, and administrators earn a certificate in STEM Education and can optionally put their work towards a Master's Degree from regionally accredited partner universities. Through the online certificate program, educators take a minimum of three courses; five if seeking a Master's Degree. In a supportive, collaborative online environment, they learn to integrate authentic data, problem-based learning strategies and student-centered STEM activities that address Next Generation Science Standards as well as Common Core State Standards. Instructors teach content and model STEM pedagogy, providing examples of data integration, which the teachers apply to their specific classroom environments. The courses allow for constant discourse and knowledge building among the participants. Teachers bring in their own ideas and experiences, which the instructors use as important starting points for knowledge growth, as suggested by the professional development literature (e.g., van Driel, Beijaard, & Verloop, 2001). Through some data sources, i.e., student work, we also studied the students of Endeavor teachers (see later section).

Data Collection and Analysis

We selected a qualitative approach to this study because we were interested in the ideas of teachers and students and the roles played by authentic data in teaching and learning. Merriam (1998) tells us that "[q]ualitative researchers are *interested in understanding the meaning people have constructed,* that is, how they make sense of their world and the experiences they have in the world" (p. 6). Our goal was to uncover the ways in which using authentic data in K-12 classrooms affects teaching and learning. Qualitative data allows for discovery, for themes to emerge from a variety of data sources rather than testing pre-determined hypotheses.

In qualitative research, the researchers must be strongly connected to their research subjects. Creswell (2003) explains that, "Qualitative researchers look for involvement of their participants in data collection and seek to build rapport and credibility with the individuals in the study" (p. 181). All three of the researchers were instructors in the NASA Endeavor program and thus knew the participants personally. It was through this personal connection that we were able to study and learn about the ways in which authentic data are affecting teaching and learning in the classroom. The case study is one method of qualitative inquiry. "A case study design is employed to gain an in-depth understanding of the situation and meaning for those involved' (Merriam, 1998, p. 19). Case studies allow us to bring together and uncover ideas that are somehow bound together, in this case, by the NASA Endeavor program and by the use of authentic earth data in the K-12 classroom. The cases presented do not necessarily suggest that all Endeavor teachers are successfully employing Earth data in their classrooms. Rather, studying these teachers has allowed us to uncover ways in which teachers can be successful in doing so, and thus inform future teacher professional development in this area.

Data Sources

Teacher Interviews

The researchers conducted conversational, semi-structured telephone interviews (Merriam, 1998) with teachers to uncover the educators' ideas about using authentic Earth data and how the practice has affected teaching and learning in their classrooms. We developed and used a common interview protocol of 12 questions but also allowed for unstructured conversation and additional questions in order to best promote sharing of ideas. Dey (1993) notes the importance of allowing subjects to help define how data are collected, " . . . the length, detail, content and relevance of the data are not determined by the researcher, but recorded 'as spoken' or 'as it happens' . . ." (p. 14).

Teachers were purposefully selected (Creswell, 2003; Merriam, 1998) for interviews based on recommendations from Endeavor instructors. The researchers asked instructors to recommend teachers who demonstrated interest/intent to implement strategies of using authentic data in their classrooms. The goal was not to generalize ideas for all teachers, but rather to examine "representative cases"(Creswell, 2007) of teaching and learning using authentic earth data. The length of the interviews varied from about 20 to 50 minutes, and were recorded and transcribed. Additionally, the researchers took notes turning the interview, which were reviewed as field notes.

Teacher Work

Within Endeavor courses, teachers complete assignments related to course content. Most teachers take the courses to earn graduate credit, which can then be used toward Master's Degrees and/or pay increases in their school districts. Assignments include developing lesson plans, completing discussion posts, writing papers, and reviewing online resources. As a data source, we reviewed the work of about 15 select teachers, again based on instructor recommendation and relevance to the present study. Specifically, we sought out teachers at different grade levels that referenced the use of authentic data, for instance, by creating a lesson plan that relied on such data or discussing an example in an online forum. We reviewed relevant discussion posts, lesson plans, teacher reflections and other assignments stored in the Endeavor Online Learning System (OLS).

Merriam (1998) notes the importance of using documents as data sources in addition to data collected directly by the researchers. She explains, "one of the greatest advantages in using documentary material is its stability. Unlike interviewing and observation, the presence of the investigator does not alter what is being studied. Documents are 'objective' sources of data compared to other forms" (p. 126). In this study, the teacher work and student work, including student symposium, presentations represented documentary data sources because all of these sources were produced without the researchers and for purposes other than this study.

End-of-Course Surveys

Following each Endeavor course, teachers complete end-of-course surveys, which are used by the program for formative assessment and inform course and programmatic improvements. The surveys include both multiple choice and open-ended questions. For this study, we examined survey results from five Endeavor courses over two semesters.

Student Work

In addition to analyzing documents produced by Endeavor teachers, we examined the work of their students. For instance, in December 2014, approximately 20 students from two schools in Florida and Colorado participated in an online "SPRINTT Symposium." During this symposium, student teams shared the findings of their SPRINTT climate change investigations, which rely on authentic data including sea ice satellite images, analysis of gases trapped in ice cores, treeline observations, and more. The students presented their findings and then responded to questions posed by a participating scientist and the other school. The symposium lasted just under an hour. Student presentations were transcribed and the slides collected for analysis. The symposium provided a unique opportunity to gather students' understandings and perspectives of the science topics in their own words and became an important data source for this study.

Other sources of student work were the ACES online journals and student work shared from teachers. In the ACES online journals, students record their analyses of marine animal movements with respect to parameters such as sea surface temperature. Students write their observations and justifications in these online journals, which are then accessible by their teachers and partner scientists. We analyzed approximately fifteen online journals written by students of teachers recommended by instructors. Endeavor teachers whom we interviewed also shared a few examples of student work, i.e., worksheets, which demonstrated students using authentic earth data in the classroom. Teachers were asked to share a range of student classroom work, and the researchers had access to all ACES journals of participating teachers' students.

Data Analysis and Findings

Analyzing the data sets provided a rich picture of the practice of engaging K-12 students with authentic data. The data, collected as described above, were analyzed using the techniques of grounded theory analysis (Charmaz, 2000; Dey, 1993). We went through each piece of the data, e.g., interview transcript, lesson plan and made notes about ideas that arose, getting a feel for all of the data as a whole first, or a "general sense" of the data (Creswell, 2003, p. 191). The next step was to highlight common ideas. Each piece of data was analyzed and compared to existing data sources, using constant comparison (Creswell, 2007). Examining the notes on each data source and re-reading the data through multiple passes allowed us chunk together ideas and begin describing categories and interconnections between the categories. Finally, we collapsed categories into themes supported by evidence from across data sources. These techniques are based on the processes of open and axial coding (Charmaz, 2000; Glaser & Strauss, 1967; Strauss & Corbin, 1990). This process of qualitative analysis results in emergent themes from across data sets.

As qualitative researchers, we employed several strategies to ensure trustworthiness in the findings. First, through analysis and constant comparison of several data sets, we were able to triangulate across data sources (Creswell, 2007; Guba & Lincoln, 1989; Merriam, 1998). For instance, we saw students supporting ideas with evidence in written and oral work, and heard from teachers in interviews that they observed their students using this practice. Collecting evidence from multiple data sources confirms emergent findings. Additionally, we used the process of peer debriefing (Creswell, 2007; Guba & Lincoln, 1989), in which we as the researchers discussed data and emergent themes as we analyzed and reported the themes. Finally, we recognize our biases as Endeavor instructors and present ideas that emerged but do not support our findings, "negative or discrepant information that runs counter to the themes" (Creswell, 2007, p. 196). These ideas are discussed in the later section, "Issues, Controversies, and Problems."

Throughout the data sources, teachers often mentioned that learning to use earth data was an important outcome of the Endeavor courses. For instance, on end-of-course surveys, participants were asked, "What was the most important thing you learned in this course?" Relevant answers from courses included:

- Importance of putting scientific concepts in context and connecting them to real world applications.
- I will use more data in lessons.
- I learned how to use SPRINTT polar climate change program to have student engage in research and interpret, analyze and draw conclusions from online data sets.

In analyzing more deeply, we were able to better uncover *how* teachers are using the data they discussed. Two major themes have emerged from the analysis of data sources: *Constructing Explanations* and *Making Real Life Connections.* These themes were evident across data sources and the work of both K-12 students and their teachers. The data collected showed that authentic data were used by students to construct explanations and also make connections to authentic events. These themes are described in detail below.

Constructing Explanations

Several Endeavor teachers, in their discussion posts and interviews, noted that using authentic data allowed students to employ all eight of the NGSS Science and Engineering Practices. However, through multiple passes of data analysis, we discovered that the teachers often recounted how their students constructed explanations; this practice was also consistently demonstrated by the students in their own work. NGSS Practice 6: *Constructing Explanations and Designing Solutions* is incredibly important. The standards themselves indicate, “The goal of science is to construct explanations for the causes of phenomena” (NGSS Lead States, 2013, Appendix F, p. 11). Beginning at the K-2 level, students are asked to begin using evidence to support their explanation, and this practice becomes more sophisticated as students progress. In Grades 9-12, these explanations, “are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles and theories” (p.11). Our findings show that Endeavor teachers and students are using authentic data at a variety of grade levels to achieve this goal.

3D-VIEW and Earthquake Data

At the middle school level, students of Endeavor teachers are asked, for example, to “use current online geological evidence to support the idea that the Earth’s crust/lithosphere is composed of plates that move” (student worksheet created by Endeavor teacher Eric). One Endeavor teacher, Eric (all names are pseudonyms), at a suburban school in New England, described in his interview the activity in which students organize and use the earthquake data in order to “compare different [plate] boundaries and manipulate the data sets, for instance the depth of the earthquake focus, and look for patterns with size and depth.” Eric used this activity in conjunction with parts of the 3D-VIEW ‘Lithosphere’ curriculum unit, which focuses on movements of Earth’s crust. Eric’s instructors described him as a “go getter,” explaining that he produced “top notch” assignments for his courses and seemed eager to learn and to challenge his students. His students are primarily White and middle to upper socioeconomic classes.

Eric asked students to use evidence collected from authentic data to determine whether earthquake focal depth is related to plate boundary type. In this activity, students were asked to synthesize information from a map of crustal plates and make predictions. Eric noted, “Their predictions came from what they had learned about the different boundary types; they were hypothesizing using evidence.” The next step was for students to collect focal depth data using an online viewer, organizing their data into a table.

Then students had to support their assertions and support or refute their prediction using evidence - the crux of the practice of constructing explanations. Eric noted that using the authentic data was new and a challenge for his students, saying, "It's different from what they're used to doing; it's a new experience. They're not used to higher critical thinking." Eric explained that this lesson was one of his first forays into using authentic online data in his classroom, but that he had since written some new lesson plans and was planning to do more of this type of activity. He felt that this type of work is, "well-aligned with NGSS performance tasks."

Animal Tracking

Gloria, a high school teacher, teaches biology and marine science courses in a suburban school in southern California. The majority of her students are Latino and a significant percentage of students at the school are English Language Learners. She describes the school as mostly middle class. Gloria has implemented portions of both the ACES and SPRINTT curricula in her classes. She is an experienced teacher with certifications in several science subjects as well as a bilingual education credential. Gloria is extremely passionate about her subject area and is always looking for new and better ways to improve instruction in her classroom.

In her phone interview, Gloria explained that she felt that employing authentic data was a way to engage her students in all eight of the NGSS science and engineering practices. She gave specific examples about how students employed different practices, referring back to specific curriculum elements and data the students used. Gloria emphasized that one of the practices students used most frequently was *constructing explanations,* and that authentic data helped students to support their ideas with evidence, for instance NOAA data that can include sea surface temperature (SST), sea ice, weather variables, and more.

Well, I would think that it's mostly taking the background knowledge that maybe they have, and then what they discovered through some of the investigation, and they're just kind of emphasizing that and then constructing explanations, for like maybe why a particular species, is at a particular point at a time, and where they might be going and what might happen. . . I know that when we look at some of the NOAA data—we'll look at trends over time and then maybe if there is some kind of event a certain year that was an anomaly, you know have to explain it . . .

Gloria gave several examples of how she asked students to access and analyze online data, including animal locations, ocean currents, and SSTs, and then try to use the data to explain observations they made. She also emphasized that constructing explanations from the data was a skill that students developed as they worked with real data, saying, that at the beginning, about students:

They weren't specific as to like why the source was supporting that. So, like, it really helped them to develop that [practice], and it also kind of helped me to be able to say, 'oh, okay, hey you know this is what I need you to clarify. Just do the same thing but really be specific about things.'

Once they got the hang of it, Gloria explained that when using real data that they analyze themselves, the students,

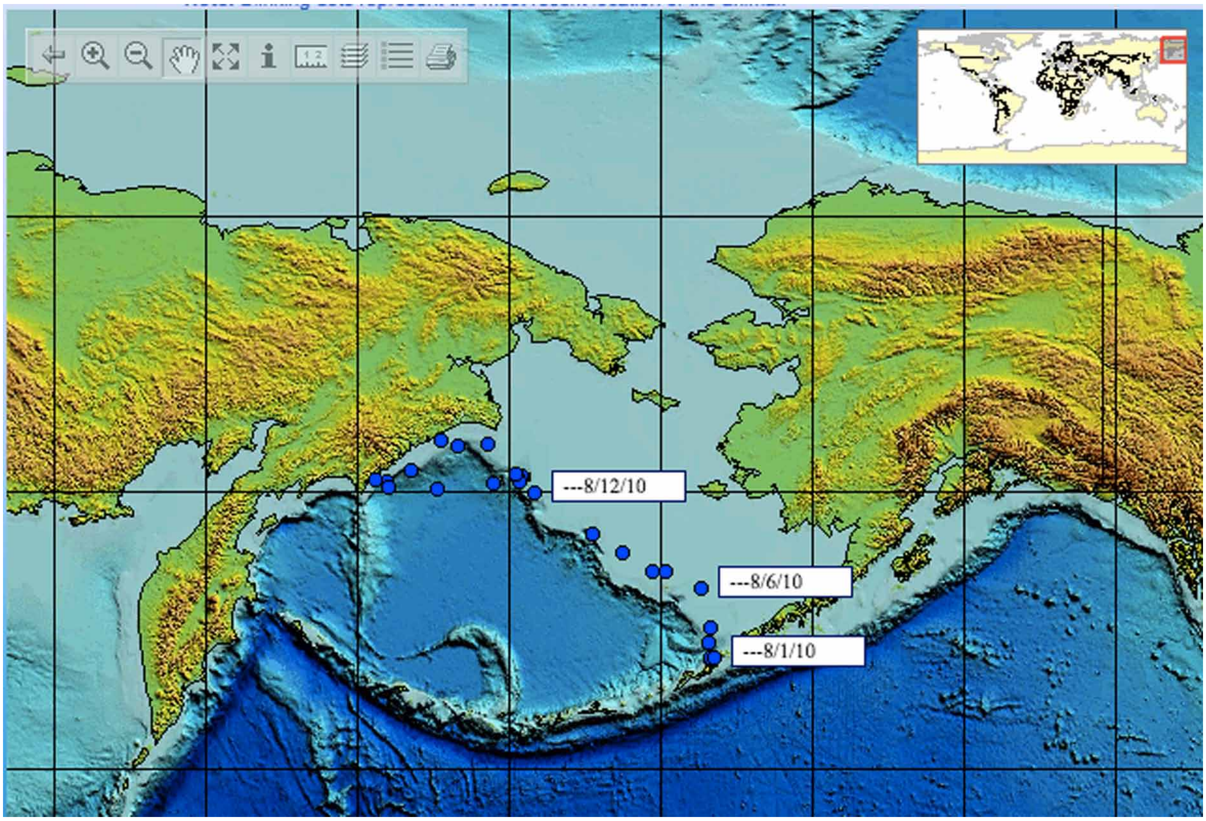
. . . really do a deeper analysis and draw conclusions. So, I thought that this was probably the most valuable . . . there were so many different types of data that when you put [them together] you get a bigger picture and can draw conclusions from that.

For this teacher, using authentic data helped to support students as they developed the practice of *constructing explanations.*

Students of other Endeavor Fellows demonstrated the ability to use this NGSS science and engineering practice in their work. For example, in an ACES journal, one student group was studying Pacific humpback whales and analyzed the movements of one animal, which they called ‘Yoda,’ off of Alaska one August (Figure 1).

During the dates 8/1/10-8/15/10, the animal follows a depth of -100 Meters and it is traveling along the continental shelf. To the south of the continental shelf the depth is around -2000 meters. For the most part the animal is traveling along those depths. Our animal the Humpback Whale 88721 (or Yoda to us) is staying on the continental shelf to eat the phytoplankton and the small organisms that eat the phytoplankton, such as schools of small fish and krill. It is on the edge of the continental shelf and the slope. This is where upwelling can occur. Upwelling gives nutrients to the phytoplankton and the whale eats the phytoplankton. Yoda, is traveling along the continental shelf from Alaska to Russia. . .

Figure 1. Humpback Whale Track in August 2010. Map courtesy U.S. Satellite Laboratory. Earth and animal data courtesy NOAA.



The students interpreted imagery, in this case, bathymetry, made observations, and then explained the animal's movements. This group made connections between the bathymetry imagery, what they knew about seafloor features and water movement, and their understandings about the humpback whale's food web to construct an explanation for why the animal was tracked where it was.

Another student followed the movements of a greater shearwater, a far-ranging seabird, with respect to chlorophyll imagery. Chase, the shearwater that the student was following, took a slightly different path than other greater shearwaters in the area, and the student used evidence from the maps to support their explanation as to why:

Based on data recorded July 19, Chase covered an area of moderately high chlorophyll concentration, approximately 1mg/m3, but the chlorophyll concentrations were higher slightly farther North in a more enclosed part of the bay, approximately 3mg/m3. There were also other tagged greater shearwaters in the area at the same time, and they appear to have remained primarily in the more enclosed part of the bay with higher chlorophyll concentrations. Since the area of highest chlorophyll concentration appears to also have a higher concentration of shearwaters, I suspect that Chase left the more populated region where hed [sic] been earlier in the summer and moved out over the open water to avoid competition for food. Since greater shearwaters eat primarily fish and squid, he could find food out in open water even without the highest chlorophyll concentrations.

In his or her explanation of the bird's movements, the student uses several pieces of evidence to support the explanation: chlorophyll levels, tracks of other animals, and knowledge of the species' life history.

Climate Change Studies

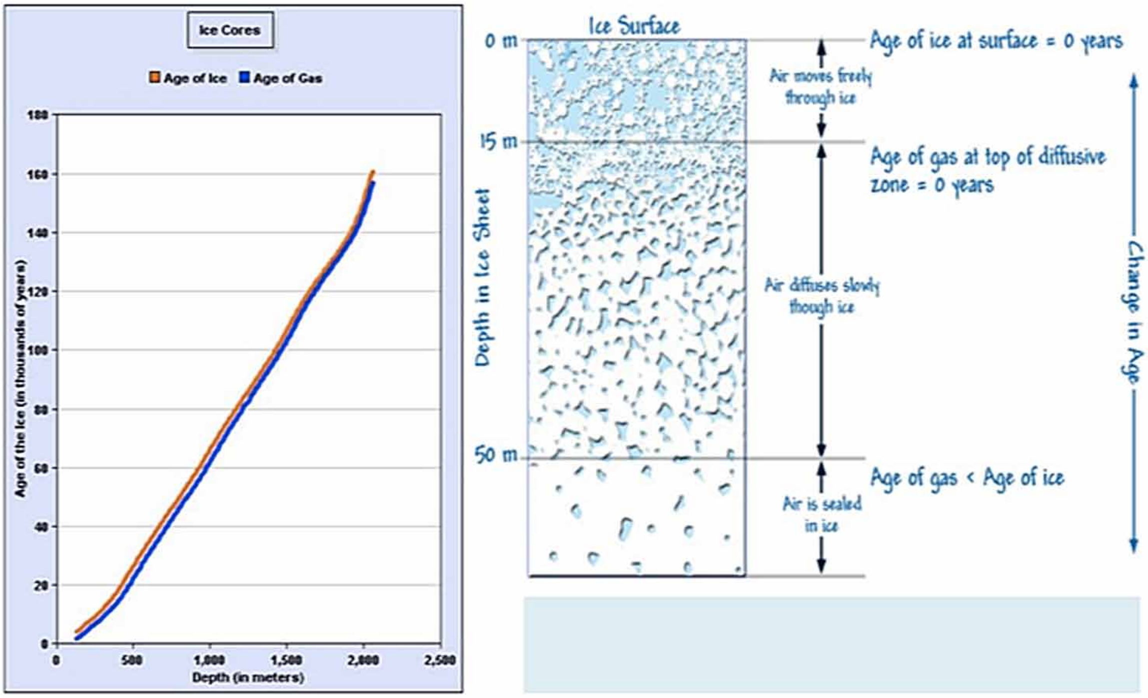
Student presenters during the SPRINTT online symposium consistently demonstrated their ability to construct explanations based on evidence. For example, eighth graders from a private school in Florida conducted a study of paleoclimatology, looking at data collected from ice cores, specifically the concentrations of different gases at different points in earth's history. As they spoke about their findings, they explicitly referred to the data in their explanations.

The first graph, to the left, shows the, uh, the age of the ice cores, and the age of the gas trapped in the ice. As you can see, from 0-15m down, air is able to move freely, but past 15m it becomes harder for the air to move. The air is sealed once the depth reaches 15 meters. These two elements, carbon dioxide and methane, have both had an effect on temperature in the past.

These students used the graph and graphic (Figure 2) as a way to better explain the topic of paleoclimatology using ice cores to their audience, explaining how air becomes trapped in the ice as the water freezes. They then used "pieces of evidence" to support their findings in the investigation, noting, for example,

The third piece of evidence was about carbon dioxide . . .As you can see in the graph above, we have found that there is a fluctuation . . . there are warming and cooling periods that have been fluctuating for more than 400,000 years because of increases and decreases in carbon dioxide. When there is more carbon dioxide in the air, it is warmer, and when there is less carbon dioxide in the air, it is cooler

Figure 2. SPRINTT student presentation slide. Courtesy U.S. Satellite Laboratory.



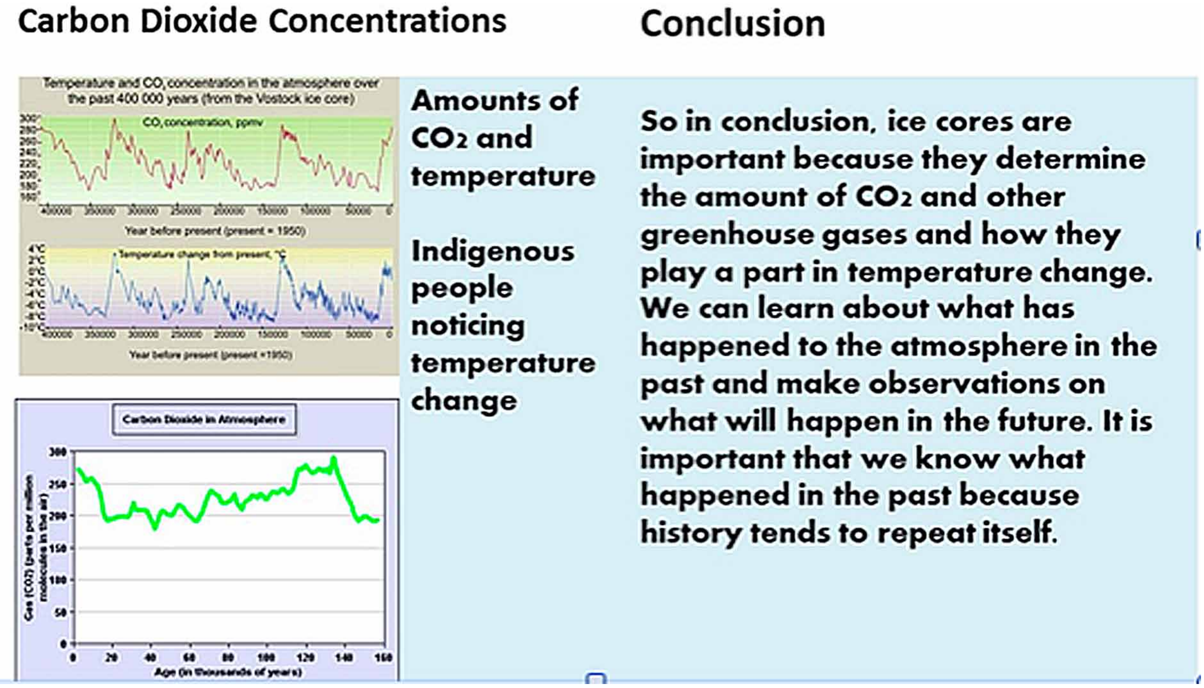
The student team again refers directly to their graphs (Figure 3) as they discuss atmospheric temperature changes and fluctuations in carbon dioxide levels.

Another team, from a high school in Colorado, presented their study of the Greenland ice sheet. More than 80% of Greenland is covered by the ice sheet; the average thickness of the ice is more than a mile. While melting occurs seasonably, scientists are observing that this ice sheet is experiencing more melting in recent years. Students who studied this investigation use data including visible satellite images of the ice sheet and coded data sets that show meltwater ponds atop the ice. During their presentation, the Colorado team noted of the Greenland ice sheet:

In 2005, almost double the amount of ice melted than in 1992. Every year the amount of ice that is melting increases. Because the ice is melting the sea life is changing. Fish that used to thrive in the cold waters are now dying out because of the water warming . .. There are more ponds that appear . . . but with the more ponds is the risk of the ice to crack.

The presenters go on to explain how Greenlanders hunt and fish atop the ice, and how they have had to change their practices, e.g., using boats instead of walking, due to increased melting. These students took the data regarding melting, to which they referred, and then discussed implications for the ecosystem as well as for humans, illustrating that they can meet expectations about science and engineering practices as delineated by the NGSS, that is,

Figure 3. Slide from a SPRINTT student presentation showing use of graphs to support explanations. Courtesy U.S. Satellite Laboratory.



Carbon Dioxide Concentrations

Amounts of CO_2 and temperature

Indigenous people noticing temperature change

Conclusion

So in conclusion, ice cores are important because they determine the amount of CO_2 and other greenhouse gases and how they play a part in temperature change. We can learn about what has happened to the atmosphere in the past and make observations on what will happen in the future. It is important that we know what happened in the past because history tends to repeat itself.

Construct a scientific explanation based on valid and reliable evidence obtained from sources (including the students' own experiments) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future (Appendix F, p. 11).

Importantly, based on some of their comments during the symposium, the students recognized the significance of using authentic data. The group studying the Greenland ice was asked by another team to name their favorite part of the investigation. A student answered, "I really liked all of the evidence, and using all of the images. Each piece of information really supported our hypothesis and supported the fact that everything is melting. . ." Another student group was asked why so many people do not believe that climate change is a problem. One student explained, stressing the importance of using evidence to support their ideas:

Personally, I think that a lot of people have trouble seeing all this, and really have trouble seeing why it's such a clear problem, because a lot of people actually haven't looked too much into it. They haven't actually seen graphs or other evidence that gives them the evidence. They are just hearing the news, or the rumors, or something of that sort. They aren't seeing the evidence.

This student refers to the data and notes several times that explanations should be based on evidence. Similarly, one team was asked what they would tell the public about climate change. A student answered:

> *We'd tell them to look at the data to research it themselves, to not only, to take the time to look at it, and get some hardcore facts that you can look at. Obviously we can say, global warming, the ocean levels are rising, we can say that but to look at the data, it would be helpful for people to understand what is going on and for them to see it themselves . . .*

Based on these comments, the SPRINTT students seem to have internalized the importance of backing up explanations with evidence. The students repeatedly note that data provide an opportunity for people to develop their own explanations.

Teachers in the SPRINTT course also highlighted the importance of data integration for constructing explanations when planning for instruction using the program. Miriam, a middle school teacher in California, noted in a discussion post:

> *With the new argumentative writing common core standards students need to know how to use data to support their statements. Investigations that allow my students to use and analyze data helps them to see and understand the concepts they are learning, and it also teaches them how to use data as a support for their predictions and conclusions.*

It's interesting that Miriam relates her students' experience in constructing explanations more to the Common Core State Standards for ELA than to the science standards. It may be important for instructors to help science teachers to make connections between the two sets of standards. Gloria, the California teacher, discussed the SPRINTT program as a way to help students see the value of supporting their explanations with evidence, saying:

> *Giving students opportunities to gather information by analyzing multiple types of data sets provides an avenue for students to envision the real-world applications of their learning and understand how the use of scientific data provides evidence for constructing explanations for problems facing our natural world.*

She goes on to talk about how important it is for students to use evidence to support climate change assertions, since the issue has become so politically charged.

Making Real Life Connections

The other theme that emerged across the data sources is that in Endeavor classrooms, students and teachers used authentic data to make real-life connections to content. When using online data, students and teachers saw the information as relevant to their lives and important.

Using Earthquake Data

Eric, the New England middle school teacher, recognized the importance of students working with authentic data and developing their scientific practices. He mentioned in the interview that the students saw the connections to their "regular lives." He explained that the earthquake data engaged students because "This is a way to model and interpret what's going on in real life. They're [the students] in charge of it; they're changing the parameter." Eric also shared that working with the earthquake data, "definitely increased engagement. [Students understood] that earthquakes happen everywhere. This is the biggest takeaway that they're taking with them, because you don't hear about all of [the earthquakes]." Eric's students were shocked to discover, from the online data, that earthquakes do frequently occur in the northeast, although they are typically too small to be felt. Suddenly, earthquakes, which they viewed as relevant to faraway places like California and Japan, became relevant to students' lives.

Prior to this lesson, Eric had used online simulations, e.g., those created by pHET, that allow students to manipulate variables. While he noted that such simulations are useful resources, he felt that it was useful and important that students were able to use real earth data. Based on his observations of his classes, the students were more engaged and more connected when they knew they were observing and analyzing real earthquake information. This finding is echoed in other research, where three methods were compared: traditional instruction, traditional instruction with simulations and inquiry instruction using RTD. That study found little difference in student learning in the first two classroom contexts, but conducting inquiry using the authentic data was found to develop notably higher levels of scientific understandings, emphasizing the value of introducing authentic data for instruction (Ucar & Trundle, 2011).

Alana, a middle school teacher in California, also chose to incorporate earthquake data as a part of the 3D-VIEW course. As Californians, her students had certainly experienced earthquakes and community discussions of future seismic activity. She created a lesson plan in which students would access a real-time earthquake map from USGS depicting recent activity, make observations, and try to predict plate movements, In reference to the map, she explained:

I would use this diagram as an introduction to earthquakes. I could describe plate tectonics. Students could predict which plate was moving and why the earthquakes are scattered this way.

Based on her lesson plan, Alana seems to have a more traditional style of teaching, and would use the data as more of an introduction rather than engaging her students in deeper analysis as Eric did.

Connecting to the Ocean

In Southern California, Gloria's students can sometimes observe gray whales with their own eyes, even sometimes with binoculars from their school building. While most of us are not lucky enough to have our own local cetaceans to motivate students, Gloria stressed that she used authentic data to help students to understand that their actions online affect marine mammals and other ocean inhabitants.

I have them try to make some correlations between what we do and the grey whale migration. I have them look up some pollution data for the California Coast, and they can try to explain how since the gray whales tend to stay in the areas . .. they are affected.

Gloria's students accessed online pollutant data and analyzed nutrient levels to help them make connections to how what happens on land affects animals such as whales. She emphasized that using the real data was important in helping students feel connected to the science, explaining

They actually realized they are using real data. I think that most of them were just really excited . . . they are engaged in trying to figure things out. I think more so than what they would have been if they weren't using real data.

She went on to say that her students were really interested in "seeing that they could actually take the data and try to figure out what's happening in the world."

Other Endeavor teachers using ACES explain that tracking the animals helps students to feel connected to the ocean and to conservation issues. Maya, an upper elementary school teacher in Florida, explained in a reflection assignment, "Though the students were not able to go to the ocean, they were able to start making real world connections as we talked about the different facets of ocean literacy." Her students studied the movements of sea turtles and made connections to local pollution data in Tampa Bay.

In their online journals, students often write about conservation issues, even though the instructions for the journals ask students to focus on the animals' movements and earth data. One group studying loggerhead sea turtles wrote:

The Loggerhead turtles population is in danger because of their nest being destroyed by construction, their eggs are getting destroyed, and their habitats are being destroyed. Humans have destroyed their precious nesting grounds, constructing on the nesting grounds, and also tourists would disrupt the eggs or destroy them.

These students' word choices seemed to illustrate their passion about the animal they were studying. Endeavor teachers consistently note that following the paths of actual marine animals helps students better connect to human impacts on marine species and make connections to their own choices. Carrie, a middle school teacher in Massachusetts described her students' response in a reflection paper:

They showed sympathy for the animals when they were researching for this particular class. They called me over to their computer and said, "Miss, look at what happened to the turtle, why do people do this?" One student actually cried when she saw a picture of a turtle that grew with a plastic ring around its shell.

Some students of course may be affected by simply reading about some of these issues or seeing pictures like the one that Carrie described, but several teachers emphasized that actually following the animals' movements online was critical for building the real-life connections.

Denny, another teacher in southern California created a lesson plan in which his students would examine real-time tidal data and make connections to the grunion, a local fish that comes to spawn on the beach in concert with the tidal cycle. He shared observations that his students made, noting:

They were then asked to analyze their tidal graph. I thought that the analysis went well. I received many accurate observations such as;

- *"I saw that there was one bigger high tide and one smaller low tide every day."*
- *"There seemed to be high and low tides at different times each day."*
- *"Why did one day not have four tides?"*
- *"It seemed like there was one high and low tide in the morning. There was one high tide and low tide at night."*
- *"I saw that there was one high tide for the month that was the biggest."*

Overall, I was pleased with their data organization and analysis. Their observations provided evidence for the idea of a fluctuating tide and also supported our guiding question.

Denny felt that it was important for students to use data to better understand this local phenomenon. He felt that his students were successful with the task but also in making real-life connections to content.

Real-Life Connections to Climate Change

During the SPRINTT symposium, students studying paleoclimatology demonstrated that they understood how the data they were analyzing were relevant to their lives, and what is happening with climate change. They stated:

In conclusion, the ice cores are very important because they can determine the amount of carbon dioxide and the amounts of O^{18} *in the ice, and then history tends to repeat itself. That's how we can know what's happening in the future.*

In other words, this student team believed that their work was important and relevant in predicting what will happen to the future climate. Similarly, another group researching the Greenland ice sheet concluded their presentation by saying,

We need to know how global warming will affect our generation, and our children's generation. . . it could change the climate and how we live, if the Greenland ice sheet melted.

By analyzing melting patterns in the Greenland ice sheet, students became very connected and concerned about climate change.

Stephen, a teacher at a diverse high school in the suburbs of New York City, implemented portions of the SPRINTT curriculum into his classes and also found that using the data really helped students to feel more connected to climate change, that it is real and affected them. He explained that they were studying climate change in his course but that when the class accessed the online carbon dioxide data, his students finally "got it."

We started getting the idea of just pulling the data of the temperature curve and the CO_2 *concentration on what's going on. . . it was really the first time that [the students] felt involved and they could actually see what was happening. It really does make a difference.*

Stephen used real data to spark students' connection to the material and increase engagement. His school district is comprised of students from a wide range of socioeconomic backgrounds and his students have very different life experiences. He felt that using the carbon dioxide data was a way to make connections for all of his students.

In her introduction to a lesson plan he created, Maura, a teacher from New Jersey, explained how she could use data to help students make a real life connection to a local issue:

I am interested in the effect known as the "urban heat island" and have chosen to explore that topic with local data, bring its results to my classroom and then have my students conduct our own research through a hands-on laboratory. Living in northern New Jersey, with the diversity of our geographic features and the urban, suburban and rural settings so near each other, makes for a great opportunity for my students to study the "urban heat island" since they so often experience it.

In planning for this lesson, Maura found appropriate local data that she will have students analyze, and, like Gloria, pair her Earth data with a hands-on activity. She can then make larger connections to climate change.

For elementary students, it can be difficult to make the topic of climate change relevant and developmentally appropriate. One elementary teacher in Kansas, Andrea, instead proposed in a lesson plan assignment that her students look at temperature data. Her plan included the following:

Students will analyze the relationship between the sun and the Earth by analyzing temperature data from around the Earth using the following website: http://www.noaa.gov/wx.html. Each table of students will have a different area of the world to analyze. They will explain and illustrate a graph to show the different temperatures over a two-week period.

She would then have students create graphs and compare temperature data from around the world to local temperature, helping them to understand their own weather and climate and how they compare to other locations.

In discussion posts during the SPRINTT course, other teachers discussed how data could help their students make the real-life connection to climate change. These teachers had not implemented the lessons with teachers. Sandy, a middle school teacher stated:

My reflection on these investigations have helped me understand how to present the subject of climate change to my sixth grade students in a way that will help them understand we are all a part of the "REAL" climate change. This change has been documented in numerous resources such as graphs, charts, and real data has been presented in a way that is clear and easy to understand . . .

Sandy was new to using Earth data but saw it as a way for students to be connected to a real life socioscientific issue.

Our finding that using authentic, online data helps students to make real-life connections confirms previous studies in this area, (e.g., Adams & Matsumoto, 2009; McKay & McGrath, 2007; Ucar & Trundle, 2011). Moreover, this finding is important because students often report that what they learn in science classrooms has little relevance to their lives (Costa, 1995; Nieto, 1994). If students do not view science as relevant to their lives, they are not likely to view the subject as important for them to learn (Songer & Linn, 1991). Therefore, using authentic online data in science classrooms may help students feel more connected to science content and therefore more engaged in science class. Student disengagement is a significant barrier to student learning (Carini, Kuh, & Klein, 2006; Steinberg, 1996) so identifying ways to improve relevance and engagement is always important.

Issues, Controversies, and Problems

This study and others have identified many reasons why incorporating authentic, online data can support teaching and learning in K-12 classrooms. At the same time, there are some issues that arise when using this instructional strategy.

Student Comprehension of Data

Our findings show promise in students' and teachers' ability to use authentic data for constructing scientific explanations. At the same time, working with actual data sets, rather than pre-fabricated, "clean" data, can sometimes be problematic. First, it can be much more challenging for students to work with authentic data. Investigations with real data often require more steps for students to access and interpret the data, and also understand realities of scientific work, e.g., anomalies, outliers. There are often massive amounts of data and it can be a challenge for students to sift through the observations and find what they need. For instance, Eric, the 8th grade teacher in New England, worked with a colleague to teach the earthquake lesson, but his colleague felt that the investigation was "too rigorous." Eric said that some of his students were very uncomfortable with the process, and he felt that a percentage of students just "didn't get it, even with serious guidance."

Due to the often open-ended nature of working with authentic data, there can be more errors in the way students understand and use the information. For instance, during the SPRINTT symposium, one group referenced changes in Arctic sea ice as they observed on sea ice images from 1979 and 2007. While the sea ice extent has changed since 1979, it does fluctuate from year to year and 2007 saw one of the lowest extents of sea ice on record (Vizcarra, 2012), facts that the students neglected to include. By not obtaining or communicating more contextual information about their data, students may struggle to fully understand their data and correctly interpret their findings.

Similarly, in ACES journals we noticed erroneous analyses that suggest that students hold misconceptions about the content. In one ACES journal that analyzed the movements of a humpback whale, a student team wrote, "The range of the phytoplankton where our animal travels is 0-5 in the Pacific Ocean. The reason that the phytoplankton range is 0-5 [is] because SST is too cold for phytoplankton to grow." In actuality, most types of phytoplankton thrive in colder waters, which are often more nutrient-rich than warmer waters.

Teacher Comfort Levels in Using Data

Science education programs that make use of authentic earth data, either archived or real-time, are on the forefront of science education reform. Teaching with authentic data can be difficult for teachers who have no experience with this progressive approach to science education (Bodzin and Shive, 2004; Bodzin, 2008). In the Endeavor program, teachers are asked to work with authentic data throughout their three or five-course sequence of study. The required introductory course, Methods of STEM Education, introduces teachers to the idea of using authentic earth data in their lessons and shares freely available resources.

Even after many examples of ways to use authentic data are shared with teachers, the Endeavor teachers sometimes struggle to actually use the online data in their classrooms. Eric, a hardworking, smart, and passionate educator admitted that even after about a year in the Endeavor program and completing several courses, that he had only really used online data with the earthquakes activity (described in the *Data Analysis and Findings* sections).

Gloria, another experienced and thoughtful educator, noted that she used online data in her marine science course, but that she struggled to do so in her biology classes. She attributed not using the data to

. . . maybe not knowing exactly what was out there, but . . . I think most of It was just that our California content standards were so rigid before . .. I felt like we didn't really have time to do some of these proj-

ects even though it would have been great to take more class time, we had to follow a pacing guide. And now we have . . . our Next Generation Science Standards . . .and I have actually done more this year.

Like many teachers, Gloria has struggled with the realities of a very full curriculum and the time it takes to use inquiry-based strategies like employing authentic data. She noted that some of her students' investigations with data "took longer than planned." She remains optimistic that with the adoption of the NGSS in her state, her students will have more opportunities to use online authentic data because she sees the value for her learners.

SOLUTIONS AND RECOMMENDATIONS

Teacher Training

The findings suggest that using authentic, online data may be one way for students to learn to effectively use the NGSS practice of constructing explanations, as well as make real-life connections to science content. We believe that one of the keys to capitalizing on these benefits is excellent and sustained teacher training. Other researchers have suggested that this approach is crucial for effectively using such data in the classroom. For instance, Bodzin (2008) cites professional development as a key component of the success of the teacher and students in pairing online data with hands-on activities. Additionally, teachers require sustained support as they continue to implement authentic data in their classrooms. Concluding their study of geospatial data in the K-12 classroom, Doering and Veletsianos (2007) state that the success of data integration will not be seen until pre-service and in-service teacher education programs include training with integration of authentic data available through technology.

The NASA Endeavor program is an example of professional development with a focus on the use of these data sets. Endeavor teachers choose courses that fit best with their curricular interests and grade level, but each course emphasizes using authentic data. In one course, teachers use space weather data to monitor solar flares and storms. In another, they analyze Mars surface features to look for evidence of water on the red planet. Back on Earth, Endeavor teachers monitor our planet's gravitational pull and water pollutants. In the post-course surveys, Endeavor teachers consistently cite learning to use authentic data as important to them. When asked what they learned in the course and how the class influenced their teaching practice, teachers reply with comments such as:

- "The importance of incorporating data from research sites"
- "I learned . . . to have students engage in science practices and interpret, analyze and draw conclusions from online data sets."
- "I will use more data." (quotes from post-course surveys)

In his interview, Stephen, the teacher in the New York City suburbs, echoed these ideas saying

I just think we need more courses like Endeavor. . . .especially for STEM teachers more, they need to take assessment of more data and enter it into the classroom because it really makes a difference for students . . .

These quotes are just a few examples that illustrate that STEM teachers appreciate authentic data and see the value of incorporating them in their own classrooms, but that they need professional development to help them do so. We believe that there should be a greater focus in pre-service and in-service science teacher education on appropriately and effectively bringing authentic, online data into K-12 classroom. Professional developers in these areas can help teachers, for instance, to appropriately scaffold the use of data for students, in order to overcome barriers of student comprehension of the data. The 3D-VIEW, SPRINTT, and ACES courses are designed to prepare teachers to implement specific Earth data-based curriculum materials in their classrooms, and it would be difficult for teachers to do so without this training. Like most available online data, it can be hard for a novice to access and interpret the data sets, and to create learning modules for their students. The professional development is a way to help teachers do so.

Using authentic Earth data to support science learning is also applicable to other settings. For instance, instructors in undergraduate courses have demonstrated success in using these types of data with their classes. In one example, undergraduates in Korea used data to make and support hypotheses about the movements of typhoons (Oh, 2011). In a long-term study, Prothero and Kelly (2008) demonstrated that engaging undergraduate oceanography students in writing activities that relied on authentic Earth data led to greater student learning outcomes. Additionally, many informal learning institutions, e.g., museums and aquaria, have begun including exhibits that have an RTD component, allowing visitors for instance, to view recent earthquake data in a geology hall.

Bringing Authentic Data into Your Classroom

While we do believe that sustained professional development is the best way to support the use of authentic online data in the classroom, we have identified several different examples of easily accessible online data sets. By using these data, students can delve deeply into the observations and use their analyses and interpretations to build conceptual understanding. In other words, students can use the same best practices of inquiry-based teaching and learning using their computers, tablets, or smartphones to access and analyze a world of data.

For example, using Google Mars (http://www.google.com/mars/) and Google Earth (http://www.google.com/earth/), students can investigate volcanoes on Mars and Earth, comparing their size, activity and location relative to other features. By looking at Mars, they ask questions about Earth, taking ownership of their study of volcanoes and plate tectonics.

One of the most simple and popular ways to use authentic online data is to investigate weather. At Weather Underground (http://www.wunderground.com/), historical weather data is available by date and is useful to research notable storms or triangulate with other data sets, such as from the National Weather Service (http://www.weather.gov/briefing/). Students can look for patterns in weather data, study the paths of storms, or research hazards affecting different parts of the country.

Students can investigate what causes wind and how we use it as a renewable energy resource. The National Renewable Energy Laboratory provides compiled data on wind speed. Additionally, NASA is collecting data (http://podaac.jpl.nasa.gov/?CFID=81aba624-5d48-4977-ad24-9f9a501e45d8&CFTOKEN=0) on wind speed at various locations around the globe. Students can access data to study wind patterns and determine the best place to build wind turbines, specifically offshore, where there is controversy over impact to wildlife. This 'real-world' question is facing scientists, engineers, and policy makers as they consider the best options for energy and the impact on the environment. Continuing studies may include data analysis from The Wind and Wildlife Institute (Wind and Wildlife Landscape Assessment Tool http://www.wind.tnc.org/#) to assess the potential impact to wildlife. In the context of the question of where best to build a wind farm, students address many important science and math concepts and access data to engage in critical thinking and analysis.

To study environmental science, students might analyze air quality in different regions (http://airnow.gov/index.cfm?action=airnow.main) of the United States. They can use archived data look for long term patterns and design solutions or mitigation techniques. Students can make connections to natural disasters, like volcanoes and wildfires, and research the impacts that air quality has on health.

Using buoy data (http://www.ndbc.noaa.gov/), students can look for evidence of ocean currents or storms out at sea. A network of buoys provides information on air and sea conditions, including temperature, wind speed, wave period, and more. Students can create graphs of data over time, or use the data to make comparisons between locations close to home and those around the world.

FUTURE RESEARCH DIRECTIONS

As the Next Generation Science Standards gain more widespread use in United States classrooms, it will be interesting to continue this research in order to uncover how students and teachers use authentic online data in order to master the standards and employ each of the eight science and engineering practices. How might online data, for instance, inform students' engineering design or help them to model scientific phenomena?

CONCLUSION

This chapter outlines some examples of the use of real Earth data with students by teachers who participated in a targeted professional development program to utilize such online resources. We have found that this learning context is engaging and promotes the use of evidence to support constructing explanations and making clear connections to the real world. Findings from data collected from both teachers and students revealed the development of students' use of evidence and the role evidence plays in student learning of content, especially as it relates to human impact on our world. Further, the use of real data sets brought the science content to life for students – providing a real connection to content in their courses. Although some barriers exist for implementation, the benefits for student learning far outweigh these issues and we encourage STEM educators to find real data resources to use with their students whenever possible.

REFERENCES

Adams, L. G. (2011). Engaging middle school students with technology: Using real-time data to test predictions in aquatic ecosystems. *Science Scope*, *34*(9), 28–32.

Adams, L. G., & Matsumoto, G. (2009). Enhancing ocean literacy using real-time data. *Oceanography (Washington, D.C.)*, *22*(2), 12–13. doi:10.5670/oceanog.2009.55

Bell, W. H., Fowler, E. M., & Stein, J. A. (2003). Coastal seas as a context for science teaching: A lesson from Chesapeake Bay. *Marine Pollution Bulletin*, *47*(1-6), 253–259. doi:10.1016/S0025-326X(02)00468-X PMID:12787628

Bodzin, A. M. (2008). Integrating instructional technologies in a local watershed investigation with urban elementary learners. *The Journal of Environmental Education*, *39*(2), 47–58. doi:10.3200/JOEE.39.2.47-58

Bodzin, A. M. (2011). The implementation of a geospatial information technology (GIT)-supported land use change curriculum with urban middle school learners to promote spatial thinking. *Journal of Research in Science Teaching*, *48*(3), 281–300. doi:10.1002/tea.20409

Bodzin, A. M., & Shive, L. (2004). Designing for watershed inquiry. *Applied Environmental Education and Communication*, *3*(4), 249–258. doi:10.1080/15330150490881903

Carini, R. M., Kuh, G. D., & Klein, S. P. (2006). Student Engagement and Student Learning: Testing the Linkages*. *Research in Higher Education*, *47*(1), 1–32. doi:10.1007/s11162-005-8150-9

Charmaz, K. (2000). Grounded theory: Objectivist and constructivist methods. In Y. S. Lincoln & N. K. Denzin (Eds.), *Handbook of qualitative research* (2nd ed.; pp. 509–535). Thousand Oaks, CA: Sage.

Cheng, M. M. W., & Gilbert, J. K. (2014). Students' visualization of metallic bonding and the malleability of metals. *International Journal of Science Education*, *36*(8), 1373–1407. doi:10.1080/09500693.2013.867089

Chin, C. A., & Malhotra, B. A. (2002). Epistemologically authentic inquiry in schools: A theoretical framework for evaluating inquiry tasks. *Science Education*, *86*, 2175–2218.

Costa, V. B. (1995). When science is "another world": Relationships between worlds of family, friends, school, and science. *Science Education*, *79*(3), 313–333. doi:10.1002/sce.3730790306

Creswell, J. W. (2003). *Research Design: Qualitative, quantitative, and mixed methods approaches* (2nd ed.). Thousand Oaks, CA: Sage.

Creswell, J. W. (2007). *Qualitative Inquiry and Research Design: Choosing among five approaches* (2nd ed.). Thousand Oaks, CA: Sage.

Crotty, M. (1998). *Introduction: The research process. In The foundations of social research: Meaning and perspective in the research process*. Thousand Oaks, CA: Sage.

Dey, I. (1993). *Qualitative Data Analysis*. New York: Routledge. doi:10.4324/9780203412497

Doering, A., & Veletsianos, G. (2007). An investigation of the use of real-time, authentic geospatial data in the K–12 classroom. *The Journal of Geography*, *106*(6), 217–225. doi:10.1080/00221340701845219

Duit, R., & Treagust, D. (1998). Learning in Science-- From behaviorism towards social constructivism and beyond. In B. J. Fraser & K. G. Tobin (Eds.), International Handbook of Science Education (pp. 3-25). Kluwer Academic Publishers.

Edelson, D. C. (1998). Realising authentic science learning through the adaptation of scientific practice. International Handbook of Science Education, 1, 317-331.

Gilbert, J. K. (2004). Models and modeling: Routes to more authentic science education. *International Journal of Science and Mathematics Education*, *2*(2), 115–130. doi:10.1007/s10763-004-3186-4

Glaser, B. C., & Strauss, A. L. (1967). *The discovery of grounded theory: Strategies for qualitative research*. Chicago: Aldine.

Gray, L., Thomas, N., & Lewis, L. (2010). Educational Technology in U.S. Public Schools. U.S. Department of Education.

Guba, E. G., & Lincoln, Y. S. (1989). *Judging the quality of fourth generation evaluation. In Fourth Generation Evaluation* (pp. 228–251). Thousand Oaks, CA: Sage.

Hawkins, J., & Pea, R. D. (1987). Tools for bridging the cultures of everyday and scientific thinking. *Journal of Research in Science Teaching*, *24*(4), 291–307. doi:10.1002/tea.3660240404

Lee, H. S., & Butler, N. (2003). Making authentic science accessible to students. *International Journal of Science Education*, *25*(8), 923–948. doi:10.1080/09500690305023

Marrero, M. E., Davey, B. T., Davis, H. B., & Schuster, G. S. (2011). Climate Change as an Integrating Context for Learning. *Journal for Activist Science and Technology Education*, *3*(1).

Marrero, M. E., & Mensah, F. M. M. (2011). Socioscientific Decision Making and the Ocean: A Case Study of 7th Grade Life Science Students. *Electronic Journal of Science Education, 14*(1).

Marrero, M. E., & Schuster, G. (2010). Students making environmental connections to achieve scientific literacy: From local schoolyards to half a world away. In J. Hoot & J. Szente (Eds.), *The Earth is Our Home* (pp. 93–108). Olney, MD: Association for Childhood Education International.

Marrero, M. E., Schuster, G., & Bickerstaff, A. (2013). Earth System Science in Three Dimensions: Perspectives of Students and Teachers on NASA's Project 3D-VIEW. In K. Fletcher & L. Lennex (Eds.), Cases on 3D Technology Application and Integration in Education (pp. 253-280). Hershey, PA: IGI Global.

McKay, M., & McGrath, B. (2007). Real-world problem solving using real-time data. *International Journal of Engineering Education*, *23*(1), 36–42.

Merriam, S. B. (1998). *Qualitative research and case study applications in education*. Hoboken, NJ: Jossey-Bass.

Minner, D. D., Levy, A. J., & Century, J. (2010). Inquiry-based science instruction: What is it and does it matter? Results from a research synthesis years 1984 to 2002. *Journal of Research in Science Teaching*, *47*(4), 474–496. doi:10.1002/tea.20347

NGSS Lead States. (2013). *Next Generation Science Standards: For States*. Washington, DC: By States.

Nieto, S. (1994). Lessons from students on creating a chance to dream. *Harvard Educational Review*, *64*(5), 392–426. doi:10.17763/haer.64.4.4846361m306pl670

Oh, P. S. (2011). Characteristics of abductive inquiry in earth science: An undergraduate case study. [Case Study]. *Science Education*, *95*(3), 409–430. doi:10.1002/sce.20424

Prothero, W. A. Jr, & Kelly, G. J. (2008). Earth data, science writing, and peer review in a large general education oceanography class. *Journal of Geoscience Education*, *56*(1), 61.

Richardson, V. (Ed.). (1997). *Constructivist teacher education: Building new understandings*. New York: Routeledge.

Songer, N. B., & Linn, M. C. (1991). How do students' views of science influence knowledge integration? *Journal of Research in Science Teaching*, *28*(9), 761–784. doi:10.1002/tea.3660280905

Steinberg, L. (1996). *Beyond the classroom: Why school reforms have failed and what parents need to do*. New York: Simon and Schuster.

Strauss, A. L., & Corbin, J. (1990). *Basics of qualitative research: Grounded theory procedures and techniques*. Newbury Park, CA: Sage.

Ucar, S., & Trundle, K. C. (2011). Conducting guided inquiry in science classes using authentic, archived, web-based data. *Computers & Education*, *57*(2), 1571–1582. doi:10.1016/j.compedu.2011.02.007

van Driel, J. H., Beijaard, D., & Verloop, N. (2001). Professional Development and Reform in Science Education: The Role of Teachers' Practical Knowledge. *Journal of Research in Science Teaching*, *38*(2), 137–158. doi:10.1002/1098-2736(200102)38:2<137::AID-TEA1001>3.0.CO;2-U

Vizcarra, N. (2012). Arctic sea ice extent breaks 2007 record low. *Arctic Sea Ice News & Analysis.* Retrieved February 12, 2015, from http://nsidc.org/arcticseaicenews/2012/08/arctic-sea-ice-breaks-2007-record-extent/

Wilson, M. E. (2009). *Assessing the Impact of High-Fidelity Implementation of 3D-VIEW on Student Achievement*. Purdys, NY: EDU, Inc.

KEY TERMS AND DEFINITIONS

Authentic Online Data: Collections of observations, such as of earth and space parameters, that are accessible via the internet.

Data: Collections of observations, such as measurements.

Real Time Data (RTD): Observations collected and made available virtually immediately.

Science and Engineering Practices: Eight skills or behaviors used by scientists and engineers, as identified by the Next Generation Science Standards.

Visualization: The process of changing numbers or other data into a graphical format.

APPENDIX

Instruments

A. Interview Protocol: The researchers conducted semi-structured interviews to uncover teachers' use of authentic data in their classrooms using the following protocol:
   1. What grade(s) do you teach, and what subject(s)? Tell me a little bit about your school demographics, etc. Which Endeavor programs are you using (e.g., ACES, 3D-VIEW, SPRINTT)?
   2. What is your certification area? How much experience do you have with STEM content?
   3. What was your experience in using authentic data and visualization prior to Endeavor?
   4. What are some examples of data visualization you are now using in your classroom?
   5. What do you think are the benefits of using authentic data in your classroom?
   6. How have your students reacted to using real data? What have their attitudes been?
   7. In what ways have authentic data helped students to learn science concepts? Please describe some examples.
   8. In what ways has using authentic data helped students to improve their science practices? Please describe some examples.
   9. How do you pair data visualization with hands-on activities in your classrooms?
   10. Where would you want to go next with this idea?
   11. Would you be willing to share any student work related to how they use visualization?
   12. Anything else you'd like to share?

B. End of Course Survey Open-Ended Questions: The End of Course Survey is the same for each course and includes a mix of LIkert-type and open-ended questions. The open-ended questions are:
   - How, if at all, did this course influence your teaching practices?
   - What was the most important thing you learned in the course?
   - What role, if any, did the online community play for you?
   - Offer a suggestion as to how the course can improve.
   - Please enter any additional comments.

Section 3

Educational Technologies for Use in STEM

Chapter 14

Exploring Physics and Technology:

A Study in Teaching Kinematics to Student-Athletes

Loraine Snead
YSC Academy, USA

Yushaneen Simms
YSC Academy, USA

ABSTRACT

It is becoming increasingly important to incorporate engaging and relevant interactive technologies into the physics and general study curricula of K-12 students. Theoretical principles of kinematics can be brought to life by including complementary technologies and activities that require manipulation and construction of textbook knowledge. This chapter explores the use of Adidas Smart Ball technology, the Physics Education Technology (PhET) online simulation, and Apex Digital Learning in grades nine through twelve enrolled in a small private college preparatory academy. The chapter is centered on the development of a kinematics unit that encourages higher-order cognitive skills in the classroom by focusing on how a combination of technologies and non-technology modalities demonstrate Bloom's cognitive skills: remembering, understanding, applying, analyzing, evaluating, and creating. Furthermore, it is shown that the combination of all three technologies, rather than independent use of a singular technology, can achieve higher-order thinking in science. This was demonstrated through the culmination of the project with student-designed and -driven physics experiments. This chapter further supports the widely held belief that teachers should employ the interests and passions of students in the context of teaching STEM subjects.

DOI: 10.4018/978-1-4666-9616-7.ch014

INTRODUCTION

This chapter describes a seven-week project developed for student-athletes in physics classrooms. The goal of the project was two-fold. First, to assess whether the incorporation of three specific technologies designed to enhance content acquisition would also encourage higher order cognitive skills according to Bloom's Revised Taxonomy (Anderson & Krathwohl, 2001). Second, to determine whether an authentic application of great interest to the students would improve their motivation to learn physics principles.

Soccer Academy (pseudonym) is an all boys private school with a population of sixty-seven students from grades eight through twelve. The Academy combines world-class soccer training with a rigorous college preparatory program. The uniqueness of the student body offers the opportunity to teach physics principles through an authentic application by capitalizing on a passion shared by every student at the institution. Thirty students enrolled in four classes participated in the applied physics unit taught by two teachers. There were thirteen students in grade nine, eleven in grade ten, three students in grade eleven, and three students in grade twelve. The students' ages ranged from fourteen to eighteen. Each class met twice a week for one hour with additional work time on Fridays as needed. All students played soccer on an elite club team and participated in one and one-half hour soccer training sessions in the morning, and an approximately two-hour practice after school everyday. The students had soccer games every weekend during the season, and often traveled long distances. Occasionally, there was weekday travel; when this occurred the students completed their assignments through a blended learning program provided by Apex Online Learning. The Academy provided a take-home laptop computer for every student.

Academy students start playing soccer at a young age, and most aspire to be professional soccer players. Under the tutelage of coaches and trainers, they improve their skills by imitating demonstrations of proper technique, trial and error, and a great deal of practice. What most student-athletes are seldom taught is the science behind the sport, and how they can use science principles to understand the underpinnings that rule the motion of the ball. To this end, the physics courses at the Academy were designed to include an applied kinematics unit employing specific technologies in an effort to enhance learning the basic principles of motion and to promote higher order thinking skills.

The primary technologies used in this project were the Adidas miCoach Interactive Personal Training and Coaching System soccer ball (the "Smart Ball"), the Physics Education Technology Project (PhET) online simulations, and Apex Digital Learning. The Adidas miCoach Smart Ball is a Major League Soccer (MLS) size 5-regulation weight (0.445 kg) ball. The Smart Ball has an embedded sensor that captures the ball's launch speed, spin velocity, spin type, strike area on the ball, and the flight path data within 0.75 seconds after it is kicked. PhET is a free online library of over seventy-five interactive simulations created for students and teachers to use as a visual tool for learning principles in physics, chemistry, biology, earth science, and mathematics. Apex Online Learning, a National Collegiate Athletic Association (NCAA) approved provider of blended and virtual online learning platforms, was used to complement Smart Ball and PhET instruction.

The final assessments in this project were student-designed experiments used to determine the effectiveness of technology in content acquisition and the development of higher-order cognitive skills. A teacher-designed rubric was used to assess content knowledge of the final evaluation. Additionally, a scale was made for the Revised Bloom's Taxonomy of Educational Objectives to evaluate the degree to which each technology helped the students to achieve higher order thinking. The students provided anecdotal comments to informally describe their level of motivation in this unit as compared with their previous classroom experience using traditional textbook examples in physics.

The goals of this project were: a) to demonstrate that the specific technologies implemented in this study were successful in helping Academy students to achieve higher order cognitive skills and full comprehension of kinematic principles, and b) to support the belief that the use of a context that is of great interest to students provides more motivation to learn science, engineering, and math (STEM) subjects.

LITERATURE REVIEW

Promoting Higher-Order Cognitive Thinking Through the Use of Technology

Science educators have known for decades that using a conventional lecture approach and "plug and chug" methods do little to increase the knowledge of students in calculus and non-calculus introductory physics courses (Halloun & Hestenes, 1985). Recent studies corroborate their findings, indicating that students who use technology in the classroom can greatly expand their problem-solving abilities and conceptual understanding while promoting critical thinking skills (Bain & Weston, 2011). There is a wealth of research studying increased student engagement through the use of technology in STEM classrooms (Bain & Weston, 2011; Drayton *et al*., 2010; Lowther *et al*., 2003). Draper *et al.* (2010) argues that there is still a need for teachers to implement technology in a meaningful way, despite the positive effects of having a one-to-one wireless environment. He further posits that students are not being taught how to leverage technology to improve problem-solving skills. His study reveals that interactive and engaging methods of teaching make a substantial difference in course assessments. While the use of computer technologies is purported to teach higher-order thinking skills, the technology must extend beyond simple drill and practice or tutorial software, and include activities that require students to examine and manipulate technology to construct the knowledge (Baylor & Richie, 2002).

It can be a challenge for teachers to develop activities that promote higher-level cognitive thinking and comprehension of STEM principles. Researchers have long agreed that the pedagogy used in the classroom can have a strong influence on the pace of developing higher-order thinking skills (Byrnes, 1988; Healy, 2004). One way to approach this challenge is by using a combination of different technologies in tandem, and assessing them by seeing how well they align with Bloom's taxonomy of cognitive domains. The Revised Bloom's Taxonomy (RBT) is a well-defined and accepted tool for assessing levels of cognitive development (Anderson & Krathwohl, 2001). The revised taxonomy categorizes types of thinking into different levels: Remember, Understand, Apply, Analyze, Evaluate, and Create. Each level builds upon the last, with Analyze, Evaluate, and Create considered to be elevated thinking, and each a form of higher-order cognitive skills. Ideally, the "Create" level of learning, "putting elements together to form a novel, coherent whole or make an original product," is the intended level of comprehension each student should comfortably understand at the end of a unit (Krathwohl, 2002, p. 215). In the context of this project, higher-order thinking skills are understood to be when students can take information and ideas from one context and infer their meaning and implications in another.

If teachers are to successfully prepare students by increasing the use of technology in science education, they need to incorporate specific real-life skills and practices in the classroom. Practicing scientists apply their knowledge, design new experiments, and use higher-order cognitive skills to tackle new situations. Students should be taught these same cognitive skills through an application that stimulates their interest and motivation to learn. Furthermore, there is a need for a constructive alignment of the curriculum using learning activities, new approaches to science topics, and interactive technologies in the promotion of higher order thinking.

Increasing Student Interest in the Physics Classroom

Häussler and Hoffmann (2002) report a decline in students' interest in physics in secondary education. They suggest that physics curricula be changed to include topics of interest and represent shared student experiences and lifestyle. Their research shows that students who are passionate about the topics and see the relevance to their lives are more engaged and interested in physics. Moreover, Swarat *et al.* (2012) conclude that a genuine interest in science is an important part of science literacy and is critical to student learning. The need to develop curricula that is meaningful and relevant to students is not limited to science content. In her writings on culturally responsive teaching in social studies, Gay (2002) reports that academic content is learned more easily and thoroughly if the context is personally meaningful and taught from the frame of reference of the students lives. While contextualized teaching is not a novel approach, these studies highlight the need for teachers to construct lessons based on the passions and significant interests of the students.

The student-athletes of Soccer Academy utilize a large amount of their non-academic (school) time playing sports, training, or reviewing sporting events. When they are not engaged in active physical or mental training, many students enjoy recreational game simulations, playing video games such as NBA Live, The International Federation of Football Association (FIFA) and other Electronic Arts (EA) Sports games. Since so much of their time is spent engrossed in sports, why not take the additional time to understand the fundamentals of the motion of the ball, and learn how science is ingrained with every game? Learning the how and whys of motion of a ball can be deeply satisfying for a student intensely interested in physical activity and sports. If students are more attuned to the how and whys of a soccer game they will be motivated to improve specific skills in the game; conversely, if they are taught physics through the how and whys of a soccer game, they will be more motivated to take ownership of their learning.

While studies show that technology can enhance learning, the knowledge of how to use technology to teach more effectively is limited (Ertmer, 2005). The relationship between technology and content knowledge can be leveraged better to achieve maximum cognitive thinking skills from students. Moreover, combining technologies with non-technological pedagogy, often called blended learning, can provide an optimal environment for students to develop the highest levels of Bloom's Revised Taxonomy. This project explores how teachers can develop students' interest in science by using soccer as an applicable topic to engage them in learning kinematics while improving their higher order cognitive skills through the use of relevant technologies.

METHODOLOGY

Introduction

Thirty students participated in this project. There were thirteen students in grade nine, eleven students in grade ten, and three students in the eleventh and twelfth grades respectively. While all students were taught the material from Unit 3 Kinematics (Table 1), the depth of each lesson depended on the students' grade and math ability. Ninth grade students were taught the math necessary to solve single variable

Table 1. Apex learning physics core unit

Unit 3 Kinematics
1. Displacement, Velocity and Acceleration
2. Nonlinear Motion
3. Doing Science Kinematics
4. Kinematics Wrap-Up
5 Diagnostic

equations in physics, and their reinforced their understanding was with extra sessions given by Academy math teachers. Each student attended physics class twice a week, with extra practice and work time on Fridays as needed. The content lessons described in this section were mostly conducted by grade level, but all students worked together during the implementation of the Smart Ball activities, with the assistance of two Academy science teachers and one sports science instructor.

Students often do not see the relationship between schoolwork and real-world applications. This study employs a physics kinematics project developed to explicitly connect real-world interests of the students to theoretical knowledge. Each lesson in the applied physics unit was designed with the purposeful integration of technology as the priority. The first technology applied to this project was the online learning platform, Apex Learning. Apex was used as a primary content resource and consists of lesson slides, outlines of study guides, short quizzes, and practice questions for each section. As an electronic resource, Apex has the ability to provide students with immediate feedback and scoring after each lesson. After students were introduced to their topic of study through Apex, they then explored the topic further with PhET simulations. These computer simulations were primarily used to investigate position, velocity, acceleration, and projectile motion. Apex and PhET were implemented directly into the classroom. Adidas Smart Ball technology was designed to capture data via an iPad or iPhone, and was used during soccer drills. The Smart Ball application, miCoach, captures real-time data that includes launch speed, spin, spin type, and flight path.

Apex Online Learning

Apex served as the primary content resource for the kinematics unit. This platform can be accessed in the classroom or remotely, allowing absent or traveling students to stay on pace with their academic work. In addition to content specific passages, Apex offers a variety of activities (many of which are interactive) and labs within each chapter. At the end of each Apex section there is a multiple choice quiz that students take to assess their learning. At the end of each unit there is a larger assessment that includes multiple choice and open-response questions. Quizzes are computer scored, giving students immediate feedback on their progress. For this study, students worked in the Physics Core course using Lessons 3.1-3.2 in Unit 3: Kinematics (Table 1).

PhET Simulations

The Projectile Motion simulation was accessed from the PhET library. The activities used with this simulation were modified versions of lesson plans created by teachers who posted their work on PhET or were created by Soccer Academy science teachers (Appendix A).

In-Class Simulation

The simulation allowed students to select a projectile from a list including a tennis ball, golf ball, or bowling ball, or to enter their own specifications. In this study, the students used the dimensions of a regulation soccer ball. Additional inputs include angle of launch, initial speed, time of flight, drag coefficient and altitude, and air resistance. Range, height and time can be measured based on the input variables. Objects are launched from a cannon and may be aimed at a movable target that displays horizontal distance. The word “score” appears on screen if range requirements are met. Unlike the data collected on the field by the Smart Ball, the simulation does not take ball revolution (spin) and spin direction into account. This feature allowed the students to use the projectile in the simulation as a control variable.

During this activity, students were asked to complete three tasks. In Part I, they changed a single independent variable to find the impact on a single dependent variable. Independent variables included air resistance, initial speed, and launch angle, and the dependent variables were range and time of flight. These values were compared to the results obtained from the field drills with Smart Ball. To conclude this experience, students were asked to reflect on the information gathered during the simulation to define the following vocabulary terms in their own words: initial velocity, launch angle, range, air resistance, projectile, and parabola.

Part II of the activity allowed students to explore projectiles of different sizes that were fired horizontally (no angle), at various angles, and with air resistance, or without it. Kinematic equations were used to determine where the projectile should theoretically land. Students were able to compare and contrast the calculated results with the results of the simulation.

Part III asked students to use data acquired in the Projectile Motion simulation along with data collected during the on-field drills with the Smart Ball. Students were asked to account for the differences and/or similarities between the measured, simulated and calculated values of a single variable.

Adidas Smart Ball

The Adidas Smart Ball was used as a training tool with the ability to analyze a players’ kick through an electronic sensor embedded in the ball. The miCoach application was downloaded to an iPad and used to collect data from the Smart Ball. The app contains several features that can be used to analyze a kick, including showing the contact point on the ball, and where the kick should have been made depending on the individual’s goal. The part of the app that was used in this study is called “Get Better.” In the “Get Better” app one can choose either the “Over the Wall” or the “Around the Wall” feature. “Over the Wall” is used when the player intends to kick the ball over a line of defenders from the opposing team, and Around the Wall is primarily used when a kick involves the ball curving up and around the left or right side of the wall. Both features allow the collection of launch speed, ball revolution, spin direction, ball strike, and flight path data (Table 2). Students used their smartphones to collect time. Distances were measured after each kick and recorded as the range.

Table 2. Adidas smart ball data collection summary

	Long Pass Drill	Shooting Drill	Shaping Drill
Smart Ball Data	velocity, ball revolution (spin), spin direction	velocity, ball revolution (spin), spin direction	velocity, ball revolution (spin), spin direction
Student Measured Data	time, range	time, range	time, range
miCoach iPad application	Over the Wall app	Around the Wall app	Over the Wall app

Table 3. Technology summary

Technology	Description	Physics Unit Activity
Adidas Smart Ball	Adidas Smart Ball is a MLS size 5-regulation weight soccer ball that captures the launch speed, spin, spin type, strike area on the ball and flight path data.	On-field drills to collect real-time data
PhET Simulation	The Physics Education Technology Project is a free online educational simulation demonstrating principles in physics, chemistry, biology, earth science and mathematics.	Position, Velocity and Acceleration simulation (Moving Man) version 2.05 Projectile motion simulation version 2.03
Apex On-line Learning	A virtual online learning system with complete course curricula in science, English, math, social studies, world languages and electives.	Content reading materials, videos, formative assessments and study guides

On-Field Drills

The study designed a series of three on-field soccer drills using the Smart Ball (Appendix B). Each drill focused on a different soccer skill though all involved using the soccer ball as a projectile. These drills were performed at the beginning of the kinematics unit.

In Drill #1, students were asked to kick a soccer ball from a distance of 35m into an upright trashcan. The trashcan and four cones were used to create the point zones. Points were awarded based on where the soccer ball landed. Placing the ball in the center of the target earned 5 points, hitting the outside of the trashcan earned 3 points, a circular zone closest to the target earned 2 points, and the largest circular zone earned 1 point. All balls that did not hit the target earned 0 points.

In Drill #2, students were asked to strike the ball from a distance of 15m. Hoops of two different sizes were hung from either side of a soccer goal to serve as the targets. Points were awarded based placement of the soccer ball. A ball that went through a small hoop target earned 5 points and the going through the larger hoop target earned 3 points. Placing the ball into the goal earned 1 point. Balls that bounced before going into the goal or did not make it into the goal earned 0 points.

In Drill #3, students were asked to strike the ball from a distance of 18m. Hoops of two different sizes were hung on either side of the soccer goal to serve as the targets, as seen in the shooting drill. In addition, 5 mannequins were placed 9.0 m away from the goal to form a wall. A single cone was placed to the left or the right of the wall to serve as a stand for the soccer ball. This drill served as the “Over the Wall” and “Around the Wall” app. Schematics of the three drills can be found in Appendix B.

Non-Technology Descriptions

- **In-Class Discussions:** In-class discussions and lectures on physics topics occurred throughout this unit. There were also practice sessions with the students designed to reinforce the learning by providing problem sets that encouraged students to practice using kinematic equations and other algorithms to solve problems.
- **Final Task - Student Designed Experiments:** After completing the three parts of this project, the students were asked to design their own projectile experiment, incorporating the knowledge gained from Apex learning, the on-field drills, simulation activities, and their own personal interests in soccer.

The objective of the student's experimental design was to further explore the relationship between an independent and dependent variable of their choosing, while incorporating data gathered from both the on-field drills and simulation activities. Students might choose to explore the effect that spin has on the horizontal distance (range) that a soccer ball travels. Optionally, since the PhET projectile simulation does not take ball revolution (spin) into account, it made a perfect control to what occurred on the field during the drills. The student-designed experiments used technology and non-technology modalities and were assessed by a teacher-scored rubric. Examples of a Grade nine and Grade eleventh student experiments and the rubric can be found in, Appendix C.

Assessing Teaching Modalities using the Revised Bloom's Taxonomy of Educational Objectives

This project assessed each teaching modality using cognitive skill levels from the Revised Bloom's Taxonomy (Table 4). Each cognitive level is comprised of verb stems that describe the action necessary to accomplish that level. Areas that demonstrated the verb stems for Create, Evaluate, and Analyze were given the highest point value of 3, as these levels are indicative of higher order thinking. Understand and Apply verb stems were given a point value of 2, and Remember stems were given a point value of 1. The distribution of points assigned to each technology and non-technology are illustrated in Table 5.

Table 4. Revised Bloom's taxonomy

Cognitive Level	Verb Stems
Create	Design, produce, invent, construct, make
Evaluate	Interpret, critique, argue, judge, measure
Analyze	Deconstruct, compare, classify, dissect
Apply	Implement, use, carry out, execute
Understand	Interpret, infer, explain, paraphrase
Remember	Recognize, retrieve, list, recall, name

Table 5. Cognitive levels earned points per technology and non-technology

RBT → Points	Remember 1	Understand 1	Apply 2	Analyze 3	Evaluate 3	Create 3	Total Points
Technology							
Apex Online Learning	Recognize kinematic equations; recall vocabulary defined in lessons	Infer information given in lessons to answer questions on quizzes	Use kinematic equations to solve problems on quizzes and in the lesson slides				4
Adidas Smart Ball	Recognize units and definitions of terms; spin (rpm)	Interpret terms (e.g. over-the-top spin vs. back-spin)	Use measurements collected to insert in kinematic equations				4
PhET simulations	Recall vocabulary	Interpret relationships between variables (launch angle of projectile and range)	Interpret graphs of position, velocity, and acceleration				4
Non-technology							
In-class discussion and solving problems with equations	Recall vocabulary in order to articulate questions during class	Infer information to answer teacher and student-led questioning	Use knowledge to articulate understanding of material				4
Final student-designed experiment	Recall vocabulary in order to write clearly	Interpret relationships between variables chosen for the experiment	Apply knowledge to design unique research question based on soccer interest	Analyze data from Adidas Smart Ball, PhET Simulations and Calculated data from algorithms	Interpret discrepancies between Adidas Smart-Ball data and theoretical data calculated from algorithms	Design an experiment using variables of choice	13

Anecdotal Student Comments

At the end of their self-designed experiments, students were asked two questions to informally evaluate the project:

Question 1: Which learning tools worked best for me? Choose from these options; you may choose more than one:

a. Apex Slides and Quizzes;
b. Activities in the classroom or on the field (Projectile simulation, on-field activities with Smart Ball);

c. Lecture or short discussion on the topic;
d. Working problem sets using kinematic equations;
e. Individual meetings with teacher.

Actual responses received from students:

Student 1: B and C
Student 2: B
Student 3: A and E
Student 4: E
Student 5: C and E
Student 6: B
Student 7: B
Student 8: E
Student 9: B
Student 10: B, C, D
Student 11: B
Student 12: E

Question 2: When did I have an 'aha' moment in learning (when did I first realize that I learned any physics principles about kicking a soccer ball)?

Actual responses received from students:

- When I was fooling around with the simulation on PhET. I found what values affect velocity and how far the ball ultimately travels;
- I understand everything that we have gone over in science, my aha moment was when I realized how to set up functions of x and y with (teacher) to help me with problems;
- I think at the end of the unit when we were tying all of the pieces together with the project were when I learned something because the physics unit to me seemed very choppy and didn't flow together. This cause an unsmooth learning experience and therefore I don't think I learned as much as I could have;
- When I first realize that I learned that before;
- When my brother sat down with me and help with me through the process;
- The first 'aha' moment in this unit was when I went onto the field the day after a science class for a game, and was taking a free kick (merited by a foul on the other team) and really thought about what I had learned in science class in terms of how to hit it and it what manner. (This was a first);
- When we started using the same formula in math class and I realized that I knew how to do everything. It felt good and helped me to get a great grade in math;
- The field activities with the ball (especially the projectile motion);
- I was struggling with kinematics until I started to meet for individual meetings. After that, I began to notice that I was understanding the topic more and more;

- I learned during the lectures with [teacher], and I felt I learned when [teacher] discussed problems with us during the Kinematics worksheets. Also I thought I learned during the smart ball activity on the field;
- One time when I had an "aha" moment, while learning physics, was when I read the SmartBall results. It seemed as if everything had just clicked actually doing it and seeing it happen. (Previously, we were only doing trials on the computer simulator) For example, I understood the concepts better of how spin could affect the range or speed of the ball;
- When I realized I was learning something it was with my teacher. She explained how to plug and chug, and she taught me an easier way to understand how to pull things into another and how the equation should end up looking like.

DISCUSSION

The findings in this preliminary study centered on the integration of three different technologies to promote higher-order cognitive skills. In this project, the technologies were leveraged so that the students were able to take information and ideas from Apex Digital Learning, PhET simulations, and the Adidas Smart Ball and incorporate these ideas into a student-designed experiment. By doing this, the students inferred learning from one area and transferred it in a meaningful way to their own ideas, and, if successful, achieved higher order thinking skills.

It was clear during this project that it was not effective to use any technology in the classroom for the sake of including technology, but rather how the technology was used that affected the learning outcomes. The synergy between Apex, PhET, and the Smart Ball was leveraged to enhance learning content. The final student-designed experiments helped us assess whether or not the technologies worked from the standpoint of seeing whether students could infer the information given in the technology to the context of designing an experiment.

Apex Learning served as a digital curriculum for introducing the theoretical fundamentals of the topic. It provided practice problems related to kinematics as well as short activities designed to supplement learning. Apex technology allowed all of our students, whether absent or traveling, to access the day's lesson. While we recognize that a textbook could have achieved much of the same purpose, we found that the interactive aspect of Apex demonstrations and activities helped students to stay engaged in the lesson. The lessons provided multiple opportunities for students to practice concepts, revisit areas where they had difficulties, and receive immediate feedback from formative assessments. This active approach assisted students' learning comprehension, and provided an outlet to apply their knowledge. This area of the project meets the first three cognitive skills of the Revised Bloom's Taxonomy: Remember, Understand, and Apply. The total points assigned to Apex's online learning technology earned 4 points, 1 point higher than the non-technology areas.

Manipulating variables in the PhET simulations provided students with an opportunity to investigate cause-and-effect relationships, primarily through projectile behavior. Early in this study, the simulation provided experiences that helped students to define the technical vocabulary associated with one dimensional motion and projectiles. As the study progressed, students were asked to make predictions about how far a projectile would travel using different variables such as launch speed and angle, and then to use kinematic equations to test their predictions. Completing this task required students to access the knowledge that they acquired throughout the unit in a comprehensive manner thus allowing them to apply what they learned. The immediate feedback about the effect of manipulating variables encouraged students to learn from their initial hypotheses. Working independently, students were not pressured or embarrassed to make an incorrect prediction as they may have been in front of peers or teachers. This freedom to "experiment" with different independent and dependent variables allowed students to take ownership of their work. Therefore, PhET simulations were categorized as demonstrating the same cognitive skills and total points as Apex Digital Learning, but for the reasons stated above.

On-field tests utilized the Adidas Smart Ball and miCoach Smart Ball application for the iPad. Utilizing this technology allowed for precise and accurate capturing of data. This tool streamlined the data collection process and provided real-time access to this information. Students could kick the ball and see the results of the kick, giving them immediate feedback, further engaging them in the lesson. Anecdotally, they eagerly checked their results between trials, often trying to improve their technique during the next trial.

Throughout the unit there were times when more traditional or non-technology related teaching approaches were used. These approaches included direct instruction, practice problem sets that required repetitive algorithms, and in-class discussion. The non-technology areas served as a place where students could apply what they learned by solving problems related to projectile motion and determining if the final answers in the calculations made sense based on what they experienced working with the simulations and on-field drills. Additionally, students articulated understanding of the concepts during class discussions, incorporating vocabulary such as velocity, trajectory, range, projectile, and other kinematic terms. Students were far less enthusiastic about participating in these low-tech sessions. These non-traditional modalities earned 4 points, the same as any of the technological instruments individually, but ranked far below the final culminating task.

During the final task, students analyzed the simulated, calculated, and real-world data for the purposes of comparing and contrasting the results. Using this information, students designed an experiment that incorporated each of these data sources. Successful completion of this task demanded that students apply learning acquired throughout the unit to a new situation, utilizing learning from all of the technology and non-technological modalities. As this task required the students to apply, evaluate, and create, it ranked above the other modalities as it included all of the Revised Bloom's higher order cognitive skills. The total number of points earned for the final task was 13, the maximum on the rubric. The rubric used for assessing this final task is shown Appendix A, but graded student evaluations were not available.

Twelve of the thirty students who participated in this project provided anecdotal evaluations of their experiences. Of the students who answered the first question, "Which learning tools worked best for me? Choose from these options; you may choose more than one," seven of the twelve chose option B, "Activities in the classroom or on the field", and five of the twelve students chose "Individual meetings with teacher", option E. These options may suggest that a majority of the students preferred to engage in active learning versus lectures, however, benefit from the one-on-one tutoring sessions.

The anecdotal responses are useful, but unfortunately a majority of the students who participated in the project were not polled. Because of this, no distinct trends derived from their responses. The lack of findings from the response may also be due to the ambiguity of the questions themselves, as well as the sample size. While nothing conclusive can be stated about these results, the responses do serve as an initial guide for a qualitative assessment of this type of project, and can be revised and improved in future research.

CONCLUSION

The purpose of this study was to demonstrate that the incorporation of complementary technologies encourages higher-order cognitive skills. Using a context of great interest to the Academy students, further enhanced student engagement and ownership of learning, while promoting student motivation. The technology ensured that the students would eagerly participate in the activities because of the direct link to their passion—soccer. The Adidas Smart Ball provided immediate feedback and data within a second of the initial launch. Students were able to collect speed, revolutions of the ball per minute, type of spin - whether back or top spin, and ball strike—where they made contact. The PhET online simulation worked in a complimentary fashion with the Smart Ball to allow the students to test several variables inherent in kicking a soccer ball. For example, the data collected by the Smart Ball was from a live kick on the field, the data included the effects of air resistance and ball spin. The PhET projectile motion simulation was set up as a control and by not including air resistance and because the program does not consider spin, the effect of ball spin could be determined. A blend of technology and non-technology pedagogy can maximize learning cognition according to the Revised Bloom's Taxonomy verb stems. Apex Digital Learning, PhET simulations and the Adidas Smart Ball technologies scored 4 points each, whereas, the culminating project of combining all three technologies into a final experimental design earned 13 points.

While presumably the students eagerly participated in the project because of the link to their passion with the sport of soccer, there is no conclusive evidence to demonstrate that their motivation was not due to the general use of any interactive technology in class lessons. The few anecdotes collected from students did not provide enough data to demonstrate the second goal. Further research is necessary to determine student motivation.

Implications of Project

With the increased popularity of soccer, and the ongoing affinity for all sports in America, it is advantageous for teachers to investigate technology that can be used to develop authentic instruction and assessment for students that are interested in sports. Sports are only one area where the passions and talents of students can be utilized in the classrooms, however. This project serves as potential inspiration for the incorporation of other areas of interest to students, such as art, music, mechanics, and cooking, and illustrates the possibilities of extracurricular activities as conduits for teaching STEM subjects. When the curriculum has a high interest appeal, students will find the otherwise challenging content less onerous.

In conclusion, while the reason behind the students' motivation during this project cannot be solely attributed to the use of engaging subject matter, there is a great potential for development of STEM curricula using a combination of technologies with related concepts. While the technology used during this project certainly had an affect on the students' learning and achievement of higher-order cognitive skills, more research should be performed to determine to what degree technology should be used in the classroom, and when it should be sidelined for traditional in-class discussion and one-on-on work with instructors.

ACKNOWLEDGMENT

The authors wish to express our gratitude to the following people for their assistance with various aspects of this study: the students of the Academy, Kevin Carvalho, Mackenzie Snead, Dr. Nooha Ahmed-Lee, Head of School, Tommy Wilson, Philadelphia Union Academy Director, Garrison Draper, Director of Sport Science, Liz Wahlberg, Athletic Development Trainer, Dr. Christian DiBenedetto, Adidas Innovation Team Senior Director.

REFERENCES

Anderson, L. W., & Krathwohl, D. R. (Eds.). (2001). *A taxonomy for learning, teaching, and assessing: A revision of Bloom's taxonomy of educational objectives*. New York: Longman.

Bain, A., & Weston, M. E. (2011). *The learning edge: What technology can do to educate all children.* New York: Teachers College Press.

Baylor, A. L., & Ritchie, D. (2002). What factors facilitate teacher skill, teacher morale, and perceived student learning in technology-using classrooms? *Computers & Education*, *39*(4), 395–414. doi:10.1016/S0360-1315(02)00075-1

Drayton, B., Falk, J. K., Stroud, R., Hobbs, K., & Hammerman, J. (2010). After installation: Ubiquitous computing and high school science in three experienced, high-technology schools. *The Journal of Technology, Learning, and Assessment*, *9*(3), 1–57.

Ertmer, P. A. (2005). Teacher pedagogical beliefs: The final frontier in our quest for technology integration? *Educational Technology Research and Development*, *53*(4), 25–39. doi:10.1007/BF02504683

Gay, G. (2002). Preparing for culturally responsive teaching. *Journal of Teacher Education*, *53*(2), 106–116. doi:10.1177/0022487102053002003

Halloun, I. A., & Hestenes, D. (1987). The initial knowledge state of college physics students. *American Journal of Physics*, *53*(11), 1043. doi:10.1119/1.14030

Häussler, P., & Hoffman, L. (2002). An Intervention study to enhance girls' interest, self-concept, and achievement in physics classes. *Journal of Research in Science Teaching*, *39*(9), 870–888. doi:10.1002/tea.10048

Lowther, D. L., Ross, S. M., & Morrison, G. M. (2003). When each one has one: The influences of teaching strategies and student achievement of using laptops in the classroom. *Educational Technology Research and Development*, *51*(3), 23–44. doi:10.1007/BF02504551

Marley, K. A. (2014). Eye on the Gemba: Using student-created videos and the revised Bloom's Taxonomy to teach lean management. *Journal of Education for Business*, *89*(6), 310–316. doi:10.1080/08832323.2014.903888

National Science Teachers Association. (2015). *Sports teams boost STEM learning*. Retrieved from http://www.nsta.org

Swarat, S., Ortony, A., & Revelle, W. (2012). Activity matters: Understanding student interest in school science. *Journal of Research in Science Teaching*, *49*(4), 515–537. doi:10.1002/tea.21010

Wiggin, G., & McTighe, J. (2005). *Understanding by Design template*. Academic Press.

ADDITIONAL READING

Goff, J. E. (2010). *Gold medal physics: The science of sports*. Baltimore, MD: The John Hopkins University Press.

Heacox, D. (2012). *Differentiating instruction in the regular classroom: How to reach and teach all learners*. Minneapolis, MN: Free Spirit Publishing Inc.

Kuhlthau, C. C., Maniotes, L. K., & Caspari, A. K. (2007). *Guided inquiry learning in the 21st century*. Westport, CT: Libraries Unlimited.

Pitler, H., Hubbell, E. R., & Kuhn, M. (2012). Using technology with classroom instruction that works (2nd Ed.). Alexandria, VA: Association for Supervision and Curriculum Development (ASCD).

Wankel, C., & Blessinger, P. (2013). *Increasing student engagement and retention using classroom technologies: Classroom response systems and mediated discourse technologies (Cutting-Edge Technologies in Higher Education)*. UK: Emerald Group Publishing Limited.

KEY TERMS AND DEFINITIONS

Adidas miCoach Smart Ball: A soccer ball that is embedded with electronics used to analyze players kicks.

Air Resistance: The opposing friction to gravity caused by molecules in the atmosphere.

Engaged in Learning: Interest in and vested in learning a topic or concept.

Higher-Order Thinking: When students can take information and ideas from one context and infer their meaning and implications in another.

Interactive Curriculum: A learning framework that may involve kinesthetic motion of the participants but also incorporates critical thinking, collaboration and problem solving.

Motivation: The impetus for students to give sustained effort to work through an academic task.

PHET Simulation: The Physics Education Technology Project free online simulations used to demonstrate the principles of science subjects.

Projectile: Any object whose motion is affected by gravity.

Soccer: A competitive International sport played between two teams of 11 players where an approximate 450 g ball is kicked, headed or bounced off any part of the players' body except their hands (except goalkeepers).

Sport: An athletic activity usually played by people who are skilled and passionate about the competitiveness of the activity.

APPENDIX A: PhET PROJECTILE MOTION LESSON

Science of Punting and Projectile Motion

- Objectives:
    - Investigate how certain variables (angle, initial velocity, air resistance, mass, shape) influence the range (distance) of a projectile;
    - To explain why increasing the initial velocity will increase the range a projectile travels;
    - Identify the angle for maximum range, neglecting air drag;
    - Understand that there are two angles that will produce the same range, but for the larger angle, the object will stay in the air longer;
    - Describe how a punter might use concepts of projectile motion in different situations (for example, at times it is preferable to maximize hang time, while other times it is preferable to maximize distance).
- Materials:
    - Science of NFL Football video "Punting and Projectile Motion;"
    - PHET online simulation.
- Anticipatory Set (Lead-In):
    - What do basketball, baseball, soccer, football, tennis, golf, and volleyball all have in common? Write your answers on your Student Sheet;
    - Watch the NBC Lean Science of NFL Football video "Projectile Motion and Parabolas." http://www.nbclearn.com/portal/site/learn/ science-of-nfl-football.

Part I: Introduction

1. Define the following terms before you start the simulation and write your answers on your Students Sheet: initial velocity, launch angle, range, air resistance, drag coefficient:
    a. Go to the simulation website: http://PhET.colorado.edu/web-pages/simulations-base.html. On the left bar, click on the Physics and then Motion and scroll down to select the Projectile Motion simulation. Spend a few minutes familiarizing yourself with the simulation.
2. Practice firing different the objects into red and white target on the ground. Then answer the following questions on the student sheet:
    a. What objects were particularly difficult to toss into the target? Why?
    b. Draw the paths (trajectories) of the different objects and answer the questions on your Student Sheet.

Part II: PhET Simulation

1. **Air Resistance (Drag Coefficient) vs. Range:** Create and conduct an investigation with the simulation to determine how air resistance (drag coefficient) affects the range of a projectile. Answer the follow questions before you begin.
    a. Briefly describe the technique you will use. What variable(s) will you change and what variable(s) will you measure?

   b. Use the table provided to record your results.
   c. After you've conducted the experiment look at your values in the data table and explain what you found about the effect of air resistance on the range of a projectile.
2. **Initial Speed vs. Range:** Create and conduct an investigation to determine how initial speed affects the range of a projectile:
   a. Briefly describe the technique you will use. What variable(s) will you change and what variable(s) will you measure? Use what you did in the previous experiment to help you organize this information.
   b. Make a table to record your results.
   c. Reflect upon your data table and explain what you found about the effect of initial speed on the range of a projectile.
3. **Launch Angle vs. Range:** Create and conduct an investigation to determine how the launch angle affects the range of a projectile (Note: try many angles between 0° and 90°):
   a. Briefly describe the technique you will use. What variable(s) will you change and what variable(s) will you measure?
   b. Make a table to record your results.
   c. Reflect upon your data table and explain what you found about the effect of launch angle on the range of a projectile.
4. **No air resistance:** Find the angle that will produce the maximum range and record this angle:
   a. Is this angle different for different objects?
5. **With Air resistance:** Find the angle that will produce the maximum range and record this angle:
   a. Is this angle different for different objects?
6. **For a football:** Find 2 different angles that produce the same range. Record these two angles and the range on your student sheet:
   a. Compare the time in the air for each of these angles, and explain any difference.
7. What advice about angle and kicking speed would you give to a punter who wants to maximize the distance of a punt? Why?
8. What advice about angle and speed would you give a punter that is **NOT** trying to maximize distance, but instead wants a long "hang time" to allow his teammates as much time as possible to get downfield.

Science of Punting and Projectile Motion Part III: Your Turn

Part III: Introduction

Probably the most spectacular thing in soccer is seeing a player curving a soccer ball into the back of the net. Most fans will choose Roberto Carlos as the best free kick soccer player because of his amazing skill in dipping and bending the ball. We now know that a soccer ball in flight is simply a projectile that is flying through the air with an initial velocity. The reason the ball curves is because the kicker kicks that ball at a certain angle and velocity. Once the ball is in the air, it is really the air that is curving the ball. Professional soccer players will usually kick the ball and add a little spin on it to neglect as much air resistance as possible. But, in a free kick, which is usually 18 to 30 meters away from the goal, players would actually want air resistance because the air will curve and bend the ball in a way to trick the goalkeeper. This all sounds easy but you know that it is extremely difficult. Players must hit the soccer ball with a precise velocity and with a particular spin.

In a normal kick, the ball will travel at roughly about 65 mi/hr. The ball will spin at around 10 revolutions/ second. Once the ball travels about 10 meters, its speed will substantially drop and drag will dramatically increase. Once the ball's velocity drops the Magnus effect will start to increase. The Magnus effect is the reason the ball curves through the air. This activity will help you to see the affect of spin on a kicked soccer ball.

- Objectives:
  - Convert Imperial (British) units to metric;
  - Investigate how spin may influence the time of flight;
  - Compare calculated values using kinematic equations to actual values collected during the drill.
- Materials:
  - PHET Projectile online Simulation;
  - Adidas miCoach Smart Ball;
  - Adidas miCoach app;
  - Stopwatch;
  - Measuring tape.

Part III: Effect of Spin on Flight Time

Example of data table is shown in Table 6.

Procedure

1. Convert the units of velocity and spin from your on-field data to m/s and rev/s respectively, record the values into Table 6.

Table 6. Data table example

On-Field Drill			**PhET**
Variables	**Curving Drill Values**	**Long Pass Values**	**Simulation Values**
Initial Velocity (m/s)			
Angle of kick or canon (degrees)	12°	12°	12°
Mass of object (kg)	0.445	0.445	0.445
Diameter (m)	0.22	0.22	0.22
Spin (rev/s)			
Range (horizontal distance) (m)			
Time (s)			

2. What is the one variable that is not in the list above that is very important to the flight path of a soccer ball?
3. Spin vs. Time of Flight, in order to see the effect that spin has on the time of flight, enter all of the same data from one of the on-field drills (your choice as to which drill you choose) into the Simulation column except for time.
4. Go to the PhET website: http://PhET.colorado.edu/web-pages/simulations-base.html. Run the simulation using the data from the simulation and record the time. Compare this time with your field time:
   Simulation time of flight ________s
   Field time of flight ________s
   Compare the time in the air for the simulation and the field and explain any difference.
   Calculate the time in flight for the drill you chose using an appropriate kinematic equation.
   Calculated time ________s
   Show calculations:
   Compare all three times, simulation, field and calculated time, explain any differences or similarities.
5. Calculate range: Use the data from Shaping Drill and calculate the horizontal distance of the soccer ball using the appropriate kinematic equations. Compare the calculated horizontal distance to your actual range. Explain any differences.
   Calculate the range using data from the long pass drill, record in the data table.
6. What variable(s) can we not accurately predict in the simulation? These can be considered as errors in the experiment. Explain how these errors may have affected your results?

APPENDIX B

Figure 1 depicts the schematics of the first on-field drill used during Part III of the project. The orange triangles represent the cones, while the “X” illustrates where the student stood. The blue circle demonstrates the zone that earned a student 2 points, while the red circle demarcates the zone that was worth 1 point. Figure 2 depicts the schematics of the shooting drill, where students attempted to project the soccer ball into one of four hoops (zones) attached to the frame of a soccer goal. The smaller red zones earned a student 5 points, while the larger blue zones earned a student 3 points. Placing the ball into the goal earned 1 point. Balls that bounced before going into the goal or did not make it into the goal earned 0 points. Figure 3 depicts the schematics of the shaping drill, where students were asked to strike the ball from a distance of 18m. The same hoops (zones) and point system from drill 2 served as the targets. In addition, five mannequins were placed 9.0m away from the goal to form a wall between the student and the goal. This drill served as a real-life counterpart to the Over the Wall and Around the Wall apps.

Figure 1. Long pass drill

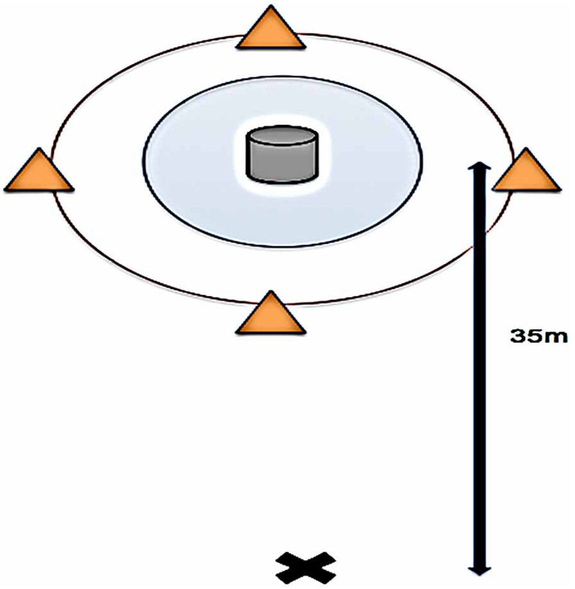


Figure 2. Shooting

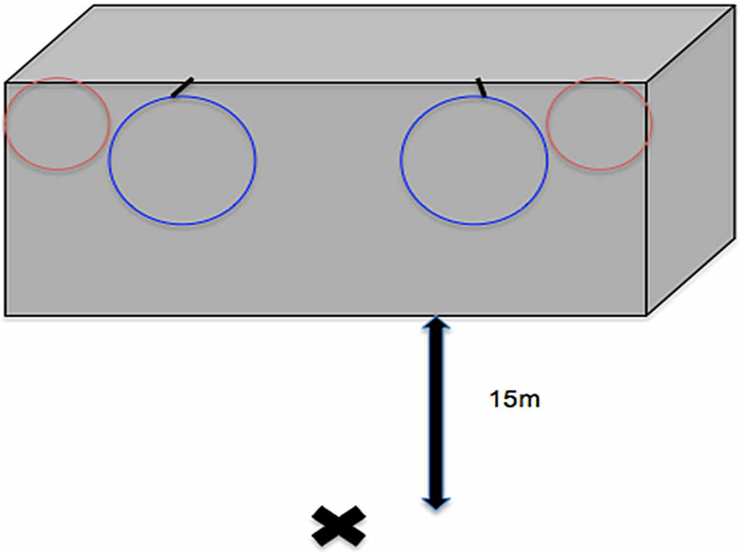
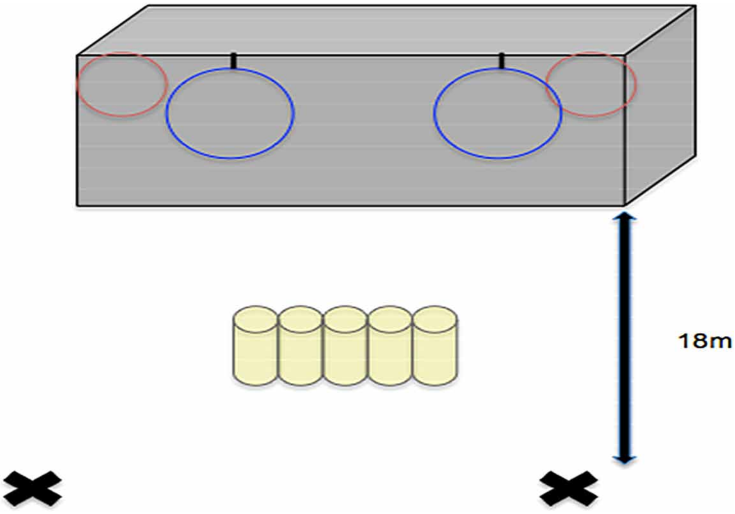


Figure 3. Shaping



APPENDIX C: FINAL TASK – STUDENT DESIGNED EXPERIMENTS

Grade 9 Student

Soccer with Projectile Motion

Problem: How does spin affect the range and time of flight of a soccer ball?

Background: Zidane is a world-renowned legend in the sport of soccer. His class on the field defines him as one of the best players to play the game. He has won all possible things in soccer; Ballon D'or and World Cup. Zidane was known for his exquisite touch, controlled dribbling, and finishing from any situation. If Zidane worked on his defending, he could play any position on the field. If he were to work on his heading ability he could be dangerous off corner kicks.

My name is __________. I am a player for the Philadelphia Union Academy. My versatility allows me to play anywhere on the field. I feel like I can pass at all ranges and with different parts of the foot. I also am very comfortable with using both feet and I feel really comfortable when using my left foot. I have good vision, which is a good trait to have in the midfield. I need to work on knowing what to do before I receive a pass. I also need to work on my defending so that I can help the defenders behind me and make their job easier.

I am a center defensive midfield or holding mid. The job of this position is to support the defenders and to be the anchor of the midfield. To be comfortable at this position you need the following skills; excellent passing because if you give it away they are close to the goal, strong defensive ability so you can stop the opponent's attack and help your defenders. The last skill you need is being able to receive the ball under pressure since you are in the midfield there is always pressure so this is very important.

Soccer Ball as a Projectile: Projectile motion describes how a projectile, or object, travels in air. The projectile travels along a curve, going up then down. This is called a parabolic curve. This is an important factor in soccer because of score a goal you have to get the ball under the crossbar, but out of the goalkeeper's range. In our experiment we two different drills: the long passing drill and the curving drill. In the long passing drill you were you try and kick the ball into a trash bucket and in the curving drill, you had to curve the soccer ball around a wall of mannequins. The Magnus effect is the commonly observed effect in which a spinning ball curves away from its principal flight path. For example if you apply top spin to the ball the ball will dip down and if you add back spin the ball will be lofted in the air and have addition hang time.

Hypothesis: In this experiment I believe that the range of the soccer ball is affected by how much spin is put on it. I will change the places I make contact with the ball (bottom, top, or sides), which will ultimately change the initial velocity, number of revolutions per second, the distance in which the ball travels, and the time in which the ball is in the air. Some variables you have to keep the same such as the mass of the soccer ball, angle of kick, and diameter of the ball; this is called the constant variable.

Materials: The following materials are utilized:

- Calculator
- PHET Projectile website
- Soccer Ball
- Goal
- Trash Bucket

Procedure: For this experiment, we first started by giving a background of us as a soccer player and discussing our strengths and weaknesses. Next, we went to YSC and we conducted the Long Pass drill and the Curling drill. In the Long Pass Drill, you were to try and kick the soccer ball into a trash bucket. In the Curling Drill, you were to curl the ball around the wall of mannequins and into the goal. We used an Adidas Smart Ball that can find the velocity, time in flight, revolutions per second, and the total distance the ball was kicked. *For some reason the Smart Ball messed up the range on the long passing drill, so we were not able to use that drill in my examples*. We collected the numbers and put them on an excel sheet. Next, we were to conduct a question and try and find a conclusion on what you though. We used our data to plug the numbers into equations and get different calculations. From this we could specify whether our hypothesis was correct (see Table 7).

Table 7. Results (data)

Variables	Curving Drill Values	Long Pass Values	Simulation Values
Initial Velocity (m/s)	18.91	13.86	18.91
Angle of kick (degrees)	12°	12°	12°
Mass of Object	0.445	0.445	0.445
Diameter (m)	0.22	0.22	0.22
Spin (rev/s)	7.05	6.46	7.05
Range (horizontal distance) (m)	16.72	Unknown	16.72
Time (s)	2.23	1.28	2.23

First we were to try and find if spin affects the amount of time the ball is in flight. I started by using PHET projectile motion simulation on the Internet. I plugged in the angle, mass, diameter, and initial velocity of the curving drills into the launch specifications. Then if you click “fire” the simulations calculates the time and range of the projectile. From using this simulation I got that the estimated time would be about 1.0 s. Next, I used the distance formula, d = 0.5(a) (t^2) + (v) (t), to find time. I plugged in my knows and got 16.72 = (4.9)t^2, then simplified it to get t^2 = 3.4122449. Then I simplified that by finding the square root, which is, 1.847 and that is how I found time. In conclusion all three times were different: on the field the Smart Ball recorded that the time of flight was 2.23 s, using the simulation it said that the time of flight was 1.0 s, and using the equation I found that the time was 1.847. From this I can conclude that spin does affect the time that the ball is in the air because all three times were different.

Next I was to compare range by looking at what the smart ball recorded and using the range formula, R = (v^2/g) (sin 2Ø). The range of the ball that the Smart Ball recorded was 16.72 m. Next I used the equation and got (18.91^2/-9.8) x (sin (24). Once you simplify this you get 14.841 m. As a result from these two answers I can conclude that spin also has an effect on the range of the ball.

Conclusion: From the results I conducted my hypothesis was correct. Three different methods of finding the time resulted in three different answers, so I can conclude that spin does have an effect on the time of flight. Next I tried to see if spin had an effect on the range or distance the ball traveled. I used the results from the Smart Ball and used the range formula, R = (v^2/g) (sin 2Ø). From using the Smart Ball I got that the range was 16.72 m and for the equation I got 14.841 m. From this I can conclude that spin does affect the range of the ball.

This experiment could have been very tricky because it is hard to get the same launch angle repetition after repetition. Also it is almost impossible to exert the same amount of force on the ball time after time.

This experiment has helped me understand how I should pass and shoot the ball in the future. If I want to kick a ball to its farthest potential I must put backspin. If I want to bend the ball around a wall for a free kick I need to use sidespin.

Grade 11 Student

Velocity vs. Distance

Problem: How does Velocity affect the Distance and time the ball travels?

Background: I have trained with this soccer player since we were just kids. He just recently signed a professional contract in Germany. It is awesome to see him succeeding, and hopefully I will follow in his footsteps. He contains great physical traits: tall, tone, and fast. Technique wise his diving, handling and kicking are all very strong parts of his game. He said he is continuing to work on his weak foot because at the higher level it is crucial to be able to play with both feet. In soccer over the years it is becoming more and more important to have a goalie comfortable with their feet because the goalkeeper is the one who is starting the attack. He also said he would like to work on the mental side of things. Since he is younger than most of the professionals he has to keep a good mindset. A lot is expected of him and if he does not deliver he will be yelled at. During these times he has to remain calm and work harder to change their minds.

In my game three things that I excel at are similar to those of Zack. I contain size, strength, technique and feet. The two things I would like to work on are like Zack my weak foot, speed, and physique. I want to slim down a little bit and become more tone. Overall if I am able to increase these things I will become faster, more explosive, and an overall better goalkeeper. This is my main focus this year as well as my left foot. The goal is by late next year my left foot is just as good as my right.

Projectile motion is a form of motion that travels in an arc shape under the influence of gravity. Once it reaches its peak it then accelerates downwards. This relates to every facet of soccer because as soon as the ball leaves ones foot it is being acted on by gravity, and will eventually accelerate in the downward direction.

My classmates and I, to test this theory did two drills. The first of which was a long pass drill, in this we set up a trashcan around 15m from where the player was standing and the whole objective of the drill was to try and get the ball as close to the trashcan as possible. The second drill we did we set up a wall around 18 yards from the goal. The objective of this drill was curve the ball around the wall into the net. Doing this allowed us to test the amount of curve each student had.

The whole basis of the project was to develop an understanding of how a soccer ball exhibits projectile motion and the Magnus effect. A kicked soccer ball is a projectile that follows a curve but not necessarily a parabolic curve, because of the Magnus effect. The Magnus effect is observed as being an effect in which a spinning ball or cylinder curves away from its principal flight path. Magnus effect is what makes the ridiculous curves in that game we love possible. Following is a great definition of how the Magnus effect works that I discovered through my research: "The Magnus effect works by developing an interaction between the air layers on the side of the ball that rotates in the opposite direction of the ball movement and the surrounding air creates a low-pressure area. This will ultimately curve the balls trajectory." (http://www.aviation-for-kids.com/the-magnus-force.html)

Hypothesis: I believe that it is possible that the greater the velocity the greater the distance and time will be. Velocity is divided into two directions, horizontally and vertically. Therefore using common knowledge if each of those components is increased it is possible that the distance and the time in the air would increase. For this experiment the dependent variables and will independent variables will follow:

- **Dependent:** Time and distance;
- **Independent:** The velocity;
- **Constant:** Height, angle, mass and diameter.

Materials: The only material you will need for this particular experiment is a computer. We will use a simulation that can be found *here* to test how velocity affects the distance and time a ball travels.

Procedure: Firstly open the webpage (http://PhET.colorado.edu/sims/projectile-motion/projectile-motion_en.html). Now we will enter the constant variables:

- **Object:** Users choice
- **Diameter:** .22
- **Mass:** .445
- **Angle:** 12

Next plug in 10 for velocity (initial speed) and hit fire and record your findings for range and time in Table 8. Repeat these steps with a velocity of 20 and 30 m/s.

Table 8. Results

Velocity (m/s)	Range (m)	Time (s)
10	7.3	0.8
20	21.1	1.1
30	42.3	1.4

Conclusion: Through doing this experiment I found that as velocity increases so does range and the time in the air. This is evident through my research and recorded data in Table 8. Thus, meaning that my hypothesis was indeed correct.

Luckily by using an online simulation we instantly reduced our chance of error to little or none. The only errors that could potentially occur are ones by the person entering the information. For example putting 10 for the angle when the angle should actually be 15. By using the online simulation errors become little to non-existent.

I can implement my knowledge on velocity to my everyday soccer career now because I understand how it works. I understand if I want to kick it longer I must hit the ball with a greater initial velocity, then if I wanted to kick it short. Velocity like previously stated is divided between two directions horizontal and vertical. If I want more height I must strike under the ball to increase the vertical height, but if I want more distance I must find a common ground between the two (see Table 9).

Table 9. Teacher scored student designed experiment report rubric

Criteria	4	3	2	1
Date, Title, Lab partner,	All elements are present; title and author bolded; lab partners present first name, last with semi-colon separating partners	All elements present but lack required punctuation or bold format.	One or two of the elements are missing but punctuation and bold format are present	One or two or the elements are missing and format is not present
Hypothesis including rationale	Hypothesis is appropriate for the experiment; is in complete sentences with no ambiguity in the wording.	Hypothesis is appropriate for the experiment; is in complete sentences, but contains ambiguity.	Hypothesis is appropriate with little or no ambiguity but lacks sentence structure	Hypothesis is inappropriate for the experiment.
Background	Contains pertinent information about topic and shows research conducted	Contains some information about topic, but research is minimal.	Contains little information and no research	Information is not pertinent to the topic
Materials	All materials used for the experiment are listed.	Materials are listed but one or two items are not present	Some of the materials are listed.	Few or none of the materials are listed
Procedure	All steps are listed in clear concise instructions. Steps are numbered and reader could duplicate the experiment with little or no questions.	All steps are listed but lack clarity. The reader would need some clarification to duplicate the experiment.	Most of the steps are listed but lack proper order. Reader would require additional communication to duplicate the lab.	Few or none of the steps are listed. Reader would not be able to duplicate the experiment.

continued on following page

Table 9. Continued

Criteria	4	3	2	1
Data	Data is presented in table format with appropriate headings and precise wording is used to describe the data.	Data is presented in table format with appropriate headings but wording lacks clarity	Data is complete but arranged in a tedious or confusing manner for the reader.	Data is incomplete or not present
Analysis	Data is analyzed and interpreted correctly. Difficulties are communicated thoroughly and clearly to the reader with appropriate scientific terminology, in complete sentences with proper order and flow. Discussion questions, if any, are clearly addressed.	Data is analyzed and interpreted correctly. Appropriate science terminology is present but words are occasionally used incorrectly. Discussion (post-lab) questions are clearly addressed	Data is analyzed and interpreted correctly, but explanation may be confusing or lack use of appropriate science terminology and there are no calculations.	Little or no analysis/ calculations procedures and/or difficulties are discussed.
Conclusion	Explains whether or not results support the hypothesis completely with brief but concise reasoning that ties in the data and analysis.	Explains whether or not results support the hypothesis but reasoning does not tie in the data and analysis.	Explains whether or not results supports the hypothesis somewhat but leaves the reader with questions	Does not mention anything about supporting or not supporting the hypothesis.
Possible Sources of error	Two or more possible sources or error are discussed including the possible consequences of the errors including sufficient number of trials	Two or more sources of error are discussed but the consequences of errors are not clear. Less than three trials	One source of error is discussed but consequences of the error are not clear.	One or no source of error is listed and lacks discussion and consequences. Only one trials completed.
Extension (Extra Credit)	Discuss how you could adapt the experimental procedure or data. Where in real life could you apply the knowledge gained or procedure learned?	Not Applicable for this assignment	Not Applicable for this assignment	No Applicable for this assignment
Total Score				**Possible Total: 36 or 40**

Chapter 15

Computer Programming in Elementary and Middle School:

Connections across Content

Danielle Boyd Harlow
University of California – Santa Barbara, USA

Charlotte Hill
University of California – Santa Barbara, USA

Hilary Dwyer
University of California – Santa Barbara, USA

Ashley Iveland
University of California – Santa Barbara, USA

Alexandria K. Hansen
University of California – Santa Barbara, USA

Anne E. Leak
University of California – Santa Barbara, USA

Diana M. Franklin
University of Chicago, USA

ABSTRACT

Computing has impacted almost all aspects of life, making it increasingly important for the next generation to understand how to develop and use software. Yet, a lack of research on how children learn computer science and an already impacted elementary school schedule has meant that very few children have the opportunity to learn computer science prior to high school. This chapter introduces literature on teaching computer programming to elementary and middle school, highlights three studies that span elementary and middle school, and discusses how programming can be integrated into other content areas and address national standards.

INTRODUCTION

To become the next generation of innovators, today's children must learn to create with technology. To create new technology or innovate on existing technology increasingly requires learning computer programming skills. Computer science in K-12 classrooms is rapidly expanding as technology, programming environments designed for children, and computer science curricula become available. Both the

DOI: 10.4018/978-1-4666-9616-7.ch015

International Society for Technology in Education (ISTE, 2007) and the Computer Science Teachers Association (CSTA) have developed standards relevant to computer programming and computer use.

Teaching computer programming to elementary and middle school children has been facilitated by the development of graphical programming environments that allow children to create programs by dragging and dropping commands (represented as images of blocks) onto a screen, lowering the cognitive barrier to programming (e.g., Maloney, Peppler, Kafai, Resnick, & Rusk, 2008) and increasing novices' interest and excitement in programming (e.g., Malan & Leitner, 2007). These programming environments allow younger students to access computer science ideas without first learning complicated syntax and formatting – attributes of traditional programming. Despite these developments in programming environments and curricula, as well as nationwide efforts to include computer programming at all levels, the vast majority of children do not learn programming in schools prior to high school.

Computer science, when it is taught to younger children, is often limited to outreach events, summer camps, and projects with parents. These informal types of learning experiences have shown success, but they impact only self-selected students, often those already interested in computers and those from middle and upper class families (e.g., Margolis & Fisher, 2003). Integrating computer science into elementary and middle school classrooms, rather than only out-of-school environments is important for addressing equity issues. The current demographics in computer science and computer engineering are indicative of a larger access gap in technology fields. Currently, female students receive a slight majority of all undergraduate degrees nationally, yet they represent only 14.5% of Computer Science degrees awarded. Latino/a students earn only 6.5% of undergraduate computer science degrees while representing 14% of the national population (Computing Research Association, 2013). The disparity in interests and experience with computer programming must be addressed early in students' education. In fact, research indicates that students' reported interest in pursuing a career in science and engineering areas as 8th graders is a strong predictor of whether or not they will pursue a science career (Tai, Liu, Maltese, & Fan, 2006). This means that students' experiences prior to 8th grade are important to recruiting students to careers into science careers, including computer science.

To reach all students, computer science needs to be integrated into the elementary school classroom at the elementary and middle school levels. Yet, integrating computer science into the school day is challenging, in part, because the school day is already full, making adding an additional topic difficult. To be widely integrated into the elementary and middle school curriculum, computer programming activities must address the content standards in mathematics, literacy, and science that teachers are held accountable for in their K-12 classes.

The United States recently made significant changes to educational standards to ensure the nation's graduating students are college and career ready and equipped with the skills and knowledge necessary to be competitive on a global scale. These new standards include the Common Core State Standards (CCSS) for English Language Arts and Mathematics (National Governors Association Center for Best Practices & Council of Chief State & School Officers, 2010) and the Next Generation Science Standards (NGSS) (NGSS Lead States, 2013). All focus on practices of the discipline along with important disciplinary ideas. One important aspect of the NGSS is that, for the first time, engineering design is included in standards. Engineering design is the process by which engineers develop innovative solutions to problems. The process involves understanding the problem, generating ideas, selecting an idea based on multiple constraints, and improving the idea, a process consistent with computer programming.

This shift in educational standards provides an opportunity to consider how computer programming can support students' learning as they work to meet standards in other content areas. Rather than teaching computer programming as a separate subject entirely, it can be integrated into traditional classroom subjects, such as reading, mathematics or science. For example, students can create digital book reports by programming a story that includes character development or program imagined alternate endings to stories, supporting language learning. Students can also create programs that draw shapes of specified angles and numbers of sides, supporting mathematics learning. To support science learning, students can program stories that require the use of specific science content, such as interdependent relationships in an ecosystem. Integrating computer programming with other content areas is not only desirable from a scheduling perspective, but also from a student learning perspective. When computer science is integrated with other content areas, students learn that programming can be useful across disciplines. Computer programming allows teachers and their students to explore concepts across the curriculum and creatively communicate learning, providing children with opportunities to use content in novel ways such as creating learning experiences for other children (e.g., Kafai, 2006).

Computer programming is not only useful for supporting other content areas or even for the types of thinking it encourages. Learning to program allows children to create software that can be viewed and used by others. Kafai and Burke (2014) argue that the value of programming is that provides a mechanism for children to express themselves and connects them to networks of digital communities. That is, programming provides students an opportunity to participate in the construction of digital spaces and resources. This idea resonates with Papert and Harel's (1991) theory that people learn best when creating things that can be seen or used by others. Resnick (2006), the developer of Scratch, one of the most popular programming environments for children, expanded on why learning through making is so powerful. He described that the design cycle of trying out and testing ideas "can be seen as a type of play: children play out their ideas with each new creation. In design activities, as in play, children test boundaries, experiment with ideas, and explore what's possible" (Resnick, 2006, p. 196).

This chapter overviews three projects designed to help elementary and middle school students learn programming and computational thinking using block-based programming environments. Following this overview, considerations are discussed to assess the suitability of programming languages and environments for use with elementary and middle school students.

BACKGROUND

Computational Thinking

One of the eight practices included in the NGSS is "mathematics and computational thinking," an indicator of the importance of computational thinking and computers in the field of science. Broadly, computational thinking means to consider how to formulate a problem so that a computer can solve it. While the articulation of the NGSS practice largely focuses on the mathematics part of this practice and, thus far, has not described computational thinking in much detail, the Computer Science Teachers' Association (CSTA) has developed a set of standards that defines this practice and describes how it relates to other disciplines. In developing the standards, they used a definition of computational thinking reported by Barr and Stephenson (2011) and developed at workshops collaboratively hosted by CSTA and NSTA:

> *CT [Computational Thinking] is an approach to solving problems in a way that can be implemented with a computer. …CT is a problem-solving methodology that can be automated and transferred and applied*

across subjects. The power of computational thinking is that it applies to every other type of reasoning. It enables all kinds of things to get done: quantum mechanics, advanced biology, human-computer systems, development of useful computational tools. (Barr & Stephenson, 2011, p. 51)

The term computational thinking was first used by Papert (1996) and further defined by Wing (2008a, 2008b). Seiter and Foreman (2013) later articulated a learning progression for computational thinking based on their observations of what children were able to do at each grade level in elementary school. They found that children in grades three and four were able to develop many of the components of computational thinking necessary for digital story-telling, including animating characters and creating conversations. Brennan and Resnick (2013) developed a framework for computational thinking that added practices and perspectives to concepts. According to their model, computational thinking concepts include sequences, loops, events, parallelism, conditionals, operators, and data; practices include being incremental and iterative, testing and debugging, abstracting and modularizing; and perspectives include questioning, connecting, and questioning. Grover and Pea (2013) point out the computational thinking overlaps with other disciplinary ways of thinking such as engineering, mathematical, and design thinking, and extends these ways of thinking in ways specific to computing.

Here, computational thinking is considered to be a set of problem solving processes and concepts that relate to solving problems both on the computer and in everyday life. Table 1 describes five ideas related to computational thinking that are appropriate for elementary and middle school students and focused on in the three studies discussed in this chapter. These ideas have applications not only in programming, but in how we solve problems everyday.

Many of these ideas can be taught either on or off the computer. CS Unplugged (Bell, Witten, & Fellows, 2009), for example, is a set of activities designed to teach computational thinking independent of computer programming. This chapter focuses primarily on on-computer computer programming tasks.

Table 1. Elementary and middle school computational thinking ideas with related examples from everyday problem solving and programming

Computational Thinking Idea	Everyday Example	Programming Example
Sequencing: Creating an ordered list of instructions to complete a task.	Explaining to someone how to get from one place to another.	Putting commands in the correct order so that the computer accomplishes a specific task.
Breaking down actions: Breaking an event into smaller parts.	Recognizing that events (e.g., "get dressed") involve several smaller steps (e.g., "put socks on, put shoes on").	Recognizing that to make a character move across a screen requires combinations of turning and moving forward.
Looping: Repeating a set of instructions multiple times.	When clapping, you put your hands together and then apart repeatedly.	Repeating a piece of code a specific number of times. For example, to draw a square, you can move and turn 90 degrees four times in a row.
Event-driven Programming: Identifying how one circumstance triggers another.	Many everyday actions are triggered by events. If it rains (a triggering event), one might open an umbrella.	Creating a code that occurs in response to another event. For example, when the space bar is pressed (triggering event), a bat moves across the screen (reaction).
Message Passing: Coordinating actions across code or characters	Messages in everyday interactions can be heard or seen. For example, a traffic light turning red indicates that cars should stop.	Programming one object to send a message after an action. Programming another object to act when that message is received. For example, one character says, "Hello" and broadcasts a message. Another character says, "How are you?" after receiving the message.

Learning Computer Programming

Computer programming is the process of creating code that tells the computer what to do. This requires not only the ways of thinking described above, but knowledge of a computer language or programming environment. Children have been programming since at least the early 1980's when Seymour Papert (1980) introduced Logo, the first educational programming language designed specifically for children. In Logo, children programmed an image of a turtle to draw using simple commands like "FORWARD 100" which directed the turtle to move forward 100 steps. Papert described how students could learn mathematics and physics through programming, and proposed that children at any grade level could learn to program in the classroom. Papert's work set the stage for the next decades of computer science education research.

Even with simpler languages like Logo, novice programmers of all ages must learn the structure and execution of the programming language, names of commands, and other syntactical and formatting rules. Kelleher and Pausch (2005) noted that those new to programming "must also learn rigid syntax and rigid commands that have seemingly arbitrary or perhaps confusing names" (p. 83). In response, block-based languages were developed to reduce the need to remember codes and syntax, enabling students to focus on programming. Block-based languages and programming environments provide a set of programming commands in graphical blocks that users drag onto the screen and snap together like puzzle pieces to create scripts (see Figure 1 for example of a script). These scripts often control characters or other images that can be used to create a game, tell a story, or more.

Block-based programming languages have gained popularity in recent years, particularly in online applications for iPads and other tablets. Block-based languages are a natural fit for tablets since typing is minimal and dragging and dropping is the primary way of interacting with the environment. These apps and web-based programs range from programming environments that allow users to create their own games and digital stories to more structured game or tutorial-environments designed to teach computer programming. These block-based languages are often inspired by Scratch, a block-based programming language and environment developed by MIT in 2003 (Resnick et al, 2009).

Figure 1. Scratch program (right) to draw a square with sides of length 100. The equivalent Logo program would be a single line of code reading, "repeat 4 [forward 100 right 90]".

```
when ⚑ clicked
pen down
repeat 4
    move 100 steps
    turn ↻ 90 degrees
```

In classrooms, teachers must structure the time students spend coding in some way. This may be an unstructured as allotting time to work on independent projects or through more organized curricular tasks. Existing coding curricula range from standards to guide teachers in designing their own lessons, lesson plans for teachers to follow, to online tutorials that guide students through the material. The Computer Science Teaching Association (CSTA) offers general standards for teachers to follow when incorporating programming into their K-8 classes (Seehorn et al., 2011). ScratchEd provides lesson plans for teaching coding with Scratch and an online community where educators can help each other with the material (ScratchEd, 2014). Other curricula, such as the ones provided by code.org, consist of interactive tutorials that students can use either in the classroom with the support of their teacher or independently. Introduced in 2011, Computer Science Education Week (Hawthorne, 2011) has grown in popularity in recent years, and now multiple platforms provide short tutorials or projects every December for students to try out programming.

Whether designed by classroom teachers or part of existing curricula, programming activities developed for students using block-based programming environments typically take two main forms: (1) open-ended and (2) pre-populated. With open-ended programming activities, there are no existing scripts (short pieces of code) provided to students. Instead, there is a blank coding area. Students are provided with the programming equivalent of a blank sheet of paper. In contrast, pre-populated lessons included some sprites (programmable objects or characters) on the screen when the activity is opened and these sprites have some pre-coded scripts. Pre-populated activities may engage students in games (such as programming a character to move through a maze) or challenges to complete or fix an existing project.

Computer programming, even when using block-based programming environments depend on children knowing what the words used as commands mean. In the early 1980's significant work was done to understand the role of natural language in learning programming with mixed results. Some found that using natural language aided programming. Others found that using words that had alternate everyday meanings caused confusion (Wright & Cockburn, 2005). Since programming languages are malleable, if children do not understand the words used for commands or other aspects of the programming environment, new words can be used. As a result, most studies of language in computer science education have focused on the *programming language* and how to make these languages accessible to novices. However, when learning programming, children need to understand not only the words used as commands, but also the language that surrounds computer science and instructional context – which may include the teachers' spoken instructions, explanations, and questions, or written language on worksheets or instructions. Children learn programming in a language-rich context that includes much more than just the commands in the programing language (Dwyer et al., 2015).

Further, since the first programming languages for children were built and tested, there has been a significant shift in students' backgrounds and experience. Census data indicates that between 1980, when Logo was introduced, and 2010, there has been a 158% increase in the number of people who speak a language other than English at home. In contrast, the total US population only increased by 38% (Ryan, 2013). This change in demographics has significant impacts for schools and for the complexity of the relationship between learning language and learning computer programming because many children are learning programming in English-speaking classrooms while still learning English.

The following section describes three studies of elementary and middle school children learning computer programming in ways that augmented other content areas and improve students' access to computer science thinking and practices.

METHODS

Participants and Study Designs

To illustrate the possibilities of computer programming across grade levels, this chapter describes three separate studies. These were all "entry" experiences for students, meaning that all three projects assumed students began with no programming background. Students did not continue from one experience into another. Two were conducted in elementary classrooms and involved elementary school teachers, and one was an outreach program taught exclusively by computer scientists and undergraduate and graduate students. In one study the students learned the computer programming skills necessary to draw geometric shapes. In the other two studies, the students learned the computer programming skills necessary to create digital stories. For the digital stories, students programmed characters and scenes that interacted with one another. We discuss the participants and data collection for the three projects beginning with the youngest students. Table 2 summarizes information about participants and curricula for the three studies.

The participants in the first study presented were 20 third grade students (eight and nine years old) in one elementary school classroom in California and their teacher. Underrepresented ethnic groups (mostly Latino/a) constituted 31.5% of the student population. Nearly one-fifth (19%) were identified as English Language learners. The classroom was evenly divided across gender. The teacher and his students were part of a project using XO laptops, a computer developed as part of the One Laptop per Child (OLPC) project. The students were video recorded once a week for one hour during class time devoted to using the XO's. The analysis focused on class periods in which the teacher chose to use TurtleArt, a simplified block-based programming environment that was included as one of the many applications available on the computer. The teacher used TurtleArt for teaching geometry, and also allowed students free time

Table 2. Overview of participants, curricular structure, programming environment, and goals of studies. N/A indicates that these data were not collected for the indicated study.

	Lower Elem. Study	**Upper Elem. Study**	**Middle School Study**
Grade Level	3rd	4th-6th	Entering 6th-8th
Participants (N)	20	1,250	120
Gender	50% female, 50% male	50% female, 50% male	76% female, 24%male
Ethnicity	N/A	N/A	64% Hispanic, 36% other
English Language Learners	19%	2%-82% (depending on school)	N/A
Qualified for free or reduced lunch	24%	4%-100% (depending on school)	N/A
Study Duration	1 year	3 years	3 years
Programming Environment	TurtleArt	LaPlaya	Scratch
Time spent on CS	1 hr/wk (4 hrs on Turtle Art)	16 hours	30 hrs (of a 60 hr camp)
Final Project	Drawing shapes	Digital Story	Digital Story
Computer Science Goals	Sequencing, Looping, Spatial Reasoning	Sequencing, Breaking Down Actions, Initialization, Event-Driven Programming	Sequencing, Event-Driven Programming, Initialization, Message Passing

to explore the programming platform and to make drawings of their choosing. Unlike the other studies that will be described in this chapter, the focus of this study was exploratory and focused on what children did when using TurtleArt, not as a means to inform future instruction. The data analysis was designed to identify how ideas moved across the classroom with particular attention to new ideas and outputs expressed by the students. Videos of class periods using TurtleArt were event-mapped (Collins & Green, 1992) and episodes in which children shared ideas were transcribed and coded based on verbal and non-verbal interactions between students and their peers, teachers, and laptops. See Harlow and Leak (2014), for more details.

The second study focused on upper elementary school students (grades four through six, ages nine through eleven). The study participants included over 1,250 fourth through sixth graders in schools across California. The first year of implementation included 15 classrooms with over 400 students, and in the second year included more than 35 classrooms with over 850 students. Classrooms of students were selected to represent California's diverse population, with a particular effort to include schools with large populations of underrepresented ethnic minorities and English Language Learners. Participating schools ranged from 2% to 82% English Language learners and from 4% to 100% students qualifying for free and reduced lunch, a proxy for socioeconomic status. This research followed a design-based methodology, a way to research learning in the context of a complex learning system. The research on learning is both informed by the context and informs the design of curriculum, pedagogy, and contexts (Barab & Squire, 2004). In this case the research on student learning informed the design of the programming environment, curricular tasks and goals, and pedagogical training of participating teachers. Teachers attended a summer workshop to learn the curriculum and then taught approximately one 45-minute lesson per week for sixteen weeks in their classrooms. The curricular activities consisted of scaffolded pre-populated projects and a cumulative open-ended digital story project. Extensive qualitative data were collected both years at schools within driving distance of the host university. This included classroom observations, interviews with students informally during activities and more formally after they completed a module, online and written student work, and exit interviews with local teachers. At the schools further than 100 miles away, written work, periodic snapshots of all computer projects, responses to online surveys and assessment questions were collected. Analysis included coding of qualitative data and quantitative analysis of the periodic snapshots of computer projects and focused on instances when students or teachers were frustrated or completed projects in unexpected ways. This allowed us to understand how children learned computer science and to identify unintentional barriers to learning or insufficient scaffolding and adjust the curriculum or programming environment in response (e.g., Dwyer et al., 2015; Franklin et al., 2015; Hill, Dwyer, Martinez, Harlow, & Franklin, 2015).

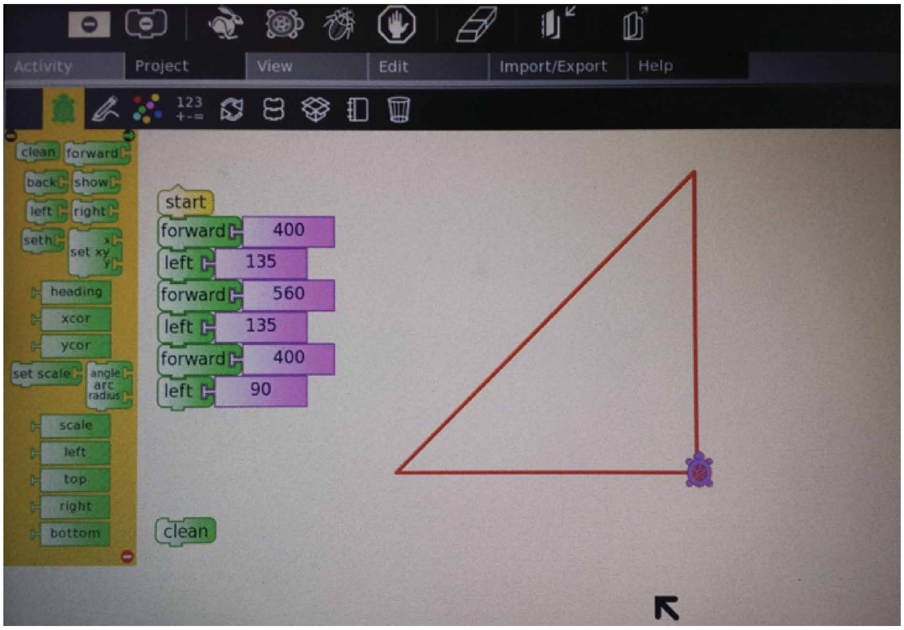
The third study presented focused on middle school students. The participants of this study were enrolled in a two-week day camp (six hours/day) taught once each summer for three summers. Approximately 40 students attended the camp each summer on the campus of a local university. The students were primarily Latino/a (64%), female (78%), and entering grades six through eight. Unlike the other two projects in which the computer science lessons were taught primarily by classroom teachers, the middle school camp was taught by project staff which consisted of three university faculty members (two in computer science and one in Chicana/o studies), three graduate students (from Chicana/o studies, education, and computer science departments), and six undergraduates (mostly computer science). Also unlike the other two studies where all students in a classroom participated, these participants were self-selected. Data collected on the middle school project included quantitative pre/post assessments of student interest, field notes on students' requests for assistance and completed student projects with a focus on assessing student learning and the effectiveness of the project. Analysis focused on student interest and their learning about computer science as a result of the summer camp (Franklin, Conrad, Aldana, & Hough, 2011, Franklin et. al., 2013).

Programming Environments

The three studies used different, but related, block-based programming environments: TurtleArt, LaPlaya, and Scratch. The youngest group of students (grade three) used TurtleArt (e.g., Bontá, Papert, & Silverman, 2010; Pilco, 1990) to create drawings (see Figure 2). TurtleArt is a derivative of Logo. In Logo, children command a turtle on the screen to move and draw by typing commands such as Forward 100 and Right 90. TurtleArt uses these same commands, but the commands are displayed as two-dimensional blocks that are dragged and dropped onto a programming area and snap together like puzzle pieces to create a script or code. The interface is similar to the Scratch interface (Resnick et al, 2009) used by older children, but TurtleArt has a smaller scope and number of available commands. TurtleArt commands are limited to those commands that direct the turtle to move and draw. Unlike Scratch programs, which are capable of including multiple interacting programmable entities (sprites), TurtleArt programs typically command only a single programmable agent (the turtle), simplifying the process.

The upper elementary school students (grades four through six) used a modified version of Scratch, called LaPlaya (see Figure 3). LaPlaya differs from Scratch in that the developer can select the commands that will be visible to the user to limit distractions and reduce the number of commands available to the students. It also adds the functionality of hiding scripts (pieces of code) so that, when students are learning, they can focus only on the sprite of interest. These features of LaPlaya allow for pre-populated projects in which students can focus only on parts of the full project and assist in implementing lessons in the context of short lab periods (see Hill et al., 2015).

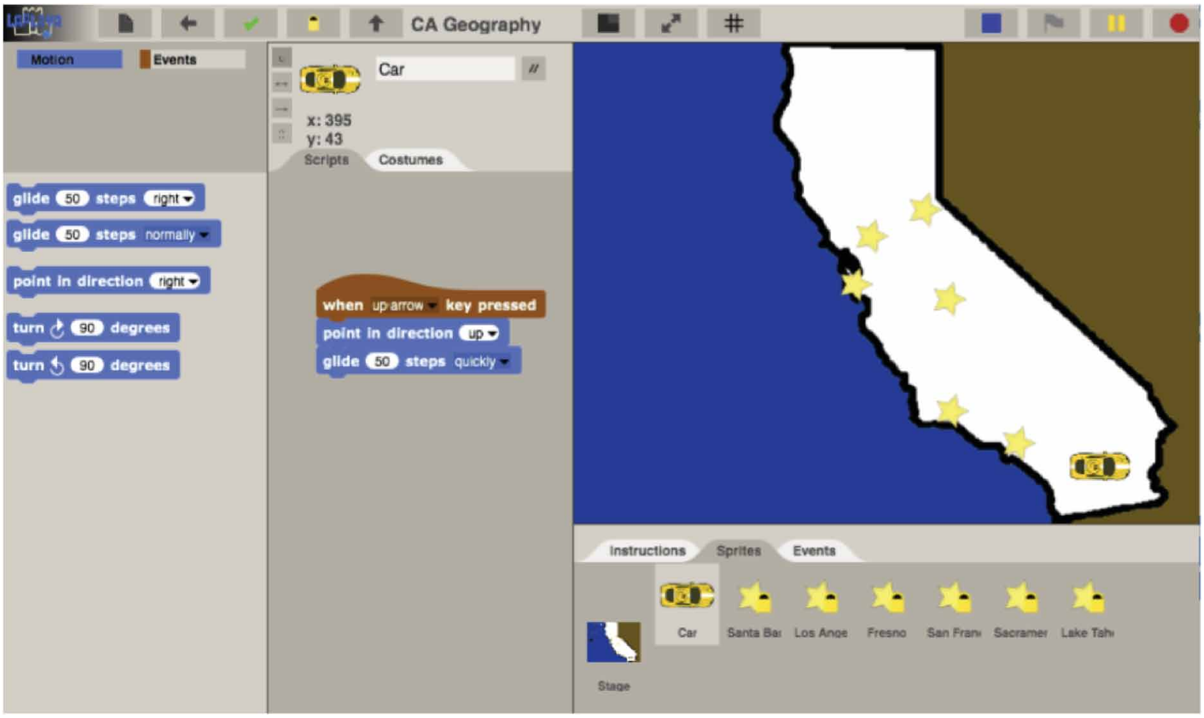
Figure 2. TurtleArt programming environment used with lower elementary school students



```
start
forward 400
left 135
forward 560
left 135
forward 400
left 90

clean
```

Figure 3. LaPlaya programming environment used with upper elementary school students



```
when up arrow key pressed
point in direction up
glide 50 steps quickly
```

The middle school students used the freely available Scratch programming environment (see Figure 4). Scratch includes a selection of blocks (commands) that are divided into categories based on their function. A menu of categories is visible in the upper left of the environment on the left side of the screen. Below this, all the blocks in the selected category are displayed. Students drag these scripts onto the programming area (center area of screen). The lower right area shows the sprites, or programmable objects, used in the program. The scripts displayed are those of the selected sprite. The upper right area of the environment shows the program output.

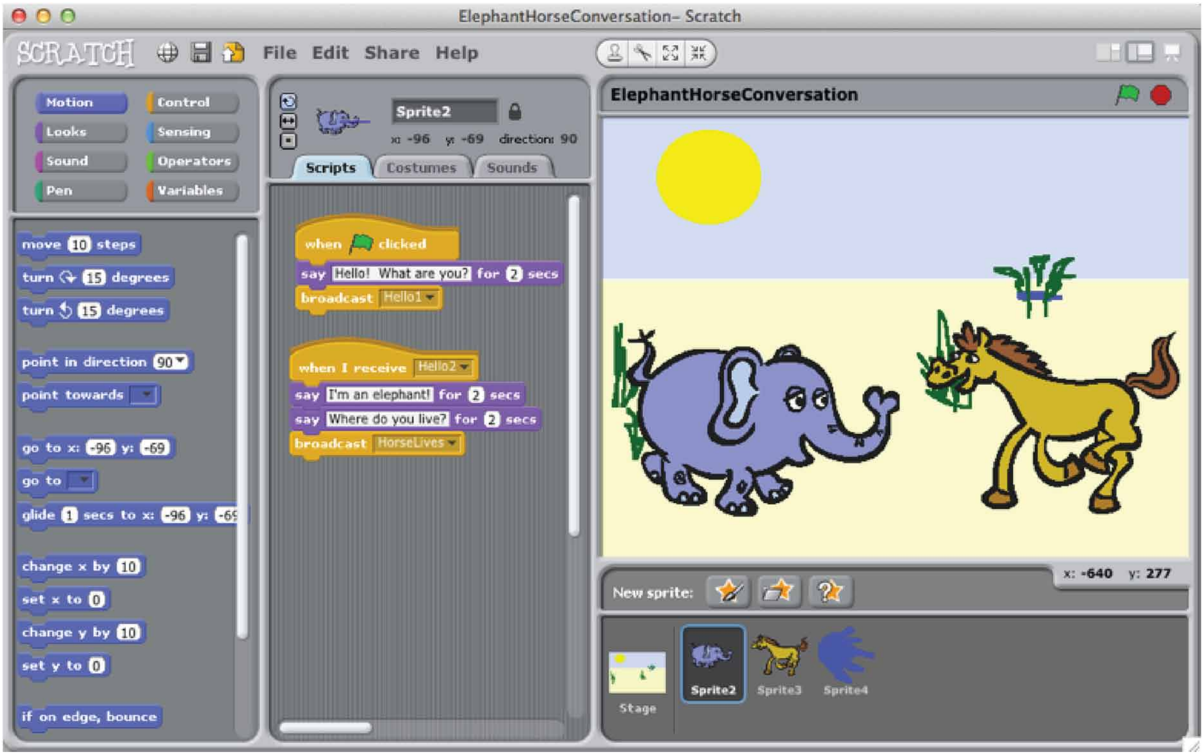
FINDINGS

Lower Elementary School Students: Drawing Shapes

As described above, in the study of the youngest children, third graders used TurtleArt to create geometric shapes. The teacher and researchers identified TurtleArt as a particularly valuable context for students developing creative ideas and for taking ownership of their ideas, a focus of the teacher's instruction.

In this project, the teacher allowed students time to explore with TurtleArt without instructions. That is, the children were engaged in open-ended programming. During this time, some students tried to draw with specific goals in mind (e.g., tried to draw their name), while others explored what happened when they put blocks together, noticing patterns and shapes (see example in Figure 5). At other times, the

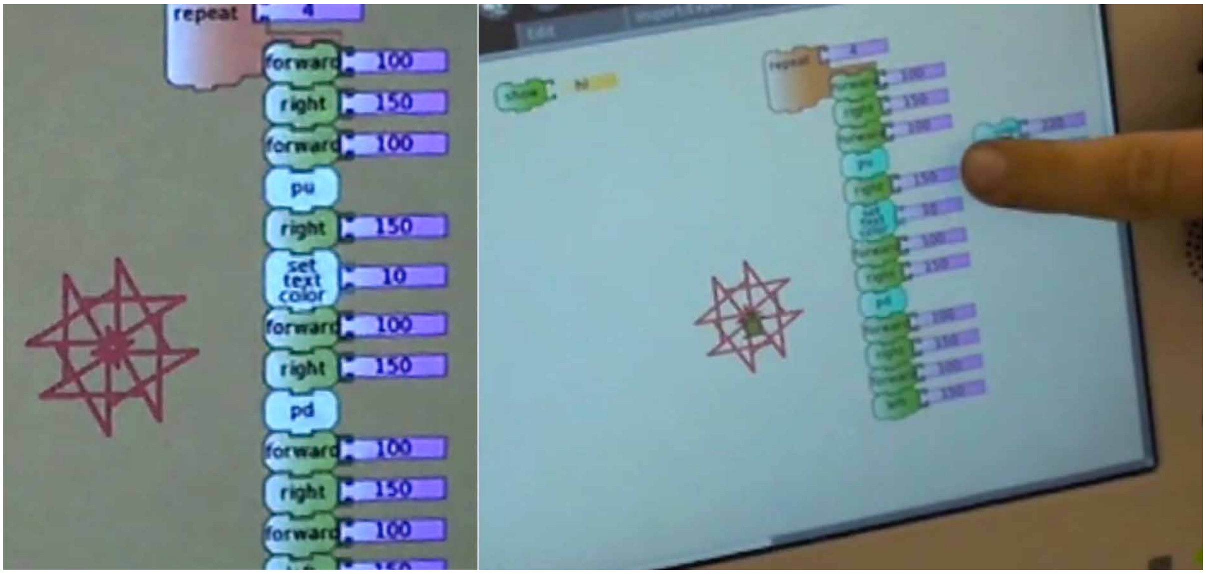
Figure 4. Scratch programming environment used for with middle school students



```
when [green flag] clicked
say [Hello! What are you?] for (2) secs
broadcast [Hello1]

when I receive [Hello2]
say [I'm an elephant!] for (2) secs
say [Where do you live?] for (2) secs
broadcast [HorseLives]
```

Figure 5. Screen shot of student work exploring patterns and shapes



```
repeat 4
  forward 100
  right 150
  forward 100
  pu
  right 150
  set text color 10
  forward 100
  right 150
  pd
  forward 100
  right 150
  forward 100
```

teacher set specific challenges to target mathematical or computer science concepts or skills. Examples of challenges included drawing squares of different sizes or in specific positions, drawing triangles, and shapes such as houses that were created by combining multiple shapes, tasks that require the computational thinking ideas of sequencing and the mathematical ideas of angles and measurement. Other tasks included drawing a square in the smallest possible number of steps, prompting students to consider looping, and drawing shapes that only use multiples of 360 for the angles, a geometry idea in their math instruction. Guiding instruction with challenges helped students to create new shapes more efficiently.

In the TurtleArt programming environment, the program and resulting drawing are shown in the same area of the screen. This means that the output (drawing) and process (code) are easily and simultaneously visible to an onlooker. This made TurtleArt a useful platform for sharing ideas with their peers. The researchers developed a representation for mapping *how* the ideas changed as they were taken up and developed by other children in the class, identifying changes in the output and changes in the program. Ideas were then mapped based on these codes to explore how they moved between students and evolved over time. In mapping these ideas and their resulting changes in programs and outputs, we were able to identify the context in which ideas moved through the classroom. More efficient programming techniques were usually prompted by questions or comments from the teacher. For example, when the teacher asked a child if he could make the same shape in fewer steps, two children, Cory and Tom (pseudonyms), worked together and figured out how to use looping to make their program more efficient.

***Cory:** Look at this! Heather, look at this.*
***Mr. Mills:** How many clicks, Cory?*
***Cory:** Um, a lot.*
***Tom:** No, just tell me*
***Cory:** I don't know, I don't remember.*
***Tom:** Clean and do it over and then tell many clicks and I can make it do it in one click.*
***Cory:** I don't know how to do that*
Tom: (leaning over and pointing to Cory's screen) *repeat. No, you put it there.*
***Cory:** Forward, forward, forward, forward. Like that?*
***Tom:** Okay good, now forward, click, forward.*
***Cory:** Whoa, that's a lot* [*of steps*]
Tom: (In a loud voice) *He did it in one click. He taught himself to do it.*

In contrast, once students developed skills, new uses of these techniques were usually student-driven. For example, a student asked her friend how she had made a triangle and then returned to her own computer to put triangles together and make a flower. Third grade students in this study shared and changed their ideas, using similar programs to create original outputs. In some cases, ideas developed in one class meeting were taken up again and further replicated and evolved in subsequent class periods, sometimes weeks or months later. The shared ideas became part of the classroom knowledge and ideas that the children could access when using TurtleArt. Programming in the TurtleArt environment provided third graders with an opportunity to explore mathematical content in a way that they took ownership of their ideas.

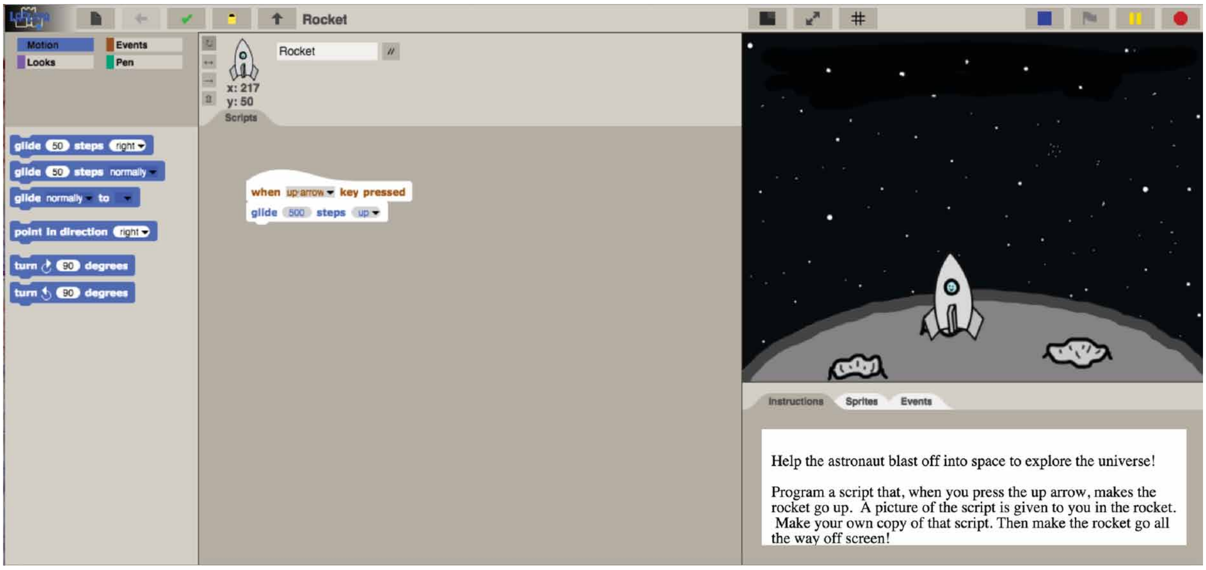
Upper Elementary School Students: Scaffolded Projects and Digital Story Telling

The studies of fourth through sixth graders were part of a larger project, which had two interdependent goals: (1) designing computer science curriculum for upper elementary school students and (2) investigating how upper elementary school students learn computer science. The curriculum, called Kids Engaged in Learning Programming – Computer Science (KELP-CS), is a scaffolded curriculum that emphasizes computational thinking, basic programming, and NGSS engineering design. In the first round of implementation, a minimally modified version of Scratch was used as the programming environment. As students struggled with aspects of Scratch, the interface was further modified. The current version is called LaPlaya (see Hill et al., 2015 for description).

KELP-CS incorporated both on-computer and off-computer activities, but analysis focused primarily on the on-computer activities. In the on-computer skill building activities, students completed a series of small programming projects at their own pace that incrementally became more challenging. The goal of these lessons was for students to learn the skills for programming digital stories (e.g., sequencing, event-based programming, etc.). Most of the on-computer tasks used pre-programmed projects. For example, in one project, students programmed a bear to navigate a maze to reach a honey pot and avoid bushes. The honey pot was programmed to display a congratulatory message when the bear reached it and the bushes programmed to display an error message and send the bear back to the starting point. Another activity tasked students with programming a rocket to move when the arrow keys were pressed (see Figure 6).

Students also completed a culminating engineering design project (a digital story). As students progressed through the curriculum, they created and revised their final project. The curriculum was implemented in three ways depending on the structure of the specific elementary school: (1) a teacher taught lessons to his or her homeroom class either in the computer lab or on laptops in their classrooms, (2) a teacher taught lessons to students in an entire grade throughout the week as classes visited the computer lab, or (3) a technology specialist taught lessons in the computer lab as classes visited each week.

Figure 6. Screen shot of rocket task



```
when up arrow key pressed
glide 500 steps up
```

Help the astronaut blast off into space to explore the universe!

Program a script that, when you press the up arrow, makes the rocket go up. A picture of the script is given to you in the rocket. Make your own copy of that script. Then make the rocket go all the way off screen!

Focus groups were conducted with fourth graders before implementing the computer science curriculum showed that students had foundational computational thinking skills (Dwyer, Hill, Carpenter, Harlow, & Franklin, 2014). These interviews engaged groups of children in off-computer tasks such as writing instructions to draw complex figures, following such instructions, and sorting objects by weight. In the interviews, fourth graders recognized the need for specific instructions, were able to critique peers' instructions, and could create basic algorithms (instructions to solve problems). These findings provided a starting place for building the curriculum. During implementation of KELP-CS, students successfully completed projects related to sequencing, event-driven programming, and message passing, key computational thinking ideas (refer to Table 1) as well as initialization, costume changes, and scene changes. The culminating digital story projects (see Killian et al., in press, for more details) engaged students in engineering design as they iteratively revised what stories or information to share and ways to implement such narratives in through programming.

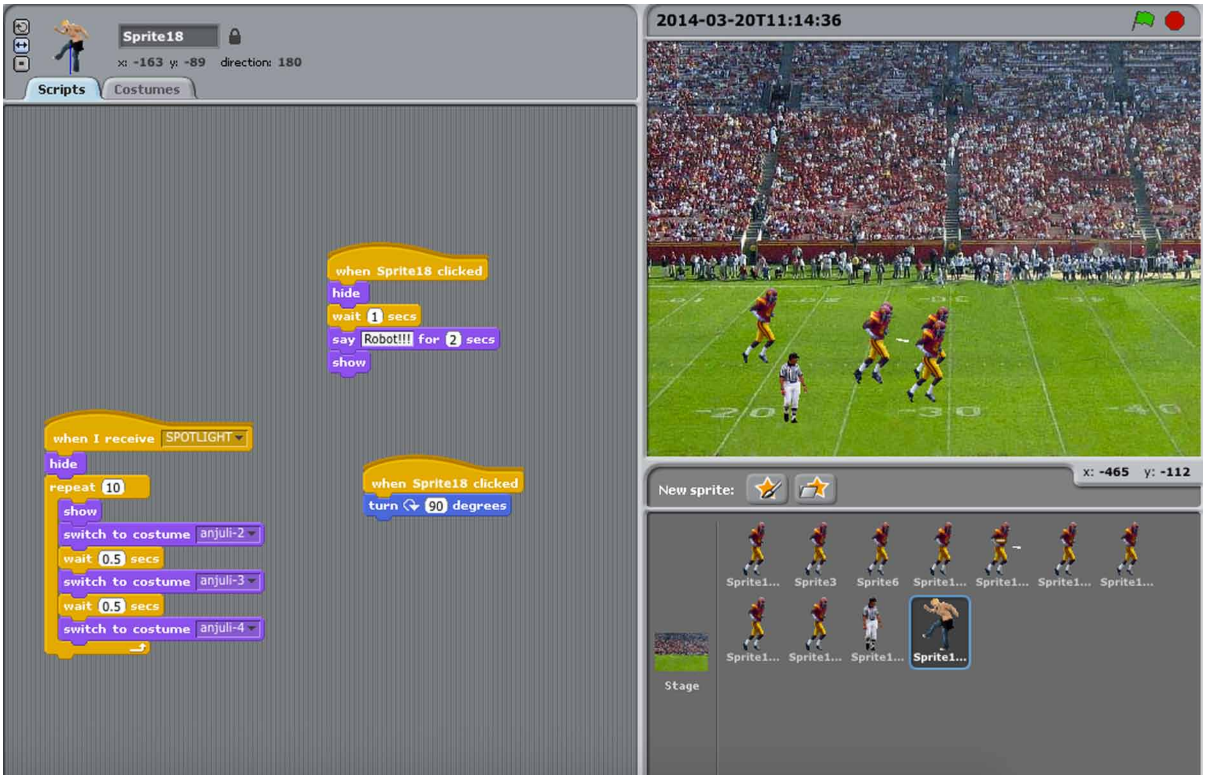
Students' difficulties with the curriculum and the programming environment pointed to barriers to learning programming related to their language skills, mathematical knowledge, as well as complexities of programming. Several target classrooms in this study included populations of near 80% English Language Learners, most of whom spoke Spanish at home. This meant that the majority of students in these classrooms were reading instructions, listening to a teacher, and creating programs in a language they were still learning. This compounded the difficulty of learning the meaning of commands and the specialized language of computer science. Analysis of classroom videos focusing on student difficulties indicate that children struggled to distinguish between commands that had different functions but used words that had similar meanings in English (see Dwyer et al, 2015). For example, the commands "glide" means to move to another location with visible motion and "go to" means to disappear from one location and instantly appear at another. Other language related difficulties included larger concepts like broadcasting messages. In Scratch and LaPlaya, events can be coordinated by sending messages from one sprite to another. Instead of the "send message" command, children tried to use the "say" command, which displays a speech bubble and text above the sprite. Ongoing research on this project is attempting to tease apart the experiences of English Language Learners, as compared to fluent English speakers to better support their learning.

The initial programming environment used with these students (a minimally edited version of Scratch) also required mathematical knowledge above fourth grade level to successfully create even simple digital stories. These ideas included negative numbers, percentages, and the x/y coordinate plane. Identifying these issues led to changes in the programming environment used with the fourth through sixth grade students (Hill et al., 2015).

In addition to the language and mathematics ideas, students struggled with some programming practices. The first was keeping track of and coordinating multiple events and sprites. Both Scratch and LaPlaya display only the scripts associated with a selected sprite. This means that while working on programming one sprite, the student must keep the actions of the others in mind in order to coordinate among them to create a coherent story. Providing students with tools for visually representing their stories (story boards and flow charts) was crucial to their success. Figure 7 shows a screen shot from example student work in which a student programmed a football game. This student uses message passing to control the flow of the story. Notice that only the commands directing one player are visible.

Despite the difficulties of learning to program, students overwhelmingly enjoyed creating computer programs, even when they struggled. Students were asked in focus groups at the end of the curriculum what they liked and what they did not like about the computer programming activities and whether they

Figure 7. Example of a digital story depicting a football game that uses message passing



```
when Sprite18 clicked
hide
wait 1 secs
say Robot!!! for 2 secs
show
```

```
when I receive SPOTLIGHT
hide
repeat 10
    show
    switch to costume anjuli-2
    wait 0.5 secs
    switch to costume anjuli-3
    wait 0.5 secs
    switch to costume anjuli-4
```

```
when Sprite18 clicked
turn 90 degrees
```

would recommend it to a friend. Every child answered positively. For example, when asked what they would tell their friends about learning computer programming, Robin responded, "[I would say] It's really good but I warn you one of them is really hard… That's the one where you had to make the dang chicken switch around and that took me like an hour." A second student, Lance, followed up by stating, "But that's what makes it fun. That makes it fun."

Middle School Students: Digital Storytelling

The middle school students were enrolled in an out-of-school summer program to learn about three topics: endangered species, Mayan culture, and computer programming (Franklin, Conrad, Aldana, & Hough, 2011; Franklin et al., 2013). The goal of the summer camp was to increase interest in computer science for female and Latina/o students, groups traditionally marginalized in computer science. The summer program integrated computing education with two themes: Mesoamerican culture and conservation of endangered species. Such topics built upon students' ethnic heritage and interest in endangered species. This interdisciplinary, project-based curriculum was designed with the goals of recruiting students who may not have selected computer or robotics camps, and increasing students' interest, confidence and experience in computer science.

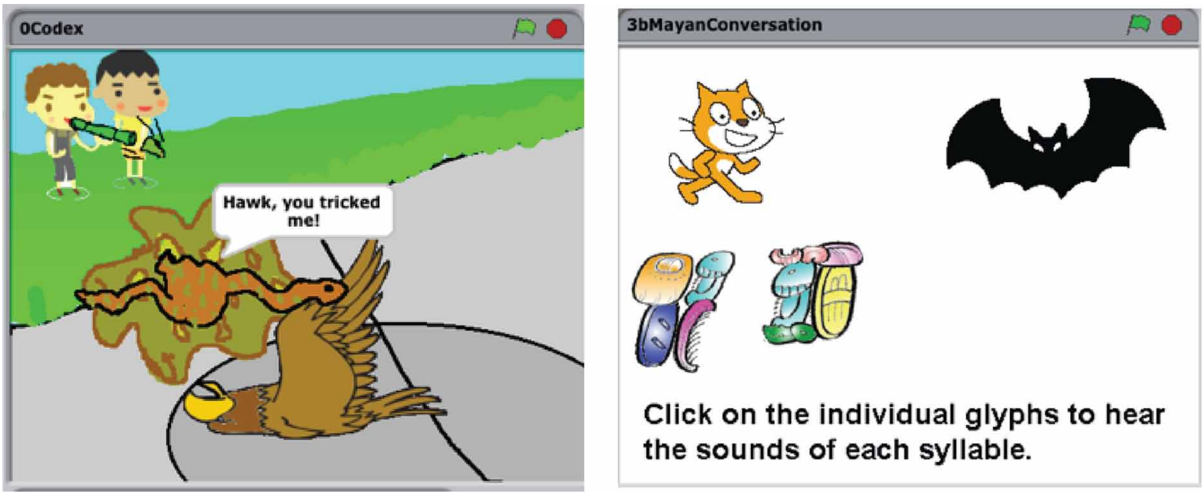
The curriculum focused on the skills necessary to complete a digital story-telling project in Scratch. This culminating project told a Mayan myth with an endangered species from the Mesoamerican geographic region. There were four activities categories: (1) learning about animals and conservation, (2) learning about Mesoamerican culture, (3) developing basics skills with art and drawing, and (4) introducing and developing programming skills. Half of each camp day was devoted to computer science projects, followed by two of the other subjects.

Students used the Scratch programming environment to complete their programming projects. Because the culminating project was a digital story, computer science content during week one consisted of lessons that taught skills and concepts needed to create digital stories. Working in pairs, students used Scratch to make a "name poem" acrostic for a selected animal (Wolz, Stone, Pulimood & Pearson, 2010). Each letter described the animal including information such as where it lived, what it ate, and ecological challenges to its survival. Students then created a digital story based on Mayan and Aztec stories. Figure 8 shows two screen shots from student work that are examples of how the summer camp activities integrated computer science and Mayan culture. The screen shot on the right depicts a myth about a snake who convinces a frog to let him eat him (to carry him) and is itself soon after eaten by a hawk. The screen shot on the left is student work from an activity where the students were provided the pictures of glyphs (Mayan writing) and a set of sounds. The students had to figure out which sound went with the glyphs, then program the glyph to say the sound when the glyph was clicked.

Each programming lesson had two parts: a warm-up exercise in which students learned one or more new computer science concepts with substantial scaffolding and support, and a small project in which students applied their new knowledge to a similar, but new, problem. In year one, the computer science topics included sequential execution, message passing, initialization, and the combination of loops and movement (complex animation). Lessons on loops, variables and branches were added in the second year.

Unlike the fourth through sixth graders, language and mathematics skills were not identified as a significant barrier to learning the computer programming. However, the students had some difficulty with the computer science ideas. Over the two years, the project directors made changes to the curriculum such as revising activities to provide more scaffolding and increasing opportunities to assess the development of student ideas. Programming ideas were introduced in targeted tasks and were built on

Figure 8. Screen shot of two examples of student work showing how computer science and Mayan culture were integrated into the summer camp activities



Click on the individual glyphs to hear the sounds of each syllable.

over time. The research on middle school students learning computer science indicated a need to revise the curriculum. The curriculum designers added detailed project checklists that included the objective of the project and the specific elements necessary to consider the project "complete." This provided a visual aid for students to recall lesson directions and expectations. A second change was the addition of guided peer sharing and review of projects, which provided an opportunity to share their work with other students. To facilitate this engagement, curriculum designers created "gallery walks" and scaffolded ways to provide constructive feedback to peers. Students were also taught two types of feedback: feedback about the way the project looked or acted and feedback that related to the computer science concepts used in the implementation of the project.

While the content of the camp included computational thinking and programming, the primary goal of the summer camp was to increase interest in computer science among females and underrepresented ethnic populations. The summer camp successfully increased both boys' and girls' interest as evidenced by pre and post assessments. The majority of the students were drawn to the camp because of the non-computer science topics (Animals and Mesoamerican Culture). In fact, in year one, only 31% of the students indicated that they selected the camp because of the computer science theme and only 22% indicated computer science as a possible career choice. After the camp 65% of the participants indicated computer science as a possible career choice. In the second year, 17% indicated computer science as a career choice before the camp and 44% indicated computer science as a possible career after the camp. That the students were drawn to the camp because of the non-computer science topics, but reported developing an interest in computer science points to the importance of combining computer science with other content areas to attract underrepresented populations.

DISCUSSION AND RECOMMENDATIONS

Connections to Content Standards

Given an appropriate task and coding environment, even elementary school children can become interested in and adept at coding. Further, computer programming can be linked to other content area standards in ways that allow children to develop programming skills while also learning mathematics, literacy, and science. Of the three studies discussed above, two (lower elementary and middle school) preceded the implementation of CCSS and NGSS. Thus, the following discussion of how these two projects addressed new mathematics and literacy standards is retroactive. In contrast, the study of upper elementary school students was conducted after the CCSS and NGSS had been written. The inclusion of engineering design as described in the NGSS was an intentional focus of the project. The connections to the CCSS and NGSS are only provided as an example of how instructors might think about using computer science instructions to link to other content areas. While each of the studies included computer science activities that could address standards in multiple content areas, only one set of standards for each grade level study is discussed.

The third grade students using Turtle Art were introduced to key concepts and skills for computer programming while learning mathematics and literacy that aligns with Common Core State Standards. In mathematics, the TurtleArt programming tasks provided opportunities for students to represent and solve problems involving addition and subtraction, apply properties of operations as strategies to multiply and divide, draw shapes and their attributes, understand concepts of angles, and draw and identify lines and angles among others. By programming in TurtleArt, they received feedback in the form of drawings. For example, if a student tried to make a drawing of a triangle, but the angles provided for each turn the turtle made did not add up to 180 degrees, the drawing would not look like a triangle.

The curriculum for fourth through sixth grade students intentionally connected to the Next Generation Science Standards. As described above, engineering design is a new requirement for science at all levels of K-12 education. Programming is a natural fit for engineering design. Students completed "engineering design" lessons with the goal of designing, revising, and implementing a digital story. In the design thinking lessons, students were given an engineering problem (e.g., create a digital story). The classroom teacher selected a topic and target audience. After identifying the problem, students brainstormed ideas and collaborated to evaluate these ideas and decide on the best one. They then created storyboards and flowcharts for their digital story. Finally, students worked on programming their digital story by testing and revising iteratively. Also, teachers may have encouraged students to create a story showing a scientific process, demonstrate a science concept, or even create an interactive world where the user could engage in the science. By doing so, students deeply engaged in a core idea within the Next Generation Science Standards. For more details, see Hansen et al. (2015).

As an integral part of the middle school curriculum, students were assigned an endangered animal from the Mesoamerican region and researched their animal, including the environment it lived in and how it was depicted in Mayan art and culture. They used this information to design and program digital stories. This research – conducted prior to programming their digital stories – required students to read fiction and non-fiction texts, thereby engaging in practices and meeting standards included in the Common Core State Standards for English Language Arts. Further, the programming task itself met standards related to writing. In creating digital stories, students established a point of view and either told the story from a narrator's perspective or from the perspective of the characters (sprites in Scratch). They also organized an event sequence. These tasks are related to Common Core Standards for English Language Arts in the seventh grade.

Recommendations

There exist many websites and apps for teaching programming through block-based programming. In addition, there are non-block-based programming environments, robotics kits that include programming, and board games, and toys designed to teach programming. Choosing an appropriate app or web-based programming environment can be challenging, especially for use in schools. The studies discussed in this chapter used block-based programming environments that were scaffolded to be appropriate for the grade level. In designing instruction and researching children's learning, each project described identified the need to balance tasks designed to teach programming skills necessary to accomplish an end goal and open-ended tasks that provided opportunities for students to innovate on the skills they had developed. Across the three studies, the programming language, programming environment, and curriculum all needed to be considered to ensure that they matched with children's physical abilities and backgrounds in reading and mathematics (see also Duncan, Bell, & Tanimoto, 2014). Below, recommendations related to the programming environment and curricula are discussed.

Mathematics and Language Demands of Programming Environments

Programming environments for block-based languages include the visual interfaces that students interact with to create and view their programs. It includes the block palette, which may either display all available command blocks or a menu that includes categories of types of command blocks. The interface also includes a space where students construct scripts or groups of blocks arranged in sequence and a place to see the output (the "stage"). There may also be an area where sprites (programmable objects) can be selected and edited. This is a complex learning space. Educators need to consider the reading and mathematics requirements for students to use the programming environment. While the middle school project used the full version of Scratch at the time of the study, the two projects for elementary school used programming environments that simplified the Scratch programming environment.

Math skills ended up being an important consideration for selection of a programming environment because not all children in the fourth grade classrooms had the requisite math skills to be comfortable with the Scratch environment. They had not yet learned coordinate planes, percentages, relative angles or negative numbers. These ideas caused problems when, for example, children attempted to set the size of a sprite to be smaller or larger than the default. To do so, students select or type a percentage or decimal values of the original size. Moving and placing sprites required understanding the x and y coordinates and the coordinate plane. As a result, the project team made changes to the programming environment. However, an equally effective solution would be to select a programming environment that does not require these skills.

Language skills is a second important factor to consider. The programming language is comprised of the set of blocks or commands that are used to create programs. Block-based programming languages do not require much typing. However, while there are notable exceptions such as ScratchJr (Flannery et al., 2013), most require children to be able to read and develop new meanings for words that they may associate with other definitions. Words like "glide" and "go to" or "broadcast" and "say" may have similar definitions in everyday interactions, but result in different actions in a program. These subtle differences were difficult for students.

Because the skill levels and experiences of classes may vary considerably, it is important for educators to evaluate any programming environment and the programming language for the pre-requisite mathematics and language skills. They should choose a programming environment that does not include unnecessary barriers to programming and they should be prepared to teach the mathematics or language skills required. In the studies described above, this was handled in both ways. The language for the lower elementary students required students to understand angles, a topic they had yet to learn in third grade. The classroom teacher chose to couple programming activities with mathematics lessons so that, as the students learned about angles and geometric shapes, they could apply this learning in their programming activities. In the upper elementary school classroom, the interface was designed to remove many barriers to learning programming, so that participating teachers would not be required to adjust the teaching of other content areas.

Curriculum and Instruction

In all cases discussed in this chapter, students learned programming skills in order to accomplish creating something of their own design. The youngest children created drawings of geometric shapes while the upper elementary and middle school students created digital stories. The *creation* of something, not just the learning of skills, was a central component. All three projects included both skill building directed exercises and open-ended activities that allowed more freedom and creativity and in all three cases, teachers and project staff grappled with achieving an appropriate balance that sufficiently scaffolded students' progress while also allowing students freedom to choose how they would use the programming. This was handled in different ways. In the elementary school classroom, much of the programming time was unstructured and students were encouraged to share what they learned with each other. The programming lessons were coupled with mathematics lessons and students were encouraged to practice their new mathematics learning. The teacher interrupted students for mini-lessons, often highlighting a new block or programming skill discovered by a student in the class. In the upper elementary school classrooms, structured skill-building activities taught programming skills that were later applied in larger open-ended projects. The programming skills learned in the structured activities could be used in their open-ended project, but the structured activities and open-ended project were separate tasks. At the middle school level, students learned the skills in the process of developing larger open-ended projects.

Structured tasks in which all students are working on the same project at the same time simplified the teachers' responsibility. Students faced similar difficulties to each other throughout the tasks. This meant that teachers only had to answer a handful of questions and they could leverage the expertise of children who finished early to assist those who were struggling. It also meant that the end goal was known. Open-ended tasks, in contrast, provided students with opportunities to follow their own interests and students sometimes had questions that teachers did not know how to solve. Further, every child could have a different question. In these cases, teachers needed to be comfortable learning along with the students or placing the responsibility to figure things out on the students.

The layout of the computer lab or classroom where instruction took place had implications for how classes were managed. Visual cues such as a post-it notes on the computer to signal to the teacher that they needed assistance allowed students to continue working. Moving young children to the front of the room (away from computers) or asking them to turn monitors off facilitated focus on group discussion or teachers' instructions. For more specific classroom management strategies see Franklin et al. (2015).

For the middle school students, the most important goal was to interest students in computer programming. In the study discussed here, this was done by integrating computer science with Mayan culture and endangered animals, topics of interest to the target populations. Hence, the focus was not on ecology or cultural studies as an end, or even technical skills in computer science, but rather the topics were used as a means to interest students in computing. The same approach was used with the upper elementary classrooms. Initially, all tasks were related to fourth grade science or social studies curriculum. In some cases, this was problematic. Requiring students to remember or look up ideas from other content areas slowed students down and distracted from the programming. As a result, the tasks were revised to provide all necessary information so that they were useful across a variety of classrooms. The level of integration of other content should be carefully considered to support learning in both computer science and the other content area.

Finally, as has been discussed earlier, access and equity are important to consider. Children have varied prior experiences that can lead to a range of comfort with technology. Failure to attend to these varied experiences may make children that are less comfortable with technology think that they are less capable that their peers who have had significantly more experience with computers.

FUTURE RESEARCH DIRECTIONS

There is scant research focused on how elementary and middle school children learn computer science, especially in school settings. Thus, there are many areas of needed research. One area is on identifying prior knowledge that can be built on to teach computational thinking. This is vital for developing appropriate curriculum and programming environments for this age group. Once prior knowledge is identified, research on learning on how children develop ideas in this area over time and how this learning is related to developmental level is critical. Much work has been done to identify learning progressions in science which can be a model for computer science education. A third area is how computer science learning at the elementary and middle school contributes to success in other learning contexts – both concurrently and to learning contexts at a later time. Research on how computer science knowledge enhances other content areas is important, as is research on what can be learned in elementary and middle school that will transfer to better success in computer science classes in high school and post-secondary education. Fourth, increasing the workforce diversity is a particular concern in computer science. Research is needed to understand how to support English language learners, students with special needs, students who lack access to technology, and female students in learning computer programming and computational thinking and developing and sustaining an interest in computer science.

As has been argued in this chapter, to reach all students, computer science education needs to be accessible to all children. This means, computer programming should be taught in classrooms, not only in out-of-school contexts. School environments differ from out-of-school environments in that all children participate, not just self-selected students, teachers are held accountable for addressing state and national standards, and classroom elementary and middle school teachers may neither be experts in computer science nor have sufficient free time to learn computer science at the level of out-of-school providers. How to support schools, teachers, and students to engage in meaningful computer science activities is an area of needed research. Related to this, future research should also focus on the knowledge that teachers need to support student learning of computer programming and mechanisms for providing professional development for practicing teachers and integrating this knowledge into teacher education programs for pre-service teachers.

CONCLUSION

Even from a young age, children are capable of learning computational thinking and programming. Further, learning computer programming allows them to innovate with technology, not just use technology. However, students' prior experiences with technology vary greatly. Even for those who have extensive experience using technology, transitioning from using technology to developing their own drawings, digital stories, or games through computer programming involve new skills. Many programming environments exist for teaching programming. Educators need to consider carefully the requirements of the environments and the prior experiences of their students ensure success. Programming tasks can connect children to each other and to a larger audience. As such, computer programming is a powerful tool for children. As Kafai and Burke note, "Learning to code ultimately manifests its worth when it increases an individual's capacity to participate in today's digital publics" (Kafai & Burke, 2014, p. 9).

REFERENCES

Barab, S., & Squire, K. (2004). Design-based research: Putting a stake in the ground. *Journal of the Learning Sciences*, *13*(1), 1–14. doi:10.1207/s15327809jls1301_1

Barr, V., & Stephenson, C. (2011). Bringing computational thinking to K-12: What is involved and what is the role of the computer science education community? *ACM Inroads*, *2*(1), 48–54. doi:10.1145/1929887.1929905

Bell, T., Witten, I. H., & Fellows, M. (2009). *Computer science unplugged*. Retrieved February 10, 2015, from http://csunplugged.org

Bontá, P., Papert, A., & Silverman, B. (2010). Turtle, art, TurtleArt. In Proceedings of Constructionism. Paris, France: Academic Press.

Brennan, K., & Resnick, M. (2013, April). *New frameworks for studying and assessing the development of computational thinking*. Paper presented at the American Educational Research Association (AERA), Vancouver, Canada.

Collins, E., & Green, J. L. (1992). Learning in classroom settings: Making or breaking a culture. *Redefining student learning: Roots of educational change*, 85-98.

Computing Research Association. (2013). *Computing research association Taulbee survey*. Retrieved April 17, 2015, from http://cra.org/resources/taulbee/

Duncan, C., Bell, T., & Tanimoto, S. (2014). Should your 8-year-old learn coding? In *Proceedings of the Ninth Workshop in Primary and Secondary Computing Education* (*WiPSCE '14*) (pp. 60-69). New York, NY: ACM. doi:10.1145/2670757.2670774

Dwyer, H., Hill, C., Carpenter, S., Harlow, D., & Franklin, D. (2014). Identifying elementary students' pre-instructional ability to develop algorithms and step-by-step instructions. In *Proceedings of the 45th ACM Technical Symposium on Computer Science Education* (pp. 511–516). New York, NY: ACM. http://doi.org/ doi:10.1145/2538862.2538905

Dwyer, H. A., Iveland, A., Killian, A., Hill, C., Franklin, D., & Harlow, D. B. (2015, April). *Programming languages and discourse: Investigating the linguistic context in learning computer science during elementary school*. Paper presented at the American Education Research Association (AERA), Chicago, IL.

Flannery, L. P., Silverman, B., Kazakoff, E. R., Bers, M. U., Bontá, P., & Resnick, M. (2013). Designing Scratchjr: Support for early childhood learning through computer programming. In *Proceedings of the 12th International Conference on Interaction Design and Children* (pp. 1-10). New York, NY: ACM. http://doi.org/ doi:10.1145/2485760.2485785

Franklin, D., Conrad, P., Aldana, G., & Hough, S. (2011). Animal Tlatoque: Attracting middle school students to computing through culturally-relevant themes. In *Proceedings of the 42nd ACM Technical Symposium on Computer Science Education* (pp. 453–458). New York, NY: ACM. http://doi.org/ doi:10.1145/1953163.1953295

Franklin, D., Conrad, P., Boe, B., Nilsen, K., Hill, C., Len, M., … Waite, R. (2013). Assessment of computer science learning in a scratch-based outreach program. In *Proceeding of the 44th ACM Technical Symposium on Computer Science Education* (pp. 371–376). New York, NY: ACM. http://doi.org/ doi:<ALIGNMENT.qj></ALIGNMENT>10.1145/2445196.2445304

Franklin, D., Hill, C., Dwyer, H., Iveland, A., Killian, A., & Harlow, D. (2015). Getting started in teaching and researching computer science in the elementary classroom. In *Proceedings of the 46th ACM Technical Symposium on Computer Science Education* (pp. 552–557). New York, NY: ACM. http://doi.org/ doi:10.1145/2676723.2677288

Grover, S., & Pea, R. (2013). Computational thinking in k–12: A review of the state of the field. *Educational Researcher*, *42*(1), 38–43. doi:10.3102/0013189X12463051

Hansen, A., Iveland, A., Dwyer, H., Hill, C., Franklin, D., & Harlow, D. (2015). Programming digital science stories: Computer science and engineering design in the science classroom. *Science and Children*, *53*(4), 60-64.

Harlow, D. B., & Leak, A. E. (2014). Mapping students' ideas to understand learning in a collaborative programming environment. *Computer Science Education*, *24*(2-3), 229–247. doi:10.1080/08993408.2014.963360

Hawthorne, E. K. (2011). Collaborating with CSTA for computer science education week. *ACM Inroads*, *2*(4), 25–26. doi:10.1145/2038876.2038886

Hill, C., Dwyer, H. A., Martinez, T., Harlow, D., & Franklin, D. (2015). Floors and flexibility: Designing a programming environment for 4th-6th grade classrooms. In *Proceedings of the 46th ACM Technical Symposium on Computer Science Education* (pp. 546–551). New York, NY: ACM. http://doi.org/ doi:10.1145/2676723.2677275

International Society for Technology in Education. (2007). *ISTE standards: Students*. Retrieved February 10, 2015 from http://www.iste.org/standards/standards-for-students

Kafai, Y. B. (2006). Playing and making games for learning instructionist and constructionist perspectives for game studies. *Games and Culture*, *1*(1), 36–40. doi:10.1177/1555412005281767

Kafai, Y. B., & Burke, Q. (2014). *Connected code: Why children need to learn programming*. Cambridge, MA: The MIT Press.

Kelleher, C., & Pausch, R. (2005). Lowering the barriers to programming: A taxonomy of programming environments and languages for novice programmers. *ACM Computing Surveys*, *37*(2), 83–137. doi:10.1145/1089733.1089734

Malan, D. J., & Leitner, H. H. (2007). Scratch for budding computer scientists. In *Proceedings of the 38th Technical Symposium on Computer Science Education (SIGCSE '07)*. New York, NY: ACM. http://doi.org/ doi:10.1145/1227310.1227388

Maloney, J. H., Peppler, K., Kafai, Y., Resnick, M., & Rusk, N. (2008). Programming by choice: Urban youth learning programming with scratch. *ACM SIGCSE Bulletin*, *40*(1), 367–371. doi:10.1145/1352322.1352260

Margolis, J., & Fisher, A. (2003). *Unlocking the clubhouse: Women in computing*. Cambridge, MA: The MIT Press.

National Governors Association Center for Best Practices & Council of Chief State School Officers. (2010). *Common core state standards*. Washington, DC: National Governors Association Center for Best Practices, Council of Chief State School Officers.

NGSS Lead States. (2013). *Next generation science standards: For states, by states*. Washington, DC: The National Academies Press.

Papert, S. (1980). *Mindstorms: Children, computers, and powerful ideas*. New York, NY: Basic Books, Inc.

Papert, S. (1996). An exploration in the space of mathematics educations. *International Journal of Computers for Mathematical Learning*, *1*(1), 95–123. doi:10.1007/BF00191473

Papert, S., & Harel, I. (1991). Situating constructionsim. *Constructionism*, *36*, 1–11.

Partnership for 21st Century Skills. (2011). *Framework for 21st century learning*. Retrieved February 10, 2015 from http://www.p21.org/our-work/p21-framework

Pilco, S. (1990). *The XO laptop in the classroom*. Puno, Peru: Sdenka Zobeida Salas Pilco.

Resnick, M. (2006). Computer as paintbrush: Technology, play, and the creative society. In D. Singer, R. Golikoff, & K. Hirsh-Pasek (Eds.), *Play=Learning: How play motivates and enhances, children's cognitive and social-emotional growth* (pp. 192–208). Oxford, UK: Oxford University Press. doi:10.1093/acprof:oso/9780195304381.003.0010

Resnick, M., Maloney, J., Monroy-Hernández, A., Rusk, N., Eastmond, E., Brennan, K., & Kafai, Y. et al. (2009). Scratch: Programming for all. *Communications of the ACM*, *52*(11), 60–67. doi:10.1145/1592761.1592779

Ryan, C. (2013). *Language use in the United States: 2011*. U.S. Census Bureau. Retrieved from http://www.census.gov/prod/2013pubs/acs-22.pdf

ScratchEd. (2014). *Scratch curriculum guide*. Retrieved February 10, 2015 from http://scratched.gse.harvard.edu/resources

Seehorn, D., Carey, S., Fuschetto, B., Lee, I., Moix, D., O'Grady-Cunniff, D., & Verno, A. et al. (2011). *CSTA K-12 Computer science standards: Revised 2011*. New York, NY: Computer Science Task Force.

Seiter, L., & Foreman, B. (2013). Modeling the learning progressions of computational thinking of primary grade students. In *Proceedings of the 9th Annual International ACM Conference on International Computing Education Research (ICER '13)*. New York, NY: ACM. http://doi.org/ doi:10.1145/2493394.2493403

Tai, R. H., Liu, C. Q., Maltese, A. V., & Fan, X. (2006). Planning early for careers in science. *Science*, *312*(5777), 1143–1144. doi:10.1126/science.1128690 PMID:16728620

Wing, J. M. (2008a). Computational thinking and thinking about computing. *Philosophical Transactions of the Royal Society of London A: Mathematical, Physical and Engineering Sciences, 366*(1881), 3717–3725. http://doi.org/<ALIGNMENT.qj></ALIGNMENT>10.1098/rsta.2008.0118

Wing, J. M. (2008b). Five deep questions in computing. *Communications of the ACM*, *51*(1), 58–60. doi:10.1145/1327452.1327479

Wolz, U., Stone, M., Pulimood, S. M., & Pearson, K. (2010, March). Computational thinking via interactive journalism in middle school. In In *Proceedings of the 41st ACM Technical Symposium on Computer Science Education* (pp. 239-243). New York, NY: ACM. http://doi.org/ doi:10.1145/1734263.1734345

Wright, T., & Cockburn, A. (2005). Evaluation of two textual programming notations for children. In Proceedings of the Sixth Australasian Conference on User Interface (Vol. 40, pp. 55–62). Darlinghurst, Australia: Australian Computer Society, Inc.. Retrieved from http://dl.acm.org/citation.cfm?id=1082243.1082251

KEY TERMS AND DEFINITIONS

Coding: The process of creating scripts.

Command: An instruction given to a computer. In block-based programming environments, commands are represented by a block with a word or a phrase on it.

Computational Thinking: A problem solving method that can be used to represent problems in a way that computers can solve them. This method includes abstractions, algorithmic thinking, organizing data, and other skills.

Computer Programming: The process of planning, debugging, and creating scripts to accomplish a goal or task.

Digital Story: Using digital tools to tell a story. This can include computer animation, programming, video, photos, or other digital tools.

Development Environment: An environment in which one creates and runs programs. Most provide tools for text-based languages such as autocompleting and coloring keywords. For block-based languages, they contain the blocks that make up the language.

Programming Language: A set of syntax and key words used to create programs.

Script: In a block-based environment such as Scratch, a series of blocks which control the actions of a sprite.

Sprite: A programmable object visually represented by an image.

Chapter 16

Technology's Role in Supporting Elementary Preservice Teachers as They Teach:

An Urban STEM Afterschool Enrichment Program

Anne Pfitzner Gatling
Merrimack College, USA

ABSTRACT

This chapter describes a teacher preparation model incorporating a STEM focused, technology enhanced course and field experiences for preservice teachers. This field-based science method course supports and engages preservice teachers in creating and implementing lessons for early childhood and elementary students enrolled in an afterschool STEM Enrichment Program offered in a diverse urban elementary school. Technology is woven throughout the model, supporting preservice teachers as they build their content knowledge, and research effective practices to teach and assess their students. This model also helps to address the need to enhance STEM instruction in schools and inspire preservice teachers to engage their students in the STEM learning process. Findings from the model's implementation indicates a positive impact on the preservice teachers' understanding of science content and standards, on their pedagogical practices to design STEM lessons based on the revealed understandings of students' knowledge, and on the development of their professional identities.

INTRODUCTION

Advances in science, technology, engineering and mathematics (STEM) are driving our economy and creation of jobs. Understanding this reality leads us to recognize that science literacy is essential to the democratic decision-making that affects our national and global agendas, and that acquiring an inquiring mind is vital to the cultural fabric of society. Yet, according to the World Economic Forum (2011), the

DOI: 10.4018/978-1-4666-9616-7.ch016

United States ranks 27th in developed nations in the proportion of college students receiving undergraduate degrees in science or engineering and the 52nd in the quality of mathematics and science education. According to the Federal Science, Technology, Engineering, and Mathematics (STEM) Education 5 Year Strategic Plan (2013), our K-12 educational system as compared to other international systems is in the "middle of the pack." According to the report, the assessment of students' ability to apply reading, mathematics, and science knowledge to real-life situations indicated that out of thirty-three countries "12 countries had higher scores than did the United States in science and 17 had higher scores in mathematics (vii)."

Other realities of research from national and international measures of student performance confirm that in the United States, children are seriously lacking in their understanding of the STEM disciplines. Furthermore, a lack of exposure to these disciplines narrows children's school and life options due to an insufficient background and lack of confidence in themselves as learners of mathematics and science (Archer, DeWitt, Osborne, Dillon, Willis, & Wong, 2012). In addition, many elementary teachers are woefully unprepared and lack the confidence and knowledge to teach these subjects well, particularly in urban schools (Barton, 2007). Yet, nearly all elementary teachers must teach science and mathematics and will thus set the stage for students' interest or disinterest in the STEM disciplines. Based on this research, it follows that STEM education in teacher preparation programs, including those leading to licensure at the early childhood and elementary level, is a national priority.

Preservice teachers (PST) will strongly influence the generation of students that require STEM literacy; therefore, it is critical that their education programs develop their essential content knowledge and effective teaching strategies. The teacher preparation programs are instrumental in changing and molding the PST's knowledge, skills, and dispositions necessary for building STEM literacies for themselves and their students. By its nature, STEM education can inspire PST through its authentic applications in the classroom. As they acknowledge the contributions of science and mathematics to society, it will help PST understand the value of these disciplines in advancing their own students' educational experience. Due to engineering's interdisciplinary nature, math, science and technology are all leveraged for elementary students' motivation and engagement in STEM related investigations. This helps them feel less overwhelmed with the concepts in math and science (Perrin, 2004), and positively impacts their perceptions and dispositions of these subjects (Bagiati, Yoon, Evangelou & Ngambeki, 2010). Elementary students involved in STEM related instruction could possibly develop an interest in pursuing higher level math and science courses as they progress through the grades (DeJarnette, 2012).

So the question remains, how do we effectively address what is needed in teacher education programs that will encourage STEM Education?

BACKGROUND

Many schools of education are ill prepared to provide the training necessary for early childhood and elementary majors to teach inquiry-based science or STEM. Research demonstrates that a one-semester science methods course may be insufficient in developing the skills or experience necessary for effective inquiry-based instruction that supports science investigations (Newman, Abell, Hubbard, McDonald, Otaala, & Martini, 2004). Cotabish, Dailey, Robinson, & Hughes showed a statistically significant gain in science knowledge and process skills after participation in a one year STEM initiative (2013).

The problem is confounded by the difficulty PST have in transferring knowledge and skills gained in methods to their classroom (Black, 2004) since much of what is taught in methods courses is taken out of the context of the schools (Goodlad, 1990) and reflects on teaching and learning in the abstract (Darling-Hammond & Barataz-Snowden, 2005). Yet they have even fewer opportunities to practice teaching science in classroom settings (Fulp, 2002; Hewson, Tabachnick, Zeichner, & Lemberger, 1999). The theory becomes far too removed from practice. Problems can arise when teachers struggle to transition from learning how to think like a teacher to learning how to act like a teacher (Darling-Hammond, 2006).

The field-based placement component of a science education program can be a critical component to a science education program's success (Ellis, 2001). The time PST spend teaching science to elementary students can greatly enhance their confidence in science instruction (Cantrell, Young, & Moore, 2003). Moreover, PST in placements often do not feel as if they are the teachers and rarely get enough opportunities to practice (Boz, 2006), especially in the field of science. Without the proper supports, teachers struggle with this "problem of enactment" (Kennedy, 1999) once they reach their new classroom. It is difficult to find placements in a classroom where science is taught.

Typically, PST in their field-based placements observe science instruction that is teacher centered (Smith, Banilower, McMahaon, & Weiss, 2002). This is much different from the STEM learning environments where the teacher is more of a facilitator allowing the students to be active learners making sense of the activities for themselves (Anderson, 2002). The inquiry-based instruction provides contextual exploration of natural phenomena, authentic language opportunities, and communication of ideas for diverse learners (Fathman & Crowther, 2006; Lee, Deaktor, Hart, Cuevas, & Enders, 2005; Rosebery, Warren, & Conant, 1992). Inquiry-based instruction results in greater student achievement, including diverse students, than traditional approaches (Duschl, Schweingruber, & Shouse, 2006).

Therefore, it is recommended that teacher education programs offer student teachers "consistent opportunities to apply what they are learning, analyzing what happens, and adjust their efforts accordingly" (Darling-Hammond & Barataz-Snowden, 2005, p. 31). Bransford, Brown, & Cocking concur stating that teacher education programs often "fail to provide the types of learning experiences which lead to learning for understanding or teaching for understanding" (1999, p. xvii). They suggest that in order for PST to become effective teachers they need opportunities for deliberate practice where coaches provide specific feedback to improve instruction.

In order to achieve this, it is important that field-based experiences are integrated with university-based courses. Using a situated learning model, Eick, Ware, and Williams (2003) placed PST from their science methods course in a co-teaching placement with middle school teachers once a week. One partner taught the first period, reflected with the second partner in a free period and then the second partner taught. They found that these PST gained comfort and confidence in science teaching, built critical reflection through modeling their cooperating teacher's lesson, were more confident in managing student behavior, and experienced the positive effect of seeing and doing inquiry in practice. They suggested more research on the effects of real time teaching assistance.

A great challenge for the field is providing PST opportunities to teach science in diverse school settings while receiving critical feedback and timely support (Clift & Brady, 2005). Research on urban field experiences also notes certain qualities of experiences that enhance the probability of prospective teachers developing the skills and confidence to teach in urban settings with linguistically diverse populations. In fact, studies of the effects on teacher candidates' field experiences in urban and diverse schools are complex and, at times, yield contradicting results (Cook & Van Cleaf, 2000; Fry & McKiney, 1997).

It appears that although quality placements in urban schools may inspire teacher candidates to become dedicated to teaching in urban settings, field experiences in urban schools can also cause culture shock, cognitive dissonance, and a lack of efficacy among future teachers (Rushton, 2000).

Research indicates that teaching and learning is enhanced through the use of effective and appropriate technology that supports the science concepts being taught across grade levels (Maeng, Mulvey, Smetana, & Bell, 2013; US Department of Education, 2012). Technology is inherent in the teaching of science concepts and should be modeled in both the college methods courses and in the field-based experience.

Additionally, both state and national standards require the use of technology in the planning and implementation of lessons as a professional standard for teachers. The Next Generation Science Standards [NGSS] (2013) addresses the concepts and practices integrating the technology in the engineering process across grade levels from kindergarten to high school. According to the National Research Council's Framework for K-12 Science Education (2012):

Advances in technology, in turn, provide scientists with new capabilities to probe the natural world at larger or smaller scales; to record, manage, and analyze data; and to model ever more complex systems with greater precision. In addition, engineers' efforts to develop or improve technologies often raise new questions for scientists' investigations. (Appendix J, p. 1)

The use of technology evolves from basic enhancement steps to more advanced transformational levels as indicated in a SAMR model of assessment presented by Puentedura (2009). The SAMR model begins with a basic two step enhancement where *substitution* is technology that substitutes, and *augmentation* is defined as technology that substitutes with some improvement. The more advanced two steps are the transformation levels that is *modification* where technology is significantly redesigned *and redefinition* is technology that redefines the development new tasks.

A TECHNOLOGY SUPPORTED FIELD-BASED PRE-SERVICE TEACHER MODEL

One way to address the concept of teaching to learn is through the wider lens that focuses on the PST investment in a teacher education program where they have experiences in a variety of courses and field-based settings with diverse social structures and interactions. These components merge together to support their development as an educator and leader. I developed an experiential model for elementary and early childhood and elementary education PST enrolled in my science methods course. The model integrates the content knowledge of PST and students, the pedagogical practices of science and technology, and the development of PST' professional identities.

Integration of a Science Methods Course, Field-Based Experience and School Setting

Using the situative nature of cognition, the PST knowledge of teaching and learning is analyzed through the situations and activities in which they are experienced, attained and used. The contexts of the social interactions among PST, inservice teachers, students, the college professor, the social practices in the college and school settings, and physical location of the settings are part of overall experience and are used to analyze growth of knowledge. The situative perspective allows reflection on details drawn from various contexts and the analysis of knowledge acquisition and learning outcomes based on these contexts (Borko, Peressini, Romagnano, & Knuth, 2000).

The model for teacher preparation used in this paper supports the PST learning and development supported through experiences and interactions embedded in the context of a science methods course using inquiry and technology based strategies. It was enhanced and supported through the field-based experience and embedded in the context of an after-school setting. As in the work of Borke, et al. (2000), the compatibility of these settings are important in the transfer of knowledge experienced in each. In these settings, PST actively participated, formulated and assessed problems, developed questions, analyzed, drew conclusions and projected further solutions. These experiences will influence how their growth in knowledge and develop their professional identities.

Inquiry-Based Methods for Teaching and Learning Science

The second theoretical framework of the model is the inquiry-based method for teaching and learning science, technology, engineering and mathematics. Research supports the use of inquiry-based science practices to improve the science knowledge of students (Cantrell, Young, & Moore, 2003; Kim et al., 2011; Robinson, Shore, & Enersen, 2007). The National Council of Teachers of Mathematics, the NGSS and the National Research Council all recommend inquiry methodologies for teaching.

Inquiry-based methods develop the critical thinking skills of students, promotes problem solving, generates further investigations and questions and is found to be a motivator for learning. Scientific inquiry is defined by the National Research Council (NRC) in the National Science Education Standards (1996) as:

> *A multifaceted activity that involves making observations; posing questions, examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions, and communicating the results. (p. 23)*

Science instruction based in inquiry has a wide range of approaches, ranging from confirmation or structured inquiry where the students are given a direct procedure to follow from the teacher, to guided inquiry where the students are provided with a problem to investigate but given freedom to determine the best methods to resolve it, and finally to open or independent inquiry where students develop their own questions and design their own investigations. As one progresses from structured to open inquiry, the investigations become more challenging for the students and more complex for teachers to manage and prepare (National Research Council, 2000). Furthermore, pre-service teachers who engaged in authentic inquiry research were able to translate that experience into their own teaching and were better able to support their students in developing skills for inquiry (Britner & Finson, 2005). The NGSS raise engineering to more level terms with inquiry stating that "students are expected to be able to define problems—situations that people wish to change—by specifying criteria and constraints for acceptable solutions; generating and evaluating multiple solutions; building and testing prototypes; and optimizing a solution" (Appendix, p. 1, 2013).

INTEGRATED COMPONENTS OF THE TEACHER EDUCATION MODEL ENHANCED BY TECHNOLOGY

Science Methods Course

This science methods course was offered in the early childhood and elementary teacher preparation programs in a 4-year college in Massachusetts. The fifteen-week course met weekly on campus and addresses the PST content knowledge, the pedagogy of teaching, and the development of their professional identity. For four weeks, the students were in their field-based experience along with the professor to implement lessons for a STEM Enrichment Club. Technology was embedded in all three aspects of the course to support PST as they learned and taught content and then assessed their student learning. Additionally, the PST learned effective technological tools and pedagogical practices, through their own investigative experiences in the classroom with the assistance of their professor. These practices in turn were used and transferred to experiences they shared with their students in the field-based experience.

Preservice teachers explored the NGSS and investigated the guiding principles of the Science and Engineering Practices. They used the NGSS to create and implement a unit of study in a field-based experience.

Teaching Cycle

The science methods course was structured around the concept of inquiry and introduced by Wilson, Shulman, and Richet (1987) that explores four different stages involved in instruction: 1) clarifying learning goals: students' knowledge and practice, 2) learning environment: teacher planning and strategies, 3) assessment, reflection, and revision, and 4) reflection and inquiry on teacher practice. The course components will be introduced through these stages. Table 1 highlights the technology incorporated into each step of this teaching cycle.

Step 1 - Clarifying Learning Goals: PST Knowledge and Practice

- **Assessment of the preservice teachers' content knowledge:** Many PST do not have a strong background in STEM content. Regardless of their knowledge and skills for teaching, early childhood and elementary teachers were expected to teach subject matter knowledge in these fields.

Table 1. Technology incorporated into each step of the teaching cycle

STEP	Teaching Cycle Steps	Technology Incorporated at Each Step
Step 1	Clarifying learning goals – PST knowledge & practice	National Science Teacher Association's (NSTA) Learning Center Glogster©, Prezi©
Step 2	Learning environment: teacher planning, strategies, assessment reflection and revision	iPad, Apple TV Misconceptions-Oriented Standards Based Assessment Resources for Teachers (MOSART)
Step 3	Assessment, Reflection and Revision: The Field-Based Experience	iPad, Google Drive Bee-Bots©, Learning Resources Zoomy Handheld Digital Microscopes©, UFO Ball©, Squishy Circuits©
Step 4	Reflection and Inquiry on teacher practice	iPad - iMovie

> One of the most challenging aspects of this science methods model was working to build the PST content knowledge during the semester and prior to their interaction with K-4 students in the afterschool STEM club.

In the context of the course and to prepare for a field-based experience, PST selected science concepts generally from either the Physical or Earth Sciences as described in the NGSS Standards. The PST developed a unit of study for the grade level they were assigned to teach. The concepts included light, electricity, sound, energy, force and motion, three states of matter, magnetism, and soil quality. The standards they selected were varied so that there was a wide representation of content and NGSS standards being researched and taught.

Once the standards were selected, the PST used the National Science Teacher Association's [NSTA] Learning Center (2014) to take a brief quiz focused on their newly adopted discipline. NSTA then provided the PST with related readings, videos, discussions, etc. around the areas they failed to pass. Having this site available for their research began to build their subject matter knowledge and provided a growing confidence in their ability to present the information to their students. Preservice teachers wrote a reflection on their growth in content knowledge based on their exposure to the NSTA Learning Center. One response included the following statement, "My knowledge definitely grew over the four weeks at (field placement site) because I had forgotten about this information and when it was time to teach I learned it all over again and grew to understand the material very well." While it may be hard to determine how well this PST understood her content, there was a conscious effort for her to review the content and later assess her own understanding of content as she prepared to teach.

The PST team taught lessons with a peer (described later) and during the semester created what is called the "TED" Talk of Science Content Knowledge. This multi-media presentation through Glogster or Prezi was based on their teaching experience in the field and highlighted their students' misconceptions and related growth as well as their own. The reflection investigates their own knowledge and misconceptions on their selected concept and standard. They were exposed to other NCSS standards content explored by their peers that helped to strengthen their subject matter knowledge across many content standards. A second agenda to this multi-media presentation and process was to prepare them for the state mandated teacher multi-subject test required for early childhood and elementary teachers' licensure.

The implications technology had to improve the PST work with the students continually grew throughout the semester. Utilizing Apple TV, PST showed lab results from investigations in class, rather than writing them on the board and shared their key learning moment from their content focused articles, videos and models from NSTA's Learning Center and later a favorite science or engineering lesson they were getting ready to enhance.

- **Pedagogical content knowledge:** Teaching to learn involves identifying appropriate practices that enhanced the learning process. To do this, PST must apply what they know about the content to what they know about how to teach that content (Shulman, 1986). This course introduced the PST to the teaching cycle, the inquiry-based practices for science learning and the reflective nature of teaching.

Throughout the semester, several inquiry-based investigations coupled with engineering design challenges grounded the course. It was imperative that students experience this type of learning as they were expected to implement in the field-based experience (Britner & Finson, 2005). Preservice teachers additionally analyzed videos of inquiry focused elementary classrooms on websites like learner.org.

Preservice teachers then selected grade appropriate performance expectations from the NGSS that would determine their unit of study. Yet, prior to creating investigations to support these science concepts, the PST conducted a misconception interview with K-5th grade students in the afterschool STEM Club. Student responses during that interview helped to clarify and differentiate the learning goals for the unit of study. In an effort to prepare for their first meeting with their students in the afterschool club, the PST researched student misconceptions closely related to their adopted performance expectations.

- **Uncovering common science misconceptions of K-5 students:** Young children develop knowledge outside of the classroom that consists of incomplete or inaccurate ideas. Student misconceptions could be based on their developmental understanding of the world and/or their experiences and not generally accepted by the science community. When PST lack knowledge of these misconceptions or preconceptions children have, they may try to teach a lesson based on a foundation that makes the learning difficult for the children. Research indicates the importance of identifying the misconceptions children hold (Kambouri, 2011; Smolleck & Hershberger, 2011; Torish, 2000).

To prepare for their first visit to the afterschool club, PST developed misconception interviews that they administered to their students. The course assignment required PST to describe the content based on the NGSS performance expectation they adopted and list related common student science misconceptions are represented in rich research literature and websites, including MOSART (2015), listed with the university's library online guide. They additionally developed a concept map using Kidspiration or Inspiration program software to help them organize the content knowledge they will teach to their students. This gave a visual overview of the concept and the relationships and connections inherent in it that helped the PST develop a better understanding of the content and its relationships to crosscutting concepts as presented in the NGSS. Finally, PST worked hard to relate the content they choose to teach and the questions they designed for the misconception interview to the lives of the students with whom they are to teach. It was important for them to understand the context of the school and local community prior to STEM Club.

The STEM Enrichment Program is held in a local urban school as part of the 'enrichment' portion of their day. This field-based experience took place in a local urban school which had 618 students in K-8th grades, 90% of whom are eligible for free and reduced lunch, 86% are Hispanic and 25% are labeled as English Language Learners. For the last two years this school reached the state's highest level of achievement, Level 1. The school administration noted that their current year Level 1 designation was due to their bonus science points.

The first meeting was to get to know the students and a misconception interview. The second and third visits were focused on inquiry-based investigations helping the students build experience and knowledge necessary to begin to tackle the engineering design challenge in the fourth visit.

In the first visit to the elementary school, PST first established a rapport with their students through activities involving cooperative games and creating a team name. These personal connections help the PST make the content more relevant to their student lives building a strong rapport between the two (Rivet & Krajcik, 2008). After the get to know you games, the PST conducted misconception interviews to assess the students' understanding. The student responses during the misconception interview were videotaped with their iPad and then were analyzed to determine how conceptual information was being received by the student. The analysis of the interview guided both the students' and the PST own subsequent learning. This aligned well with Black and William's (2009) research that when:

> *Evidence is elicited, interpreted, and used by teachers, learners or their peers, to make decisions about the next steps in instruction that are likely to be better, or better founded, than the decisions they would have taken in the absence of the evidence that was elicited. (p. 9)*

One PST explained the role of the misconception interview' role in her team teaching and planning, "When figuring out what to include (in lessons) it was useful to go back to our (taped) misconception interview and see what the students knew and what they didn't know." The videotaped misconception interview became invaluable as this PST designed each of her lessons for the students.

- **Pedagogy of technology:** The class met on campus the week following the misconception interview so PST could analyze the interviews. With the Apple TV, PST would then share the top minute or two of the recording that represented a key understanding into the way this child or these children think. The videos also gave the professor an opportunity to capture the PST questioning and instructional style. As a class, the PST discussed each of these brief glimpses and began designing instruction to best meet their students needs and interests clarifying the learning goals they would prepare for the field based experience.

Step 2 - Learning Environment: Teacher Planning, Strategies, Assessment Reflection and Revision

Understanding and addressing these misconceptions allowed PST to consider their student understandings and determine the need for change in their perceptions. They now had some key knowledge to guide them as they designed worthwhile tasks that aligned with the NGSS and involved discourse and inquiry. The goal of each lesson was to guide the students through inquiry-based investigations as they provided the rich learning opportunities to modify and refine the students' knowledge base through experiences and investigations.

Drawing upon the Understanding by Design model (Wiggins & McTighe, 2005) for unit development and using the information acquired on misconception interviews, the PST analyzed the student misconception interview results and once again reviewed the related Math and NGSS to develop a performance based engineering design project and six related supporting inquiry based lessons. While most engineering curriculum available online often fails to indicate what standards are being met in each activity (Bagiati, Yoon, Evangelour & Ngambeki, 2010), the PST determined which Math and NGSS performance expectations were being met for each lesson they are teaching.

As they planned to implement their lessons, the PST used the practices they researched and experienced in the course classroom. Inquiry based methods were used to promote learning. Students became more active participants in investigating, problem solving, and communicating their experiences supporting their claims with evidence. Using the engineering design and technology further motivates the students to learn and expand their interests in the STEM curriculum.

Each visit to the elementary school students would race to find their PST team. Once reunited, they would move to their 'mini classrooms' a few tables in the cafeteria, a corner in the hall, etc. The professor then rotates between groups checking in by observing, occasionally asking students to share what they are doing, giving a bit of feedback to the teachers.

As the pedagogical practices for effective use of technology in the teaching and learning of STEM are investigated and researched as part of the class, their value will be further appreciated. The iPad is one such tool that was used in the course and field-based experience that has gained more prominence in its implementation.

For example, some of the lessons the PST designed involved the use of ramps and balls or cars. The iPad was utilized to bring the investigation to a new level on Puentedura's (2009) SAMR model. The PST used the iPad to record each of the pupil's trials of a car running down a ramp. They then brought their pupils together to play back the video asking them to watch closely to see what is happening as they watch the car. Preservice teachers asked questions like, "What do you notice while the car was still at the top, and in motion down the ramp, and out onto the floor?" The video was stopped at various points to discuss the process. By breaking this investigation into the key elements of force and motion, the PST took using the technology of the iPad from its original basic Substitution level up to the Augmentation level. Now the technology is serving as a tool that was greatly improved (Puentedura, 2009). Another application for the iPad related the laws of motion could be used when demonstrating the conservation of energy with balls, similar to a Newton's cradle.

Step 3 - Assessment, Reflection and Revision: The Field-Based Experience

This science methods course was an intensive field-based experience driven course where PST then taught a NGSS standards-based STEM curriculum to diverse urban elementary students in an after-school STEM Enrichment program as a core component of the course. The field-based experience consisted of four classes at the field site. At four different meetings, PST were paired for team teaching for groups of four to five students in kindergarten through fifth grades. Their instruction was supported by continual visits from the college professor.

The PST integrated several types of technology in their units for the STEM Enrichment Club.

Bee-Bots© were basic programmable robots that can easily be used by kindergarteners and first graders to learn sequencing by completing simple 'challenges' such as planning a route from a home to a store on a 'community map' or finding letters to spell a word on an 'alphabet mat'. The Bee-Bots are little bees with forward, back, right, left, pause and clear buttons to program. Students predicted moves and may actually pick the bee up to think about which keys they need to push. Students predicted their route, program their Bee-Bot and then learned cause and effect when they watched their little bee follow a path that maybe wasn't what they planned. Students then have to retrace their steps. Finally, students can also set up a simple maze with blocks to create a path for the Bee-Bots.

Another favorite was the Learning Resources Zoomy Handheld Digital Microscopes© that allowed students to take videos or still images of up to 43X magnification. This was an invaluable addition to the handheld magnifiers because students could record what they were seeing both in the field and again back in the classroom. Students could also use these images to create their own electronic reports or stories.

Finally, PST brought their iPhones or iPads into the STEM Enrichment Club to either show videos, demonstrations, or to document their student growth in understanding as they work through the inquiry based lessons and the final engineering design.

Electricity was one example of a typical unit developed and taught by the PST pairs in this project. While electricity as a topic was typically taught at a higher-grade level, these PST worked to introduce more basic concepts around electricity at a younger level. The related NGSS related performance expectation: *3*-PS2-3. Ask questions to determine cause and effect relationships of electric or magnetic interactions between two objects not in contact with each other (NGSS, 2013). While they taught the traditional electricity unit with static electricity, these PST also extended the traditional unit of study for electricity by incorporating other forms of technology. Tools for this unit included the UFO Ball© (explained below) and Squishy Circuits©, which incorporated homemade play dough (insulating and conductive), battery packs, wires, LED's and motors. This gave the students (and PST) an opportunity to conduct an inquiry-based investigation to determine what was necessary to light an LED while avoiding the traditional cumbersome wires and batteries to make a circuit.

A UFO Ball© was a ping-pong like ball that illuminated when a complete closed circuit connection is made. The students and PST enjoy holding hands in circle and testing the least amount of touch to keep it lit. One of the PST reflected:

> *One of my favorite moments from the entire time. . . we made insulators and conductors and tried to have them work in different ways to create a closed circuit. The lesson itself went well, but I felt that I lost them a little bit at the end when it was time to describe the terms on the board. My last second idea was to break out the 'wonder ball' (UFO ball) that lights up when everyone is holding hands completing the circuit. For one girl everything clicked and it was amazing to see. She tried different things, making note that our skin worked as a conductor, but our fingernails were insulators. She then, unprompted, recapped both my partner and my previous two lessons for the entire class perfectly. It was my first moment as an educator where I could see a student have a full understanding of a topic based on my teaching and examples.*

Here the PST noticed that the students were momentarily lost or disconnected from her lesson on conductors and insulators. But once the UFO ball was introduced, it helped one girl begin to make connections to all she had learned over the past three lessons. She turned it into a true inquiry-based investigation, testing all that would conduct and not. In the process the students came to life. This UFO ball worked as a tool to provide the other elementary students in this group an opportunity to apply their knowledge of circuits, conductors, and insulators as well. It inspired and motivated them to want to know more. This was the same group that had one of their students go home and have his parents buy all the materials they had used on a separate day.

- **Technology for organization:** Each visit to the school incorporated three Google drive documents. These documents are shared between the professor and both members of the teaching team for feedback and support. The teaching team alternated throughout the 4 sessions. For example, after the first lesson was taught by Lead Teacher #1 they would submit a reflection journal, Lead Teacher #2 would submit a draft of lesson #2 and post supplies needed by the partners for implementation of their lesson the following week. The open communication between the team and the professor were vital in a smooth transition between the course and the field-based experiences. Additionally, as PST posted their lesson drafts, the professor responded with comments, and the students then collaboratively resolved these issues within the Google doc, creating a faster feedback loop. For years, this process was completed using Word's tracked changes in a Word docu-

> ment via email. The cumbersome steps involved began to take too much time especially as class sizes grew. With Google Docs, each step of the correspondence was documented helping the professor see the progression of the PST' understanding of the growth in their students' learning as it relates to the content and lesson components each week. At any point, the revision history could be pulled up to review earlier drafts. Reflections from the teaching team and feedback from the professor ensured that the best positive experiences are being offered to the students in the STEM Enrichment Afterschool Program.

At the end of each session with the students at the STEM Enrichment Club, students went back to their homerooms and the PST and the professor gathered together in the school library to debrief and reflect as a class. Preservice teacher reflections covered things that went well, acknowledged celebrations; and, raised and answered questions or concerns the PST may have to share. A detailed discussion, where both peers and the instructor contributed, offered instructional techniques and other suggestions for the teaching team to consider for the next week's lesson. In the last 30 minutes of class, topics were covered that may not have surfaced during the discussion to build further understanding of science instruction including such topics as claims, evidence and reasoning, as well as, strategies for teaching diverse learners.

Step 4 - Reflection and Inquiry on Teacher Practice

Finally, the documentation of student learning that the PST gathered during the STEM Enrichment Club was complied and put into an iMovie. The PST as partners worked to create and edit an iMovie presentation that provided evidence of student learning, demonstrated change in their understandings and misconceptions, and documented their awareness of the power that STEM education has to engage and challenge students. Preservice teachers included related state science, math, technology and engineering standards, student misconceptions, student work, pictures and videos to highlight their students' growth in understanding the content through the science investigations and final Engineering Design Investigation. With the videos, both the PST and the professor were able to capture elementary student misconceptions and their learning, and document the PST questioning and instructional style. The completed presentation helped PST reflect and evaluate and what happened in an effort to improve instruction.

After reviewing her video clips and notes, one PST remarked:

The lesson I was most proud of would be the last lesson, which was the engineering design one I made because when we did the lesson with the kids, everything seemed to click for them. It was amazing to watch because you could see that they knew the material we taught them and they ended up going above and beyond what we had planned.

The video provided additional opportunities for the PST to reflect and think more deeply about their teaching and its impact on student learning. On Puentedura's chart, this iMovie project was a true redefinition where the old assignment of developing a final unit of 10 lessons and a final reflection had been transformed into a project that brought the whole experience alive bringing out details from the projects that were never discovered before. Preservice teachers selected pieces of student work, video, snapshots, related community items, all in an effort to tell their story. They selected the transitions, the music, and the related standards and pulled it all together into a 2-3 minute video.

PROFESSIONAL IDENTITY

This was the only university supported opportunity for PST to teach in the school setting outside of the college mandated pre-practicum experience, and almost the only opportunity for these PST to teach science to diverse learners. This approach gave context for the PST. Working closely with the elementary students helped PST quickly realize the need to strengthen their own STEM focused subject matter knowledge and pedagogical skills and thus seek resources and support.

Preservice teachers were developing their professional identities through the contexts of the course, the field-based experiences, the school setting involving the population of students, location of the school, and the physical layout of the instructional room. Their development was also impacted by the social interactions with their peers, the students, the course professor, and the inservice teachers involved, as well as, the social structures of the site (e.g. materials, rules of engagement, etc.)

Some PST even reflected on the content and its relationship to the grade level the PST is to teach. One preserve teacher reflected on this process in her final reflection:

We also used different teaching websites, the NSTA website, and other links that informed us of the different standards that we were required to use and of the content that went along with Matter. We made our decision by making sure the ideas were at the appropriate learning level for the first graders, and by wanting to make sure we implemented things that they use, see and work with every day so that they have more to connect to.

The PST identified her sources for lessons and content knowledge as well as demonstrating her care in reaching the student level of understanding and experience.

One student reflected on this stating:

Both my partner and I had to teach ourselves the information and get a better understanding before we even could think of asking students about them. It was a learning process and of course some questions that the students asked us we could not answer. This, however, I believe contributed to my learning of different things about simple machines that I could not have learned without them asking.

Another student explained, "This experience forced me to step out of my comfort zone and teach a topic that I was not comfortable with. It also gave me confidence that with hard work I am able to teach anything."

Finally, through the creation of their iMovies, many of the PST received a first glimpse of their own instruction. They were able to see the growth that their students made as a result of their hard work. As a result of this process of creating an 'electronic reflection' some even discovered new standards they addressed during their instruction that they hadn't initially planned for in their lesson. One PST said, "It helped to go back and see what happened in an effort to reflect on ways to improve instruction."

Some of the PST submitted their iMovie projects from this course to *Google and WGBH's STEM Teacher Video Challenge*. This helped to further the PST investment as it creates another level for an authentic audience for their work (Blair, 2012).

CONCLUSION

The teacher education model described in this chapter highlighted its components that provide an enriching experience for PST as they developed and refined their own professional identities and secured their comfort and confidence in teaching STEM education. This confidence could continue to develop as they become elementary teachers and seek opportunities to explore more progressive uses of technology. Their subject matter knowledge and pedagogical knowledge growth was documented through reflective journals and collaborative discussion groups during the course and field-based experience. Their science content knowledge base was supported as they explored their weakness in certain content and in the misconceptions of their students. In both contexts, their attention was focused on learning and teaching science. Like the concepts they learned, the pedagogical practices of inquiry-based methodologies, unit development, technology, the teaching cycle, reflection on practice, and assessment of misconceptions they experience first-hand in the classroom and then refine for students in the afterschool STEM Club. Technology enhanced each of these steps.

The pre-service teachers had several opportunities for growth. They documented and reflected upon the changes in student understanding by examining student work, videos and pictures of the investigations taken with smartphones and iPads. These PST also gained knowledge through the weekly group discussions. They reflected not only on their student learning but also their own development as teachers and their ability to facilitate student learning in the STEM focused interdisciplinary goals. As one PST said, "This was a mutual learning experience for both the student and me. I dealt with situations I will need to deal with in the future and it was good to be comfortable with my students."

It is important for our education students to become familiar with educational technology and iPads so they are knowledgeable about its value as a tool to support improvements in instruction and learning. This model also addressed the need to enhance science instruction in schools and inspired PST to engage their students in the STEM learning process. Both the PST and students were digital natives (Prensky, 2001) who in one way or another have grown up with technology. The goal was to demonstrate to the PST that technology was not a game, but a tool that can enhance and strengthen learning and provide feedback. This will serve them well in their classrooms.

REFERENCES

American Institute of Physics. (1998). *Children's misconceptions about science*. Retrieved February 18, 2015, from http://amasci.com/miscon/opphys.html

Anderson, A. (2002). Reforming science teaching: What research says about inquiry. *Journal of Science Teacher Education*, *13*(1), 1–12. doi:10.1023/A:1015171124982

Bagiati, A., Yoon, S. Y., Evangelou, D., & Ngambeki, I. (2010). Engineering curricula in early education: Describing the landscape of open resources. *Early Childhood Research and Practice, 12*(2). Retrieved January 15, 2015, from http://ecrp.uiuc.edu/v12n2/bagiati.html

Barton, A. C. (2007). Science learning in urban settings. In S. Abell & N. L. Lederman (Eds.), *Handbook of research on science education* (pp. 319–343). Mahwah, NJ: Lawrence Erlbaum Associates.

Black, K. (2004). Science in the trenches: An exploration of four pre-service teachers' first attempts at teaching science in the classroom. *International Journal of Science and Mathematics Education*, *00*, 1–20.

Black, P., & William, D. (2009). Developing the theory of formative assessment. *Educational Assessment, Evaluation and Accountability*, *21*(1), 5–31. doi:10.1007/s11092-008-9068-5

Blair, N. (2012). Technology integration for the new 21st century learner. *Principal*, (Jan/Feb): 8–12.

Borko, H., Peressini, D., Romagnano, L., & Knuth, E. (2000). *Teacher education does matter: A situative view of learning to teach secondary mathematics*. Lawrence Erlbaum.

Britner, S. L., & Finson, K. D. (2005). Preservice teachers' reflections on their growth in an inquiry-oriented science pedagogy course. *Journal of Elementary Science Education*, *17*(1), 39–54. doi:10.1007/BF03174672

Cantrell, P., Young, S., & Moore, A. (2003). Factors affecting science teaching efficacy of preservice elementary teachers. *Journal of Science Teacher Education*, *14*(3), 177–192. doi:10.1023/A:1025974417256

Clift, R., & Brady, P. (2005). Research on methods courses and field experiences. In M. Cochran Smith & K. M. Zeichner (Eds.), *Studying teacher education: The report of the AERA panel on research and teacher education* (pp. 309–424). Washington, DC: Lawrence Erlbaum Associates.

Conderman, G., & Woods, S. (2008). Science instruction: An endangered species: In light of America's recent scientific decline, teaching elementary science should be an imperative. *Kappa Delta Pi Record*, *44*(2), 76–80. doi:10.1080/00228958.2008.10516499

Cook, D. W., & Van Cleaf, D. W. (2000). Multicultural perceptions of 1st-year elementary teachers' urban, suburban, and rural student teaching placements. *Urban Education*, *35*(2), 165–174. doi:10.1177/0042085900352003

Cotabish, A., Dailey, D., Robinson, A., & Hughes, G. (2013). The Effects of a STEM Intervention on Elementary Students' Science Knowledge and Skills. *School Science and Mathematics*, *113*(5), 215–226. doi:10.1111/ssm.12023

Cotabish, L., DeWitt, J., Osborne, J., Dillon, J., Willis, B., & Wong, B. (2012). Balancing acts: Elementary school girls' negotiations of femininity, achievement, and science. *Science Education*, *96*(6), 976–989.

Crawford, B. A. (1999). Is it realistic to expect a preservice teacher to create an inquiry- based classroom? *Journal of Science Teacher Education*, *10*(3), 175–194. doi:10.1023/A:1009422728845

Davis, E. (2006). Preservice elementary teachers' critique of instructional materials for science. *Science Education*, *90*(2), 348–375. doi:10.1002/sce.20110

DeJarnett, N. K. (2012). America's children" Providing early exposure to STEM (science, technology, engineering and math) initiatives. *Education*, *133*(1), 77–84.

Duschl, R. A., Schweingruber, H. A., & Shouse, A. W. S. (Eds.). (2006). *Taking science to school: Learning and teaching science in grades K-8*. Washington, DC: The National Academies Press.

Ellis, J. D. (2001). A dilemma in reforming science teacher education: Responding to students' concerns or striving for high standards. *Journal of Science Teacher Education*, *12*(3), 253–276. doi:10.1023/A:1014208127958

Epstein, D., & Miller, R. (2011). SLOW OFF THE MARK Elementary school teachers and the crisis in STEM education. *Education Digest*, *77*(1), 4–10.

Fathman, A. K., & Crowther, D. T. (Eds.). (2006). *Science for English Language Learners: K-12 Classroom Strategies*. NSTA Press.

Federal Science, Technology, Engineering, and Mathematics (STEM) Education 5 Year Strategic Plan: A Report from the Committee on STEM Education, National Science and Technology Council. (2013, May). Retrieved from http://www.whitehouse.gov/sites/default/files/microsites/ostp/stem_stratplan_2013.pdf

Fry, P. G., & McKiney, L. J. (1997). Qualitative study of preservice teachers' early field experiences in an urban, culturally different school. *Urban Education*, *32*(2), 184–201. doi:10.1177/0042085997032002002

Fulp, S. L. (2002). *2000 National survey of science and mathematics education: Status of elementary school science teaching*. Chapel Hill, NC: Horizon Research.

Hewson, P. W., Tabachnick, B. R., Zeichner, K. M., & Lemberger, J. (1999). Educating prospective teachers of biology: Findings, limitations, and recommendations. *Science Education*, *83*(3), 373–384. doi:10.1002/(SICI)1098-237X(199905)83:3<373::AID-SCE6>3.0.CO;2-3

Kambouri, M. (2011). *Teachers and Children's Misconceptions inScience*. BEI's Education-line collection. Retrieved November 12, 2014 from http://www.leeds.ac.uk/bei/COLN/COLN_default.html

Kim, H. K., VanTasse-Baska, J., Bracken, B. A., Feng, A., Stanbaugh, T., & Bland, L. (2011). Project Clarion: Three years of science instruction in Title I schools among K-third grade students. *Research in Science Education*, *42*(5), 813–829. doi:10.1007/s11165-011-9218-5

Lee, O., Deaktor, R., Hart, J. E., Cuevas, P., & Enders, C. (2005). An instructional intervention's impact on the science and literacy achievement of culturally and linguistically diverse elementary students. *Journal of Research in Science Teaching*, *42*(8), 857–887. doi:10.1002/tea.20071

Maeng, J. L., Mulvey, L. K., & Bell, R. L. (2013). Preservice teachers' TPACK: Using technology to support inquiry instruction. *Journal of Science Education and Technology*, *22*(6), 838–857. doi:10.1007/s10956-013-9434-z

National Research Council. (1996). *National science education standards*. Washington, DC: National Academy Press.

National Research Council (NRC). (2012). *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas.* Washington, DC: The National Academies Press.

National Science Teachers Association. (n.d.). *The NSTA Learning Center*. Retrieved October 20, 2014, http://learningcenter.nsta.org

Newman, W. J. J. Jr, Abell, S. K., Hubbard, P. D., McDonald, J., Otaala, J., & Martini, M. (2004). Dilemmas of teaching inquiry in elementary science methods. *Journal of Science Teacher Education*, *15*(4), 4. doi:10.1023/B:JSTE.0000048330.07586.d6

NGSS Lead States. (2013). *Next Generation Science Standards: For States, By States*. Washington, DC: The National Academies Press.

Perrin, M. (2004). Inquiry-based pre-engineering activities for K-4 students. *Journal of STEM Education: Innovations and Research*, *5*(3/4), 29–34.

Prensky, M. (2001). Digital natives, digital immigrants. *On the Horizon, 9*(5). The President and Fellows of Harvard College. (n.d.). *The Project MOSART (Misconceptions-Oriented Standards Based Assessment Resources for Teachers) Self-Service Website*. National Science Foundation. Retrieved October 12, 2014, from https://www.cfa.harvard.edu/smgphp/mosart/index.html

Puentedura, R. (2009). *As We May Teach: Educational Technology from Theory into Practice*. Retrieved January 20, 2015, from http://www.hippasus.com/rrpweblog/archives/000025.html

Putnam, R., & Borko, H. (2000). What do new views of knowledge and thinking have to say about research on teaching? *Educational Researcher*, *29*(1), 4–15. doi:10.3102/0013189X029001004

Resnick, L. B. (1991). Shared cognition: Thinking as social practice. In L. B. Resnick, J. M. Levine, & S. D. Teasley (Eds.), *Perspectives on socially shared cognition* (pp. 1–20). Washington, DC: American Psychological Association. doi:10.1037/10096-018

Rivet, A. E., & Krajcik, J. S. (2008). Contextualizing instruction: Leveraging student prior knowledge and experience to foster understanding of middle school science. *Journal of Research in Science Teaching*, *45*(1), 79–100. doi:10.1002/tea.20203

Robinson, A., Shore, B. M., & Enersen, D. L. (2007). *Best practices in gifted education: An evidence-based guide*. Waco, TX: Prufrock Press.

Rosebery, A. S., Warren, B., & Conant, F. R. (1992). Appropriating scientific discourse: Findings from language minority classrooms. *Journal of the Learning Sciences*, *21*(1), 61–94. doi:10.1207/s15327809jls0201_2

Rushton, S. P. (2000). Student teacher efficacy in inner-city schools. *The Urban Review*, *32*(4), 365–383. doi:10.1023/A:1026459809392

Saxton, E., Burns, R., Holveck, S., Kelley, S., Prince, D., Rigelman, N., & Skinner, E. A. (2014). A common measurement system for K-12 STEM education: Adopting an educational evaluation methodology that elevates theoretical foundations and systems thinking. *Studies in Educational Evaluation*, *40*, 18–35. doi:10.1016/j.stueduc.2013.11.005

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher*, *15*(2), 4–14. doi:10.3102/0013189X015002004

Smith, P., Banilower, E., McMahon, K., & Weiss, I. (2002). *The national survey of science and mathematics education*. Chapel Hill, NC: Horizon Research.

Smolleck, L., & Hershberger, V. (2011). Playing with Science: An Investigation of Young Children's Science Conceptions and Misconceptions. *Current Issues in Education, 14*(1). Retrieved from http://cie.asu.edu/ojs/index.php/cieatasu/article/view/

Thomas, A., Jalkio, J., Gunderson, B., Schmidtbauer, M., & Johnson, S. (n.d.). *Welcome to the Squishy Circuits Website Page*. Retrieved October 20, 2014, from http://courseweb.stthomas.edu/apthomas/SquishyCircuits

U.S. Department of Education, Institute of Education Sciences, What Works Clearinghouse. (2012, May). *Science intervention report: Technology Enhanced Elementary and Middle School Science (TEEMSS)*. Retrieved from http://whatworks.ed.gov

Wiggins, G., & McTighe, J. (2005). Understanding by Design (2nd ed.). Alexandria, VA: Association for Supervision and Curriculum Development.

Wilson, S., Shulman, L., & Richert, A. (1987). 150 different ways of knowing": Representations of knowledge in teaching. In J. Calderhead (Ed.), *Exploring teacher's thinking* (pp. 104–123). Eastbourne, UK: Cassell.

Windschitl, M. M. (2003). Inquiry Projects in Science Teacher Education: What Can Investigative Experiences Reveal about Teacher Thinking and Eventual Classroom Practice? *Science education*, *87*(1), 112–143. doi:10.1002/sce.10044

World Economic Forum. (2011). *The Global Competitiveness Report 2010-2011*. Retrieved May, 12, 2014 from http://reports.weforum.org/global-competitiveness-2011-2012

Chapter 17

Technology-Assisted Formative Assessment

Karen E. Irving
The Ohio State University, USA

ABSTRACT

Reliable just-in-time assessments are the foundation of informed teaching and learning. Modern electronic technologies assist in the formative assessment process by supporting classroom environments that allow students and teachers to assess learning and providing mechanisms to present information about student learning during instructional sequences. To implement formative assessment practices, students and teachers benefit from rich educational tasks that invite students to share information about their understanding of the lesson while the lesson is occurring in order to nurture productive learning by both teacher and student. Formative feedback is facilitated by technologies such as connected classrooms, videography, online formative quizzes, and manuscript multi-draft editing. Technology-assisted formative assessment represents a powerful option to promote improved classroom communications that support formative assessment practices for teachers in twenty-first century classrooms.

INTRODUCTION

Reliable just-in-time assessments are the foundation of informed teaching and learning. With the focus on high-stakes testing and accountability, teachers are challenged to balance assessment *for* learning with assessment *of* learning (Black, Harrison, Lee, Marshall, & Wiliam, 2003). In recent years, resource allocation and policy attention have been driven primarily by summative assessments intended to measure student learning and used subsequently to rank teachers, schools, and districts. The desire to improve student achievement, especially in science, is driven largely by the performance of US students on international assessments such as the Trends in International Mathematics and Science Study (Martin, Mullis, Foy, & Stanco, 2012).

Some have argued that summative high-stakes tests can be used for program improvement and thus represent an example of formative assessment. For the purposes of this article, formative assessment will be defined as “a planned process in which assessment-elicited evidence of students’ status is used

DOI: 10.4018/978-1-4666-9616-7.ch017

by teachers to adjust their ongoing instructional [practices] or by students to adjust their current learning tactics" (Popham, 2008, p. 6). Formative assessment defined in terms of student and teacher action is classroom based and does not include program adjustments that might result from analysis of high-stakes tests. Four unique elements of formative assessment include (a) task selection and implementation, (b) questioning to probe student understanding, (c) teacher/student awareness of student progress, and (d) follow-up feedback informed by teacher/student knowledge of student learning (Shirley & Irving, 2014).

The first step of the formative assessment process involves the selection of rich instructional tasks (Torrance & Pryor, 1998) that provide opportunities for high levels of student engagement and productive classroom discourse (Bell & Cowie, 2001; Cowie & Bell, 1999 Ruiz-Primo & Furtak, 2006, 2007; Torrance & Pryor, 1998). Collection of data that measures student learning, aggregation of those data, followed by meaning making from the data lead to knowledge about the state of student understanding during an instructional sequence. Change in teaching and/or learning strategies for either individual students or for the whole class completes the formative assessment cycle (Black & Wiliam, 1998; Cowie & Bell, 1999; Wiliam, 2006). When the teacher commands a sufficient toolbox of instructional strategies to act on this knowledge, or the student acknowledges the need for a change in learning strategy and acts to improve his/her learning success, the subsequent adjustment in strategies completes one iteration of the formative assessment cycle.

This chapter explores technology-assisted formative assessment – the use of electronic resources to support the implementation of formative assessment practices in science classrooms. Two primary aspects of the formative assessment cycle lend themselves particularly well to assistance from modern electronic technologies – (1) task selection and implementation, and (2) formative feedback processes. After a description of formative assessment, the article highlights how electronic technologies support the design and implementation of rich tasks in science classrooms using simulations and online data sets as key examples. Next, the article describes the role of electronic technologies in nurturing communication patterns unique to twenty-first century electronic classrooms. In particular, the role of feedback as a tool in the formative assessment process is examined through video analysis, connected classrooms, editorial feedback on written work, and the use of classroom management systems to provide students feedback before summative assessments. The chapter concludes with recommendations for technology-assisted formative assessment practices and suggestions for future research directions.

BACKGROUND

Formative Assessment

In the traditional *transmission* paradigm of learning, the teacher tells and the students listen. Little opportunity exists in this paradigm for information flow from student to teacher regarding student learning. Teacher-centered activities such as lecturing maximize the presentation of material and have proven efficient in covering large amounts of content, but provide little opportunity for teachers to learn about student thinking or for students to explore their understanding or develop self-regulated learning behaviors (Black, Harrison, Lee, Marshall, & Wiliam, 2003). In the *constructivist* paradigm of learning, students actively engage in the learning process and build understanding based on their prior knowledge. By selecting an instructional task that requires students to analyze, to discuss, to write, to synthesize, and to question, teachers create opportunities for both themselves and for their students to learn about student thinking and to gather useful data to inform their teaching and learning decisions. The use of rich instructional tasks that enhance opportunities to learn optimizes the environment for formative assessment practices.

Classroom teachers are challenged to implement formative assessment for a number of reasons. Designing lessons that provide opportunities for collecting data on student learning during a relatively short instructional period can be difficult. Logistically, collecting, aggregating, and analyzing reliable data on student learning on-the-fly during an instructional sequence proves a highly complex and demanding task. Both lack of pedagogical skill and the time pressures of the school structure contribute to findings that formative assessment represents a weak aspect of many teacher's practice (Daws & Singh, 1996).

The design and implementation of rich tasks in the classroom represents a primary challenge for teachers. Both the cognitive elements as well as the social elements of the classroom play a role in how teachers design and implement lessons. The cognitive aspect of learning is best summed up by the premises articulated by Gerace, (1992): (a) first, students construct knowledge for themselves; (b) next, learners must actively and purposively engage in the learning process; (c) the knowledge students bring with them to the learning context impacts the learning process; and (d) initial evidence of learning in one context may not transfer to a new and different context. Learning involves a complex process of reorganization and growth in a student's conceptual ecology. Hence, the nature and context in which learning occurs plays a key role in the learning process. When teachers plan lessons to maximize opportunities to engage in formative assessment in classroom contexts, they must attend to how students choose to interact with the instructional activity (Beatty & Gerace, 2009).

The social aspect is equally central in the learning and teaching process. In order to create classroom contexts that support conceptual change, teachers are tasked with creating a classroom environment that supports discourse. Mastering school language or academic language to be able to 'talk science' represents a complicated undertaking (Lemke, 1990). According to Zwiers (2014), learning is about students developing fluency in both the social and technical language of science, the language used to describe the natural and physical worlds. Research in bilingualism reveals a clear difference between the social language used in every day communications, *basic interpersonal communicative skills (BICS)*, and the *cognitive academic language* of the classroom (Cummins, 1979). As Zwiers points out, academic "language serves as an evolving set of tools and skills used to construct and communicate ideas" (2014, p. 24). In science, academic language is used to describe complex concepts, relationships, and processes. Higher-order thinking skills require mastery of the language of the discipline to solve problems and express ideas. Students are asked to analyze, seek information, compare and contrast, inform, explain, predict, classify, justify, hypothesize, solve problems, synthesize, persuade, interpret, evaluate, and summarize (Zwiers, 2014). A rich task in a science lesson plan provides opportunities for students to engage with and to talk science. These discourse events present both students and teachers with information about how the lesson is progressing and opens a window to student thinking during the instructional sequence.

Popham (2008) describes four levels of formative assessment that focus on classroom behaviors, climate, and building/district wide practice (see Table 1). In this discussion, we will focus primarily on in-class formative assessment with teacher and students as participants. The distinction between lesson design and formative assessment is important. Carefully designed and implemented instructional sequences may be effective in the absence of formative assessment. However, significant research

Table 1. Four levels of formative assessment (adapted from Popham, 2008)

Teacher actions	Teachers make evidence-based decisions about whether and/or how to adjust immediate or upcoming instruction to improve effectiveness.
Student actions	Students use evidence-based reasoning to evaluate their learning tactics and whether/how to adjust them to improve learning outcomes
Shift in classroom climate	The consistent use of evidence-based reasoning to adjust instruction to meet the needs of students produces a learning-dominant classroom environment.
School wide implementation	Professional development and professional learning communities spread the use of formative assessment beyond the classroom to schools and districts.

indicates that when formative assessment is practiced in classroom situations student learning gains often follow. In a seminal meta-analysis, Black and Wiliam (1998) reported effect sizes from 0.4 to 0.7 based on their analysis of 43 research studies that demonstrated both evidence of student learning and formative assessment practices.

Electronic technologies have greatly enlarged the choices for rich task design and implementation in science classrooms. Thoughtful selection of rich tasks for classroom implementation and coordinated orchestration through lesson planning can create multiple opportunities through verbal discourse and artifact production for teachers and students to assess learning progress. Teacher and student formative assessment actions are further elaborated in Table 2. This iterative process, when played out in the classroom produces an environment that supports student engagement and student learning. In the following section, the characteristics of rich tasks are explored. In addition, two key examples of how rich tasks expand the opportunities for formative assessment practice in science classrooms are presented, the use of electronic simulations, and the inclusion of authentic data sets from online resources.

TECHNOLOGY ASSISTED RICH TASKS

What makes an instructional task rich? Research in the mathematics education community has pointed to some characteristics of mathematically rich tasks designed for classroom use. Stein and Lane (1996) report student performance gains on an assessment that required high level mathematical thinking and reasoning when instructional tasks were selected that engaged students in doing mathematics or immersed students in meaningful procedures. In their framework for instructional task features, the authors identify three key rich task elements: (a) a task that has multiple solution pathways and/or strategies, (b)

Table 2. Formative assessment: Teacher and student steps (adapted from Popham, 2008, p. 53 & 82)

	Teacher	Student
Step 1	Decides when during the lesson adjustments can be made	Recognizes when evidence will be available to inform about progress
Step 2	Selects and administers assessments	Understands formative nature of assessment; participates actively
Step 3	Determines in advance what level of performance will trigger instructional adjustment	Compares personal success to expected performance and to performance of peers
Step 4	Teacher makes instructional adjustments	Students consider teacher adjustments and adjust their learning tactics

a task that includes multiple representations, and (c) a task that requires student explanations. A rich task invites students to explore several points of entry and offers multiple potential solution strategies. When considering if the task is rich in the classroom setting, both the features of the task and the enactment of the task are important characteristics. A task with potentially multiple solutions that elicits a single solution from all students would not be considered as 'rich' as a task that actually produced multiple student solutions.

The University of Queensland, as part of a curriculum initiative, provides another take on rich task description with a slightly different set of descriptors. Macdonald, Hunter, and Tinning (2007) describe rich tasks as (a) having demonstrable and substantive intellectual and educational value; (b) bridging multiple disciplinary boundaries; (c) focusing on problems connected to the real-world; (d) valid for educators, parents, and community members; and (e) representing sufficient developmental, cognitive, and intellectual depth and breadth to be implemented across a significant span of grade bands. A consistent feature of a rich instructional task is the high level of student engagement and the opportunity for classroom discourse.

Unlike traditional lecture based teaching methods, rich tasks provide opportunities for teachers and students to engage in formative assessment practices. Students are challenged with a task that during enactment expects them to engage in discourse with each other and/or the teacher or to provide artifacts demonstrating their learning progress. These conversations and artifacts provide vital windows into what students are thinking and present teachers with evidence to guide decisions about how to continue the lesson. In addition, students also receive feedback to make judgments about their learning progress in time to make changes to their learning tactics while the instructional session is still ongoing.

The characteristics of the task selected by the teacher determine the width of the opportunity for students and teachers to assess their learning. A rich task is distinguished by multiple opportunities for students to self-assess and teachers to gather reliable data through verbal interactions and artifact production (written text, outcomes of discovery learning events, data tables and data displays) about student progress during the instructional sequence. Some tasks offer few opportunities to assess until the task is completed, offering little indication of progress during the instruction. Only at the conclusion of the task does the student receive helpful feedback. In contrast, rich tasks provide multiple points throughout the task implementation for students and teacher to assess progress and either get help or offer help. A teacher should be able to recognize, design, and implement a rich task with an assessment profile that promotes formative assessment opportunities.

Electronic technology has greatly expanded the options for classroom instructors to design and implement rich tasks in their instructional plans. In the following sections, two examples of how technology has given rise to possibilities for rich task design that were not available 20 years ago are discussed including the use of electronic simulations and the role of online data sets as tools for inquiry based classroom instruction. Although not considered in this chapter, many other technologies such as virtual laboratory experiments, digital images and video of science topics, multiple author editable web pages such as wiki-type documents, Twitter, and other social media options also afford the potential for teachers to create rich tasks designed to promote formative assessment practice.

Rich Tasks with 21st Century Technologies: Simulations

Electronic technologies have greatly expanded the options for classroom instructors to implement rich inquiry lessons. Electronic animations and models such as the PhET simulations (http://phet.colorado.edu), the simulations produced the Concord Consortium at the Molecular Workbench site (http://mw.concord.org), or purchased online simulations such as ExploreLearning (www.explorelearning.com) provide classroom teachers opportunities to engage in formative assessment practices. Electronic planetarium programs such as Starry Night (http://astronomy.starrynight.com/) or open source sites such as Stellarium (http://www.stellarium.org/) offer 21st century teachers innovative electronic resources to teach astronomy topics and to foster in-class inquiry and discourse. The efficacy of these electronic resources in science teaching and learning has been demonstrated by many researchers (e.g., Bell & Smentana, 2008; Rutten, van Joolingen, & van der Veen, 2012; Wieman, Adams, & Perkins, 2008; Smentana & Bell, 2012). Carefully constructed lesson plans that provide engaging tasks and intermediate check points using simulation technology as the platform afford multiple opportunities for formative data gathering during lesson implementation.

Using a data set of over 275 student interviews and think-alouds, researchers at the University of Colorado studied how students interact with computer simulations and identified some features of effective simulations (Adams et al., 2008). Their research report highlights how these simulations function to provide formative assessment in the form of immediate feedback for students. Adams et al. examined both demonstration settings with students watching another person manipulate the simulation and situations where the students were able to interact with the simulations themselves. The importance of students asking their own questions was highlighted as key in educationally productive interactions. Animations and interactivity engaged students and promoted questions, especially when students were participating rather than just watching. Incorporation of small puzzles or clues stimulated student exploration. More than one representation for the same concept contributed to rich simulation design by providing multiple views and prompted students to make connections between different depictions of the same scientific idea. Students were more likely to engage with entertaining Flash and Java simulations than with simulations that looked intimidating or tedious. However, Adams et al. asserted that too much fun seemed to distract from learning. Students engaged in exploration more readily if they found the simulations to be credible. Although non-science majors were particularly trusting of simulations, the higher the educational level of the student, the greater the level of skepticism. If a student perceived that they were already well-informed about a topic, they were less motivated to explore and learn to use a simulation. The researchers found that students in their study generally benefited from inclusion of visual models in the simulations.

The theoretical basis of the findings made by Adams et al. (2008) regarding the benefits of simulations rests on the benefit of *engaged exploration*, a form of active learning. Students received immediate feedback based on questions that they developed and could without delay receive answers by observing the results of their own trials with the simulations. The interactive engaged exploration meets the criteria for a formative assessment with an immediate response targeted at particular questions posed by the student. Engaged exploration, a variation on active learning, is supported by work done by Minstrell and Kraus (2005), Bonwell and Eison (1991) and others. Likewise, Prince (2004) reviewed the benefits of active learning and found broad support.

Rich Tasks with 21st Century Technologies: Online Data Sets

Engaging learners in scientifically oriented questions through data gathering, analysis, and formulation of explanations is greatly enhanced by the online availability of archived data sets from primary sources (Haury, 2001). The use of electronic data sets extends inquiry beyond the classroom and engages students with authentic science. Both access to bona fide data sets and collaborations with scientists and other school groups broaden the opportunities for students to learn through rich tasks. The wide access to spreadsheets and graphing technologies opens the window for graphical displays of data to reveal patterns and relationships. While the number of online data sets is far too numerous to name in this chapter, some examples are presented below.

Utilizing online cloud storage options, scientists can store data sets from research activities for interaction with teachers, students, and colleagues. Government sponsored web sites such as the United State Geological Survey (USGS) site on earthquakes [http://earthquake.usgs.gov/earthquakes/?source=sitenav] combine data analysis and online mapping technology to create maps showing worldwide earthquake activity. Other government agencies such as the National Oceanographic and Atmospheric Administration also provide web sites that target students and teachers and promote rich tasks for engaging classroom inquiry based lessons [http://tidesandcurrents.noaa.gov/]. These interactive web sites allow students to generate testable questions for in-class inquiry activities and provide rich opportunities for classroom discourse. Through close attention to student talk as well as student artifacts, teachers and students can identify progress in developing scientifically rich understandings, a key step in the formative assessment process. These data sets and lessons designed for classroom use provide constructive opportunities for students to engage in cutting edge scientific inquiry (Komoroske, Hameed, Szoboszlai, Newson, & Williams, 2015).

The QuarkNet program (https://quarknet.i2u2.org/), a collaboration between the US Department of Energy and the National Science Foundation, provides teacher professional development and lessons for their students to calculate the Z boson mass using data collected from CERN's Large Hadron Collider (LHC). High school physics students explore fundamental particle physics using live online data as they engage in inquiry investigations. An online data portal gives students access to analysis tools and provides an editable log book that can be viewed by their teachers for feedback. Students are introduced to data from CERN's Compact Muon Solenoid (CMS), the Hanford WA Laser Interferometer Gravitational-Wave Observatory (LIGO) experiment and cosmic ray muon detectors located in classrooms around the world (Nucci, Doherty, Lung, & Singhota, 2011).

A similar example from the geosciences domain introduces students in environmental science classes to the use of marine sediment data to study past climate change. Students are provided data sets taken from ice core samples collected on scientific expeditions to Antarctica by scientists in organizations such as the Integrated Ocean Drilling Program (IODP), the Antarctic Geological Drilling Program (ANDRILL), and others. These online data sets are accompanied by suggestions for carefully structured rich classroom tasks to engage students and provide opportunity for students and teachers to formatively assess their progress throughout the lesson (St. John, Leckie, Jones, Pound, & Krissek, 2012). Many other examples of online data sets, simulations, and virtual field trips provide opportunities for teachers to structure rich tasks that promote fertile classroom environments for formative assessment practice to flourish.

TECHNOLOGY ASSISTED FORMATIVE FEEDBACK

Feedback in classroom teaching and learning plays an important role in formative assessment practices (e. g. Bangert-Drowns, Kulik, Kulik, & Morgan, 1991; Kluger & DeNisi, 1996; Kulhavy & Wager, 1993). In order to know if mid-stream correction is needed, students and teachers must assess their learning progress and accept re-direction to improve the learning process. While feedback is seen as one of the most powerful influences on learning, research on the topic demonstrates both positive and negative impacts (e. g. Hattie & Timperley, 2007; Shute, 2008). Formative feedback is defined by Shute as "information communicated to the learner that is intended to modify his or her thinking or behavior for the purpose of improving learning" (p. 154). While both teacher and student may receive formative feedback, their response to the feedback differs. Teachers may modify their instructional strategies in response to knowledge about how the lesson is going. Research has demonstrated that teachers who are more reliably informed about student thinking and understanding can use that information to foster student learning and engagement (Abrahamson, 2006; Irving, Sanalan, & Shirley, 2009; Roschelle, Penuel, & Abrahamson, 2004). With reliable information about classroom progress, students may be more motivated to engage in the lesson, to ask questions, and to gain a better perspective on their progress relative to their classmates in a classroom environment that aids students with visual representations of individual and group progress (Lee & Irving, 2015).

New technologies enter the marketplace with breathtaking speed. Keeping up with the latest and greatest technology innovations can seem like a full time occupation for instructors and students. In this unstable and constantly evolving world of technology advances, new gadgets present formative assessments opportunities that offer both convenience for students as well as temporal advantages for feedback available when it is needed to make on-the-spot changes in learning strategies (Irons, 2007). While technology can assist in availability and rapid response turn-around times, the decision making about how to proceed in the learning process remains a choice that must be acted on by teachers and students. The technology does not know what to do next. However, more reliable and timely information can inform behaviors and actions.

Brown, Race and Bull (1999) identified three benefits for the use of electronic technologies for formative assessment: (a) potential for reduced workload for instructors by automating feedback processes, (b) more efficient and timely feedback for students, and (c) interacting with students using the technology medium with which they are most familiar. Other potential benefits include the opportunities to reach a more diverse population of students, providing more flexibility for students to interact with their instructors, in some cases providing automated immediate feedback, as well as providing a greater variety of feedback opportunities through online discussion groups (Irons, 2007).

Modern electronic technologies can assist in the feedback process in a variety of ways. Some examples include automatic and immediate electronic feedback, participation in formative assessment dialogue with peers, and electronic instructional quizzes designed to provide students with information about their progress. While many other technology-assisted feedback options are possible, this chapter will discuss four examples: video formative feedback; connected classroom feedback with audience response system technologies; use of word processing and track changes to provide corrective feedback on written work, and computer aided automatic feedback systems.

Video Formative Feedback

Video feedback has been used in a wide variety of disciplines that require human interactions and has been defined by some as the gold standard of communication (Kurtz, Marshall, & Banspach, 1985). Not long after the video recorder was invented in 1951, educational applications of video feedback began. Allen at Stanford first described microteaching with video recording of student mini teaching episodes as a form of feedback mechanism in 1966. Initially, Allen's use of video included a micro teaching experience for a teacher candidate with a small audience and a short performance time. The video tape was then reviewed once (or more) with ensuing discussion of observed behaviors.

Video feedback allows people to see themselves as others see them, from a distance, and with time for reflection. Repetition of viewing allows for more in depth and detailed analysis of ephemeral real world events. Micro behaviors are observable such as hand gestures, head-nodding, body stance, eye gaze and gaze direction. Interpersonal skills such as warmth, kindness, or sensitivity can be inferred from video viewing and quantified using a variety of qualitative measures. Verbal aspects of a presentation can be evaluated such as the content, intonation, prosody, pace, and voice volume. Analysis of the spoken words can provide insights into questioning strategies, preferential treatment of particular students, and the clarity of expression particularly for difficult to understand content (Kurtz, Marshall, & Banspach, 1985).

Unstructured video replay dominated early efforts to use video to inform practice (Dowrick, 1983). More recently, the role of positive self-imaging has dictated a focus on successful interactions with an eye toward reinforcement of desired target behaviors. With Bandura's social learning theory as a theoretical frame, positive empowerment is seen as pedagogically preferable for video feedback uses (Fukkink, Trienekens, & Kramer, 2011). Feedback that results in an erosion of personal sense of worth has been demonstrated to be less effective (Hattie &Timperley, 2007; Kluger & DeNisi, 1996). In addition, feedback must build on a foundation of knowledge. The process begins with a student response to initial instruction and continues with feedback related to that instructional goal. If a student has no foundation for the feedback (total lack of knowledge in the field), then the feedback may be received as threatening and has been shown to have little impact on learning (Hattie & Timperley, 2007; Kluger & DeNisi, 1996).

Some variations on how video is used as a feedback tool relate to specific technical possibilities such as slow motion, replay, use of freeze-framing, picture-only viewing, or sound-only viewing. More recently, split screen techniques show both teacher and students at the same time so the viewer can infer the effect of a particular teacher behavior on the students in the classroom (Fukkink et al., 2011). Annotation of video by one or more individuals offers a more recent variation that allows a professional learning community to share their impressions of a classroom episode (http://www.edthena.com/). With cloud storage behind protective firewalls, video of classroom teaching can be annotated by coaches near and far as well as by selected peer groups. Summary feedback and suggestions can be provided just-in-time for teachers and teacher candidates. Creating video clips of teaching episodes and reflecting on classroom performance is part of the Teacher Performance Assessment developed by Stanford University in partnership with the American Association of Colleges for Teacher Education (AACTE) and currently utilized as a measure of student teaching performance in 35 US states and the District of Columbia (http://edtpa.aacte.org/).

Research on the effective characteristics of video formative feedback reveal that interventions clearly focused on a target and related to the instructional goals of the lesson are more effective than those without (Fukkink et al., 2011). A structured observation form provided to participants offers sufficient scaffolding to focus their attention on the targeted elements of the lesson. Participants are able to zoom in to the part of the instruction that the training program has targeted. No relationship was found between a participant's developmental level and the results of video feedback training. Both novice and more expert participants benefited from video feedback regardless of how far along they were in their development of target skills. Short video feedback enjoys wide acceptance by the technologically sophisticated students of the 21st century classroom. The concept of using feedback to 'feed-forward' emphasizes the role of feedback in promoting improved future performance (Crook et al., 2012).

Overall, research clearly demonstrates that video formative feedback is associated with positive outcomes in educational settings.

Feedback in Connected Classrooms

Technologies that serve to connect teachers and students in the classroom have emerged as a powerful genre of instructional tools to facilitate classroom communications and to enhance formative assessment (Pape et al., 2013). Connected classrooms are equipped with wireless communication technology (CCT) that connects a teacher's computer and students' handheld device (clickers, cell phones, tablets, graphing calculators or other portable computational devices) to facilitate teacher-student communication and student engagement with content.

Hegedus and Moreno-Armella (2009) coined the term representational expressivity to describe the emergence of a wider classroom discourse space enabled by the use of classroom connectivity technologies. These emerging technologies support: (a) the ability to project multiple representations related to science topics, and (b) the accurate and just-in-time collection and aggregation of data contributed by students. By enabling public display of scientific representations and inviting student participation and discourse, the technology encourages examination of one's scientific ideas as well as comparisons to others. This exchange provides timely and accurate formative feedback for both students and teachers during instruction. The anonymous nature of student participation in connected classrooms has been suggested to "broaden the 'bandwidth' of classroom collaboration" (White, 2006, p. 359) by providing social camouflage. The standard Initiation-Response-Evaluation (IRE) triadic dialogue of the classroom is disrupted and replaced by a "one-question-to-all" strategy with expectations of multiple student responses (Pape et al., 2010). Studies of student attitudes toward CCT technology reveals that students welcome what they perceive as a safe learning environment (Herman, Meagher, Abrahamson, & Owens, 2013).

Implementation of effective formative assessment practice makes multiple demands on a classroom teacher. The teacher must determine student need, gather and interpret data in a timely way, and provide feedback to students in a palatable format that students will take-up in the classroom (Shute, 2008). The use of classroom communication technology offers improved speed and accuracy of information flow between teachers and students and provides opportunity for improved formative feedback (Pape et al., 2011). With improved real time communication, students and teachers benefit from greater shared understandings during instructional sequences. The ability of teachers to adjust instruction during the lesson sequence based on accurate information about student learning embodies the heart of formative assessment practice (Wiliam & Thompson, 2008). Evidence of the effectiveness of audience response system technologies in improving student achievement is provided by the results of a large random control trial of student achievement in Algebra 1 classrooms. Significant improvement in student learning after one year with a medium effect size of 0.30 (Pape et al., 2013) and a continued pattern of similar improvement in student achievements over three years is attributed to improved opportunities to learn through formative assessment and enhanced patterns of discourse in classrooms with connected classroom technology (Pape et al., 2013; Irving, Pape, Owens, Abrahamson, Silver & Sanalan, 2010).

Instructors who engage primarily in lecture based instruction have successfully infused audience response system (ARS) technologies to provide formative feedback opportunities in a traditionally didactic instructional mode (see Caldwell, 2007; MacArthur & Jones, 2008; Laxman, 2011; Beatty & Gerace, 2009; Kay & LeSage, 2009). Studies have demonstrated mostly positive student attitudes and either positive or benign effects on student performance on exams as a result of ARS use in college instruction. Caldwell offers a set of best practice tips for introducing clicker systems in university instruction including daily use, careful advance planning, clear explanation to students about how the experience will factor into their course evaluations, and practice in writing effective questions. Other researchers, including Hake (2002) and Simpson and Oliver (2006) reiterate the theme of careful attention to the specific questions selected for lecture based use of audience responses systems to optimize conditions for successful formative feedback.

The importance of distinguishing between the pedagogy of a connected classroom and the technology implementation has been carefully studied and explicated by Beatty and Gerace (2009). The theoretical basis of their work rests in a blending of theory from the cognitive dimension of learning, conceptual change, constructivist theory, and sociocultural views of the classroom. The pedagogy they present includes four key criteria for what they coin *Technology-Enhanced Formative Assessment (TEFA)*: (a) teachers need specific actions and practices that are doable in real classroom circumstances; (b) the pedagogy should be theoretically based in what we know about how people learn; (c) *TEFA* should be consistent with the research base on what we know about learning, teaching, and effective classrooms; and (d) *TEFA* should be doable by real people in real classrooms and result in real student learning (2009).

Computer Assisted Formative Feedback on Writing

Both written and spoken forms of discourse provide fruitful territory for formative assessment practices. Corrective feedback related to student generated text aims to develop student writing skills while providing feedback in the form of error identification, the correct written form, or metalinguistic information about particular errors. Providing feedback through revisions rather than at the summative evaluation stage promotes a multi-draft improvement process. Research on the use of computer-mediated corrective feedback during the writing process demonstrates that students perform significantly better on the post-writing task when they received feedback on early drafts during the writing process. The most successful treatment combined both word processor mediated feedback and track changes feedback and resulted in improved writing skills that were retained in a delayed post-assessment (AbuSeileek, 2013).

The identity of the feedback provider may affect both the quality of the information as well as the level of student uptake. Students may value instructor feedback over peer feedback. While research has established that peer assessment promotes student learning (e.g. Venables & Summit, 2003), the quality of the feedback that students provide may be inconsistent and could actually be detrimental to the quality of their final written product. Li, Liu and Steckelberg show that the quality of peer feedback correlates positively with student learning gains (2010). However, the ability of students to critically assess the quality of the feedback they receive is also reflected in their ability to produce higher quality written products (Li, Liu, & Zhou, 2012). The implication of these findings is that student ability to judiciously use available feedback may affect their success in the revision process.

Trautmann (2009) also examined peer review of writing and found it associated with higher rates of manuscript revision, and presumed higher quality of the final document. Study of the impact of writing and web-mediated peer review on the quality of research reports written by undergraduate science students showed that students who received peer-mediated comments made more revisions of their initial drafts than those who did not participate. *Receiving feedback* prompted more revision than *giving feedback*, but student responses to a post-questionnaire item indicated that both giving and receiving feedback were highly valued by the study participants (Trautmann, 2009).

Study Modules and Practice Quizzes as Online Formative Feedback

Online feedback assessments have been shown to be effective as formative feedback tools. With the widespread use of classroom management systems in secondary schools as well as institutions of higher education, instructors have the option of providing online quizzes or study modules to encourage students to engage with the content before the test. Several models of online assessments were evaluated in a study by Marden, Ulman, Wilson, and Velan (2013). The study participants included large cohorts of undergraduate students taking introductory physiology. Of the four variations tested, one model (unsupervised, open book, unlimited attempts allowed, and untimed) showed significant improvement in mean summative end-of-session examinations. In another study, the frequency of self-assessment prior to examinations was found to significantly correlate with examination scores, regardless of the success experienced by students on the self-quizzes. More than 85% of potential students availed themselves of this opportunity and a significant positive relationship was reported for the number of quiz attempts and examination success (Panus, Stewart, Hagemeier, Thigpen, & Brooks, 2014). Despite some findings reported in the literature indicating little correlation between formative assessment opportunities and student achievement (e. g. Peat & Franklin, 2003; Urtel, Bahamonde, Mikesky, Udry, & Vessely, 2006), many others show strong association with significantly better performance on summative examinations (e.g., Buchanan, 2000; Dobson, 2008; Kibble, 2007, 2011).

RECOMMENDATIONS

Timely and reliable data about student learning represents a critical element in effective teaching. With increased attention on student achievement, formative assessment represents a potentially powerful strategy to improve learning outcomes. Formative assessment occurs during instruction when teachers and students become aware of their successes and challenges in the learning tasks set before them and then choose to change their strategies to improve their learning success. Teachers find the logistical challenges inherent in this on-the-fly performance highly complex and difficult. Modern 21st technology can ease the challenges to formative assessment practice in two primary ways: (a) supporting the design of rich classroom tasks that enhance the opportunity for information flow about learning successes to be displayed for teachers and students to ponder; and (b) easing the logistical challenges of collecting just-in-time data, aggregating, displaying, and making meaning of those data during instructional sequences or with a frequency that allows students to improve their learning outcomes. The power of computing makes rich tasks available to engage students and to expose them to multiple representations and animations of complex scientific and engineering concepts, to encourage them to collaborate with scientists and peers around the world to analyze archived real data sets to see what science is all about, and to create artifacts as part of their learning that reveal their progress in learning. Analysis of video-taped sequences of teaching performance enhanced by a learning community's annotations offers unique opportunities for novice teachers to critique their classroom teaching in a safe and informative way. Feedback from peers or experts on written work in the form of track changes and embedded comments provides students with information about how to improve their writing before the final draft is completed. In lecture halls, students can engage in question response sequences using audience response system technology in which every student in the room responds to every question and the learning community instantly sees the diversity of thought around the ideas for the day. Online formative feedback in the form of quiz questions posted on classroom management systems with unlimited re-try options offer inducements to students to find out their performance levels before the test when time is still available to remedy deficiencies. Technology-assisted formative assessment represents a powerful option to promote improved classroom communications that support formative assessment practices for teachers in twenty-first century classrooms.

FUTURE RESEARCH DIRECTIONS

Innovation in modern technology continues unabated. Computing devices are smaller, more user friendly, connected to Wi-Fi networks, and touch sensitive. Science educators continue to develop rich tasks using new technologies to challenge themselves and their students. The design of these lessons should explicitly target formative assessments and provide data collection sites mid-lesson. The development of learning progressions in many scientific domains as well as the wealth of information regarding student naïve conceptions provide the background knowledge needed to insert formative assessment probes in every lesson plan with the intent to provide students and teachers reliable and timely information about the learning progress and challenges during lesson implementation. Strategies to move forward with the instruction could take the path of alternative ending lesson plans with different choices presented to accommodate anticipated student challenges in a lesson sequence. Work is needed to develop appropriate formative assessment questions that diagnose student learning at different stages of the learning progressions that describe the major theories and concepts of mathematics and science. As students and teachers learn to use these tools in classroom settings and through distance education venues, the possibilities for enhanced formative feedback will grow. Researchers should investigate the many models possible for engaging students with conceptually difficult materials and with feedback systems. Further study in the mechanisms of peer feedback are needed to optimize this powerful tool to improve the quality of student written work. If the past is an indication of the future, electronic technologies will continue to evolve to provide formative assessment opportunities to enhance teaching and learning in 21st classrooms.

REFERENCES

Abrahamson, L. (2006). A brief history of networked classrooms: Effects, cases, pedagogy, and implications. In D. A. Banks (Ed.), *Audience response systems in higher education: Applications and cases* (pp. 1–25). Hershey, PA: Information Science Publishing. doi:10.4018/978-1-59140-947-2.ch001

AbuSeileek, A. F. (2013). Using track changes and word processor to provide corrective feedback to learners in writing. *Journal of Computer Assisted Learning*, *29*(4), 319–333. doi:10.1111/jcal.12004

Adams, W., Reid, S., Lemaster, R., McKagan, S., Perkins, K., Dubson, M., & Wieman, C. (2008). A study of educational simulations: Part I – engagement and learning. *Journal of Interactive Learning Research*, *19*(3), 997–419.

Allen, D. W. (1966). A new design for teacher education: The teacher intern program at Stanford University. *Journal of Teacher Education*, *17*(3), 296–300. doi:10.1177/002248716601700304

Bangert-Drowns, R. L., Kulik, C. C., Kulik, J. A., & Morgan, M. T. (1991). The instructional effect of feedback in test-like events. *Review of Educational Research*, *61*(2), 213–238. doi:10.3102/00346543061002213

Beatty, I. D., & Gerace, W. J. (2009). Technology-enhanced formative assessment: A research-based pedagogy for teaching science with classroom response technology. *Journal of Science Education and Technology*, *18*(2), 146–162. doi:10.1007/s10956-008-9140-4

Bell, B., & Cowie, B. (2001). The characteristics of formative assessment in science education. *Science Education*, *85*(5), 536–553. doi:10.1002/sce.1022

Bell, R. L., & Smentana, L. K. (Eds.). (2008). *Using computer simulations to enhance science teaching and learning in technology in the secondary science classroom*. Washington, DC: NSTA Press.

Black, P., Harrison, C., Lee, C., Marshall, B., & Wiliam, D. (2003). *Assessment for learning*. Berkshire, England: Open University Press.

Black, P., & Wiliam, D. (1998). Inside the black box: Raising standards through classroom assessment. *Phi Delta Kappan*, *80*(2), 139–148.

Bonwell, C. C., & Eison, J. A. (1991) *Active learning: Creating excitement in the classroom*. Association for the Study of Higher Education (ASHE) ERIC Higher Education Report No. 1. Washington, DC: George Washington University.

Brown, S., Race, P., & Bull, J. (1999). Computer-assisted assessment in higher education. Birmingham, UK: Staff and Educational Development Association (SEDA).

Buchanan, T. (2000). The efficacy of a world-wide web mediated formative assessment. *Journal of Computer Assisted Learning*, *16*(3), 193–200. doi:10.1046/j.1365-2729.2000.00132.x

Caldwell, J. E. (2007). Clickers in the large classroom: Current research and best-practice tips. *CBE Life Sciences Education*, *6*(1), 9–20. doi:10.1187/cbe.06-12-0205 PMID:17339389

Cowie, B., & Bell, B. (1999). A model of formative assessment in science education. *Assessment in Education: Principles, Policy & Practice*, *6*(1), 101–116. doi:10.1080/09695949993026

Crook, A., Mauchline, A., Maw, S., Lawson, C., Drinkwater, R., Lundqvist, K., & Park, J. et al. (2012). The use of video technology for providing feedback to students: Can it enhance the feedback experience for staff and students? *Computers & Education*, *58*(1), 386–396. doi:10.1016/j.compedu.2011.08.025

Cummins, J. (1979). Cognitive/academic language proficiency, linguistic interdependence, the optimum age question, and some other matters. *Working Papers on Bilingualism*, *19*(1), 121–129.

Daws, N., & Singh, B. (1996). Formative assessment: To what extent is its potential to enhance pupils' science being realized? *The School Science Review*, *77*(281), 93–100.

Dobson, J. (2008). The use of formative online quizzes to enhance class preparation and scores on summative exams. *Advances in Physiology Education*, *32*(4), 297–302. doi:10.1152/advan.90162.2008 PMID:19047506

Dowrick, P. (1983). Self-modeling. In P. Dowrick & S. Biggs (Eds.), *Using video: Psychological and social applications* (pp. 105–124). New York: Wiley.

Fukkink, R. G., Trienckens, N., & Kramer, L. J. C. (2011). Video feedback in education and training: Putting learning in the picture. *Educational Psychology Review*, *23*(1), 45–63. doi:10.1007/s10648-010-9144-5

Gerace, W. J. (1992). Contributions from cognitive research to mathematics and science education. In D. Grayson (Ed.) *Proceedings of the Workshop on Research in Science and Mathematics Education*, (pp. 25-44). Pietermaritzburg, South Africa: Teeanem Printers (Pty) Ltd.

Hake, R. (2002). Lessons from the physics education reform effort. *Conservation Ecology, 5*(2), 28. Retrieved from http://www.consecol.org/vol5/iss2/art28/

Hattie, J., & Timperley, H. (2007). The power of feedback. *Review of Educational Research*, *77*(1), 81–112. doi:10.3102/003465430298487

Haury, D. (2001). *Teaching science through inquiry with archived data* (Report No. EDO-SE-01-11). Columbus, OH: Office of Educational Research and Improvement. (ERIC Digest No. ED 465 545).

Hegedus, S. J., & Moreno-Armella, L. (2009). Intersecting representation and communication infrastructures. *ZDM Mathematics Education*, *41*(4), 399–412. doi:10.1007/s11858-009-0191-7

Herman, M., Meagher, M., Abrahamson, L., & Owens, D. (2013). Student perceptions on use of a classroom communications system in mathematics classes. *The International Journal for Technology in Mathematics Education*, *20*(2), 45–67.

Irons, A. (2007). Enhancing learning through formative assessment and feedback. Florence, NY: ProQuest eLibrary.

Irving, K. E., Pape, S. J., Owens, D. T., Abrahamson, L., Silver, D., & Sanalan, V. (2010, May). *Longitudinal Study of Classroom Connectivity in Promoting Mathematics and Science Achievement: Years 1-3.* Paper presented at the 2010 AERA Annual Meeting, Denver, CO.

Irving, K. E., Sanalan, V. A., & Shirley, M. L. (2009). Physical science connected classrooms: Case studies. *Journal of Computers in Mathematics and Science Teaching*, *28*(3), 247–275.

Kay, R. H., & LeSage, K. (2009). Examining the benefits and challenges of using audience response systems: A review of the literature. *Computers & Education*, *53*(3), 819–827. doi:10.1016/j.compedu.2009.05.001

Kibble, J. (2007). Use of unsupervised online quizzes as formative assessment in a medical physiology course: Effects of incentive on student participation and performance. *Advances in Physiology Education*, *31*(3), 253–260. doi:10.1152/advan.00027.2007 PMID:17848591

Kibble, J. (2011). Voluntary participation in online formative quizzes is a sensitive predictor of student success. *Advances in Physiology Education*, *35*(1), 95–96. doi:10.1152/advan.00053.2010 PMID:21386008

Kluger, A. N., & DeNisi, A. (1996). The effects of feedback on interventions on performance: A historical review, a meta-analysis, and a preliminary feedback intervention theory. *Psychological Bulletin*, *119*(2), 254–284. doi:10.1037/0033-2909.119.2.254

Komoroske, L. M., Hameed, S. O., Szoboszlai, A. I., Newson, A. J., & Williams, S. L. (2015). A scientist's guide to achieving broader impacts through K-12 STEM collaboration. *BioScience Advance Access.* doi:10:1093/biosci/biu222

Kulhavey, R. W., & Wager, W. (1993). Feedback in programmed instruction: Historical context and implications for practice. In J. Dempsey & G. Ales (Eds.), *Interactive instruction and feedback* (pp. 3–20). Englewood Cliffs, NJ: Educational Technology Publications.

Kurtz, P. D., Marshall, E. K., & Banspach, S. W. (1985). Interpersonal skill-training research: A 12-year review and analysis. *Counselor Education and Supervision*, *24*(3), 249–263. doi:10.1002/j.1556-6978.1985.tb00482.x

Laxman, K. (2011). A study on the adoption of clickers in higher education. *Australasian Journal of Educational Technology*, *27*(8), 1291–1303.

Lee, S. C., & Irving, K. E. (2015). Teachers' use of interactive technology to enhance students' metacognition: Awareness of student learning and feedback. *Journal of Computers in Mathematics and Science Teaching*, *35*(2), 175–198.

Lemke, J. L. (1990). *Talking science: Language, learning and values*. Norwood, NJ: Ablex Publishing.

Li, L., Lui, X., & Steckelberg, A. (2010). Assessor or assesse: How student learning improves by giving and receiving peer feedback. *British Journal of Educational Research*, *41*(3), 525–536.

Li, L., Lui, X., & Zhou, Y. (2012). A re-analysis of assessor and assesse's roles in technology-facilitated peer assessment. *British Journal of Educational Technology*, *43*(3), 376–384. doi:10.1111/j.1467-8535.2011.01180.x

MacArthur, J. R., & Jones, L. L. (2008). A review of literature reports of clickers applicable to college chemistry classrooms. *Chemical Education Research Practice*, *9*(3), 187–195. doi:10.1039/B812407H

Macdonald, D., Hunter, L., & Tinning, R. (2007). Curriculum construction: A critical analysis of rich tasks in the recontextualisation field. *Australian Journal of Education*, *51*(2), 112–128. doi:10.1177/000494410705100202

Marden, N., Ulman, L., Wilson, F., & Velan, G. (2013). Online feedback assessment in physiology: Effects on students' learning experiences and outcomes. *Advances in Physiology Education*, *37*(2), 192–200. doi:10.1152/advan.00092.2012 PMID:23728137

Martin, M. O., Mullis, I. V. S., Foy, P., & Stanco, G. M. (2012). *TIMSS 2011 international results in science*. Chestnut Hill, MA: TIMSS & PIRLS International Study Center, Boston College.

Minstrell, J., & Kraus, P. (2005). Guiding inquiry in the science classroom. In M. S. Donovan & J. D. Bransford (Eds.), *How students learn: History, mathematics, and science in the classroom* (pp. 475–513). Washington, DC: The National Academies Press.

Nucci, J. A., Doherty, P., Lung, L., & Singhota, N. (2011). How researchers can help K–12 teachers bring materials science into the classroom. *Materials Research Society Bulletin*, *36*(04), 284–289. doi:10.1557/mrs.2011.40

Panus, P., Stewart, D., Hagemeier, N., Thigpen, J., & Brooks, L. (2014). A subgroup analysis of the impact of self-testing frequency on examination scores in a pathophysiology course. *American Journal of Pharmaceutical Education, 78*(9). *Article*, *165*, 1–8.

Pape, S. J., Bell, C. V., Owens, S. K., Bostic, J. D., Irving, K. E., Owens, D. T., . . . Silver, D. (2010, May). *Examining verbal interactions within connected mathematics classrooms.* Paper presented at the Annual Meeting of the American Educational Research Association, Denver, CO.

Pape, S. J., Irving, K. E., Bell, C. V., Shirley, M. L., Owens, D. T., Owens, S., & Lee, S. C. et al. (2011). Principles of effective pedagogy within the context of connected classroom technology: Implications for teacher knowledge. In R. N. Ronau, C. R. Rakes, & M. L. Niess (Eds.), *Educational technology, teacher knowledge, and classroom impact: A research handbook on frameworks and approaches*. Hershey, PA: IGI Global.

Pape, S. J., Irving, K. E., Owens, D. T., Boscardin, C. K., Sanalan, V. A., Abrahamson, L., & Silver, D. et al. (2013). Classroom connectivity in *Algebra 1* classrooms: Results of a randomized control trial. *Effective Education*, *4*(2), 169–189. doi:10.1080/19415532.2013.841059

Peat, M., & Franklin, S. (2003). Has student learning been improved by the use of online and offline assessment opportunities? *Australasian Journal of Educational Technology*, *19*, 87–99.

Popham, W. J. (2008). Transformative assessment. Alexandria VA: Association for Supervision and Curriculum Development (ASCD).

Prince, M. (2004). Does active learning work? A review of the research. *The Journal of Engineering Education*, *93*(3), 223–231. doi:10.1002/j.2168-9830.2004.tb00809.x

Roschelle, J., Penuel, W. R., & Abrahamson, L. (2004). The networked classroom. *Educational Leadership*, *61*(5), 50–54.

Ruiz-Primo, M. A., & Furtak, E. M. (2006). Informal formative assessment and scientific inquiry: Exploring teachers' practices and student learning. *Educational Assessment*, *11*(3/4), 205–235.

Ruiz-Primo, M. A., & Furtak, E. M. (2007). Exploring teachers' informal formative assessment practices and students' understanding in the context of scientific inquiry. *Journal of Research in Science Teaching*, *44*(1), 57–84. doi:10.1002/tea.20163

Rutten, N., van Joolingen, R., & van der Veen, J. (2012). The learning effects of computer simulations in science education. *Computers & Education*, *58*(1), 136–153. doi:10.1016/j.compedu.2011.07.017

Shirley, M. L., & Irving, K. E. (2014). Connected classroom technology facilitates multiple components of formative assessment practice. *Journal of Science Education and Technology*, (October): 1–13. doi:10.1007/s10956-014-9520-x

Shute, V. J. (2008). Focus on formative feedback. *Review of Educational Research*, *78*(1), 153–189. doi:10.3102/0034654307313795

Simpson, V., & Oliver, M. (2006). *Using electronic voting systems in lectures*. Retrieved February 14, 2015 from http://www.academia.edu/274635/Using_Electronic_Voting_Systems_In_Lectures

Smentana, L. K., & Bell, R. L. (2012). Computer simulations to support science instruction and learning: A critical review of the literature. *International Journal of Science Education*, *34*(9), 1337–1370. doi:10.1080/09500693.2011.605182

St. John, K., Leckie, R. M., Pound, K., Jones, M., & Krissek, L. (2012). *Reconstructing earth's climate history: Inquiry-based exercises for lab and class*. Hoboken, NJ: Wiley-Blackwell.

Stein, M. K., & Lane, S. (1996). Instructional tasks and the development of student capacity to think and reason: An analysis of the relationship between teaching and learning in a reform mathematics project, Educational Research and Evaluation. *An International Journal on Theory and Practice*, *2*(1), 50–80. doi:10.1080/1380361960020103

Torrance, H., & Pryor, J. (1998). *Investigating formative assessment: Teaching, learning, and assessment in the classroom*. Philadelphia, PA: Open University Press.

Trautmann, N. (2009). Interactive learning through web-mediated peer review of student science reports. *Educational Technology Research and Development*, *57*(5), 685–704. doi:10.1007/s11423-007-9077-y

Urtel, M., Bahamonda, R., Mikesky, A., Udry, E., & Vessely, J. (2006). On-line quizzing and its effects on student engagement and academic performance. *Journal of Scholarly Teaching and Learning*, *6*, 84–92.

Venables, A., & Summit, R. (2003). Enhancing scientific essay writing using peer assessment. *Innovations in Education and Teaching International*, *40*(3), 281–290. doi:10.1080/1470329032000103816

White, T. (2006). Code talk: Student discourse and participation with networked handhelds. *Computer-Supported Collaborative Learning*, *I*(3), 359–382. doi:10.1007/s11412-006-9658-5

Wieman, C., Adams, W., & Perkins, K. (2008). PhET: Simulations that enhance learning. *Science*, *332*(5902), 682–683. doi:10.1126/science.1161948 PMID:18974334

Wiliam, D. (2006). FA: Getting the focus right. *Educational Assessment*, *11*(3/4), 283–289. doi:10.1080/10627197.2006.9652993

Wiliam, D., & Thompson, M. (2008). Integrating Assessment with Learning: What will it take to make it work? In C. A. Dwyer (Ed.), *The future of assessment: Shaping teaching and learning* (pp. 53–82). New York: Lawrence Erlbaum.

Zwiers, J. (2014). Building academic language: Meeting Common Core Standards across disciplines, grades 5-12 (2nd ed.). San Francisco, CA: Jossey-Bass.

ADDITIONAL READING

García-Peñalvo, F. J. (2008). Advances in E-Learning: Experiences and Methodologies; Hershey, PA: IGI Global. ISBN13: 9781599047560|ISBN10: 159904756X|EISBN13: 9781599047584|; Doi:10.4018/978-1-59904-756-0

Ifenthaler, D., Prinay-Dummer, P., & Spector, J. M. (Eds.). (2008). *Understanding Models for Learning and Instruction: Essays in Honor of Norbert M. Seel. Springer*. Edition.

KEY TERMS AND DEFINITIONS

Connected Classroom: Wireless communication technology (CCT) that connects a teacher's computer and students' handheld technology to facilitate teacher-student communication and student engagement with content (Pape et al., 2013).

Formative Assessment: A planned process in which assessment-elicited evidence of students' status is used by teachers to adjust their ongoing instructional [practices] or by students to adjust their current learning tactics (Popham, 2008, p. 6).

Formative Feedback: Information communicated to the learner that is intended to modify his or her thinking or behavior for the purpose of improving learning (Shute, 2008. p. 154).

Representational Expressivity: Hegedus and Moreno-Armella (2009) coined the term representational expressivity to describe the emergence of a wider classroom discourse space enabled by the use of classroom connectivity technologies.

Chapter 18

Using Reason Racer to Support Argumentation in Middle School Science Instruction

Marilyn Ault
University of Kansas, USA

Janis Bulgren
University of Kansas, USA

Jana Craig-Hare
University of Kansas, USA

Isa Kretschmer
Independent Researcher, USA

James D. Ellis
University of Kansas, USA

Bruce B. Frey
University of Kansas, USA

ABSTRACT

With secondary students reporting that they are not attracted to science, technology, engineering, or mathematics (STEM) disciplines, educators are turning to games as one strategy to engage students. The goal of integrating games into science learning is to create an excitement difficult to achieve with typical instruction. This chapter reviews games in education, particularly in STEM. Recognizing that teachers often lack the time to integrate role-playing games, the use of casual games is suggested. Casual games are easy to learn and simple to play, and incorporate game features designed to compel students to repeated play. The Reason Racer game addresses the difficult skill of scientific argumentation in a casual, competitive game. Evaluated with more than 700 students, those who played the game at least 10 times during science instruction over 6-weeks improved in every aspect of argumentation, and reported an increase in confidence and motivation to engage in science, compared to those who did not play the game. Readers are walked through the game and the resources in the Teacher Portal.

INTRODUCTION

This chapter has several purposes related both to the use of games to support teaching and learning and the challenge of teaching middle school students the very difficult skill of scientific argumentation. The first part of the chapter provides an overview of the use of games in education, particularly in science, technology, engineering, and mathematics (STEM) education, and a discussion of casual game features

DOI: 10.4018/978-1-4666-9616-7.ch018

that are specifically designed to engage students and can impact learning. The second part of the chapter provides a synopsis of the science practice of argumentation and the effectiveness of the *Reason Racer* game in engaging students in this difficult skill. The remainder of the chapter focuses on the features of the multiplayer *Reason Racer* game and an explanation of how to use the game and the accompanying Teacher Dashboard to support scientific argumentation teaching and learning.

As with any innovation, there are issues, problems, and tentative solutions. These are presented as challenges, not caveats. Our hope is that educators and researchers will include casual games as one of many resources available to support science instruction. Games, such as *Reason Racer,* can be both as engaging as any arcade-style game yet challenge middle school students in the higher order skill of scientific argumentation.

THE INSTRUCTIONAL USE OF GAMES

Games in Education

Teachers have been using games to engage students in learning long before the advent of technology-based games, understanding that games have the potential to excite students while engaging them in content, a condition optimal for learning (Blanchard & Cheska, 1985; Klopfer, 2008; Lepper & Cordova, 1992; Malone & Lepper, 1987). Early work with technology and computers recognized that features of computer-based games could increase student engagement and opportunities to practice skills, particularly for struggling learners. Early research and development of games included, for example, the MathKeys games (Xin, 1999) developed by the Minnesota Educational Computing Company (MECC) and the Arcademic Skillbuilder games (Chaffin, 1982; Chaffin, Maxwell, & Thompson, 1982) from the Developmental Learning Materials (DLM) Company. These games incorporated features such as moving images, user-control, rapid play, and immediate feedback to engage students. These games, however, were single-player and installed on a unique computer, which limited the scope of play. They do, however, provide an early demonstration of the power of technology-based games to engage students and build basic mathematical skills. Subsequent online games have evolved since this early development and can now be multiplayer and engage students in more complex skills.

Research on the effect of technology-based games has consistently shown positive results regarding motivation, persistence, curiosity, attention, and attitude toward learning (Shin, Sutherland, Norris, & Soloway, 2012), that students can have significantly higher cognitive gains when working with games when compared to receiving traditional instruction (Vogel et al., 2006), and that games promote learning and/or reduce instructional time across multiple disciplines and ages (Van Eck, 2006).

For an experience to be considered a game it will usually include goals, rules, challenges, and interaction (Crawford, 2003). Some suggest that games also require competition and quantifiable outcomes (Salen & Zimmerman, 2004) as well as the possibility for error and failure (Squire, 2006). There are many different types of educational game genres, usually defined by the type of game-action rather than the content of the game (Apperley, 2006). Prensky (2005) points out the need to deliver educational content using differing game genres and mechanics because, as he suggests, different types of content and learning require different pedagogical approaches. All game genres, recognizing that games have to contain essential engaging elements, should be considered when selecting a game to support learning a specific skill or knowledge (De Byl & Brand, 2011).

There are several different types of game formats that have shown promise in education (Dickey, 2007; Shin, Sutherland, Norris, & Soloway, 2012; Vogel et al., 2006). de Freitas (2006) demonstrated the wide array of game types that are successfully being used in education. These include, for example, games as metaphors (such as fantasy worlds for exploration), games as micro-worlds for experimentations, or games as skill builders to improve specific skills and parts of complex tasks. A loose categorization of general game genres, whether single or multi-player, may include, for example, role-playing, immersive exploration, single shooter, sports, strategy, and casual or arcade-like games. Regardless of the technology, however, characteristics that should be evident with any learning technology include interactivity, autonomy, problem solving, and analysis (Darling-Hammond et al., 2009) in order to successfully engage students in the targeted outcomes. Games focused on providing students with experience and learning in STEM have taken advantage of all of these game types.

Games in STEM Education

Technology offers many attractive ways to engage students in thinking about and doing science, including simulations, virtual reality (VR) experiences, and online games. Recent research suggests that using technology in all these formats can be engaging for students, can positively affect learning outcomes (Shin, Sutherland, Norris, & Soloway, 2012; Vogel et al., 2006; Warschauer & Matuchniak, 2010; Wenglinsky, 2005) and provide students with challenges that span the range of thinking skills described in Bloom's taxonomy (Churches, 2008).

Two comprehensive reviews of the literature have demonstrated that a variety of games are successfully used in STEM education (Li & Tsai, 2013; Mayo, 2009). Mayo's 2009 work reviews the developing use of video games in the STEM disciplines. She presents an analysis of why, based on the existing literature at the time, video games consistently produce better learning outcomes over a science lecture program, and may be of more benefit to struggling learners. For example, playing the *River City* ecology game (Ketelhut, Dede, Clarke, & Nelson, 2006) diminished the learning gap between D and B students to the point where nearly all students were performing at the B level. This is because, according to Mayo, many well-designed science-based video games incorporate features to engage learners and sustain interaction. For example, video games are able to present information in many visual and auditory modes, break tasks into smaller component parts, and allow practice of small, component skills before being combined into a more complex sequence. Using *Quest Atlantis* (Barab, Thomas, Dodge, Carteaux, & Tuzun, 2005; Barab et al., 2007) as an example, Mayo notes that science content is reinforced through continuous, immediate feedback. She suggests that this feedback results in greater self-confidence/self-efficacy, leading to persistence and a higher level of achievement. Games also can support well-constructed social interactions that encourage learner engagement and achievement in science-based activities (Barab et al., 2007) and provide multiple decision points during play, engaging students in evaluation activities in order to move through the game. Mayo suggests that it is the participatory style of learning in games that departs from the traditionally passive lecture, engaging students in active learning. These game-based tasks often require the formation of hypotheses, experimentation, and discovering the consequences of actions taken, very similar to the tasks involved in inquiry-based learning. And finally, games provide an environment in which student are more likely to spend more time engaging in science content, a key variable in learning (Kebritchi, Hirumi, & Bai, 2010).

Li and Tsai (2013) more recently conducted a qualitative content analysis of empirical studies investigating the use of games in STEM education. As did Mayo, they express a concern about the disadvantages of traditional science teaching and that students' interest and willingness to study science decreases with an increase emphasis on memorization (Honey & Hilton 2011; Mayo 2007). Li and Tsai analyzed 31 studies that addressed the use of games in STEM instruction and categorized them in terms of learning perspectives and foci. This list of games included *River City* and *Quest Atlantis,* addressed above, as well as numerous additional games. While this list is not exhaustive of the available STEM games, the analysis provides a synopsis of the types and purpose of science games, the theoretical perspective used in their development, and design consideration and target audience.

Li and Tsai's analysis identified that science game development and research between 2000 and 2011 fall within four primary learning perspectives: cognitivism (knowledge or mental structure acquisition, information processing), constructivism (active construction of knowledge through experience), socio-cultural perspective (interaction between learning and the socio-cultural context), and enactivism (learning through acting and participating). Within these perspectives they identified six learning foci that occur individually, or in combination, within science games. These include: scientific knowledge, scientific process, problem solving, affect, engagement, and socio-contextual learning. Even though they analyzed science game research that addressed each of these categories and foci, most of the games promoted scientific knowledge/concept learning, less than one third engaged students in problem solving skills, and only a few engaged students in science based on scientific processes, affect, engagement, and socio-contextual learning. Most of the studies reviewed developed and utilized single-player games targeting high school or college students.

Because collaboration is seen as a critical component of science learning as well as a game feature that sustains engagement (Khalili, Sheridan, Williams, Clark & Stegman, 2011; Sánchez & Olivares, 2011; Shih, Shih, Shih, Su, & Chuang, 2010), Li and Tsai (2013) focus specifically on the use of collaboration in the games they reviewed. Some games utilized multi-player environments, with real-world collaboration included more often than collaboration in virtual worlds. Even if collaborative opportunities were present, however, most learning was based on individual actions in the games, not the collaborative activity, and the collaborative activity was not structured nor a part of the game-play activity. Li and Tsai suggest that teachers, and researchers, should make better use of multi-player gaming environments for virtual collaboration opportunities and to promote collaborative problem-solving abilities of students. *Reason Racer* is an example of a multiplayer STEM educational game that utilizes competition as one of several game features designed to engage middle school students in the difficult skill of scientific argumentation. This game can best be described as a casual STEM educational game.

Casual Games

Casual or arcade-style games provide a specific type of game experience that is fast-paced, easy to learn, and provides quick feedback. Most casual, arcade-type games are usually considered to provide students with rapid, competitive, drill-and-practice experience in remembering and applying knowledge, skills which are identified at the lower end of Bloom's taxonomy (Anderson et al., 2001). There are many examples of mathematics games, both cooperative and competitive, that are designed to increase fluency through practice and result in significantly improved motivation and achievement (Ke & Grabowski, 2007; Kebritchi, Hirumi, & Bai, 2008; Plass, O'Keefe, Homer, Case, Hayward, Stein, & Perlin, 2013).

Casual arcade-type games are, however, the most popular game-type played on the Internet and include users from every demographic group (Wallace & Robbins, 2006). This is because they are highly engaging, using speed, competition, rapid responding, and quick feedback in an easy-to-learn and quick-to-play environment. Immersive and role-playing educational games tend to be single player, are more involved to learn, and require players to provide more complex responses. But arcade-like causal games are immediately engaging, establishing what developers describe as a *compulsion* to play or the drive to play a game over and over (Garris, Ahlers, & Driskell, 2002; Koster, 2005; Lazzaro, 2004). Developers specifically design games that create the strong desire to repeat or extend play by providing players with a sense of flow.

Flow as a Goal of Casual Games

The experience of flow draws players into playing a game over and over, seemingly "compelling" them to play (Garris, Ahlers, & Driskell, 2002; Koster, 2005; Lazzaro, 2004). The concept of "flow" is an accepted construct describing intense engagement in an activity (Csíkszentmihályi, 1975, 1997). Flow describes the experience of feeling totally involved in an activity. During a game, for example, the player achieves a state of total focus, complete immersion, and limited awareness of time. It is generally assumed that the experience involves intense involvement and concentration, as well as enjoyment. Authors of a series of studies, summarized by Hoffman and Novak (2009), suggest that flow is a complex process, influenced by many elements. Features demonstrated to elicit a sense of flow include focused goals, ease of learning, simplicity of play, immediate feedback, quick rewards, and fast-paced game-play (Tams, 2006; Wallace & Robbins, 2006; Waugh, 2006), reward systems and challenges (Evans et al., 2013; Hamlen, 2013), interactivity (Huang, 2003, 2006; Skadberg & Kimmell, 2004; Choi, Kim, & Kim, 2000), ease of use and perceived usefulness (Agarwal & Karahanna, 2000; Hsu & Lu, 2004; Sanchez-Franco, 2006), and attractiveness, novelty, and playfulness (Agarwal & Karahanna, 2000; Huang 2003, 2006; Skadberg & Kimmel, 2004; Choi, Kim, & Kim, 2000). The social context of the game, both collaboration and competition, also has been demonstrated to be important in creating the motivation to play and a significant contributor to the play experience (Choi & Kim, 2004; Hsu & Lu, 2004; Koster, 2005).

A Casual STEM Educational Game Providing Practice in Scientific Argumentation

The *Reason Racer* game, unlike most casual games, utilizes the arcade-like features to engage players in higher-order thinking skills such as analyzing, evaluating, and creating within a competitive environment. The theoretical framework suggests that an educational game specifically designed to increase engagement and the experience of flow will provide an environment in which students strive to improve their performance. This drive is assumed to be a result of the emotional attachment created from an experience of flow during play. A game that provides multiple opportunities to practice a skill in a fast-paced engaging environment with a variety of content, immediate feedback, and supports for discourse, creates a unique environment in which to develop knowledge and skills of argumentation.

The *Reason Racer* game was developed using an iterative, participatory design process with a diverse population of students and teachers as co-researchers at Argentine Middle School in Kansas City. Participatory design (Muller & Druin, 2010; Namioka & Rao, 1996; Nikolova-Houston, 2005), involving a diverse group of middle school teachers and students, for whom the game is targeted, as co-developers (Danielsson, & Wiberg, 2006; Guha et al., 2005) deviates from the traditional game-design process that involves a designer creating the game and subjecting it to testing by experienced play-testers (Crawford, 1984, 2003; Moreno-Ger et al., 2008; Shelton, 2007). Participatory design ensures that the game and resources can be easily and effectively used as intended.

The effectiveness of *Reason Racer* as an instructional option in middle school science was studied with more than 700 middle school students in five schools who played the game at least 10 times during science instruction across a six-week period. Overall, these students improved in every aspect of argumentation skill and judgment, and reported an increase in confidence and motivation to engage in science, compared to students who did not play the game (Ault, Craig-Hare, Frey, Ellis, & Bulgren, 2015). These students also reported a heightened sense of intense engagement while playing the game, similar to what is described as "flow" (Csíkszentmihályi, 1975, 1997). Finally, students who engaged in discourse through the chat part of the game improved in the quality of their interactions. They increased questioning of other players' conclusions, engaged in more interactions, presented more reasons for their own decisions, and helped their peers successfully complete the game (Ault, Craig-Hare, & Frey, 2014).

Reason Racer was developed to assist middle school science teachers in engaging their students in the difficult task of scientific argumentation. The development of this skill has increased in importance with its inclusion as a Science and Engineering Practice in the Next Generation Science Standards Framework (NGSS) (Achieve, 2013) as well as the Common Core State Standards (CCSS) (NGA & CCSSO, 2010).

SCIENTIFIC ARGUMENTATION

Argumentation is a very difficult skill to learn; yet it is essential for daily discourse and is a significant part of higher-order thinking and reasoning across curriculum content areas. The ability to reason has many manifestations, and one important aspect is the ability to evaluate claims or statements, especially when a complex argument with data and opinions is presented to convince a reader or listener. Toulmin, Rieke, and Janik (1984) defined argumentation as "the whole activity of making claims, challenging them, backing them up by producing reasons, criticizing those reasons, rebutting those criticisms, and so on" (p. 14). Argumentation as a practice in which to engage students in supporting deeper learning is well documented (Pellegrino & Hilton, 2013).

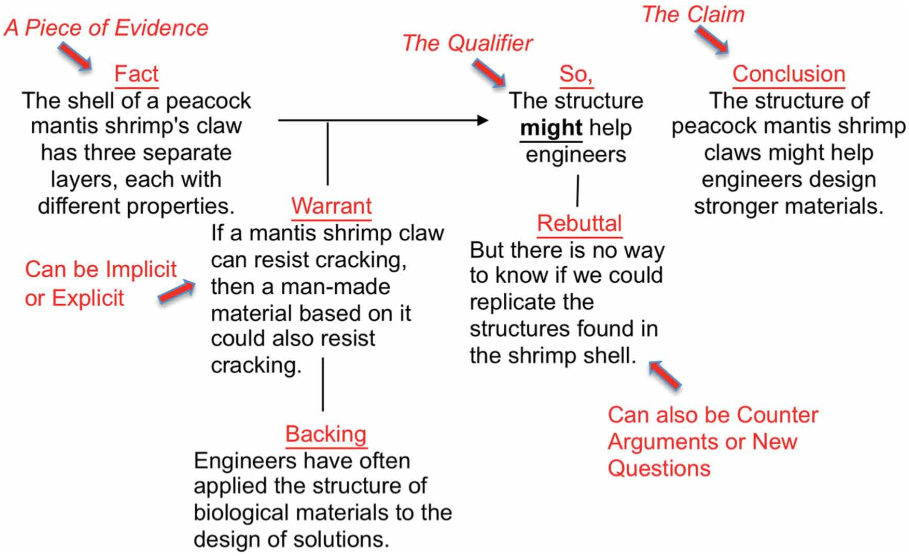
Argumentation as Described by Stephen Toulmin

Stephen Toulmin (1922-2009) was a British philosopher and logician. He first proposed his model of argumentation in the 1958 book, *The Uses of Argument*. An updated edition was published in 2003. He created this model of argumentation as a way to understand arguments that can be used in real-world situations. He was attempting to get away from the classical model of arguments based around syllogisms. In logic, a syllogism is a three-statement argument of a claim, evidence and warrant (or reasoning). For example:

1. Socrates was a man (Evidence);
2. All men are fallible (Warrant or Reasoning);
3. Socrates was fallible (Claim).

Toulmin (1958, 2003) was unsatisfied with the absolute nature of this type of argument, and felt that such arguments did not reflect the real world, where arguments were often more convoluted and required more than three parts. He took the basic three parts of an argument or syllogism, and added three supporting components. These are: backing, qualifiers, and rebuttal, as shown in Figure 1. In Toulmin's

Figure 1. Toulmin's diagram of the components of an argument using a claim from the Reason Racer scenarios, identifying the elements addressed in the game. Adapted from Toulmin (1958, p.105).



view, good arguments take into account exceptions, because in life, there are very few absolutes. Backing provides additional information about the warrant, or reasoning. Qualifiers let people know when a claim is not always true. Rebuttals are known objections to a claim, such as an alternative interpretation of the evidence.

The inclusion of reasoning and argumentation across the CCSS (NGA & CCSSO, 2010) emphasizes the need for students to know how to take a critical stance when confronted with an argument, think logically about the relationships among concepts, evaluate a logical chain of reasoning, and defend their claims with appropriate justification and reasoning.

Argumentation within National Educational Standards

The importance of argumentation is found in both the Common Core State Standards (NGA & CCSSO, 2010) and the Next Generation Science Standards (Achieve, 2013). These documents emphasize the need for students to know how to take a critical stance when confronted with an argument, evaluate the quality of what they read, see or hear, and defend their claims with appropriate evidence and reasoning. Argumentation, as defined by the NGSS, is "a mode of logical discourse used to clarify the strength of relationships between ideas and evidence that may result in revision of an explanation" (Achieve, 2012). Experts in STEM education call for an emphasis on investigation, evaluation, argumentation, and engagement in the practices of STEM, rather than a narrow focus on science content knowledge (Bybee, 2011; NRC, 2007; NRC, 2012). Integrating argumentation, a key practice of science, into science instruction is, however, a significant challenge (Alozie, Moje, & Krajcik, 2010) with a clear need for a variety of resources to support teaching and learning.

Science teachers are beginning to include the process of scientific argumentation among classroom objectives. This has been difficult, however, possibly a result of relatively low opportunity for students to think critically and to a lack of instructional resources focusing on argumentation. Data from national assessments such as the National Assessment of Educational Progress suggest that most young Americans do not have a firm mastery of higher-order thinking skills (National Center for Education Statistics, 2012). In addition, Duschl and Osborne (2002), Jimenez-Alexandre and Erduran (2007), and Osborne, Simon, Christodoulou, Howell-Richardson, and Richardson (2013) highlighted the lack of quality instruction on scientific argumentation and discourse in science classrooms for several decades. Sadler (2004) suggested that the difficulties in teaching argument analysis might be due, in part, to the complex interrelationships between socio-scientific issues and the nature of science. Innovative instruction and resources are needed to reverse these trends.

Argumentation in Middle School

Middle school standards now require students to develop literacy in science that supports argumentation, including reading complex text and integrating visual information with other text information. These standards also have moved the focus of student learning from memorization of facts to analysis, evaluation, and synthesis of information. This includes argumentation skills. The research on effective strategies for teaching and learning argumentation in science is emerging, as called for in new rigorous standards for middle school students. Organizations such as What Works Clearinghouse and others have identified instructional procedures shown to help students learn (e.g., Kamil et al., 2008; Pashler et al., 2007). Among those procedures are arranging for active student engagement and discourse as part of the learning process, use of direct explicit instruction, and incorporation of learning scaffolds such as graphic organizers, especially when combined with verbal descriptions and deep level questioning. In addition, some have argued that questioning techniques become even more powerful when incorporated with cognitive strategies (Pressley & McCormick, 1995; Rosenshine, Meister, & Chapman, 1996).

One instructional model incorporates these recommended components into the Argumentation and Evaluation Routine (AER) (Bulgren, Ellis, & Marquis, 2014). A study with middle and secondary school students indicated that those instructed in the AER had significantly higher test scores and large effect sizes when compared to students not instructed in the AER. There were, however, challenges related to the time constraints needed to engage students with the full set of AER components (Bulgren & Ellis, 2012). The design of the *Reason Racer* game is based on the elements of argumentation addressed in the AER, but using the engaging environment of a game. Ultimately, the goal of teaching argumentation in middle school is that students learn to apply scientific practices to everyday challenges and develop defensible ways to convince others of the strength of a conclusion (Lawson, 2003). Most broadly, many argue that scientific argumentation is a fundamental aspect of scientific literacy for all citizens (Driver, Newton, & Osborne, 2000) and at a global level, students must engage in this type of higher-order thinking to compete in the world economy of the 21st century (Conley, 2008; Heller & Greenleaf, 2007). *Reason Racer* is one tool that middle school teachers have available to engage students in the difficult skills of scientific argumentation.

REASON RACER AS A PART OF MIDDLE SCHOOL SCIENCE INSTRUCTION

The *Reason Racer* .org game website provides both an online, multi-player game and a Teacher Dashboard with access to performance data and resources to support the integration of argumentation and the game into science instruction. The following section reviews each of these components.

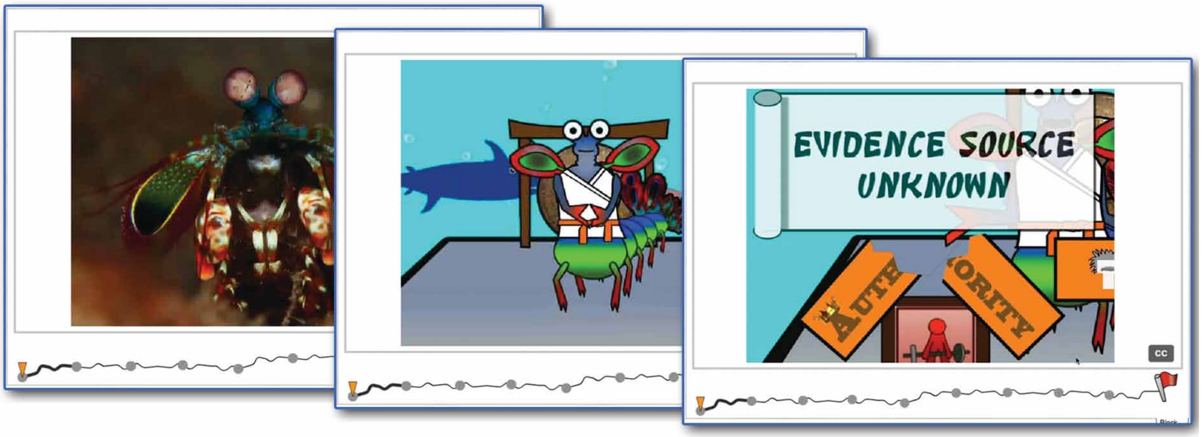
The Reason Racer Game Elements

Reason Racer is divided into four parts, each part designed to engage students in the knowledge and skill of argumentation in a different way. The four parts of *Reason Racer* that engage students in argumentation and discourse include*: Orientation, Practice, Decision,* and *Discourse*. These four game parts represent the actions of the game in which students watch and listen (or read), evaluate and race, make decisions, and discuss. The science content that is addressed as students play through a session is pulled from one of 40 different scenarios featuring topics in the areas of physical, life, earth, and space science, as well as engineering, technology and the application of science. These scenarios were identified and written to be interesting and engaging for students and were validated with our team of student co-developers. When setting up a game-play session from the Teacher Dashboard the teacher selects the scenarios that will be played.

The first part of the game involves *Orientation* and presents the players a humorous 30-second video about the content of a particular scenario and elements of scientific argumentation reasoning and discourse, as seen in Figure 2. In designing the videos, focus groups were conducted with middle school students to evaluate what they thought about different styles of videos. Some of the video styles included: newscast style, YouTube talking-head style, science video explanation style, and animation style. There was a clear preference for a simple animated style, which appealed equally to both genders and age groups.

The videos were designed to be short, engaging, educational, and conducive to repeated viewings. Each video consists of an opening fact related to one of the 40 different game scenario topics. It then introduces animated characters that discuss an aspect of one of the components of scientific reasoning specified by Toulmin, while simultaneously relating it to a scenario topic. For example, one of the scenarios is about scientists studying the peacock mantis shrimp, which has very hard claws. The claim for this scenario is "The structure of peacock mantis shrimp claws may help engineers design stronger materials." The opening section of the video starts with the question "Did you know the peacock mantis shrimp can punch as fast as a bullet? It moves so fast it can boil the water around it." Then the video introduces a character of a peacock mantis shrimp in an underwater karate dojo. The shrimp then deals

Figure 2. Screens from the brief, humorous video that introduces the scenario titled "That Shrimp Packs a Punch!"



with types of evidence and "karate chops" examples of weak use of authority, theory, and logic. Through watching this video the students will be introduced to new knowledge about the scenario topic as well as a component of scientific reasoning. Finally, they will be asked a question to invite further discussion. A list of the argumentation or discourse skill addressed in the introductory video for each scenario is listed in Table 1 and is available at http://reasonracer.wikispaces.com/Video+Topics, with a link to each video on YouTube, accessible outside of the *Reason Racer* game environment.

The second part of the game, *Practice*, engages the players, in small groups, in a competitive, multi-player rally-race; alternating between challenges, or Pit Stops, and racing segments across a variety of

Table 1. Scenario by science and argumentation/discourse topic

Scenario Name	Scenario Science Topic	Argumentation or Discourse Video Topic
1908 Russian Explosion	Meteoroids and comets	Evaluating a Claim: Rebuttals
Are We Alone?	Life in the solar system	Evaluating a Claim: Withholding Judgment
Artificial Leaf	Artificial leaf – a step toward energy independence.	Using the Discussion Section
Aspirin Reduces Cancer Deaths	Low dose aspirin therapy for cancer treatment	Do's and Don'ts: Reasonable Arguments
Beam Me Up	Teleportation	Types of Logic: Analogy
Bridges Singing in the Rain	Using sound to test bridge safety	Do's and Don'ts: Reasonable Arguments
Carbon Dioxide Sponge (Keep It Clean!)	Absorbing carbon dioxide	Evaluating Evidence
Chernobyl - A Wildlife Sanctuary	Ecological effects of radiation	Do's and Don'ts: Reasonable Arguments
Deep Oceans and Global Warming	Global warming	Types of Reasoning: Theory
Dogs Can Read Human Faces	Dog intelligence	Making Good Claims
Doors to Your Memory	Memory and recall	Ranking Evidence Quality
Eating Fatty Foods	Fat triggered endocannabinoids and overeating	Evaluating Evidence: Reliability
Eight Glasses of Water	Hydration and human health	Confirmation Bias
Elevator to Outer Space	Large scale engineering projects	Scientific Laws
Energy Drinks? Don't Waste Your Energy	Risks associated with energy drinks	Qualifiers
Gender Inequality in Teen Drinking	Brain development and health	Do's and Don'ts: Reasonable Arguments
Graphene Valley	Can graphene replace silicon?	Types of Reasoning: Theory and Logic
Leapin' Lizards	Search and rescue robots	Gathering Evidence/Methodology
Mindless Eating	Nutrition	Types of Evidence: Data
Music and Hearing Loss	Impact of musical training on hearing loss	Poor Arguments
Panda Poop to the Rescue	New technology for biofuel production	Types of Evidence: Fact and Opinion
Pennies from Heaven	Penny falling from skyscraper	Believability of Claims
Pollution Stops Rain	Weather	Do's and Don'ts: Reasonable Arguments
Return of the Mammoth	Scientists trying to clone a mammoth	
Snake Oil – Good for What Ails You?	Treating heart failure	Fraudulent Claims (Poor Authority)
Some Sports Can Be Dangerous	Head injuries from contact sports	Do's and Don'ts: Reasonable Arguments

continued on following page

Table 1. Continued

Scenario Name	Scenario Science Topic	Argumentation or Discourse Video Topic
Take It from the Tap	Purity of bottled water	Logical Reasoning: Generalization
Terraforming Mars	Changing Mars to support human life	Do's and Don'ts: Reasonable Arguments
That Shrimp Packs a Punch!	Super-strong materials from shrimp	Weak Reasoning
The Earth's Two Moons	New theory explains features of Earth's moon	Types of Logic: Cause and Effect
The New North	Reversal of the Earth's magnetic poles	Evaluating a Claim: New Questions
Toads Can Predict Earthquakes	Toads have predicted earthquakes	Types of Logic: Correlation
Using the AIDS Virus to Cure Cancer	Development of vaccines	Do's and Don'ts: Reasonable Arguments
Violent Video Games and the Brain	Violent video games and aggressive behavior	Evaluating a Claim: Counterarguments
Vitamin Supplements	Value of vitamin supplements	Do's and Don'ts: Reasonable Arguments
Was Einstein Wrong?	Speed of light	Types of Reasoning: Theory
Weather Is One Big Headache	Relationship between weather and migraine headaches	Types of Reasoning: Authority
We're All Neanderthals	Human evolution	Types of Reasoning: Logic
Worm Glue: Give Me a Break!	Biomimicry leads to possible new bone glue	Claims
Yellowstone Could Blow Up	Supervolcanoes	Do's and Don'ts: Reasonable Arguments

racecourses. The Pit Stops, as seen in Figure 3, require the players to address components of argumentation within the context of one science scenario at a time. In each of seven Pit Stops the students make decisions about the components of scientific argumentation such as the type of evidence, the best claim statements, qualifiers that limit a claim, the type and quality of evidence, or the type and strength of reasoning. During each Pit Stop, students attempt to move through the challenge as quickly as possible, with as few errors as possible, while receiving feedback on each answer. The game is designed so that the speed and accuracy of the player's performance in a Pit Stop affects the speed at which his or her car can move through the next racing segments to arrive at the next Pit Stop. Incorrect responses slow down the presentation of items in the Pit Stop, providing a disincentive for guessing. The player's goal is to win the race, to move through the Pit Stops and racing segments, to the finish line, before the other members of the group in their game play session.

For example, the scenario *That Shrimp Packs a Punch!* (Life Sciences; Engineering, Technology and Applications of Science) presents a claim that the structure of peacock mantis shrimp claws might help engineers design stronger materials. To play the game, players navigate cars through a race against other students, stopping to complete challenges, or "Pit Stops," connected to the scenario. In each Pit Stop the challenge addresses a different component of scientific argumentation. Even though all the players are engaged in the same scenario, each student experiences the items in each Pit Stop in a different order. In the first Pit Stop, the players have to differentiate between a fact statement, such as "A shrimp is a crustacean." and an opinion statement such as "It is impressive how strong mantis shrimp shells are." In another Pit Stop they read a synopsis of the article and select the best claim statement from five options, choosing between statements such as "Peacock Shrimp claws can be used to make life saving products." or "To be effective, strong materials must be lightweight, tough and not crack easily." In another Pit

Figure 3. Sample of the "Practice" portion of the game in the pit stops that engage the players in actions common to fast-paced games, such as matching, ranking, and sorting, all within a rally-race game interface where the relative positions of the other players are visible

Pit Stop Task: Determine the type of evidence stated in the sentence below. (10 correct ansv

6) Polymer theory explains how large molecules can be very strong and elastic.

Pit Stop Task: Determine the best claim for the article.

The peacock mantis shrimp packs a powerful punch. The crustacean uses its hammer-like claws to smash through mollusk shells and even aquarium glass without getting injured. Now, a new study reveals what makes its claws so tough. The shrimp claws are made up of different layers, each of which has special properties. Together, their composition and structure stops cracks in their tracks. This research could help engineers design lighter, stronger materials for military, medical, and other applications.

Choose the best claim:

1) Development of a strong, light material may be important to the military and medicine

Pit Stop Task: Splash the qualifier in the claim. (3 correct answers)

Pit Stop Task: Rank the statements by how well they support the claim.

The structure of peacock mantis shrimp claws might help engineers design stronger materials.

One layer of the shrimp's claw is designed to stop cracks, while a different layer

Mantis shrimp survive by stunning small fish and cracking open mollusk shells for food.

You have completed the Pit Stop!

Continue on your way!

Pit Stop Task: Determ ority, logic, or theory.

The best way to make stronger surfaces is to combine multiple layers that support each other.

If a mantis shrimp claw can resist cracking, a material based on it could also resist cracking.

Pit Stop Task: Evaluate whether the quality of the reasoning is strong or weak.

The structure of peacock mantis shrimp claws might help engineers design stronger materials.

5) If the design of their shell protects a shrimp's claw, we can use the same design to make strong materials.

6) The best way to make stronger surfaces is to combine multiple layers that support each other.

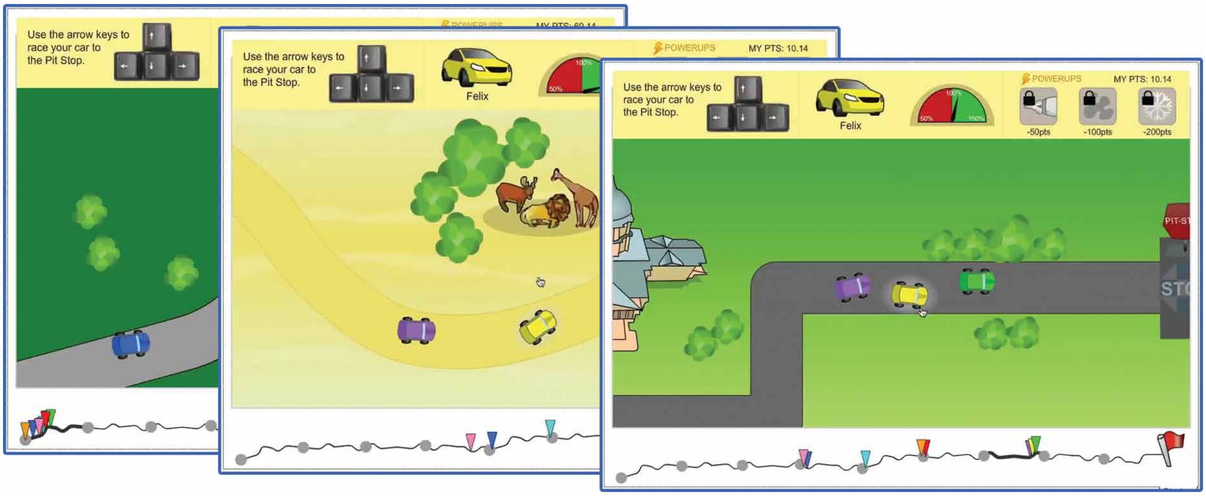
7) Most materials are either stiff or tough, but not both.

Stop the task is to rank the quality of the evidence as it applies to the claim "The structure of peacock mantis Shrimp claws might help engineers design stronger materials." Evidence to rank may include "The shrimp's punch accelerates so quickly, it boils the water surrounding the target." or "The shrimp's claws contain a material similar to the enamel in human teeth." or "The shell of a shrimp's claw has three separate layers, each with different properties." Finally, the players are asked to identify the type and strength of reasoning used to support the claim. For example, they have to decide the type of reasoning that the statement "If a mantis shrimp claw can resist cracking, a material based on it could also resist cracking" represents and whether the reasoning is strong or weak as applied to the claim. In the last Pit Stop before the decision part of the game, players have to identify the type of objection to the claim as a counter argument, such as "Materials made from replicating the shell of a shrimp likely would be too thick to wear, due to the increase in size from shrimp to man." or rebuttal, such as "Tooth enamel may be hard, but teeth crack all the time. How can that be strong enough to stop bullets?" The Pit Stops require actions that are common to fast-paced games such as matching, ranking, sorting, and discriminating, all within a rate-based game interface.

A competitive racing component is completed between each Pit Stop and at the end of the game. Here, similar to many racing games, students navigate through various racing tracks around obstacles and turns, as quickly as possible to move to the next Pit Stop (Figure 4). The speed and accuracy of the player's performance in the Pit Stop will affect the speed with which his or her car can move through the next racing segment, thus providing a disincentive for guessing. The rally-race format, therefore, requires players to alternate completing challenging tasks as quickly and correctly as they can with rapid-play racing segments of the game (Ault, Craig Hare, Bulgren, & Ellis, 2012). There is evidence to suggest that students who have the opportunity to engage in a competitive race *between* each Pit Stop perform more accurately and quickly *in* each Pit Stop, when compared to students who only have access to the Pit Stop without the racing component (Ault, Craig-Hare, & Frey, 2014). The effect of the competitive racing portion of the game on overall game performance suggests that game features not specifically addressing science content can be used to support engagement and learning.

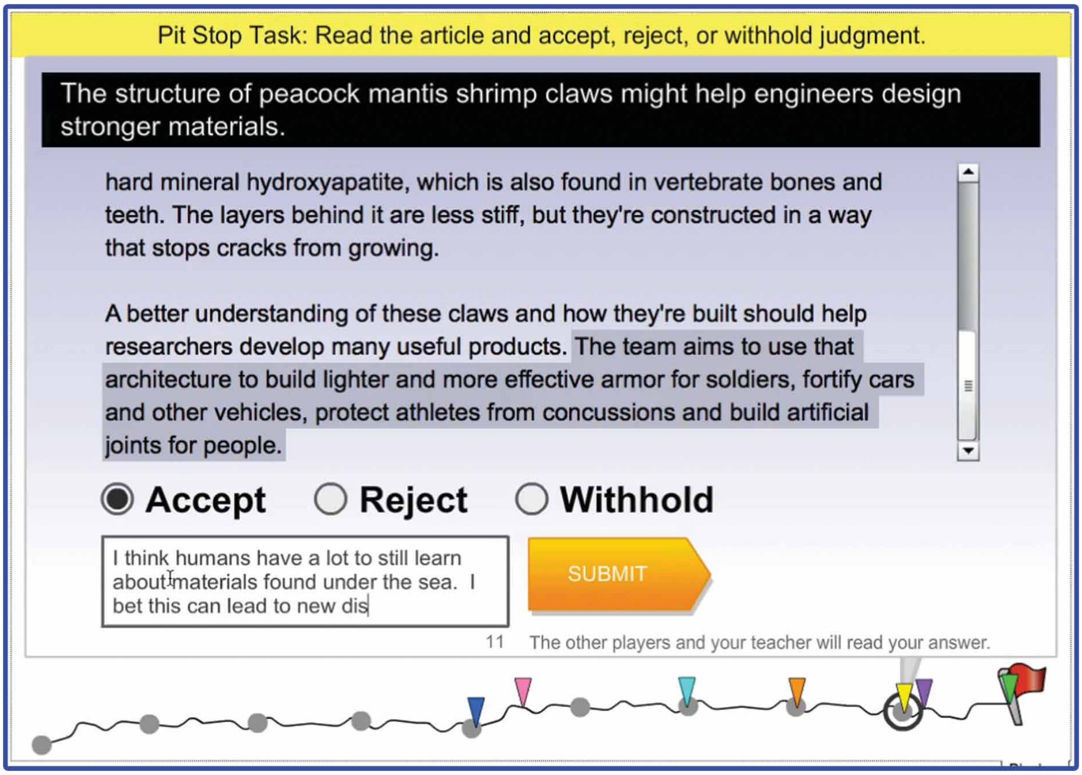
In the *Decision* portion of the game, (Figure 5) students read the full article that supported the claim with evidence and reasoning. This article contains the substantive information in each of the preceding Pit Stops, so the students have become familiar with the claim, evidence, and reasoning through the session of game play. At this point, students have to make a decision and determine whether they will

Figure 4. Examples of the racetracks that occur between each pit stop, including the relative positions of all the players at the bottom of the screen



Use the arrow keys to race your car to the Pit Stop.

Figure 5. The Decision part of the game where students have to declare their judgment about a claim and enter their reasoning in the text box



Pit Stop Task: Read the article and accept, reject, or withhold judgment.

The structure of peacock mantis shrimp claws might help engineers design stronger materials.

hard mineral hydroxyapatite, which is also found in vertebrate bones and teeth. The layers behind it are less stiff, but they're constructed in a way that stops cracks from growing.

A better understanding of these claws and how they're built should help researchers develop many useful products. The team aims to use that architecture to build lighter and more effective armor for soldiers, fortify cars and other vehicles, protect athletes from concussions and build artificial joints for people.

● Accept ○ Reject ○ Withhold

I think humans have a lot to still learn about materials found under the sea. I bet this can lead to new dis

11

The other players and your teacher will read your answer.

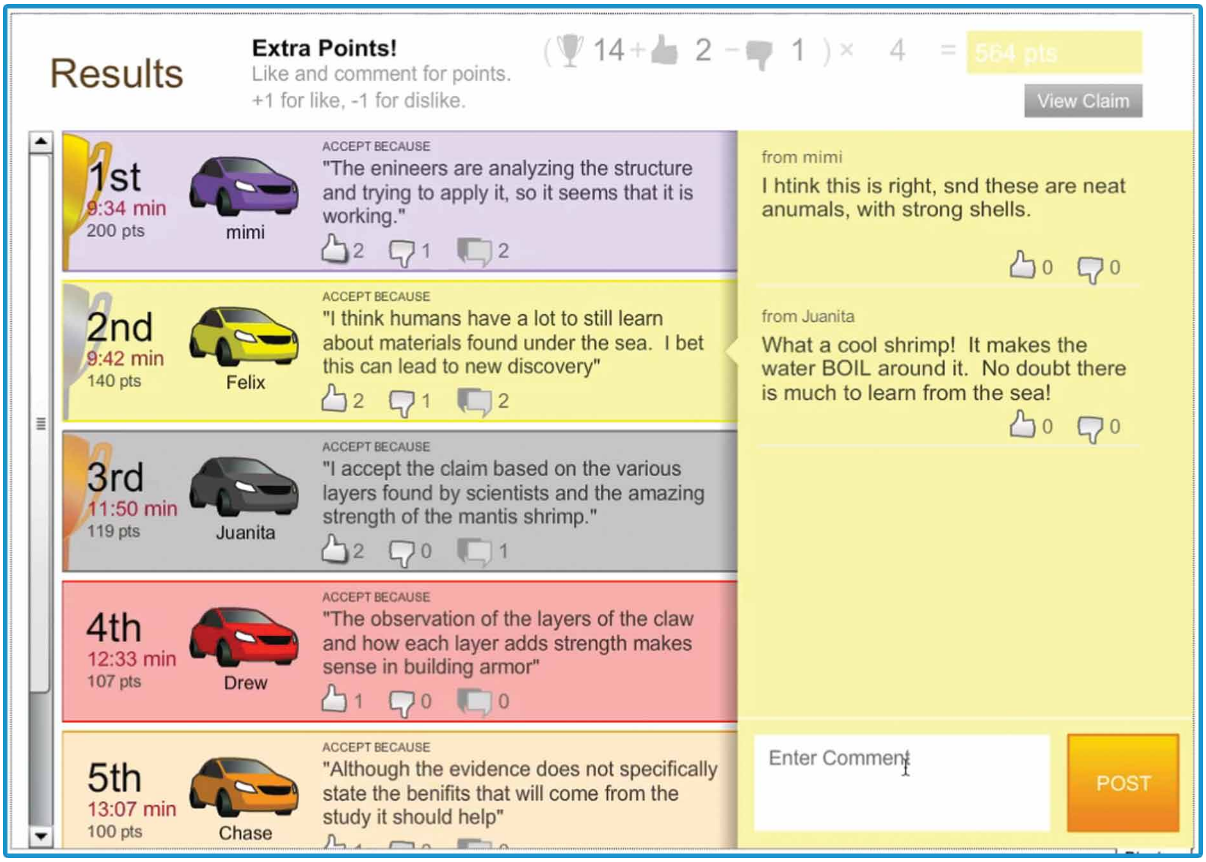
accept, reject, or withhold judgment about the claim. They also provide a written rationale for their decision. When playing the *That Shrimp Packs a Punch!* scenario, each player has to either accept, reject, or withhold the claim that "The structure of peacock mantis shrimp claws might help engineers design stronger materials," then justify and support their decision through discourse with other players in a chat-type environment within the game.

The decision and rationale statement that the player enters in Pit Stop Eight will populate the chat line for each student that is viewable in the Discourse portion of the game. In the *Discourse* portion (Figure 6), students interact with the other players in their game session, usually between four to eight of classmates. They defend, justify, and draw conclusions through interaction with the other members of their game play session, attempting to reach consensus about the claim.

In addition to engaging in a chat with the other players in their session, students have the ability to add to or delete overall points from other players based on their comments in the chat. There is no time limit on participation in the Discourse portion of the game. Players can continue the discussion, but generally end and start a new game session at the teacher's direction or when all the points have been distributed to peers.

Many educational game developers recognize the power of incorporating a chat component in online games to engage youth. This is particularly true as the new educational standards in mathematics, science, language arts, and civics, include discourse and argumentation as key skills to develop across

Figure 6. The Discourse portion of the game, where students discuss their reasoning and add to or remove points from others using "thumb up" or "thumb down" based on the quality of the comments



Results

Extra Points!
Like and comment for points.
+1 for like, -1 for dislike.

(14 + 2 − 1) × 4 = 564 pts

View Claim

1st
9:34 min
200 pts
mimi
ACCEPT BECAUSE
"The enineers are analyzing the structure and trying to apply it, so it seems that it is working."
2 1 2

2nd
9:42 min
140 pts
Felix
ACCEPT BECAUSE
"I think humans have a lot to still learn about materials found under the sea. I bet this can lead to new discovery"
2 1 2

3rd
11:50 min
119 pts
Juanita
ACCEPT BECAUSE
"I accept the claim based on the various layers found by scientists and the amazing strength of the mantis shrimp."
2 0 1

4th
12:33 min
107 pts
Drew
ACCEPT BECAUSE
"The observation of the layers of the claw and how each layer adds strength makes sense in building armor"
1 0 0

5th
13:07 min
100 pts
Chase
ACCEPT BECAUSE
"Although the evidence does not specifically state the benifits that will come from the study it should help"

from mimi
I htink this is right, snd these are neat anumals, with strong shells.
0 0

from Juanita
What a cool shrimp! It makes the water BOIL around it. No doubt there is much to learn from the sea!
0 0

Enter Comment

POST

all grades. The problem with providing a chat function, however, is that the discussion that emerges is often unrelated to the educational target of the game. Many times the chat that occurs within the game is inconsequential, off target, or inappropriate. Teachers often are unable to provide a real-time monitor for ongoing chat as students play online competitive games. A solution to this problem is the ability for competitive players to increase or decrease the score of other players in the game by scoring a "thumb up" or "thumb down" to others' comments. This capability with the *Reason Racer* game is based on the idea of collective intelligence (Malone, 2012; Woolley et al., 2010), which suggests that the group of competitive players in the game will moderate frivolous comments and will shape ongoing discourse to address the educational challenge of the game. It is assumed that, over many sessions of play and with instruction from the teacher, players will learn that to acquire more points in the game, their discourse within the chat environment must be substantive and informative to other players. They will have the ability to lower scores based on inappropriate or frivolous comments and respond positively to good and informative comments. This provides the teacher with an online, social-mediating resource to encourage productive argumentation and dialogue. The impact of this feature within the game has yet to be fully evaluated, although focus group data with student co-researchers validate this assumption.

How to Integrate Reason Racer into Instruction

According to a recent report by the Joan Ganz Cooney Center at Sesame Workshop (Takeuchi & Vaala, 2014), 74% of elementary and middle school teachers use games as a part of instruction, and 80% of these use games several times a month. Most of these teachers use game play that fits into a period of class time, rather than engaging their students in the use of immersive games requiring longer periods of play. These teachers also find that game play involving small groups supports the development of other social skills as well as the skills targeted by the game. While the use of immersive science games to support exploration and inquiry is often promoted as an optimal use of games (de Freitas, 2006, 2008), most teachers find the management and instructional integration of these games to be problematic (Takeuchi & Vaala, 2014). In contrast, one session of *Reason Racer* game play requires less than 10 minutes of class time, with the design intent to have students play the game multiple times; that is, more than 10 times, with different scenarios and different groups of students across the semester or year. *Reason Racer* was designed to be a game that could support instruction at any point. Teachers have used game play as a preview, review, or class activity when emphasizing science practices and different science content. Teachers may think of these instructional points as before, during, or after the activity of a lesson or unit of instruction.

Before Game Play

Prior to using the game in class, the teacher should set up an account. Behind the teacher sign-in and in the Teacher Dashboard are all the necessary class-management links. The next step is to set up classes, enroll students, assign scenarios for play, and view tips on how to begin a game-play session. Resources to move through these steps are available at http://reasonracer.wikispaces.com/ under the *Using Reason Racer in the Classroom* navigation heading.

Generally, teachers select scenarios for each class they teach based on the science content. Some, however, also consider the argumentation skill that is to be introduced or reviewed by the class when selecting the scenario. The introductory video that appears before each scenario addresses a different component of argumentation, as presented in Table 1. Teachers will determine the number of scenarios that are available to a class through the Teacher Dashboard. This number varies, based on the teacher's intent and knowledge of the students. Some teachers limit the number of scenarios, focusing on specific content. If, for example, the class is addressing health, the teacher may only make *Eating Fatty Foods, Eight Glasses of Water*, or *Energy Drinks? Don't Waste Your Energy*, three of the many health-related scenarios, available to the class. Alternatively, if the class is studying earth and space, the teacher may make all 13 scenarios under this topic available for selection by the class. These decisions are under the control of the teacher, based on knowledge of the students and class dynamics.

Teachers will make a decision about the size of the groups in the class to play through a scenario, and how to determine size and membership. The game allows for 20 simultaneous players; however, this group-size makes discussions about the science claim difficult for the Discourse portion of the game. As a result, teachers generally establish groups within the class ranging from four to eight students. Strategies for deciding which students will be in which group vary. Membership in a group may be predetermined by the teacher, determined during class as a result of seating in groups, or decided by the students.

Of course, teachers need to review the practice of scientific argumentation and discourse within the context of the lesson and instructional plan. There are a number of resources to assist in this instruction at http://reasonracer.wikispaces.com/ under the *Teaching Argumentation through Learning Links* and *Baloney Detection Kit* navigation headings. Teachers may elect to review all the components of argumentation and discourse at one time, or space the discussion of these skills across many game-play sessions, using the introductory video to support discussion of each skill. Teachers may choose to review these components prior to playing the game or after students have some exposure to the argumentation skills and discourse for discussion and analysis. Again, these decisions are the teacher's, based on an understanding of the students and content.

A review checklist of the tasks needed prior to class play is available at http://reasonracer.wikispaces.com/ under the *Integrating Reason Racer into Instruction* navigation heading. This list details what to do before class, in class but before game-play, and while initiating play.

During Game Play

During game play the teacher's role is primarily one of management. This involves reorganizing groups, answering questions about vocabulary, and encouraging students to work with each other. The list under the *Integrating Reason Racer into Instruction* navigation heading suggests providing students time for "open play," without explicit instructions. Alternatively, the teacher can engage individual students or small groups in discussion about the challenging aspects of the game, allow students to share with the class aspects of the game they have figured out or think are interesting, or assist individual students or groups with conceptual difficulties. The teacher should also provide some pacing for the students by suggesting about how long various aspects of the game should take to complete or when to begin a new game. The teacher should be aware of all students' progress in the game and be able to address any issues with the use of technology.

After Game Play

After game play, the teacher should facilitate discussion about the science content used in the game, the components of scientific argumentation, and the productivity of the student discussion in the Discourse portion of the game where students defend their reasoning. This may involve reviewing the transcripts from the Discourse portion of the game for each group and engaging students in a reflection about the quality of the comments and the use of the peer-scoring feature to moderate the conversation. The teacher should additionally assess student learning by accessing the reports for the assigned scenario, all within the Teacher Dashboard.

Teachers have also suggested that students engage in a discussion about the size of the groups, multiple play sessions, the use of chat, and suggestions for how to engage peers in the Discourse portion of the game. There are no set directions or requirements for these decisions; rather, they should reflect the students' attitudes towards their peers and games, their understanding and use of the skills in scientific argumentation and discourse, and overall class management.

The Use of Student and Class Performance Data

Games provide an ideal method of assessing student knowledge and skill. This is because games provide immediate performance feedback to the players in an engaging environment in which they are motivated to do better, get to the next level, compete against other players, and succeed. Games, particularly casual games, also allow for experimentation and even mistakes without significant negative consequences as noted in the *NMC Horizon Report: 2012 Higher Education Edition* (Johnson et al., 2013).

Reason Racer provides students with immediate feedback on their performance and monitors their progress. Each player must answer a question correctly before moving to the next question, can access prompts, and receives performance feedback at the end of the game. Because this is a game and the students are highly motivated to compete against their peers, students quickly learn to pay attention to the questions and answers. Making mistakes slows down play.

Reason Racer also provides teachers, in the Teacher Dashboard, with performance data on each student as well as an overall picture of the class's performance. This provides in-depth information on students' misconceptions and progress in each component of argumentation. These reports are available in order to guide teachers' review of the game and the application of the components of argumentation to other science content. The reports from Pit Stop 1 through Pit Stop 7 address the various components of argumentation. Teachers have access to both class and individual data on students' successes and challenges. The Pit Stops that reflect the most difficulty for students can guide class activities and discussion, while those Pit Stops that reflect success can be used to maintain engagement. By selecting the Pit Stops that reflect the most difficulty, as reflected by the "Average correct" score for the whole group, the teacher has quick access information about student performance in the basic skills of argumentation.

Whole Class Data

A variety of summary pages are available in the Teacher Dashboard to provide teachers with information about students' learning. These reports can be accessed from the "Assignment Report" page behind the teacher login. This page lists all of the assignments or games that the teacher has made for the class. An assignment represents one game scenario played by students in one class. A teacher may assign the same scenario multiple times, within a class, or across classes. At other times, teachers may make assignments for several different scenarios.

The Assignment Report page provides an overview view about the number of games played by the whole class. The summary report also presents information about the total games played as well as number of games played in one of the many scenarios. Subsequent pages provide the same "big-picture" whole-class information for each scenario. For example, whole-class information includes percent of correct performance across the whole class for each Pit Stop, a summary of most common mistakes and most correct responses per Pit Stop, and a scatter plot of overall responses.

Individual Data

The teacher can also access the reports for each assignment, including individual and class performance for each of the Pit Stops. For most of the Pit Stops this information includes the percent correct, and in some instances, the answers that were most correct or those that presented the most difficulties for students. The teacher can select any student's name and be provided with an individual report for a student in a Pit Stop.

The Reports Page also provides the teacher with in-depth information about the activity during the Discourse portion of the game. The teacher receives information about the decision to accept, reject, or withhold judgment and the student's rationale statement. While there is not a "right" answer to the challenge about the claim, this information will allow the teacher to determine which students are engaged in the process and those who are not attempting to respond to the challenge. It also provides the students' reasoning statement, their use of the "thumb up" or "thumb down" feedback, and a transcript of the discussion that occurred in the Discourse portion of the game. The teacher can follow up the game with classroom dialogue about the students' decision to accept, reject, or withhold judgment about the claim and why. Using a rubric, such as reflected in Table 2, students can assess their understanding of the process.

Students should be encouraged to self-assess their understanding of the process of argumentation. The rubric can be used as a strategy for collaboration during which students can reflect on each other's argumentation skills and learning.

ISSUES, CONTROVERSIES, PROBLEMS

Integrating Argumentation into Science Instruction

The practice of argumentation as an important student outcome for science literacy has been a focal point of discussion in science education for at least 15 years (Driver, Newton, & Osborne, 2000). Argumentation, however, was brought to the forefront when it was included in the CCSS (2010) and the NGSS (Achieve, 2013). As described in the background section of this chapter, several researchers have been investigating questions such as: What are the essential components of the practice of argumentation that students need to learn? What does argumentation (including student discourse) look like in the classroom and how should it be assessed? How are the knowledge and ability of teachers to support the learning of argumentation in the classroom developed? How are students engaged and supported in the practice of argumentation in the classroom?

The NGSS identifies argumentation as one of a few scientific and engineering practices to be intertwined throughout the teaching of all disciplinary core ideas and crosscutting concepts in science. There are multiple challenges, however, with achieving full integration of argumentation into science teaching and learning. First, few science teachers have a good, working understanding of the processes of scientific argumentation. Second, most science teachers lack pedagogical-content knowledge of how to integrate science instruction with argumentation, provide effective student learning opportunities to achieve mastery of argumentation, and establish a learning environment to support productive student argumentation discourse that also promotes learning of disciplinary core ideas and crosscutting concepts. Third, there is a lack of the explicit inclusion of scientific argumentation in extant instructional resources in science, because there has not been sufficient time for curriculum development to catch up with the vision of NGSS. Fourth, good assessments of the knowledge and practice of argumentation have not yet been included in instructional materials or state science tests. Until these four challenges are met with high quality pre-service and in-service professional development on 1) the knowledge and practice of scientific argumentation, 2) the pedagogical-content knowledge and abilities for helping students master scientific argumentation, and 3) the development of instructional resources for science that intertwine scientific argumentation with the disciplinary core ideas and cross-cutting concepts for three-dimensional learning, it is unlikely that the vision of the NGSS of a scientifically literate citizenry that is college and career ready will be achieved. Such resources are described in the Educators Evaluating the Quality of Instructional Products (EQuiP) Rubric for Lessons and Units: Science Developed by

Table 2. Reason racer argumentation student self-assessment rubric

Instructions: Use this rubric to self-assess your ability to create and defend your own argument or the argument of others in order to accept, reject or withhold a decision about the claim it makes.					
	4	**3**	**2**	**1**	**Score**
Evidence	I can identify evidence as data, fact, opinion or theory.	I can usually identify evidence as data, fact, opinion or theory.	I can identify some types of evidence but need help with others.	I have difficulty identifying types of evidence.	
Claim	I can state a claim that clearly expresses a position on a topic or can identify when someone else has done this.	I can usually state a claim that expresses a position on a topic or can identify when someone else has done this.	With help, I can state a claim that expresses a position on a topic or can identify when someone else has done this.	I confuse claims with other types of statements.	
Qualifier	I can clearly identify and use a single word or phrase as a qualifier to limit my claim or can identify when someone else has done this.	I can usually identify a qualifier to limit my claim or recognize a qualifier used by someone else.	I sometimes have difficulty identifying a qualifier, but I know what they are.	I do not understand how to use a qualifier in a claim or recognize one when used by someone else.	
Quality of Evidence	I can evaluate the quality of evidence for such things as validity, reliability, objectivity/bias or controlled experiment.	I can usually evaluate the quality of evidence for such things as validity, reliability, objectivity/bias or controlled experiment.	I can sometimes evaluate the quality of some of the evidence, but not always.	I do not understand how to evaluate the quality of evidence.	
Chain of Reasoning	I can use theory, authority or logic in a chain of reasoning to clearly support a claim or can recognize when someone else has done this.	I can usually identify a chain of reasoning, but I may not know for sure which type reasoning was used.	I understand the need for the identifying the chain of reasoning, but have difficulty explaining it.	I do not understand how to use theory, authority or logic to support a chain of reasoning.	
Quality of Reasoning	I can accurately evaluate the quality of a chain of reasoning using logic, strength of authority or correct application of scientific theory.	I can usually evaluate the quality of a chain of reasoning using logic, strength of authority or correct application of scientific theory.	I understand the need for the chain of reasoning but I may not be able to clearly explain the quality as logic, authority or correct application of scientific theory.	I do not understand how to explain a chain of reasoning.	
Challenges to the Claim	I can accurately identify challenges to a claim as counter arguments, rebuttals, or new questions.	I can usually identify challenges to a claim as counter arguments, rebuttals, or new questions.	I understand there are types of challenges to a claim, but may not be sure as to whether they are counter arguments, rebuttals, or new questions.	I do not understand how to identify challenges to a claim.	
Conclusion & Explanation	I can accept, reject or withhold a decision about a claim and provide an explanation based on relevant evidence from reliable sources.	I can accept, reject or withhold a decision about a claim and can usually provide an explanation based on evidence.	I can accept, reject or withhold a decision about a claim but sometimes have difficulty with an explanation.	I can accept, reject or withhold a decision about a claim but not provide an explanation.	
	Total Score				

Achieve (2014). There is a clear need for the development of formative and summative assessments for teachers to use at all grade levels to assess the progression of student learning of scientific argumentation to guide teaching and learning. Furthermore, there is a need for the development of state tests that validly, reliably, and authentically assess student mastery of scientific argumentation as aligned with state standards for science education.

Cross-Curricular Integration of Argumentation

The integration of argumentation into science classes is necessary for preparing students for college and career readiness. While science teachers and educators struggle with this challenge, other content area standards also present similar challenges in areas such as English Language Arts, mathematics, social studies, and technology.

As a result, it is useful to document the common challenges to reinforce and support components of argumentation across curricular areas. To do this, it is useful to consider the components of argumentation shared among these standards. The consideration of common components is done with a clear acknowledgement that many components of argumentation are discipline-specific. Nevertheless, given the time constraints and multiple instructional challenges across content areas, exploration of common argumentation components that could be reinforced across curricula is worthy of consideration.

Argumentation is emphasized in the *CCSS* (NGA & CCSSO, 2010), and the NGSS (Achieve, 2013). For science, the NGSS identifies argumentation as one of the scientific and engineering practices to be intertwined throughout the teaching of all disciplinary core ideas and crosscutting concepts in science. Among these practices, engaging in argument from evidence is central for science literacy. In addition, it is closely tied to other practices that inform argumentation, including asking questions, constructing explanations, and evaluating and communicating information.

The Common Core State Standards (CCSS) share these challenges in areas such as reading informational text. For example, students are challenged to delineate and evaluate arguments and specific claims in a text, assessing whether the reasoning is sound and the evidence is relevant and sufficient, and recognizing when irrelevant evidence is introduced. These components of argumentation are further emphasized in the CCSS for literacy in history and social studies with an emphasis on distinguishing among fact, opinion, and reasoned judgment; evaluating premises, claims, and evidence by corroborating or challenging them; and assessing the extent to which reasoning and evidence support a claim. Standards in science and technical subjects in the CCSS reinforce these goals. Frequent reference is made to citing evidence, distinguishing between facts and reasoned judgment, and assessing how reasoning and evidence supports a claim. The CCSS in mathematics also present standards relative to argumentation similar to those found in the other content areas. For example, practices in mathematics include constructing viable arguments and critiquing the reasoning of others. The CCSS in mathematics specify that students are to analyze a situation, reason about data, make plausible arguments, distinguish correct from flawed logic or reasoning, consider counterarguments, compare two arguments, and justify and communicate their conclusions to others.

As a result of these practices associated with argumentation in standards among the major disciplines, cross-curricular reinforcement of higher-order thinking and reasoning becomes increasingly important. In support of this goal, some authors suggest that common underlying thinking structures in cross-domain reading and thinking should be embraced in our schools. These include consideration of cross-domain thinking (Kuhn, Schauble, & Garcia-Mila, 1992), comparative understanding of school subjects (Stevens, Wineberg, Herrenkohl, & Bell, 2003), and suggestions for teaching critical thinking for transfer across domains (Halpern, 1998). Common underlying thinking structures found in argumentation could be part of these cross-curricular efforts.

Sustainability of the Instructional Use of Online Games

While online games are engaging for students, sustaining the use of these games in the classroom is not without challenges. Technology, for instance, is one of these challenges. Initial use of the online games requires adequate access to technology equipment and Internet. Since Reason Racer is a multi-player game, it works best if everyone involved in the game has access to an internet-connected device. If devices are not available for each student, they could work in pairs to play the game. Continued use of the game in consecutive school years would require the same level of technology availability; at the very least, equipment that would not have to be replaced as it aged. Counter to deteriorating technology, Web standards for rich Internet applications continue to evolve, often requiring updates to browsers and/or plug-ins within the browsers. These updates require time and can be a challenge for classroom teachers to schedule.

Sustainability of the use of *Reason Racer* and online resources is promoted through continued professional development for teachers. Connecting professional development to classroom practice is a key paradigm, among others, for changing how teachers teach so that improved student achievement can be realized (Penuel, Fishman, Yamaguchi, & Gallagher, 2007). Oftentimes professional development programs are disconnected from classroom practice or provided as a "one shot" dosage, rather than as ongoing learning. Penuel et al. (2007) argue that effective professional development programs are designed with "proximity to practice" in mind: the professional development is about "helping teachers to prepare for their classroom practice [which] yields results directly translatable to practice." Ensuring the connection of professional development to classroom practice has been a challenge for those who prepare professional development leaders (Darling-Hammond & McLaughlin, 1995). The challenge is heightened, as they argue, because "The vision of practice that underlies the nation's reform agenda requires most teachers to rethink their own practice, to construct new classroom roles and expectations about student outcomes, and to teach in ways they have never taught before - and probably never experienced as students" (pg. 597). Reflecting on one's practice and making changes to instructional delivery is a process that is developed through time, practice, and conversations with colleagues. District leaders cannot assume teachers are trained in the use of an online game such as *Reason Racer* and therefore not provide additional follow up for reflection and peer-to-peer dialogue to support the continued use of the game.

Helping teachers adopt strategies that employ technology as a method of delivering standards-based instruction requires the use of a carefully designed professional development program. Sarama, Clements and Henry (1998) cautioned that when teachers do not perceive that the expected uses of technology are aligned closely with the curriculum, they tend to use it less often. Instructional coaching, used as an integral part of a well-designed professional development program, can provide the needed connections between conceptual understandings of technology and its actual use within the curriculum. If teachers have an opportunity to engage in reflective conversations around the use of technology to meet standards in their classrooms, observe others using technologies effectively, and receive feedback on their uses of technology through job-embedded coaching, their overall adoption and continued use of high-quality technology resources could be sustained.

Sustainable use of online games also is dependent on the availability of current resources to support the use of the game. Resources to support teachers and students need to be easily available, in addition to being up-to-date. Many online games post support materials, such as an instructor's manual, but don't continue to update these materials as new resources become available. For example, as teachers use the *Reason Racer* game, examples are shared with the team and posted to the Teacher Resource wiki (reasonracer.wikispaces.com). These examples include new strategies to introduce argumentation to students based on current events, updated rubrics, etc. This is not an easy task -- it takes commitment from the teacher users to share these examples and from the development team to continuously update the resources and support materials.

SOLUTIONS AND RECOMMENDATIONS

There are a number of recommendations that can be made to better prepare teachers to address the NGGS practices, specifically scientific argumentation. First, educators need to change what is tested so that it aligns with what is valued in the NGSS. This includes the formative and summative tests of scientific argumentation used by science teachers as well as addressing scientific argumentation in high-stakes state testing.

Second, pedagogy for teaching the practice of scientific argumentation in undergraduate science personnel preparation courses needs to be developed. This would include how to assess scientific argumentation and how to use the data from the assessments to modify and improve student learning; how to evaluate and adapt instructional resources to intertwine scientific argumentation into learning activities that teach the key disciplinary core ideas and crosscutting concepts of science; and an identification of instructional strategies, learning environments, and student interactions to enhance the learning of scientific argumentation (e.g. pedagogical-content knowledge). This may involve providing intensive, multi-year professional learning opportunities for science teachers (P-12) so they can become proficient in implementing three-dimensional learning of science (including the practice of scientific argumentation) in their science instruction.

Third, there needs to be an emphasis on the development of instructional resources on teaching the practice of scientific argumentation for use in professional learning programs for pre-service and in-service science teachers at the elementary, middle, and high school levels. These might be stand-alone modules or resources integrated into science education textbooks and on-line resources. An example may be the development of multimedia samples of science teachers and students effectively engaged in teaching and learning of science argumentation to learn disciplinary core ideas and crosscutting concepts. Science educators and groups of science teachers would be able to examine these examples to learn how to integrate scientific argumentation into school science. The focus of development is to integrate scientific argumentation into the instructional resources available to science teachers, perhaps first as replacement modules that are exemplars of three-dimensional learning for a single content standard from NGSS. Ultimately, however, the goal is the integration of scientific argumentation and three-dimensional learning into instructional resources for each grade level and course in the P-12 science program.

The challenges of implementing the reforms promoted by the NGSS, those addressed with the instructional use of games and the efforts required to sustain change in instruction produces what could be considered a "wicked problem." This is a challenge, the solution to which requires a great number of people with differing roles in a community to change their mindsets and behavior (Rittel & Webber, 2000). It is beyond the scope of this chapter to fully address all of the processes that may be required to implement a new innovation, particularly one as complex as the NGSS, coupled with game-based learning. See, for example, Fullen (2014) or Garmston and Wellman (2013) for a review of the process and their recommendations on how to engage schools in sustained reform.

Because the skill of argumentation involves a process of dialogue in which the students are supported in dealing with claims, qualifiers, evidence, reasoning, and conclusions, a professional development model that supports the instruction of these skills should also embrace the process of dialogue in learning for teachers. Therefore, a recommendation for the development of a model of professional learning to support argumentation includes group communication and dialogue. The strategy of including dialogue as an approach to adult learning is based on the considerable amount of research on the role of conversation in learning. Authors such as Easton (2008), Fullan (2007), and Darling-Hammond with her colleagues (2009) have redefined what constitutes high-quality teacher learning. They suggest that teachers need to become professional learners who can learn to change and adapt on an ongoing basis in collaboration with others, versus the idea that teachers are developed or trained by others. As discussed by Darling-Hammond et al. (2009) and Fullen (2007), one shot, sit-and-get professional development days, where teachers are the passive receivers of information, have undergone a tremendous amount of scrutiny. Among other considerations, effective professional development needs to include conversations (Fullen, 2007). As summarized by Rowland (2012), many studies have analyzed this collaborative relationship as conversation-based professional development (Levine & Marcus, 2007, 2010; Nelson & Slavit, 2008; Prestridge, 2009). Additional studies have looked at the role of dialogue within various teacher-learning groups or learning communities (Craig, 2004, 2007; Darling-Hammond et al., 2009; Doppelt et al., 2009; DuFour, DuFour, Eaker, & Many, 2006; Fullan, 2007; Lave & Wenger, 1991; Servage, 2008). These researchers collectively support the idea that adult learning is socially constructed through conversation, or dialogue, and is a necessary process to move a learner towards higher-level cognition. Levine and Marcus (2007) encouraged professional development leaders to create *"spaces for teachers to talk and engage in practices together rather than seeking to control individuals and deprive them of opportunities to question or alter practices"* (p. 124). Dialogue, as a professional practice that leads to teacher learning, involves *"rich descriptions of practice, attention to evidence, examination of alternative interpretations, and possibilities"* (Feiman-Nemser, 2001, p. 1043).

FUTURE RESEARCH DIRECTIONS

The emphasis on argumentation is rich in possibilities for future research (Bulgren & Ellis, 2012). The research on and development of learning supports for the components of argumentation through educational games may well be one of those fruitful areas that could promote our understandings of how students learn within and across content areas, subjects, domains, and disciplines. For example, games could be developed that are sequenced in terms of the components of argumentation, ranging from foundational to discipline specific. As a result, some games could be developed that focus on common components of argumentation such as claims, qualifiers, evidence and reasoning. Then, subsequent games could build on what students have learned from those previous games to introduce more specialized components of argumentation required in different subject areas and disciplines.

There also remains the opportunity for continued study of the impact of casual games on learning. Questions that teachers would be able to address within their instruction are whether the positive emotional attachment to a game created by its specific features influence students' attitudes towards its content. Or, can educational games that are specifically designed to heighten emotional attachment be an integral part of the instruction of complex and difficult skills? Given the role of dialogue in learning, does the opportunity to score players' chat in the online conversation improve the overall quality of the discourse? From the teacher's perspective, there is a tremendous amount of information provided about the performance of individual students, as well as the whole class. How could teachers integrate the sharing of this information with students as a component of instruction, and does teachers' access to and use of this information improve teaching and learning?

CONCLUSION

The use of an online, multiplayer game to engage middle school students in the science practice of argumentation provides students an opportunity to engage in a very difficult to learn skill in an easy to learn game format. The overall goal of using a game, such as *Reason Racer*, is to engage students in a way that is fun and compelling. The requirement that teachers expose their students to the game across a variety of scenarios, for a minimum of 10 play sessions in a semester, is a strategy designed to give students sufficient opportunities to deal with the components of argumentation in a fast-paced environment, using both feedback and competition to engage them in play. Research demonstrates that use of the game in this manner is successful both in engaging the players in the skills and concepts related to scientific argumentation, and affecting their confidence and motivation in addressing science claims – to think like a scientist.

ACKNOWLEDGMENT

This material is based upon work supported by the National Science Foundation: Award No. ESI-0554414, Professional Development Materials to Develop Student Knowledge and Skills of Scientific Argumentation and Award No. DRL-1019842, The Evidence Games: Collaborative Games Engaging Middle School Students in the Evaluation of Scientific Evidence.

Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

REFERENCES

Achieve, Inc. (2013). *Next Generation Science Standards*. Retrieved from http://www.nextgenscience.org/

Achieve, Inc. (2014). *The Educators Evaluating the Quality of Instructional Products (EQuIP) rubric for lessons & units: Science source*. Retrieved from http://www.nextgenscience.org/equip-rubric-science-released

Agarwal, R., & Karahanna, E. (2000). Time flies when you're having fun: Cognitive absorption and beliefs about information technology usage. *Management Information Systems Quarterly*, *24*(4), 665–694. doi:10.2307/3250951

Alozie, N. M., Moje, E. B., & Krajcik, J. S. (2010). An analysis of the supports and constraints for scientific discussion in high school project-based science. *Science Education*, *94*(3), 395–427.

Anderson, L. W., Krathwohl, D. R., Airasian, P. W., Cruikshank, K. A., Mayer, R. E., Pintrich, P. R., & Wittrock, M. C. et al. (2001). *A taxonomy for learning, teaching, and assessing: A revision of Bloom's taxonomy of educational objectives, abridged edition*. White Plains, NY: Longman.

Apperley, T. H. (2006). Genre and game studies. *Simulation & Gaming*, *37*(1), 6–23. doi:10.1177/1046878105282278

Ault, M., Craig Hare, J., Bulgren, J., & Ellis, J. (2012). Analysis of a game feature designed to heighten engagement and learning. In P. Resta (Ed.), Proceedings of Society for Information Technology & Teacher Education International Conference 2012. Chesapeake, VA: AACE. Retrieved from http://www.editlib.org/p/39952

Ault, M., Craig-Hare, J., & Frey, B. (2014). *Game feature designed to increase engagement and learning*. Manuscript submitted for publication.

Ault, M., Craig-Hare, J., Frey, B., Ellis, J., & Bulgren, J. (2015). The effectiveness of Reason Racer, a game designed to engage middle school students in scientific argumentation. *Journal of Research on Technology in Education*, *47*(1), 1–21. doi:10.1080/15391523.2015.967542

Barab, S., Thomas, M., Dodge, T., Carteaux, R., & Tuzun, H. (2005). Making learning fun: Quest Atlantis, a game without guns. *Educational Technology Research and Development*, *53*(1), 86–107. doi:10.1007/BF02504859

Barab, S., Zuiker, S., Warren, S., Hickey, D., Ingram-Goble, A., Kwon, E. J., & Herring, S. C. et al. (2007). Situationally embodied curriculum: Relating formalisms and contexts. *Science Education*, *91*(5), 750–782. doi:10.1002/sce.20217

Blanchard, J. S., & Cheska, A. (1985). *The anthropology of sport: An introduction*. Bergin and Garvey.

Bulgren, J. A., & Ellis, J. D. (2012). Argumentation and evaluation intervention in science classes: Teaching and learning with Toulmin. In M. S. Kline (Ed.), *Perspectives on scientific argumentation: Theory, practice, and research* (pp. 135–154). New York, NY: Springer. doi:10.1007/978-94-007-2470-9_8

Bulgren, J. A., Ellis, J. D., & Marquis, J. (2014). The use and effectiveness of an argumentation and evaluation intervention in science classes. *Journal of Science Education and Technology*, *23*(1), 82–97. doi:10.1007/s10956-013-9452-x

Bybee, R. W. (2011). Scientific and engineering practices in K-12 classrooms. *Science Scope*, *35*(4), 6–13.

Chaffin, J. D. (1982). Arc-Ed curriculum: Applicability for severely handicapped pupils. *Journal of Special Education Technology*, *5*(4), 69–70.

Chaffin, J. D., Maxwell, B., & Thompson, B. (1982). ARC-ED curriculum: The application of video game formats to educational software. *Exceptional Children*, *49*, 173–178.

Choi, D., Kim, H., & Kim, J. (2000). A cognitive and emotional strategy for computer game design. *Journal of MIS Research*, *10*, 165–187.

Choi, D. H., & Kim, J. (2004). Why people continue to play online games: In search of critical design factors to increase customer loyalty to online contents. *Cyberpsychology & Behavior*, *7*(1), 11–24. doi:10.1089/109493104322820066 PMID:15006164

Churches, A. (2008). Bloom's Taxonomy blooms digitally. *Tech & Learning*. Retrieved from http://www.techlearning.com/article/8670

Conley, M. W. (2008). Cognitive strategy instruction for adolescents: What we know about the promise, what we don't know about the potential. *Harvard Educational Review*, *78*(1), 84–106. doi:10.17763/haer.78.1.j612282134673638

Craig, C. J. (2004). Shifting boundaries on the professional knowledge landscape: When teacher communications become less safe. *Curriculum Inquiry*, *34*(4), 395–424. doi:10.1111/j.1467-873X.2004.00304.x

Craig, C. J. (2007). Story constellations: A narrative approach to contextualizing teachers' knowledge of school reform. *Teaching and Teacher Education*, *23*(2), 173–188. doi:10.1016/j.tate.2006.04.014

Crawford, C. (1984). *The art of computer game design*. Washington State University.

Crawford, C. (2003). *Chris Crawford on game design*. San Francisco: New Riders.

Csíkszentmihályi, M. (1975). *Beyond boredom and anxiety*. San Francisco: Jossey-Bass.

Csikszentmihalyi, M. (1997). *Finding flow: The psychology of engagement with everyday life*. New York: Basic Books.

Danielsson, K., & Wiberg, C. (2006). Participatory design of learning media: Designing educational computer games with and for teenagers. *Interactive Technology and Smart Education*, *3*(4), 275–291. doi:10.1108/17415650680000068

Darling-Hammond, L., & McLaughlin, M. W. (1995). Policies that support professional development in an era of reform. *Phi Delta Kappan*, *76*(8), 597–604.

Darling-Hammond, L., Wei, R. C., Andree, A., Richardson, N., & Orphanos, S. (2009). *Professional learning in the learning profession*. Washington, DC: National Staff Development Council.

De Byl, P. K., & Brand, J. E. (2011). Designing games to motivate student cohorts through targeted game genre selection. In Handbook of research on improving learning and motivation through educational games: Multidisciplinary approaches, (pp. 567-582). Hershey, PA: IGI Global.

de Freitas, S. (2006). Learning in immersive worlds: A review of game-based learning. *Joint Information Systems Committee*. Retrieved from http://www.jisc.ac.uk/media/documents/programmes/elearninginnovation/gamingreport_v3.pdf

de Freitas, S. (2008). Serious virtual worlds: A scoping study. *Joint Information Systems Committee*. Retrieved from http://www.jisc.ac.uk/media/documents/publications/ seriousvirtualworldsv1.pdf

Dickey, M. D. (2007). Game design and learning: A conjectural analysis of how massively multiple online role-playing games (MMORPGs) foster intrinsic motivation. *Educational Technology Research and Development*, *55*(3), 253–273. doi:10.1007/s11423-006-9004-7

Doppelt, Y., Schunn, C., Silk, E., Mehalik, M., Reynolds, B., & Ward, E. (2009). Evaluating the impact of a facilitated learning community approach to professional development on teacher practice and student achievement. *Research in Science & Technological Education*, *27*(3), 339–354. doi:10.1080/02635140903166026

Driver, R., Newton, P., & Osborne, D. (2000). Establishing the norms of scientific argumentation in classrooms. *Science Education*, *84*(3), 287–312. doi:10.1002/(SICI)1098-237X(200005)84:3<287::AID-SCE1>3.0.CO;2-A

DuFour, R., DuFour, R., Eaker, R., & Many, T. (2006). *Learning by doing: A handbook for professional learning communities at work*. Bloomington, IN: Solution Tree.

Duschl, R. A., & Osborne, J. (2002). Supporting and promoting argumentation discourse in science education. *Studies in Science Education*, *38*(1), 39–72. doi:10.1080/03057260208560187

Evans, M., Norton, A., Chang, M., Deckard, K., & Balci, O. (2013). Youth and video games: Exploring the effects of learning, achievement, and engagement. *Zeitschrift fur Psychologie mit Zeitschrift fur Angewandte Psychologie*, *221*(2), 98–106. doi:10.1027/2151-2604/a000135

Feiman-Nemser, S. (2001). From preparation to practice: Designing a continuum to strengthen and sustain teaching. *Teachers College Record*, *103*(6), 1014–1055. doi:10.1111/0161-4681.00141

Fullan, M. (2007). Change the terms for teacher learning. *Journal of Staff Development*, *28*(3), 35–36.

Fullan, M. (Ed.). (2014). *Teacher development and educational change*. New York: Routledge.

Garmston, R. J., & Wellman, B. M. (2013). *The adaptive school: A sourcebook for developing collaborative groups*. Lanham, MD: Rowman & Littlefield.

Garris, R., Ahlers, R., & Driskell, J. (2002). Games, motivation and learning: A research and practice model. *Simulation & Gaming*, *33*(4), 441–467. doi:10.1177/1046878102238607

Guha, M. L., Druin, A., Chipman, G., Fails, J. A., Simms, S., & Farber, A. (2005). Working with young children as technology design partners. *Communications of the ACM*, *48*(1), 39–42. doi:10.1145/1039539.1039567

Halpern, D. F. (1998). Teaching critical thinking for transfer across domains: Disposition, skills, structure training, and metacognitive monitoring. *The American Psychologist*, *53*(4), 449–455. doi:10.1037/0003-066X.53.4.449 PMID:9572008

Hamlen, K. R. (2013). Understanding children's choices and cognition in video game play: A synthesis of three studies. *Zeitschrift fur Psychologie mit Zeitschrift fur Angewandte Psychologie*, *221*(2), 107–114. doi:10.1027/2151-2604/a000136

Heller, R., & Greenleaf, C. L. (2007). Literacy Instruction in the content areas: Getting to the core of middle and high school improvement. Washington, DC: Alliance for Excellent Education. Retrieved from http://all4ed.org/reports-factsheets/literacy-instruction-in-the-content-areas-getting-to-the-core-of-middle-and-high-school-improvement/

Hoffman, D. L., & Novak, T. P. (2009). Flow online: Lessons learned and future prospects. *Journal of Interactive Marketing*, *23*(1), 23–34. doi:10.1016/j.intmar.2008.10.003

Honey, M. A., & Hilton, M. (Eds.). (2011). *Learning science through computer games and simulations*. Washington, DC: National Academy of Sciences.

Hsu, C. L., & Lu, H. P. (2004). Why do people play on-line games? An extended TAM with social influences and flow experience. *Information & Management*, *41*(7), 853–868. doi:10.1016/j.im.2003.08.014

Huang, M. H. (2003). Designing website attributes to induce experiential encounters. *Computers in Human Behavior*, *19*(4), 425–442. doi:10.1016/S0747-5632(02)00080-8

Huang, M. H. (2006). Flow, enduring and situational involvement in the Web environment: A tripartite second-order examination. *Psychology and Marketing*, *23*(5), 383–411. doi:10.1002/mar.20118

Jiménez-Aleixandre, M. P., & Erduran, S. (2007). Argumentation in science education: An overview. In *Argumentation in science education* (pp. 3–27). Springer Netherlands. doi:10.1007/978-1-4020-6670-2_1

Johnson, L., Adams, S., Cummins, M., Estrada, V., Freeman, A., & Ludgate, H. (2013). *The NMC horizon report: 2012 higher education edition.* Retrieved from http://www.nmc.org/publications/2013-horizon-report-higher-ed

Kamil, M. L., Borman, G. D., Dole, J., Kral, C. C., Salinger, T., & Torgesen, J. (2008). *Improving adolescent literacy: Effective classroom and intervention practices: A practice guide (NCEE #2008-4027)*. Washington, DC: U.S. Department of Education, National Center for Education Evaluation and Regional Assistance.

Ke, F., & Grabowski, B. (2007). Gameplaying for maths learning: Cooperative or not? *British Journal of Educational Technology*, *38*(2), 249–259. doi:10.1111/j.1467-8535.2006.00593.x

Kebritchi, M., Hirumi, A., & Bai, H. (2010). The effects of modern mathematics computer games on mathematics achievement and class motivation. *Computers & Education*, *55*(2), 427–443. doi:10.1016/j.compedu.2010.02.007

Ketelhut, D. J., Dede, C., Clarke, J., & Nelson, B. (2006). *A multi-user virtual environment for building higher order inquiry skills in science*. Paper presented at the AERA Annual Meeting, San Francisco, CA. Retrieved from http://muve.gse.harvard.edu/rivercityproject/documents/rivercitysympinq1.pdf

Khalili, N., Sheridan, K., Williams, A., Clark, K., & Stegman, M. (2011). Students designing video games about immunology: Insights for science learning. *Computers in the Schools*, *28*(3), 228–240. doi:10.1080/07380569.2011.594988

Klopfer, E. (2008). *Augmented learning: Research and design of mobile educational games*. Cambridge, MA: MIT Press. doi:10.7551/mitpress/9780262113151.001.0001

Koster, R. (2005). *A theory of fun for game design*. Scottsdale, AZ: Paraglyph Press.

Kuhn, D., Schauble, L., & Garcia-Mila, M. (1992). Cross-domain development of scientific reasoning. *Cognition and Instruction*, *9*(4), 285–327. doi:10.1207/s1532690xci0904_1

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge University Press. doi:10.1017/CBO9780511815355

Lawson, A. (2003). The nature and development of hypothetico-predictive argumentation with implications for science teaching. *International Journal of Science Education*, *25*(11), 1387–1408. doi:10.1080/0950069032000052117

Lazzaro, N. (2004). Why we play games: Four keys to more emotion without story. *Xeodesign*. Retrieved from http://www.xeodesign.com/xeodesign_whyweplaygames.pdf

Lepper, M. R., & Cordova, D. I. (1992). A desire to be taught: Instructional consequences of intrinsic motivation. *Motivation and Emotion*, *16*(3), 187–208. doi:10.1007/BF00991651

Levine, T. H., & Marcus, A. S. (2007). Closing the achievement gap through teacher collaboration: Facilitating multiple trajectories of teacher learning. *Journal of Advanced Academics*, *19*(1), 116–138.

Levine, T. H., & Marcus, A. S. (2010). How the structure and focus of teachers' collaborative activities facilitate and constrain teacher learning. *Teaching and Teacher Education: An International Journal of Research and Studies*, *26*(3), 389–398. doi:10.1016/j.tate.2009.03.001

Li, M. C., & Tsai, C. C. (2013). Game-based learning in science education: A review of relevant research. *Journal of Science Education and Technology*, *22*(6), 877–898. doi:10.1007/s10956-013-9436-x

Malone, T. W. (2012). Collective intelligence 2012. *MIT Sloan Experts*. Retrieved from http://mitsloan-experts.mit.edu/collective-intelligence-2012-prof-tom-malone-on-how-new-technologies-are-changing-the-ways-people-and-computers-work-together/

Malone, T. W., & Lepper, M. R. (1987). Making learning fun: A taxonomy of intrinsic motivations for learning. *Aptitude*. *Learning and Instruction*, *3*, 223–253.

Mayo, M. J. (2007). Games for science and engineering education. *Communications of the ACM*, *50*(7), 30–35. doi:10.1145/1272516.1272536

Mayo, M. J. (2009). Video games: A route to large-scale STEM education? *Science*, *323*(5910), 79–82. doi:10.1126/science.1166900 PMID:19119223

Moreno-Ger, P., Burgos, D., Martínez-Ortiz, I., Sierra, J. L., & Fernández-Manjón, B. (2008). Educational game design for online education. *Computers in Human Behavior*, *24*(6), 2530–2540. doi:10.1016/j.chb.2008.03.012

Muller, M. J., & Druin, A. (2010). *Participatory design: The third space in HCI*. Hillsdale, NJ: Lawrence Erlbaum.

Namioka, A. H., & Rao, C. (1996). Introduction to participatory design. In *Field methods casebook for software design* (pp. 283–299). New York: John Wiley & Sons.

National Center for Education Statistics (NCES). (2012*). National assessment of educational progress.* U.S. Department of Education, Institute of Education Sciences. Retrieved from http://nces.ed.gov/nationsreportcard/

National Governors Association Center for Best Practices, Council of Chief State School Officers. (2010). *Common Core State Standards for English language arts & literacy in history/social studies, science, and technical subjects*. Washington, DC: Author.

National Research Council (NRC). (2007). *Taking science to school: Learning and teaching science in grades K-8.* National Academies Press.

National Research Council (NRC). (2012). *A framework for K-12 science education*. Washington, DC: National Academies Press.

Nelson, T., & Slavit, D. (2008). Supported teacher collaborative inquiry. *Teacher Education Quarterly*, *35*(1), 99–126.

Nikolova-Houston, T. (2005). Using participatory design to improve web sites. *Computers in Libraries*, *25*(9), 20–25.

Osborne, J., Simon, S., Christodoulou, A., Howell-Richardson, C., & Richardson, K. (2013). Learning to argue: A study of four schools and their attempt to develop the use of argumentation as a common instructional practice and its impact on students. *Journal of Research in Science Teaching*, *50*(3), 315–347. doi:10.1002/tea.21073

Pashler, H., Bain, P. M., Bottge, B. A., Graesser, A., Koedinger, K., McDaniel, M., & Metcalfe, J. (2007). *Organizing instruction and study to improve student learning. IES Practice Guide (NCER 2007-2004).* Jessup, MD: National Center for Education Research.

Pellegrino, J. W., & Hilton, M. L. (2013). *Education for life and work: Developing transferable knowledge and skills in the 21st Century.* Washington, DC: National Academies Press.

Penuel, W. R., Fishman, B. J., Yamaguchi, R., & Gallagher, L. P. (2007). What makes professional development effective? Strategies that foster curriculum implementation. *American Educational Research Journal*, *44*(4), 921–958. doi:10.3102/0002831207308221

Plass, J. L., O'Keefe, P. A., Homer, B. D., Case, J., Hayward, E. O., Stein, M., & Perlin, K. (2013). The impact of individual, competitive, and collaborative mathematics game play on learning, performance, and motivation. *Journal of Educational Psychology*, *105*(4), 1050–1066. doi:10.1037/a0032688

Prensky, M. (2005). Listen to the natives. *Educational Leadership*, *63*(4).

Pressley, M., & McCormick, C. (1995). *Cognition, teaching, and assessment*. New York, NY: Harper Collins.

Prestridge, S. (2009). Teachers' talk in professional development activity that supports change in their ICT pedagogical beliefs and practices. *Teacher Development*, *13*(1), 43–55. doi:10.1080/13664530902858493

Rittel, H. W., & Webber, M. M. (2000). Dilemmas in a general theory of planning. *The Science of Public Policy: Policy Analysis II, 4*, 321.

Rosenshine, B., Meister, C., & Chapman, S. (1996). Teaching students to generate questions: A review of the intervention studies. *Review of Educational Research*, *66*(2), 181–221. doi:10.3102/00346543066002181

Rowland, A. (2012). Exploring How Conversations Meet Teacher Learning Needs. In P. Resta (Ed.), *Proceedings of Society for Information Technology & Teacher Education International Conference 2012* (pp. 3043-3047). Chesapeake, VA: AACE.

Sadler, T. D. (2004). Informal reasoning regarding socioscientific issues: A critical review of research. *Journal of Research in Science Teaching*, *41*(5), 513–536. doi:10.1002/tea.20009

Salen, K., & Zimmerman, E. (2004). *Rules of play: Game design fundamentals*. Cambridge, MA: MIT Press.

Sánchez, J., & Olivares, R. (2011). Problem solving and collaboration using mobile serious games. *Computers & Education*, *57*(3), 1943–1952. doi:10.1016/j.compedu.2011.04.012

Sanchez-Franco, M. J. (2006). Exploring the influence of gender on Web usage via partial least squares. *Behaviour & Information Technology*, *25*(1), 19–36. doi:10.1080/01449290500124536

Sarama, J. C., Clements, D. H., & Henry, J. J. (1998). Network of influences in an implementation of a mathematics curriculum innovation. *International Journal of Computers for Mathematical Learning*, *3*(2), 113–148. doi:10.1023/A:1009768005398

Servage, L. (2008). Critical and transformative practices in professional learning communities. *Teacher Education Quarterly*, *35*(1), 63–77.

Shelton, B. E. (2007). Designing educational games for activity-goal alignment. In B. E. Shelton & D. Wiley (Eds.), *The design and use of simulation computer games in education* (pp. 103–130). Rotterdam, The Netherlands: Sense Publishers.

Shih, J. L., Shih, B. J., Shih, C. C., Su, H. Y., & Chuang, C. W. (2010). The influence of collaboration styles to children's cognitive performance in digital problem-solving game ''william adventure'': A comparative case study. *Computers in the Schools*, *55*(3), 982–993. doi:10.1016/j.compedu.2010.04.009

Shin, N., Sutherland, L. M., Norris, C. A., & Soloway, E. (2012). Effects of game technology on elementary student learning in mathematics. *British Journal of Educational Technology*, *43*(4), 540–560. doi:10.1111/j.1467-8535.2011.01197.x

Skadberg, Y. X., & Kimmel, J. R. (2004). Visitors' flow experience while browsing a Web site: Its measurement, contributing factors and consequences. *Computers in Human Behavior*, *20*(3), 403–422. doi:10.1016/S0747-5632(03)00050-5

Squire, K. (2006). From content to context: Videogames as designed experience. *Educational Researcher*, *35*(8), 19–29. doi:10.3102/0013189X035008019

Stevens, R., Wineburg, S., Herrenkohl, L. R., & Bell, P. (2005). Comparative understanding of school subjects: Past, present, and future. *Review of Educational Research*, *75*(2), 125–157. doi:10.3102/00346543075002125

Takeuchi, L. M., & Vaala, S. (2014). *Level up learning: A national survey on teaching with digital games*. New York: The Joan Ganz Cooney Center at Sesame Workshop.

Tams, J. (2006). Online casual games Q&A. *Minna Magazine*, 2-5. Retrieved from http://mag.casualconnect.org/MinnaMagazine_Summer2006.pdf

Toulmin, S., Rieke, R., & Janik, A. (1984). *An introduction to reasoning*. Upper Saddle Ridge, NJ: Prentice Hall.

Toulmin, S. E. (1958). *The uses of argument*. Cambridge, UK: Cambridge University Press.

Toulmin, S. E. (2003). *The uses of argument*. Cambridge, UK: Cambridge University Press. doi:10.1017/CBO9780511840005

Vogel, J. J., Vogel, D. S., Cannon-Bowers, J., Bowers, C. A., Muse, K., & Wright, M. (2006). Computer gaming and interactive simulations for learning: A meta-analysis. *Journal of Educational Computing Research*, *34*(3), 229–243. doi:10.2190/FLHV-K4WA-WPVQ-H0YM

Wallace, M., & Robbins, B. (Eds.). (2006). *IGDA 2006 casual games white paper*. Retrieved from http://www.igda.org/casual/IGDA_CasualGames_Whitepaper_2006.pdfWaugh, 2006

Warschauer, M., & Matuchniak, T. (2010). New technology and digital worlds: Analyzing evidence of equity in access, use, and outcomes. *Review of Research in Education*, *34*(1), 179–225.

Waugh, E. (2006*). An introduction to casual games.* GDC: Casual Games Summit 2006. Retrieved from http://www.gamasutra.com/view/feature/131030/gdc_casual_games_summit_2006_an_.php

Wenglinsky, H. (2005). Technology and achievement: The bottom line. *Educational Leadership*, *63*(4), 29.

Woolley, A. W., Chabris, C. F., Pentland, A., Hashmi, N., & Malone, T. W. (2010, October). Evidence for a collective intelligence factor in the performance of human groups. *Science*, *330*(6004), 686–688. doi:10.1126/science.1193147 PMID:20929725

Xin, J. F. (1999). Computer-assisted cooperative learning in integrated classrooms for students with and without disabilities. *Information Technology in Childhood Education Annual*, (1): 61–78.

Compilation of References

Abrahamson, L. (2006). A brief history of networked classrooms: Effects, cases, pedagogy, and implications. In D. A. Banks (Ed.), *Audience response systems in higher education: Applications and cases* (pp. 1–25). Hershey, PA: Information Science Publishing. doi:10.4018/978-1-59140-947-2.ch001

AbuSeileek, A. F. (2013). Using track changes and word processor to provide corrective feedback to learners in writing. *Journal of Computer Assisted Learning*, *29*(4), 319–333. doi:10.1111/jcal.12004

Achieve, Inc. (2013). *Next Generation Science Standards*. Retrieved from http://www.nextgenscience.org/

Achieve, Inc. (2014). *The Educators Evaluating the Quality of Instructional Products (EQuIP) rubric for lessons & units: Science source*. Retrieved from http://www.nextgenscience.org/equip-rubric-science-released

Adams, W. (2006). *The Future of Sustainability: Re-thinking Environment and Development in the Twenty-first Century*. The World Conservation Union. Report of the IUCN Renowned Thinkers Meeting.

Adams, L. G. (2011). Engaging middle school students with technology: Using real-time data to test predictions in aquatic ecosystems. *Science Scope*, *34*(9), 28–32.

Adams, L. G., & Matsumoto, G. (2009). Enhancing ocean literacy using real-time data. *Oceanography (Washington, D.C.)*, *22*(2), 12–13. doi:10.5670/oceanog.2009.55

Adams, W., Reid, S., Lemaster, R., McKagan, S., Perkins, K., Dubson, M., & Wieman, C. (2008). A study of educational simulations: Part I – engagement and learning. *Journal of Interactive Learning Research*, *19*(3), 997–419.

Agarwal, R., & Karahanna, E. (2000). Time flies when you're having fun: Cognitive absorption and beliefs about information technology usage. *Management Information Systems Quarterly*, *24*(4), 665–694. doi:10.2307/3250951

Akaygun, S., & Jones, L. L. (2013). Research-based design and development of a simulation of liquid–vapor equilibrium. *Chemistry Education Research and Practice*, *14*(3), 324–344. doi:10.1039/C3RP00002H

Akerson, V. L., & Dickinson, L. E. (2003). Using GIS Technology To Support K-8 Scientific Inquiry Teaching and Learning. *Science Educator*, *12*(1), 41–47.

Aklilu, T., Tilahun, T., & Mesfin, T. (2011). Effectiveness of Computer Simulations in the Teaching/Learning of Physics. In *Proceedings of the 2011 Annual Meeting of the National Association for Research in Science Teaching (NARST)*. Orlando, FL: Academic Press.

Alberti, M. (2008). *Advances in Urban Ecology: Integrating humans and Ecological Processes in Urban Ecosystems*. New York: Springer. doi:10.1007/978-0-387-75510-6

Allen, D. W. (1966). A new design for teacher education: The teacher intern program at Stanford University. *Journal of Teacher Education*, *17*(3), 296–300. doi:10.1177/002248716601700304

Alozie, N. M., Moje, E. B., & Krajcik, J. S. (2010). An analysis of the supports and constraints for scientific discussion in high school project-based science. *Science Education*, *94*(3), 395–427.

American Association for the Advancement of Science (AAAS). (1998). *Blueprints for reform science, mathematics, and technology education.* New York, NY: Oxford University Press.

American Association for the Advancement of Science. (1989, 2008). Project 2061. Science for all Americans. Washington, DC: Author.

American Association for the Advancement of Science. (1993). *Benchmarks for science literacy*. New York: Oxford University Press.

American Association of University Women Educational Foundation. (1999). *Gender gaps: Where schools still fail our children*. New York: Marlowe & Company.

American Institute of Physics. (1998). *Children's misconceptions about science*. Retrieved February 18, 2015, from http://amasci.com/miscon/opphys.html

Anderson, A. (2002). Reforming science teaching: What research says about inquiry. *Journal of Science Teacher Education*, *13*(1), 1–12. doi:10.1023/A:1015171124982

Anderson, L. W., & Krathwohl, D. R. (2001). *A taxonomy for learning, teaching, and assessing: A revision of Bloom's taxonomy of educational objectives*. New York, NY: Longman.

Anderson, L. W., & Krathwohl, D. R. (Eds.). (2001). *A taxonomy for learning, teaching, and assessing: A revision of Bloom's taxonomy of educational objectives*. New York: Longman.

Anderson, L. W., Krathwohl, D. R., Airasian, P. W., Cruikshank, K. A., Mayer, R. E., Pintrich, P. R., & Wittrock, M. C. et al. (2001). *A taxonomy for learning, teaching, and assessing: A revision of Bloom's taxonomy of educational objectives, abridged edition*. White Plains, NY: Longman.

Anderson, P. H., & Lawton, L. (2004). Simulation exercises and problem-based learning: Is there a fit? *Developments in Business Simulations and Experiential Exercises*, *31*, 183–188.

Anderson, P. H., & Lawton, L. (2007). Simulation performance and its effectiveness as a PBL problem: A follow-up study. *Developments in Business Simulation and Experiential Learning*, *34*, 43–50.

Andrei, E. (2014). Digital Technology in Three Middle School ESL Language Arts Classrooms. *TESL Reporter*, *47*(1/2), 35–50.

Annetta, L. A. (2008). Video games in education: Why they should be used and how they are being used. *Theory into Practice*, *47*(3), 229–239. doi:10.1080/00405840802153940

Annetta, L. A., Murray, M., Gull-Laird, S., Bohr, S., & Park, J. C. (2006). Serious games: Incorporating video games in the classroom. *EDUCAUSE Quarterly*, *29*(3), 16–22.

Apperley, T. H. (2006). Genre and game studies. *Simulation & Gaming*, *37*(1), 6–23. doi:10.1177/1046878105282278

Applefield, J. M., Huber, R. L., & Moallem, M. (2000). Constructivism in theory and practice: Toward a better understanding. *High School Journal*, *84*(2), 35–46.

Archer, L., DeWitt, J., Osborne, J., Dillon, J., Willis, B., & Wong, B. (2010). "Doing" science versus "Being" a scientist: Examining 10/11-year-old schoolchildren's constructions of science through the lens of identity. *Science Education*, *94*(4), 617–639. doi:10.1002/sce.20399

Arroyo, I., Woolf, B. P., Royer, J. M., & Tai, M. (2009). Affective gendered learning companion. In *Proceedings of International Conference on Artificial Intelligence and Education* (pp. 41-48). Brighton, UK: IOS Press

Ary, D., Jacobs, L. C., Razavieh, A., & Sorensen, C. (2006). *Introduction to Research in Education* (7th ed.). Belmont, CA: Thomson Wadsworth.

Ault, M., Craig Hare, J., Bulgren, J., & Ellis, J. (2012). Analysis of a game feature designed to heighten engagement and learning. In P. Resta (Ed.), Proceedings of Society for Information Technology & Teacher Education International Conference 2012. Chesapeake, VA: AACE. Retrieved from http://www.editlib.org/p/39952

Ault, M., Craig-Hare, J., & Frey, B. (2014). *Game feature designed to increase engagement and learning.* Manuscript submitted for publication.

Ault, M., Craig-Hare, J., Frey, B., Ellis, J., & Bulgren, J. (2015). The effectiveness of Reason Racer, a game designed to engage middle school students in scientific argumentation. *Journal of Research on Technology in Education*, *47*(1), 1–21. doi:10.1080/15391523.2015.967542

Austin, J. L. (1962). *How to do things with words*. Cambridge, MA: Harvard University Press.

BAESI. (2011). *Education for Sustainability Teacher Survey*. San Jose, CA: Bay Area Earth Science Institute.

Bagiati, A., Yoon, S. Y., Evangelou, D., & Ngambeki, I. (2010). Engineering curricula in early education: Describing the landscape of open resources. *Early Childhood Research and Practice, 12*(2). Retrieved January 15, 2015, from http://ecrp.uiuc.edu/v12n2/bagiati.html

Bain, A., & Weston, M. E. (2011). *The learning edge: What technology can do to educate all children.* New York: Teachers College Press.

Baker, T. R., & White, S. H. (2003). The effects of GIS on students' attitudes, self-efficacy, and achievement in middle school science classrooms. *The Journal of Geography*, *102*(6), 243–254. doi:10.1080/00221340308978556

Bakhtin, M. M. (1981). *The dialogic imagination*. Austin, TX: University of Texas Press.

Bandura, A. (1977). *Social learning theory*. Englewood Cliffs, NJ: Prentice Hall.

Bangert-Drowns, R. L., Kulik, C. C., Kulik, J. A., & Morgan, M. T. (1991). The instructional effect of feedback in test-like events. *Review of Educational Research*, *61*(2), 213–238. doi:10.3102/00346543061002213

Barab, S., & Squire, K. (2004). Design-based research: Putting a stake in the ground. *Journal of the Learning Sciences*, *13*(1), 1–14. doi:10.1207/s15327809jls1301_1

Barab, S., Thomas, M., Dodge, T., Carteaux, R., & Tuzun, H. (2005). Making learning fun: Quest Atlantis, a game without guns. *Educational Technology Research and Development*, *53*(1), 86–107. doi:10.1007/BF02504859

Barab, S., Zuiker, S., Warren, S., Hickey, D., Ingram-Goble, A., Kwon, E. J., & Herring, S. C. et al. (2007). Situationally embodied curriculum: Relating formalisms and contexts. *Science Education*, *91*(5), 750–782. doi:10.1002/sce.20217

Barnett, M., MaKinster, J., Trautmann, N., Houle, M., & Mark, S. (2012). Geospatial technologies: The present and future roles of emerging technologies in environmental education. In R. Stevenson, M. Brody, J. Dillon, & A. Walls (Eds.), International Handbook of Research on Environmental Education (pp. 327-344). Washington, DC: American Educational Research Association.

Barnett, M., Houle, M., Hirsch, L., Minner, D., Strauss, E., Mark, S., & Hoffman, E. (2013). Participatory professional development: Geospatially enhanced urban ecological field studies. In J. Makinster, N. Trautmann, & M. Barnett (Eds.), *Teaching Science and Investigating Environmental Issues with Geospatial Technology: Designing Effective Professional Development for Teachers* (pp. 13–33). New York, NY: Springer.

Barron, B., & Darling-Hammond, L. (2010). Powerful learning: Studies show deep understanding derives from collaborative methods. *Edutopia*. Retrieved Oct., 2014, from www.edutopia.org/inquiry-project-learning-research

Barr, V., & Stephenson, C. (2011). Bringing computational thinking to K-12: What is involved and what is the role of the computer science education community? *ACM Inroads*, *2*(1), 48–54. doi:10.1145/1929887.1929905

Barton, A. C. (2007). Science learning in urban settings. In S. K. Abell & N. G. Lederman (Eds.), *Handbook of research on science education* (pp. 319–343). Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Baylor, A. L., & Ritchie, D. (2002). What factors facilitate teacher skill, teacher morale, and perceived student learning in technology-using classrooms? *Computers & Education*, *39*(4), 395–414. doi:10.1016/S0360-1315(02)00075-1

Beatty, I. D. (2013). *Improving physics instruction by analyzing video games. 2012 Physics Education Research Conference* (pp. 70–73). Philadelphia: AIP Publishing.

Beatty, I. D., & Gerace, W. J. (2009). Technology-enhanced formative assessment: A research-based pedagogy for teaching science with classroom response technology. *Journal of Science Education and Technology*, *18*(2), 146–162. doi:10.1007/s10956-008-9140-4

Beauchamp, G., & Kennewell, S. (2008). The influence of ICT on the interactivity of teaching. *Education and Information Technologies*, *13*(4), 305–315. doi:10.1007/s10639-008-9071-y

Becker, K. H., & Park, K. (2011). Integrative approaches among Science, Technology, Engineering, and Mathematics (STEM) subjects on students' learning: A meta-analysis. *Journal of STEM Education: Innovations and Research, 12*(5-6), 23-37. (EJ943196)

Bell, T., Witten, I. H., & Fellows, M. (2009). *Computer science unplugged*. Retrieved February 10, 2015, from http://csunplugged.org

Bell, B., & Cowie, B. (2001). The characteristics of formative assessment in science education. *Science Education*, *85*(5), 536–553. doi:10.1002/sce.1022

Bell, P. L. (2004). On the theoretical breadth of design-based research in education. *Educational Psychologist*, *39*(4), 243–253. doi:10.1207/s15326985ep3904_6

Bell, R. L., & Smentana, L. K. (Eds.). (2008). *Using computer simulations to enhance science teaching and learning in technology in the secondary science classroom*. Washington, DC: NSTA Press.

Bell, R. L., & Trundle, K. C. (2008). The use of a computer simulation to promote scientific conceptions of moon phases. *Journal of Research in Science Teaching*, *45*(3), 346–372. doi:10.1002/tea.20227

Bell, W. H., Fowler, E. M., & Stein, J. A. (2003). Coastal seas as a context for science teaching: A lesson from Chesapeake Bay. *Marine Pollution Bulletin*, *47*(1-6), 253–259. doi:10.1016/S0025-326X(02)00468-X PMID:12787628

Bencze, J. L., & Bowen, G. M. (2007). Student-teachers' dialectically developed motivation for promoting student-led science projects. *International Journal of Science and Mathematics Education*, *7*(1), 133–159. doi:10.1007/s10763-007-9115-6

Berkowitz, A., Nilon, C., & Hollweg, K. (Eds.). (2003). *Understanding urban ecosystems: A new frontier for science and education*. New York: Springer.

Berlin, D., & Lee, H. (2005). Integrating science and mathematics education: Historical analysis. *School Science and Mathematics*, *105*(1), 15–24. doi:10.1111/j.1949-8594.2005.tb18032.x

Best, J. (2001). *Damned Lies and Statistics*. Berkeley, CA: University of California Press.

Bishop, A. J. (1988). Mathematics education in its cultural context. *Educational Studies in Mathematics*, *19*(2), 179–191. doi:10.1007/BF00751231

Black, K. (2004). Science in the trenches: An exploration of four pre-service teachers' first attempts at teaching science in the classroom. *International Journal of Science and Mathematics Education*, *00*, 1–20.

Black, P., Harrison, C., Lee, C., Marshall, B., & Wiliam, D. (2003). *Assessment for learning*. Berkshire, England: Open University Press.

Black, P., & Wiliam, D. (1998). Inside the black box: Raising standards through classroom assessment. *Phi Delta Kappan*, *80*(2), 139–148.

Black, P., & William, D. (2009). Developing the theory of formative assessment. *Educational Assessment, Evaluation and Accountability*, *21*(1), 5–31. doi:10.1007/s11092-008-9068-5

Black, S. (2005). Teaching students to think critically. *Education Digest*, *70*(6), 42–47.

Blair, N. (2012). Technology integration for the new 21st century learner. *Principal*, (Jan/Feb): 8–12.

Blanchard, J. S., & Cheska, A. (1985). *The anthropology of sport: An introduction*. Bergin and Garvey.

Blickenstaff, J. C. (2005). Women and science careers: Leaky pipeline or gender filter. *Gender and Education*, *17*(4), 369–386. doi:10.1080/09540250500145072

Bloom, B. S., Engelhart, M. D., Furst, E. J., Hill, W. H., & Krathwohl, D. R. (1956). *Taxonomy of educational objectives: The classification of educational goals. Handbook I: Cognitive domain*. New York, NY: David McKay Company, Inc.

Bodner, G. M. (2006). The role of theoretical frameworks in chemistry/science education. In *Theoretical frameworks fo research in chemistry/science education* (pp. 2–26). Upper Saddle River, NJ: Prentice Hall.

Bodzin, A. M. (2008). Integrating instructional technologies in a local watershed investigation with urban elementary learners. *The Journal of Environmental Education*, *39*(2), 47–58. doi:10.3200/JOEE.39.2.47-58

Bodzin, A. M. (2011). The implementation of a geospatial information technology (GIT)-supported land use change curriculum with urban middle school learners to promote spatial thinking. *Journal of Research in Science Teaching*, *48*(3), 281–300. doi:10.1002/tea.20409

Bodzin, A. M., & Shive, L. (2004). Designing for watershed inquiry. *Applied Environmental Education and Communication*, *3*(4), 249–258. doi:10.1080/15330150490881903

Bogdan, R. C., & Biklen, S. K. (1998). *Qualitative research for education: An introduction to theory and methods* (3rd ed.). Boston: Allyn & Bacon.

Bolter, J. D., & Grus, R. (1999). *Remediation: Understanding new media*. Cambridge, MA: MIT Press.

Bontá, P., Papert, A., & Silverman, B. (2010). Turtle, art, TurtleArt. In Proceedings of Constructionism. Paris, France: Academic Press.

Bonwell, C. C., & Eison, J. A. (1991) *Active learning: Creating excitement in the classroom*. Association for the Study of Higher Education (ASHE) ERIC Higher Education Report No. 1. Washington, DC: George Washington University.

Boon, H. J. (2011). Beliefs and Education for Sustainability in Rural and Regional Australia. *Education in Rural Austratlia, 21*(2).

Borko, H., Stecher, B. M., & Kuffner, K. (2007). *Using artifacts to characterize reform-oriented instruction: The Scoop Notebook and Rating Guide.* CSE Technical Report 707. The Regents of the University of California.

Borko, H., Peressini, D., Romagnano, L., & Knuth, E. (2000). *Teacher education does matter: A situative view of learning to teach secondary mathematics*. Lawrence Erlbaum.

Boström, M. (2012). A missing pillar? Challenges in theorizing and practicing social sustainability: introduction to the special issue. *Sustainability: Science, Practice, & Policy*, *8*(1), 3–14.

Bouras, C. J., Poulopoulos, V., & Tsogkas, V. (2010). Squeak Etoys: Interactive and collaborative learning environments. In *Handbook of research on social interaction technologies and collaboration software: Concepts and trends* (pp. 417–427). Hershey, PA: IGI Global; doi:10.4018/978-1-60566-368-5.ch037

Bowden, J., Dall'Alba, G., Martin, E., Laurillard, D., Marton, F., Masters, G., & Walsh, E. et al. (1992). Displacement, velocity, and frames of reference: Phenomenographic studies of students' understanding and some implications for teaching and assessment. *American Journal of Physics*, *60*(3), 262–269. doi:10.1119/1.16907

Bowen, G. M., & Roth, W.-M. (2003). Graph interpretation practices of science and education majors. *Canadian Journal of Science*. *Mathematics and Technology Education*, *3*(4), 498–512. doi:10.1080/14926150309556585

Bowen, G. M., & Roth, W.-M. (2005). Data and graph interpretation practices among preservice science teachers. *Journal of Research in Science Teaching*, *42*(10), 1063–1088. doi:10.1002/tea.20086

Brand, G. A. (1997). Training teachers for using technology. *Journal of Staff Development*, *19*(1).

Brennan, K., & Resnick, M. (2013, April). *New frameworks for studying and assessing the development of computational thinking.* Paper presented at the American Educational Research Association (AERA), Vancouver, Canada.

Brickhouse, N. W., Lowery, P., & Schultz, K. (2000). What kind of girl does science? The construction of school science identities. *Journal of Research in Science Teaching*, *37*(5), 441–458. doi:10.1002/(SICI)1098-2736(200005)37:5<441::AID-TEA4>3.0.CO;2-3

Briggs, M., & Bodner, G. (2007). A model of molecular visualization. In J. Gilbert (Ed.), *Visualization in science education* (pp. 61–72). Dordrecht, Netherlands: Springer.

Britner, S. L., & Finson, K. D. (2005). Preservice teachers' reflections on their growth in an inquiry-oriented science pedagogy course. *Journal of Elementary Science Education*, *17*(1), 39–54. doi:10.1007/BF03174672

Brown, S., Race, P., & Bull, J. (1999). Computer-assisted assessment in higher education. Birmingham, UK: Staff and Educational Development Association (SEDA).

Brown, A. L. (1992). Design experiments: Theoretical and methodological challenges in creating complex interventions in classroom settings. *Journal of the Learning Sciences*, *2*(2), 141–178. doi:10.1207/s15327809jls0202_2

Brown, B. A. (2006). "It isn't no slang that can be said about this stuff": Language, identity, and appropriating science discourse. *Journal of Research in Science Teaching*, *43*(1), 96–126. doi:10.1002/tea.20096

Brush, J. W., & Saye, T. A. (2002). A Summary of research exploring hard and soft scaffolding for teachers and students using a multimedia supported learning environment. *Journal of Interactive Online Learning*, *1*(2), 1–12.

Buchanan, T. (2000). The efficacy of a world-wide web mediated formative assessment. *Journal of Computer Assisted Learning*, *16*(3), 193–200. doi:10.1046/j.1365-2729.2000.00132.x

Buck, L. B., Bretz, S. L., & Towns, M. H. (2008). Characterizing the level of inquiry in the undergraduate laboratory. *Journal of College Science Teaching*, *38*(1), 52–58.

Bulgren, J. A., & Ellis, J. D. (2012). Argumentation and evaluation intervention in science classes: Teaching and learning with Toulmin. In M. S. Kline (Ed.), *Perspectives on scientific argumentation: Theory, practice, and research* (pp. 135–154). New York, NY: Springer. doi:10.1007/978-94-007-2470-9_8

Bulgren, J. A., Ellis, J. D., & Marquis, J. (2014). The use and effectiveness of an argumentation and evaluation intervention in science classes. *Journal of Science Education and Technology*, *23*(1), 82–97. doi:10.1007/s10956-013-9452-x

Burmeister, M., Schmidt-Jacob, S., & Eilks, I. (2013). German chemistry teachers' understanding of sustainability and education for sustainable developmet - An interview case study. *Chemistry Education Research and Practice*. doi:10.1039/c2rp20137b

Bybee, R. W. (2011). Scientific and engineering practices in K-12 classrooms. *Science Scope*, *35*(4), 6–13.

Caldwell, J. E. (2007). Clickers in the large classroom: Current research and best-practice tips. *CBE Life Sciences Education*, *6*(1), 9–20. doi:10.1187/cbe.06-12-0205 PMID:17339389

Campbell, J. O., Bourne, J. R., Mosterman, P. J., & Brodersen, A. J. (2002). The effectiveness of learning simulations for electronic laboratories. *The Journal of Engineering Education*, *91*(1), 81–87. doi:10.1002/j.2168-9830.2002.tb00675.x

Campbell, T., Longhurst, M., Wang, S.-K., Hsu, H.-Y., & Coster, D. (2015). Technologies and reform-based science instruction: The examination of a professional development model focused on supporting science teaching and learning with technologies. *Journal of Science Education and Technology*, *24*(5), 562–579. doi:10.1007/s10956-015-9548-6

Cantrell, P., Young, S., & Moore, A. (2003). Factors affecting science teaching efficacy of preservice elementary teachers. *Journal of Science Teacher Education*, *14*(3), 177–192. doi:10.1023/A:1025974417256

Carini, R. M., Kuh, G. D., & Klein, S. P. (2006). Student Engagement and Student Learning: Testing the Linkages*. *Research in Higher Education*, *47*(1), 1–32. doi:10.1007/s11162-005-8150-9

Carlisle, J. F., Fleming, J. E., & Gudbrandsen, B. (2000). Incidental word learning in science classes. *Contemporary Educational Psychology*, *25*(2), 184–211. doi:10.1006/ceps.1998.1001 PMID:10753546

Carlone, H. B. (2004). The cultural production of science in reform-based physics: Girls' access, participation and resistance. *Journal of Research in Science Teaching*, *41*(4), 392–414. doi:10.1002/tea.20006

Carlson, T. (2007). A Field-Based Learning Experience for Introductory Level GIS Students. *The Journal of Geography*, *106*(5), 193–198. doi:10.1080/00221340701697636

CDE (Colorado Department of Education). (2013a). *Fall 2013 PK-12 free and reduced lunch eligibility by school* [Excel file]. Retrieved from http://www.cde.state.co.us/cdereval/fall2013pk12frleligibilitybydistrictandschoolxls

CDE (Colorado Department of Education). (2013b). *2013 PK-12 pupil enrollment by school, grade, race/ethnicity and gender* [Excel file]. Retrieved from http://www.cde.state.co.us/cdereval/fall2013pupilmembershipbyschethnicitygendergradexls

Center for Applied Special Technology. (1999). *Universal design for learning.* Retrieved from http://www.cast.org/udl/

Center for Universal Design. (2008). *The principles of universal design.* Retrieved from http://www.ncsu.edu/ncsu/design/cud/

Cerezo, N. (2004). Problem-based learning in the middle school: A research case study of the perceptions of at risk females. *RMILE Online Research in Middle Level Education*, *27*, 1–13.

Chaffin, J. D. (1982). Arc-Ed curriculum: Applicability for severely handicapped pupils. *Journal of Special Education Technology*, *5*(4), 69–70.

Chaffin, J. D., Maxwell, B., & Thompson, B. (1982). ARC-ED curriculum: The application of video game formats to educational software. *Exceptional Children*, *49*, 173–178.

Chance, B., Ben-Zvi, D., Garfield, J., & Medina, E. (2007). The role of technology in improving student learning of statistics. *Technology Innovations in Statistics Education Journal, 1*(1). Retrieved from http://escholarship.org/uc/item/8sd2t4rr

Charmaz, K. (2000). Grounded theory: Objectivist and constructivist methods. In Y. S. Lincoln & N. K. Denzin (Eds.), *Handbook of qualitative research* (2nd ed.; pp. 509–535). Thousand Oaks, CA: Sage.

Chavous, T., Rivas-Drake, D., Smalls, C., Griffin, T., & Cogburn, C. (2008). Gender matters, too: The influences of school racial discrimination and social identity on academic engagement outcomes among African American adolescents. *Developmental Psychology*, *44*(3), 637–654. doi:10.1037/0012-1649.44.3.637 PMID:18473633

Cheng, M. M. W., & Gilbert, J. K. (2014). Students' visualization of metallic bonding and the malleability of metals. *International Journal of Science Education*, *36*(8), 1373–1407. doi:10.1080/09500693.2013.867089

Chin, C. (2006). Classroom interaction in science: Teacher questioning and feedback to students' responses. *International Journal of Science Education*, *28*(11), 1315–1346. doi:10.1080/09500690600621100

Ching, D. (2012). Passion play: Will Wright and games for science learning. *Cultural Studies of Science Education*, *7*(4), 767–782. doi:10.1007/s11422-012-9456-5

Chinn, C. A., & Hmelo-Silver, C. E. (2002). Authentic inquiry: Introduction to the special section. *Science Education*, *86*(2), 171–174. doi:10.1002/sce.10000

Chinn, C. A., & Malhotra, B. M. (2002). Epistemologically authentic inquiry in schools: A theoretical framework for evaluating inquiry tasks. *Science Education*, *86*(2), 175–218. doi:10.1002/sce.10001

Chi-Yan Tsui, W., & Treagust, D. (2004). Motivational aspects of learning genetics with interactive multimedia. *The American Biology Teacher*, *66*(4), 277–285. doi:10.1662/0002-7685(2004)066[0277:MAOLGW]2.0.CO;2

Chmiel, M. (2012). Learning about the game: Designing science games for a generation of gamers. *Cultural Studies of Science Education*, *7*(4), 807–812. doi:10.1007/s11422-012-9428-9

Choi, D. H., & Kim, J. (2004). Why people continue to play online games: In search of critical design factors to increase customer loyalty to online contents. *Cyberpsychology & Behavior*, *7*(1), 11–24. doi:10.1089/109493104322820066 PMID:15006164

Choi, D., Kim, H., & Kim, J. (2000). A cognitive and emotional strategy for computer game design. *Journal of MIS Research*, *10*, 165–187.

Choy, S. C., & Cheah, P. K. (2009). Teacher perceptions of critical thinking among students and its influenceon higher education. *International Journal of Teaching and Learning in Higher Education*, *20*(2), 198–206.

Church, W. & Skelton, L. (2010, May). Sustainability Education in K-12 Classrooms. *Journal of Sustainability Education, 1*.

Churches, A. (2008). Bloom's Taxonomy blooms digitally. *Tech & Learning*. Retrieved from http://www.techlearning.com/article/8670

Chval, K. B., & Chavez, O. (2012). Designing math lessons for English language learners. *Mathematics Teaching in the Middle School*, *17*(5), 261–265. doi:10.5951/mathteacmiddscho.17.5.0261

Clariana, R. B., & Strobel, J. (2008). Modeling technology. In *Handbook of research on educational communications and technology* (3rd ed., pp. 329–342). Taylor & Francis.

Clark, S. A., & Jackson, D. F. (1998). *Laboratory technology and student motivation in a conceptual physics classroom: A year-long case study.* Paper presented at the annual meeting of the National Association for Research in Science Teaching, San Diego, CA.

Clark, D., Nelson, B., Sengupta, P., & D'Angelo, C. (2009). *Rethinking science learning through digital games and simulations: Genres, examples, and evidence*. Washington, DC: National Research Council.

Clift, R., & Brady, P. (2005). Research on methods courses and field experiences. In M. Cochran Smith & K. M. Zeichner (Eds.), *Studying teacher education: The report of the AERA panel on research and teacher education* (pp. 309–424). Washington, DC: Lawrence Erlbaum Associates.

Cohen, A. D. (2005). Strategies for learning and performing L2 speech acts. *Intercultural Pragmatics*, *2-3*, 275–301.

Collins, E., & Green, J. L. (1992). Learning in classroom settings: Making or breaking a culture. *Redefining student learning: Roots of educational change*, 85-98.

Collins, A., Bielaczyc, K., & Joseph, D. (2004). Design experiments: Theoretical and methodological issues. *Journal of the Learning Sciences*, *13*(1), 15–42. doi:10.1207/s15327809jls1301_2

Computing Research Association. (2006). *Cyberinfrastructure for Education and Learning for the Future: A vision and research agenda*. Author.

Computing Research Association. (2013). *Computing research association Taulbee survey*. Retrieved April 17, 2015, from http://cra.org/resources/taulbee/

Conati, C., & Zhao, X. (2004). Building and Evaluating an Intelligent Pedagogical Agent to Improve the Effectiveness of an Educational Game. In *Proceedings of IUI '04, International Conference on Intelligent User Interfaces*. doi:10.1145/964442.964446

Conderman, G., & Woods, S. (2008). Science instruction: An endangered species: In light of America's recent scientific decline, teaching elementary science should be an imperative. *Kappa Delta Pi Record*, *44*(2), 76–80. doi:10.1080/00228958.2008.10516499

Congressional Research Service (CRS). (2012). *Science, technology, engineering and mathematics (STEM) education: A primer* (CRS Report for Congress). R42642. Retrieved on Dec., 2014, from http://www.fas.org/sgp/crs/misc/R42642.pdf

Congressional Research Services. (2011). *Selected STEM Education Legislative Activity in the 112th Congress*. Retrieved on Dec., 2014, from http://www.stemedcoalition.org/wp-content/uploads/2011/10/CRS_STEMEdin112th_asof10172011.pdf

Conley, M. W. (2008). Cognitive strategy instruction for adolescents: What we know about the promise, what we don't know about the potential. *Harvard Educational Review*, *78*(1), 84–106. doi:10.17763/haer.78.1.j612282134673638

Cook, D. W., & Van Cleaf, D. W. (2000). Multicultural perceptions of 1st-year elementary teachers' urban, suburban, and rural student teaching placements. *Urban Education*, *35*(2), 165–174. doi:10.1177/0042085900352003

Cook, S. E. (2004). New technologies and language change: Toward an anthropology of linguistic frontiers. *Annual Review of Anthropology*, *33*(1), 103–115. doi:10.1146/annurev.anthro.33.070203.143921

Costa, V. B. (1995). When science is “another world”: Relationships between worlds of family, friends, school, and science. *Science Education*, *79*(3), 313–333. doi:10.1002/sce.3730790306

Cotabish, A., Dailey, D., Robinson, A., & Hughes, G. (2013). The Effects of a STEM Intervention on Elementary Students’ Science Knowledge and Skills. *School Science and Mathematics*, *113*(5), 215–226. doi:10.1111/ssm.12023

Cotabish, L., DeWitt, J., Osborne, J., Dillon, J., Willis, B., & Wong, B. (2012). Balancing acts: Elementary school girls’ negotiations of femininity, achievement, and science. *Science Education*, *96*(6), 976–989.

Cowie, B., & Bell, B. (1999). A model of formative assessment in science education. *Assessment in Education: Principles, Policy & Practice*, *6*(1), 101–116. doi:10.1080/09695949993026

Coyle, Y., Yañez, L., & Verdú, M. (2010). The impact of the interactive whiteboard on the teacher and children’s language use in an ESL immersion classroom. *System*, *38*(4), 614–625. doi:10.1016/j.system.2010.10.002

Craig, C. J. (2004). Shifting boundaries on the professional knowledge landscape: When teacher communications become less safe. *Curriculum Inquiry*, *34*(4), 395–424. doi:10.1111/j.1467-873X.2004.00304.x

Craig, C. J. (2007). Story constellations: A narrative approach to contextualizing teachers’ knowledge of school reform. *Teaching and Teacher Education*, *23*(2), 173–188. doi:10.1016/j.tate.2006.04.014

Craik, K. (1943). *The Nature of Explanation*. Cambridge, UK: Cambridge University Press.

Crawford, B. A. (1999). Is it realistic to expect a preservice teacher to create an inquiry- based classroom? *Journal of Science Teacher Education*, *10*(3), 175–194. doi:10.1023/A:1009422728845

Crawford, C. (1984). *The art of computer game design*. Washington State University.

Crawford, C. (2003). *Chris Crawford on game design*. San Francisco: New Riders.

Creswell, J. (1998). *Qualitative inquiry and research design: Choosing among five traditions*. Thousand Oaks, CA: Sage.

Creswell, J. (2002). *Educational research: Planning, conducting, and evaluating quantitative and qualitative research*. Upper Saddle River, NJ: Pearson Education.

Creswell, J. W. (2003). *Research Design: Qualitative, quantitative, and mixed methods approaches* (2nd ed.). Thousand Oaks, CA: Sage.

Creswell, J. W. (2007). *Qualitative Inquiry and Research Design: Choosing among five approaches* (2nd ed.). Thousand Oaks, CA: Sage.

Creswell, J. W. (2007). *Qualitative inquiry and research design: Choosing among five approaches*. Thousand Oaks, CA: Sage.

Creswell, J. W. (2012). *Educational research: Planning, conducting and evaluating quantitative and qualitative research* (4th ed.). Upper Saddle River, NJ: Pearson Education.

Creswell, J. W., & Plano Clark, V. L. (2010). *Designing and conducting mixed methods research* (2nd ed.). Thousand Oaks, CA: Sage.

Crook, A., Mauchline, A., Maw, S., Lawson, C., Drinkwater, R., Lundqvist, K., & Park, J. et al. (2012). The use of video technology for providing feedback to students: Can it enhance the feedback experience for staff and students? *Computers & Education*, *58*(1), 386–396. doi:10.1016/j.compedu.2011.08.025

Crotty, M. (1998). *Introduction: The research process. In The foundations of social research: Meaning and perspective in the research process*. Thousand Oaks, CA: Sage.

Crystal, D. (2011). *Internet linguistics*. New York: Routledge.

Csíkszentmihályi, M. (1975). *Beyond boredom and anxiety*. San Francisco: Jossey-Bass.

Csikszentmihalyi, M. (1997). *Finding flow: The psychology of engagement with everyday life*. New York: Basic Books.

Cummins, J. (1979). Cognitive/academic language proficiency, linguistic interdependence, the optimum age question, and some other matters. *Working Papers on Bilingualism*, *19*(1), 121–129.

Cummins, J., Sayers, J., & Brown, K. (2006). *Literacy, technology and diversity*. Boston: Allyn & Bacon.

D'Ambrosio, U. (2007). Peace, social justice and ethnomathematics. *The Montana Mathematics Enthusiast. Monograph*, *1*, 25–34.

Damasio, A. R. (1994). *Descartes' error: Emotion, reason, and the human brain*. New York: Avon Books.

Dando, C. E., & Chadwick, J. J. (2014). Enhancing Geographic Learning and Literacy through Filmmaking. *The Journal of Geography*, *113*(2), 78–84. doi:10.1080/00221341.2013.846394

Danielsson, K., & Wiberg, C. (2006). Participatory design of learning media: Designing educational computer games with and for teenagers. *Interactive Technology and Smart Education*, *3*(4), 275–291. doi:10.1108/17415650680000068

Darling-Hammond, L., & McLaughlin, M. W. (1995). Policies that support professional development in an era of reform. *Phi Delta Kappan*, *76*(8), 597–604.

Darling-Hammond, L., Wei, R. C., Andree, A., Richardson, N., & Orphanos, S. (2009). *Professional learning in the learning profession*. Washington, DC: National Staff Development Council.

Dass, P. M. (1996). Professional development: The Iowa Chautauqua model. *Science Education International*, *7*(1), 18–21.

Dass, P. M. (1999). Science education for the 21st century: Challenges and promising approaches. *International Journal of Curriculum and Instruction*, *1*(2), 264–277.

Dass, P. M., & Yager, R. E. (1999). The Iowa Chautauqua Program: Advancing reforms in K-12 science education. *Science Education International*, *10*(2), 33–38.

Davidowitz, B., Chittleborough, C., & Murray, E. (2010). Student-generated submicro diagrams: A useful tool for teaching and learning chemical equations and stoichiometry. *Chemistry Education Research and Practice*, *11*(3), 154–164. doi:10.1039/C005464J

Davis, E. (2006). Preservice elementary teachers' critique of instructional materials for science. *Science Education*, *90*(2), 348–375. doi:10.1002/sce.20110

Daws, N., & Singh, B. (1996). Formative assessment: To what extent is its potential to enhance pupils' science being realized? *The School Science Review*, *77*(281), 93–100.

De Byl, P. K., & Brand, J. E. (2011). Designing games to motivate student cohorts through targeted game genre selection. In Handbook of research on improving learning and motivation through educational games: Multidisciplinary approaches, (pp. 567-582). Hershey, PA: IGI Global.

de Freitas, S. (2006). Learning in immersive worlds: A review of game-based learning. *Joint Information Systems Committee*. Retrieved from http://www.jisc.ac.uk/media/documents/programmes/elearninginnovation/gamingreport_v3.pdf

de Freitas, S. (2008). Serious virtual worlds: A scoping study. *Joint Information Systems Committee*. Retrieved from http://www.jisc.ac.uk/media/documents/publications/ seriousvirtualworldsv1.pdf de Jong, T., Linn, M. C., & Zacharia, Z. C. (2013). Physical and virtual laboratories in science and engineering education. *Science*, *340*(6130), 305–308. doi:10.1126/science.1230579 PMID:23599479

de Jong, T., Martin, E., Zamarro, J., Esquembre, F., Swaak, J., & van Joolingen, W. R. (1999). The integration of computer simulation and learning support: An example from the physics domain of collisions. *Journal of Research in Science Teaching*, *36*(5), 597–615. doi:10.1002/(SICI)1098-2736(199905)36:5<597::AID-TEA6>3.0.CO;2-6

de Jong, T., & van Joolingen, W. R. (1998). Scientific discovery learning with computer simulations of conceptual domains. *Review of Educational Research*, *68*(2), 179–201. doi:10.3102/00346543068002179

de Jong, T., van Joolingen, W. R., Giezma, A., Girault, I., Hoppe, U., & Kindermann, J. et al.. (2010). Learning by creating and exchanging objects: The SCY experience. *British Journal of Educational Technology*, *41*, 909–921. doi:10.1111/j.1467-8535.2010.01121.x

DeBoer, G. E. (2000). Scientific literacy: Another look at its historical and contemporary meanings and its relationship to science education reform. *Journal of Research in Science Teaching*, *37*(6), 582–601. doi:10.1002/1098-2736(200008)37:6<582::AID-TEA5>3.0.CO;2-L

DeCoito, I. (2009). *Improving Teachers' and Students' Nature of Science Conceptions- Using Reading and Writing Activities to Reflect on the Nature of Science*. Lambert Academic Publishers.

DeCoito, I. (2014). Focusing on Science, Technology, Engineering, and Mathematics (STEM) in the 21st Century. *Ontario Professional Surveyor*, *57*(1), 34–36.

Dede, C. (2005). Planning for "neomillennial" learning styles: Implications for investments in technology and faculty. In J. Oblinger & D. Oblinger (Eds.), *Educating the net generation* (pp. 226–247). Boulder, CO: EDUCAUSE Publishers.

DeJarnett, N. K. (2012). America's children" Providing early exposure to STEM (science, technology, engineering and math) initiatives. *Education*, *133*(1), 77–84.

Dekkers, J., & Donatti, S. (1981). The Integration of Research Studies on the Use of Simulation as an Instructional Strategy. *The Journal of Educational Research*, *74*(6), 424–427. doi:10.1080/00220671.1981.10885343

Denner, J. (2007). The girls creating games program: an innovative approach to integrating technology into middle school. *Meridian, A Middle School Computer Technologies Journal, 1*(10). Retrieved on Dec., 2014, from www.ncsu.edu/meridian/win2007/girlgaming/index.htm

Dey, I. (1993). *Qualitative Data Analysis*. New York: Routledge. doi:10.4324/9780203412497

Dickey, M. D. (2007). Game design and learning: A conjectural analysis of how massively multiple online role-playing games (MMORPGs) foster intrinsic motivation. *Educational Technology Research and Development*, *55*(3), 253–273. doi:10.1007/s11423-006-9004-7

Dischino, M., DeLaura1, J. A., Donnelly, J., Massa, N. M., & Hanes, F. (2011). Increasing the STEM pipeline through problem-based learning. In *Proceedings of The 2011 IAJC-ASEE International Conference.*

Dobson, J. (2008). The use of formative online quizzes to enhance class preparation and scores on summative exams. *Advances in Physiology Education*, *32*(4), 297–302. doi:10.1152/advan.90162.2008 PMID:19047506

Doering, A., & Veletsianos, G. (2007). An investigation of the use of real-time, authentic geospatial data in the K–12 classroom. *The Journal of Geography*, *106*(6), 217–225. doi:10.1080/00221340701845219

Dolan, E., & Grady, J. (2010). Recognizing students' scientific reasoning: A tool for categorizing complexity of reasoning during teaching by inquiry. *Journal of Science Teacher Education*, *21*(1), 31–55. doi:10.1007/s10972-009-9154-7 PMID:21113314

Domin, D., & Bodner, G. (2012). Using students' representations constructed during problem solving to infer conceptual understanding. *Journal of Chemical Education*, *89*(7), 837–843. doi:10.1021/ed1006037

Donovan, G. H., & Butry, D. T. (2009). The value of shade: Estimating the effect of urban trees on summertime electricity use. *Energy and Building*, *41*(6), 662–668. doi:10.1016/j.enbuild.2009.01.002

Doppelt, Y., Schunn, C., Silk, E., Mehalik, M., Reynolds, B., & Ward, E. (2009). Evaluating the impact of a facilitated learning community approach to professional development on teacher practice and student achievement. *Research in Science & Technological Education*, *27*(3), 339–354. doi:10.1080/02635140903166026

Dostál, J. (2009). Educational software and computer games - tools of modern education. *Journal of Technology and Information Education*, *1*(1), 24–28.

Dowrick, P. (1983). Self-modeling. In P. Dowrick & S. Biggs (Eds.), *Using video: Psychological and social applications* (pp. 105–124). New York: Wiley.

Drayton, B., Falk, J. K., Stroud, R., Hobbs, K., & Hammerman, J. (2010). After installation: Ubiquitous computing and high school science in three experienced, high-technology schools. *The Journal of Technology, Learning, and Assessment*, *9*(3), 1–57.

Driver, R., Newton, P., & Osborne, D. (2000). Establishing the norms of scientific argumentation in classrooms. *Science Education*, *84*(3), 287–312. doi:10.1002/(SICI)1098-237X(200005)84:3<287::AID-SCE1>3.0.CO;2-A

DuFour, R., DuFour, R., Eaker, R., & Many, T. (2006). *Learning by doing: A handbook for professional learning communities at work*. Bloomington, IN: Solution Tree.

Duit, R., & Treagust, D. (1998). Learning in Science-- From behaviorism towards social constructivism and beyond. In B. J. Fraser & K. G. Tobin (Eds.), International Handbook of Science Education (pp. 3-25). Kluwer Academic Publishers.

Duncan, C., Bell, T., & Tanimoto, S. (2014). Should your 8-year-old learn coding? In *Proceedings of the Ninth Workshop in Primary and Secondary Computing Education* (*WiPSCE '14*) (pp. 60-69). New York, NY: ACM. doi:10.1145/2670757.2670774

Duschl, R. A., & Osborne, J. (2002). Supporting and promoting argumentation discourse in science education. *Studies in Science Education*, *38*(1), 39–72. doi:10.1080/03057260208560187

Duschl, R. A., Schweingruber, H. A., & Shouse, A. W. S. (Eds.). (2006). *Taking science to school: Learning and teaching science in grades K-8*. Washington, DC: The National Academies Press.

Dwyer, H. A., Iveland, A., Killian, A., Hill, C., Franklin, D., & Harlow, D. B. (2015, April). *Programming languages and discourse: Investigating the linguistic context in learning computer science during elementary school*. Paper presented at the American Education Research Association (AERA), Chicago, IL.

Dwyer, H., Hill, C., Carpenter, S., Harlow, D., & Franklin, D. (2014). Identifying elementary students' pre-instructional ability to develop algorithms and step-by-step instructions. In *Proceedings of the 45th ACM Technical Symposium on Computer Science Education* (pp. 511–516). New York, NY: ACM. http://doi.org/ doi:10.1145/2538862.2538905

Eakin, H., & Luers, A. L. (2006). Assessing the vulnerability of social-environmental systems. *Annual Review of Environment and Resources*, *31*(1), 365–394. doi:10.1146/annurev.energy.30.050504.144352

Eamon, M. K. (2004). Digital divide in computer access and use between poor and non-poor youth. *Journal of Sociology and Social Welfare*, *31*(2), 91–112. Retrieved from http://imet.csus.edu/imet8/leu/251/articles/Article_Eamon_PoorYouth.pdf

Economics and Statistics Adminstiration. (2011). *Women in STEM: A gender gap innovation.* Washington, DC: U.S. Department of Commerce. Retrieved December 11, 2014 from http://www.esa.doc.gov/Reports/women-stem-gender-gap-innovation

Edelson, D. C. (1998). Realising authentic science learning through the adaptation of scientific practice. International Handbook of Science Education, 1, 317-331.

Edelson, D. C. (2001). Learning-For-Use: A framework for the design of technology-supported inquiry activities. *Journal of Research in Science Teaching*, *38*(3), 355–385. doi:10.1002/1098-2736(200103)38:3<355::AID-TEA1010>3.0.CO;2-M

Edelson, D. C. (2002). Design research: What we learn when we engage in design. *Journal of the Learning Sciences*, *11*(1), 105–121. doi:10.1207/S15327809JLS1101_4

Edelson, D. C., Gordin, D. N., & Pea, R. D. (1999). Addressing the challenges of inquiry-based learning through technology and curriculum design. *Journal of the Learning Sciences*, *8*(3), 391–450. doi:10.1207/s15327809jls0803&4_3

Edwards, A. (2006). *The sustainability revolution*. Gabriola Island, Canada: New Society.

Ehrlich, T. (1998). Reinventing John Dewey's "pedagogy as a university discipline". *The Elementary School Journal*, *98*(5), 489–509. doi:10.1086/461911

Ellis, J. D. (2001). A dilemma in reforming science teacher education: Responding to students' concerns or striving for high standards. *Journal of Science Teacher Education*, *12*(3), 253–276. doi:10.1023/A:1014208127958

Engelmann, C. A., & Huntoon, J. E. (2011). Improving student learning by addressing misconceptions. *Eos*, *92*(50), 465–466. doi:10.1029/2011EO500001

Ennis, R. H. (1981). Problems in testing informal logic critical thinking reasoning ability. *Informal Logic*, *6*(1), 3–9.

Entertainment Software Association of Canada (ESAC). (2011). *Canada's Entertainment Software Industry in 2011*. NDP Group.

Environmental Literacy Council. (2004). Retrieved February, 22, 2006, from http://www.enviroliteracy.org/article.php/1126.html

EPA Environmental Protection Agency. *What is sustainability? What is EPA doing? How can I help?* Retrieved February 12, 2015, from http://www.epa.gov/sustainability/basicinfo.htm

Epstein, D., & Miller, R. (2011). SLOW OFF THE MARK Elementary school teachers and the crisis in STEM education. *Education Digest*, *77*(1), 4–10.

Ertmer, P. A. (2005). Teacher pedagogical beliefs: The final frontier in our quest for technology integration? *Educational Technology Research and Development*, *53*(4), 25–39. doi:10.1007/BF02504683

Eslinger, E., White, B., Frederiksen, J., & Brobst, J. (2008). Supporting inquiry processes with an interactive learning environment: Inquiry island. *Journal of Science Education and Technology*, *17*(6), 610–617. doi:10.1007/s10956-008-9130-6

Evans, M., Norton, A., Chang, M., Deckard, K., & Balci, O. (2013). Youth and video games: Exploring the effects of learning, achievement, and engagement. *Zeitschrift fur Psychologie mit Zeitschrift fur Angewandte Psychologie*, *221*(2), 98–106. doi:10.1027/2151-2604/a000135

Fabricatore, C. (2000, September 26). *Learning and videogames: An unexploited synergy.* Retrieved August 2, 2013, from http://www.learndev.org/FabricatoreAECT2000.pdf

Faggella-Luby, M. N., Graner, P. S., Deshler, D. D., & Drew, S. V. (2012). Building a house on sand: Why disciplinary literacy is not sufficient to replace general strategies for adolescent learners who struggle. *Topics in Language Disorders*, *32*(1), 69–84. doi:10.1097/TLD.0b013e318245618e

Fang, Z. (2005). Scientific literacy: A systemic functional linguistics perspective. *Science Education*, *89*(2), 335–347. doi:10.1002/sce.20050

Fathman, A. K., & Crowther, D. T. (Eds.). (2006). *Science for English Language Learners: K-12 Classroom Strategies*. NSTA Press.

Federal Science, Technology, Engineering, and Mathematics (STEM) Education 5 Year Strategic Plan: A Report from the Committee on STEM Education, National Science and Technology Council. (2013, May). Retrieved from http://www.whitehouse.gov/sites/default/files/microsites/ostp/stem_stratplan_2013.pdf

Federation of American Scientists. (2005). *National Summit on Educational Games: Fact Sheet*. Washington, DC: Author.

Feiman-Nemser, S. (2001). From preparation to practice: Designing a continuum to strengthen and sustain teaching. *Teachers College Record*, *103*(6), 1014–1055. doi:10.1111/0161-4681.00141

Feinstein, N. (2009). *Education for sustainable development in the United Stated of America*. University of Wisconsi-Madison School of Education.

Feinstein, N. W., & Kirchgasler, K. L. (2015). Sustainability in Science Education? How the Next Generation Science Standards Approach Sustainability, and Why It Matters. *Science Education*, *99*(1), 121–144. doi:10.1002/sce.21137

Ferguson, R. (2007). Constructivism and Social Constructivism. In G. M. Bodner & M. Orgill (Eds.), *Theoretical Frameworks for Research in Chemistry/Science Education* (pp. 28–49). Upper Saddle River, NJ: Pearson Prentice Hall.

Field, A. (2012). *Discovering statistics using SPSS*. New York, NY: Sage.

Finkelstein, N. D., Adams, W. K., Keller, C. J., Kohl, P. B., Perkins, K. K., & Podolefsky, N. S. et al.. (2005). When learning about the real world is better done virtually: A study of substituting computer simulations for laboratory equipment. *Physical Review Special Topics—Physics*. *Education Research*, *1*, 1–8.

Flannery, L. P., Silverman, B., Kazakoff, E. R., Bers, M. U., Bontá, P., & Resnick, M. (2013). Designing Scratchjr: Support for early childhood learning through computer programming. In *Proceedings of the 12th International Conference on Interaction Design and Children* (pp. 1-10). New York, NY: ACM. http://doi.org/ doi:10.1145/2485760.2485785

Flavell, J. H. (1979). Metacognition and cognitive monitoring: A new area of cognitive-developmental inquiry. *The American Psychologist*, *341*(10), 906–911. doi:10.1037/0003-066X.34.10.906

Folger, P. (2008). *Geospatial information and geographic information systems (GIS): Current issues and future challenges*. Washington, DC: Congressional Report Service for Congress.

Fordham, S. (1993). "Those loud black girls": (Black) women, silence, and gender "passing" in the academy. *Anthropology & Education Quarterly*, *24*(1), 3–32. doi:10.1525/aeq.1993.24.1.05x1736t

Forest, S., & Feder, M. (2011). *Climate change education: Goals, audiences, and strategies: A workshop summary*. Washington, DC: The National Academies Press.

Forgasz, H. J., Vale, C., & Ursini, S. (2010). Technology for mathematics education: Equity, access and agency. In C. Hoyles & J.-B. Lagrange (Eds.), *Mathematics Education and Technology—Rethinking the Terrain* (pp. 385–403). New York: Springer.

Foss, B. A., & Eikaas, T. I. (2006). Game play in engineering education - Concept and experimental results. *International Journal of Engineering Education*, *22*(5), 1043–1052.

Foster, A., & Mishra, P. (2009). Games, Claims, Genres, and Learning. In R. E. Ferdig (Ed.), *Effective Electronic Gaming in Education* (Vol. 1, pp. 33–50). New York: Information Science Reference. doi:10.4018/978-1-59904-808-6.ch002

Frankenstein, M. (1987). Critical mathematics education: An application of Paulo Freire's epistemology. In I. Shor (Ed.), *Freire for the classroom: A sourcebook for liberatory teaching* (pp. 180–210). Portsmount, NH: Boyton/Cook.

Frankenstein, M. (1990). Incorporating race, gender, and class issues into a critical mathematical literacy curriculum. *The Journal of Negro Education*, *59*(3), 336–359. doi:10.2307/2295568

Frankenstein, M. (1995). Equity in mathematics education: Class in the world outside the class. In W. G. Secada, E. Fennema, & L. B. Adajian (Eds.), *New direction for equity in mathematics education* (pp. 165–190). Cambridge, UK: Cambridge University Press.

Franklin, D., Conrad, P., Aldana, G., & Hough, S. (2011). Animal Tlatoque: Attracting middle school students to computing through culturally-relevant themes. In *Proceedings of the 42nd ACM Technical Symposium on Computer Science Education* (pp. 453–458). New York, NY: ACM. http://doi.org/ doi:10.1145/1953163.1953295

Franklin, D., Conrad, P., Boe, B., Nilsen, K., Hill, C., Len, M., … Waite, R. (2013). Assessment of computer science learning in a scratch-based outreach program. In *Proceeding of the 44th ACM Technical Symposium on Computer Science Education* (pp. 371–376). New York, NY: ACM. http://doi.org/ doi:<ALIGNMENT.qj></ALIGNMENT>10.1145/2445196.2445304

Franklin, D., Hill, C., Dwyer, H., Iveland, A., Killian, A., & Harlow, D. (2015). Getting started in teaching and researching computer science in the elementary classroom. In *Proceedings of the 46th ACM Technical Symposium on Computer Science Education* (pp. 552–557). New York, NY: ACM. http://doi.org/ doi:10.1145/2676723.2677288

Freedman, M. P. (1997). Relationship among laboratory instruction, attitude toward science, and achievement in science knowledge. *Journal of Research in Science Teaching*, *34*(4), 343–357. doi:10.1002/(SICI)1098-2736(199704)34:4<343::AID-TEA5>3.0.CO;2-R

Freeman, B. (2012). Using digital technologies to redress inequities for English language learners in the English speaking mathematics classroom. *Computers & Education*, *59*(1), 50–62. doi:10.1016/j.compedu.2011.11.003

Friedler, Y., Nachmias, R., & Linn, M. C. (1990). Learning scientific reasoning skills in microcomputer- based laboratories. *Journal of Research in Science Teaching*, *27*(2), 173–192. doi:10.1002/tea.3660270208

Friedler, Y., Nachmias, R., & Songer, N. (1989). Teaching scientific reasoning skills: A case study of a microcomputer-based curriculum. *School Science and Mathematics*, *89*(1), 272–284. doi:10.1111/j.1949-8594.1989.tb11890.x

Frisk, E. & Larson, K. L. (2011, March). Educating for sustainability: Competencies & practices for transformative action. *Journal of Sustainability Education, 2*.

Fry, P. G., & McKiney, L. J. (1997). Qualitative study of preservice teachers' early field experiences in an urban, culturally different school. *Urban Education*, *32*(2), 184–201. doi:10.1177/0042085997032002002

Fukkink, R. G., Trienckens, N., & Kramer, L. J. C. (2011). Video feedback in education and training: Putting learning in the picture. *Educational Psychology Review*, *23*(1), 45–63. doi:10.1007/s10648-010-9144-5

Fullan, M. (2007). Change the terms for teacher learning. *Journal of Staff Development*, *28*(3), 35–36.

Fullan, M. (Ed.). (2014). *Teacher development and educational change*. New York: Routledge.

Fulp, S. L. (2002). *2000 National survey of science and mathematics education: Status of elementary school science teaching*. Chapel Hill, NC: Horizon Research.

Garfield, J. B., & Ben-Zvi, D. (2008). Learning to Reason about Data. In J. B. Garfield & D. Ben-Zvi (Eds.), *Developing students' statistical reasoning* (pp. 123–142). New York, NY: Springer Publishers. doi:10.1007/978-1-4020-8383-9_6

Garmston, R. J., & Wellman, B. M. (2013). *The adaptive school: A sourcebook for developing collaborative groups*. Lanham, MD: Rowman & Littlefield.

Garrett, R. K., & Weeks, B. E. (2013). *The promise and peril of real-time corrections to political misperceptions. In Proceedings of the 2013 conference on computer supported cooperative work (CSCW '13)*(pp. 1047–1058). New York, NY: ACM. Doi:10.1145/2441776.2441895

Garris, R., Ahlers, R., & Driskell, J. (2002). Games, motivation and learning: A research and practice model. *Simulation & Gaming*, *33*(4), 441–467. doi:10.1177/1046878102238607

Gay, G. (2002). Preparing for culturally responsive teaching. *Journal of Teacher Education*, *53*(2), 106–116. doi:10.1177/0022487102053002003

Geban, O., Askar, P., & Ozkan, I. (1992). Effects of computer simulations and problem-solving approaches on high school students. *The Journal of Educational Research*, *86*(1), 5–10. doi:10.1080/00220671.1992.9941821

Gee, J. P. (2013). *Good video games + good learning*. New York: Peter Lang Publishing, Inc.

Gee, J., Hayes, E., & Jenkins, P. (2013). Games and learning: an overview. In J. P. Gee (Ed.), *Good Video Games + Good Learning* (pp. 1–13). New York: Peter Lang Publishing, Inc.

Gerace, W. J. (1992). Contributions from cognitive research to mathematics and science education. In D. Grayson (Ed.) *Proceedings of the Workshop on Research in Science and Mathematics Education*, (pp. 25-44). Pietermaritzburg, South Africa: Teeanem Printers (Pty) Ltd.

Gershon, I. (2010). Media ideologies: An introduction. *Linguistic Anthropology*, *20*(2), 283–293. doi:10.1111/j.1548-1395.2010.01070.x

Gibson, H., & Chase, C. (2002). Longitudinal impact of an inquiry-based science program on middle school students' attitudes toward science. *Science Education*, *86*(5), 693–705. doi:10.1002/sce.10039

Gilbert, J. (2005). Visualization: A metacognitive skill in science and science education. In J. K. Gilbert (Ed.), *Visualization in Science Education* (pp. 9–27). Dordrecht, Netherlands: Springer. doi:10.1007/1-4020-3613-2_2

Gilbert, J. K. (2004). Models and modeling: Routes to more authentic science education. *International Journal of Science and Mathematics Education*, *2*(2), 115–130. doi:10.1007/s10763-004-3186-4

Gil-Perer, D., & Carrascosa-Allis, J. (1994). Bringing pupils' learning closer to a scientific construction of knowledge: "A permanent feature in innovations in science teaching. *Science Education*, *78*(3), 301–315. doi:10.1002/sce.3730780310

Giroux, H. A. (2011). *On Critical Pedagogy*. New York, NY: Continuum International Publishing Group.

Glaser, B. C., & Strauss, A. L. (1967). *The discovery of grounded theory: Strategies for qualitative research*. Chicago: Aldine.

Glynn, S. M. (2008). Making science concepts meaningful to students: Teaching with analogies. In S. Mikelskis-Seifert, U. Ringelband, & M. Bruckmann (Eds.), *Four decades of research in science education: From curriculum development to quality improvement* (pp. 112–125). Munster, Germany: Waxmann.

Glynn, S. M., Brickman, P., Armstrong, N., & Taasoobshirazi, G. (2011). Science Motivation Questionnaire II: Validation with science majors and nonscience majors. *Journal of Research in Science Teaching*, *48*(10), 1159–1176. doi:10.1002/tea.20442

Glynn, S. M., & Muth, K. D. (1994). Reading and writing to learn science: Achieving scientific literacy. *Journal of Research in Science Teaching*, *31*(9), 1057–1073. doi:10.1002/tea.3660310915

Glynn, S. M., Taasoobshirazi, G., & Brickman, P. (2007). Nonscience majors learning science: A theoretical model of motivation. *Journal of Research in Science Teaching*, *44*(8), 1088–1107. doi:10.1002/tea.20181

Gold, A. U., Oonk, D. J., Smith, L. K., Boykoff, M., Osnes, B., & Sullivan, S. B. (2015). Lens on climate change: Student-produced videos as an effective learning approach. *The Journal of Geography*, *0*, 1–12. doi:10.1080/00221341.2015.1013974

Goldsmith, S. (1963). *Designing for the disabled*. Newcastle upon Tyne, UK: RIBA Publications.

Gomes, C. V., & Mensah, F. M. (2013). The impact of technology on students with disabilities achieving scientific literacy. *EDULEARN13 Proceedings, 5,* 4817-4826.

Gott, R., & Duggan, S. (1995). *Investigating work in the science curriculum: Developing science and technology education*. Buckingham, UK: Open University Press.

Granic, I., Lobel, A., & Engels, R. C. (2013). The Benefits of Playing Video Games. *The American Psychologist*, *69*(1), 66–78. doi:10.1037/a0034857 PMID:24295515

Gray, L., Thomas, N., & Lewis, L. (2010). Educational Technology in U.S. Public Schools. U.S. Department of Education.

Gredler, M. (1996). Educational games and simulations: A technology in search of a (research) paradigm. In D. H. Jonassen (Ed.), *Handbook of research for educational communications and technology* (pp. 521–540). New York: Macmillan.

Green Education Foundation. (2011). *Teacher Survey.* Retrieved November 11, 2011, from Green Education Foundation: www.greeneducationfoundation.org

Green, T. (2005). Using technology to help English language students develop language skills: A home and school connection. *Multicultural Education*, *13*(2), 56.

Griffiths, K. A., & Preston, R. K. (1992). Grade-12 students' misconceptions relating to fundamental characteristics of atoms and molecules. *Journal of Research in Science Teaching*, *29*(6), 611–628. doi:10.1002/tea.3660290609

Grover, S., & Pea, R. (2013). Computational thinking in k–12: A review of the state of the field. *Educational Researcher*, *42*(1), 38–43. doi:10.3102/0013189X12463051

Guba, E. G., & Lincoln, Y. S. (1989). *Judging the quality of fourth generation evaluation. In Fourth Generation Evaluation* (pp. 228–251). Thousand Oaks, CA: Sage.

Guba, E., & Lincoln, Y. (1989). *Fourth generation evaluation*. Newbury Park, CA: Sage.

Guha, M. L., Druin, A., Chipman, G., Fails, J. A., Simms, S., & Farber, A. (2005). Working with young children as technology design partners. *Communications of the ACM*, *48*(1), 39–42. doi:10.1145/1039539.1039567

Guidelines for Assessment and Instruction in Statistics Education (GAISE) Report. (2007). A Curriculum Framework for PreK-12 Statistics Education. Alexandria, VA: American Statistical Association (ASA).

Gutiérrez, K. D., Baquedano-López, P., & Tejeda, C. (1999). Rethinking diversity: Hybridity and hybrid language practices in the third space. *Mind, Culture, and Activity*, *6*(4), 286–303. doi:10.1080/10749039909524733

Gutstein, E. (2006). *Reading and writing the world with mathematics: Toward a pedagogy for social justice*. New York: Routledge, Taylor & Francis Group.

Gutstein, E., & Petersen, B. (2013). *Rethinking Mathematics*. Milwaukee, WI: Rethinking Schools.

Hake, R. (2002). Lessons from the physics education reform effort. *Conservation Ecology, 5*(2), 28. Retrieved from http://www.consecol.org/vol5/iss2/art28/

Hallinger, P. (2005). Integrating learning technology and problem-based learning. In *Proceedings of the Second International Conference on eLearning for Knowledge-Based Society.*

Halloun, I. A., & Hestenes, D. (1987). The initial knowledge state of college physics students. *American Journal of Physics*, *53*(11), 1043. doi:10.1119/1.14030

Halpern, D. F. (1998). Teaching critical thinking across domains: Dispositions, skills, structure training, and metacognitive monitoring.[PubMed]. *The American Psychologist*, *53*(4), 449–455. doi:10.1037/0003-066X.53.4.449

Hamlen, K. R. (2013). Understanding children's choices and cognition in video game play: A synthesis of three studies. *Zeitschrift fur Psychologie mit Zeitschrift fur Angewandte Psychologie*, *221*(2), 107–114. doi:10.1027/2151-2604/a000136

Hansen, A., Iveland, A., Dwyer, H., Hill, C., Franklin, D., & Harlow, D. (2015). Programming digital science stories: Computer science and engineering design in the science classroom. *Science and Children*, *53*(4), 60-64.

Hargittai, E. (2011). Minding the digital gap: Why understanding digital inequality matters. In S. Papathanassopoulos (Ed.), *Media perspectives for the 21st century* (pp. 231–240). New York, NY: Routledge.

Hargittai, E., & Walejko, G. (2008). The participation divide: Content creation and sharing in the digital age. *Information Communication and Society*, *11*(2), 239–256. doi:10.1080/13691180801946150

Harlow, D. B., & Leak, A. E. (2014). Mapping students' ideas to understand learning in a collaborative programming environment. *Computer Science Education*, *24*(2-3), 229–247. doi:10.1080/08993408.2014.963360

Harrison, A. G., & Treagust, D. F. (1996). Secondary students' mental models of atoms and molecules: Implications for teaching chemistry. *Science Education*, *80*(5), 509–534. doi:10.1002/(SICI)1098-237X(199609)80:5<509::AID-SCE2>3.0.CO;2-F

Harrison-Pitaniello, M. (2013). Using Student-Produced Time-Lapse Plant Movies to Communicate Concepts in Plant Biology. *Journal of Microbiology & Biology Education*, *14*(1), 101–102. doi:10.1128/jmbe.v14i1.436 PMID:23858359

Harskamp, E., Suhre, C., & Van Streun, A. (2000). The graphics calculator and students' solution strategies. *Mathematics Education Research Journal*, *12*(1), 37–52. doi:10.1007/BF03217073

Hattie, J., & Timperley, H. (2007). The power of feedback. *Review of Educational Research*, *77*(1), 81–112. doi:10.3102/003465430298487

Haury, D. (2001). *Teaching science through inquiry with archived data* (Report No. EDO-SE-01-11). Columbus, OH: Office of Educational Research and Improvement. (ERIC Digest No. ED 465 545).

Häussler, P., & Hoffman, L. (2002). An Intervention study to enhance girls' interest, self-concept, and achievement in physics classes. *Journal of Research in Science Teaching*, *39*(9), 870–888. doi:10.1002/tea.10048

Hawkins, J., & Pea, R. D. (1987). Tools for bridging the cultures of everyday and scientific thinking. *Journal of Research in Science Teaching*, *24*(4), 291–307. doi:10.1002/tea.3660240404

Hawthorne, E. K. (2011). Collaborating with CSTA for computer science education week. *ACM Inroads*, *2*(4), 25–26. doi:10.1145/2038876.2038886

Hays, R. T. (2005). *The effectiveness of instructional games: Literature review*. Alexandria, VA: U.S. Army Research Institute for the Behavioural and Social Sciences.

Hegedus, S. J., & Moreno-Armella, L. (2009). Intersecting representation and communication infrastructures. *ZDM Mathematics Education*, *41*(4), 399–412. doi:10.1007/s11858-009-0191-7

Heller, R., & Greenleaf, C. L. (2007). Literacy Instruction in the content areas: Getting to the core of middle and high school improvement. Washington, DC: Alliance for Excellent Education. Retrieved from http://all4ed.org/reports-factsheets/literacy-instruction-in-the-content-areas-getting-to-the-core-of-middle-and-high-school-improvement/

Hennessy, S., Deaney, R., & Ruthven, K. (2006). Situated expertise in integrating use of multimedia simulation into secondary science teaching. *International Journal of Science Education*, *28*(7), 701–732. doi:10.1080/09500690500404656

Hennessy, S., Wishart, J., Whitelock, D., Deaney, R., Brawn, R., Velle, L., & Winterbottom, M. et al. (2007). Pedagogical approaches for technology-integrated science teaching. *Computers & Education*, *48*(1), 137–152. doi:10.1016/j.compedu.2006.02.004

Herga, N. R., & Dinevski, D. (2012). Virtual laboratory in chemistry – experimental study of understanding, reproduction and application of acquired knowledge of subject's chemical content. *Organizacija*, *45*(3), 108–116. doi:10.2478/v10051-012-0011-7

Herman, M., Meagher, M., Abrahamson, L., & Owens, D. (2013). Student perceptions on use of a classroom communications system in mathematics classes. *The International Journal for Technology in Mathematics Education*, *20*(2), 45–67.

Herrington, J., & Oliver, R. (2000). An instructional design framework for authentic learning environments. *Educational Technology Research and Development*, *48*(3), 23–48. doi:10.1007/BF02319856

Hewson, P. W., Tabachnick, B. R., Zeichner, K. M., & Lemberger, J. (1999). Educating prospective teachers of biology: Findings, limitations, and recommendations. *Science Education*, *83*(3), 373–384. doi:10.1002/(SICI)1098-237X(199905)83:3<373::AID-SCE6>3.0.CO;2-3

Hill, C., Dwyer, H. A., Martinez, T., Harlow, D., & Franklin, D. (2015). Floors and flexibility: Designing a programming environment for 4th-6th grade classrooms. In *Proceedings of the 46th ACM Technical Symposium on Computer Science Education* (pp. 546–551). New York, NY: ACM. http://doi.org/ doi:10.1145/2676723.2677275

Hmelo-Silver, C. E., Duncan, R. G., & Chinn, C. A. (2007). Scaffolding and achievement in problem-based and inquiry learning: A response to Sweller, Kirschner, and Clark (2007). *Educational Psychologist*, *42*(2), 99–107. doi:10.1080/00461520701263368

Hobbs, R. (2010). Digital and Media Literacy: A Plan of Action. A White Paper on the Digital and Media Literacy Recommendations of the Knight Commission on the Information Needs of Communities in a Democracy. Washington, DC: The Aspen Institute. Retrieved from http://www.academia.edu/2866630/Digital_and_media_literacy_A_plan_of_action

Hodson, D. (1998). *Teaching and Learning Science: Towards a Personalized Approach*. Buckingham: Open University Press.

Hofer, M., & Swan, K. O. (2008). Technological Pedagogical Content Knowledge in Action: A Case Study of a Middle School Digital Documentary Project. *Journal of Research on Technology in Education*, *41*(2), 179–200. doi:10.1080/15391523.2008.10782528

Hoffman, D. L., & Novak, T. P. (2009). Flow online: Lessons learned and future prospects. *Journal of Interactive Marketing*, *23*(1), 23–34. doi:10.1016/j.intmar.2008.10.003

Hofstein, A., & Lunetta, V. N. (2004). The laboratory in science education: Foundation for the 21st century. *Science Education*, *88*(1), 28–54. doi:10.1002/sce.10106

Hofstein, A., & Mamlok-Naaman, R. (2007). The laboratory in science education: The state of the art. *Chemistry Education: Research and Practice in Europe*, *8*(2), 105–108.

Hofstein, A., Navon, O., Kipnis, M., & Mamlok-Naaman, R. (2005). Developing students' ability to ask more and better questions resulting from inquiry-type chemistry laboratories. *Journal of Research in Science Teaching*, *42*(7), 791–806. doi:10.1002/tea.20072

Hollweg, K., Pea, C. H., & Berkowitz, A. R. (2003). Why is understanding urban ecosystsm an important forntier for education and educators? In A. R. Berkowitz, C. H. Nilon, & K. Hollweg (Eds.), *Understanding urban ecosystems: A new frontier for science and education* (pp. 19–38). New York: Springer. doi:10.1007/0-387-22615-X_2

Holm, P., Goodsite, M. E., Cloetingh, S., Agnoletti, M., Moldan, B., Lang, D. J., & Pohl, W. et al. (2013). Collaboration between the natural, social, and human sciences in Global Change Research. *Environmental Science & Policy*, *28*, 25–35. doi:10.1016/j.envsci.2012.11.010

Honey, M. A., & Hilton, M. (Eds.). (2011). *Learning science through computer games and simulations*. Washington, DC: National Academy of Sciences.

Horrigan, J. (2009). *Wireless internet use*. Retrieved from Pew Internet and American Life Project: http://www.pewinternet.org/files/old-media//Files/Reports/2009/Wireless-Internet-Use-With-Topline.pdf

Hoy, W. K. (2010). *Quantitative research in education: A primer*. Thousand Oaks, CA: Sage.

Hsu, C. L., & Lu, H. P. (2004). Why do people play on-line games? An extended TAM with social influences and flow experience. *Information & Management*, *41*(7), 853–868. doi:10.1016/j.im.2003.08.014

Huang, M. H. (2003). Designing website attributes to induce experiential encounters. *Computers in Human Behavior*, *19*(4), 425–442. doi:10.1016/S0747-5632(02)00080-8

Huang, M. H. (2006). Flow, enduring and situational involvement in the Web environment: A tripartite second-order examination. *Psychology and Marketing*, *23*(5), 383–411. doi:10.1002/mar.20118

Huelskamp, L. (2009). *The Impact of problem-based learning with computer simulation on middle level educators' instructional practices and understanding of the nature of middle level learners*. ProQuest LLC, Ph.D. Dissertation, The Ohio State University. Retrieved on Dec., 2014, from http://rave.ohiolink.edu/etdc/view?acc_num=osu1242662952

Hurd, P. D. (1998). Scientific literacy: New minds for a changing world. *Science Education*, *82*(3), 407–416. doi:10.1002/(SICI)1098-237X(199806)82:3<407::AID-SCE6>3.0.CO;2-G

Hurley, M. M. (2001). Reviewing integrated science and mathematics: The search for evidence and definitions from new perspectives. *School Science and Mathematics*, *10*(5), 259–268. doi:10.1111/j.1949-8594.2001.tb18028.x

Institute for the Promotion of Teaching Science and Technology (IPST). (2002). *The manual of content of science learning*. Bangkok: Curusaphaladphoa.

Institute for the Promotion of Teaching Science and Technology (IPST). (2008). *The Basic Education Core Curriculum B.E. 2551 (A.D. 2008) Science*. Retrieved May 3, 2015 from http://www.ipst.ac.th/web/images/files/SciCur_2008_Eng-Version.pdf

Institute for the Promotion of Teaching Science and Technology (IPST). (2013). *IPST annual report summary 2013*. Retrieved May 3, 2015 from http://www.ipst.ac.th/eng/files/AnnualReport_ 2013_Eng.pdf

Institute of Education Sciences. U.S. Department of Education, & the National Science Foundation. (2013). *Common guidelines for education research and development*. Retrieved October 24, 2011, from http://www.nsf.gov/pubs/2013/nsf13126/nsf13126.pdf

International Society for Technology in Education. (2007). *ISTE standards: Students*. Retrieved February 10, 2015 from http://www.iste.org/standards/standards-for-students

International Technology Education Association. (1996). *Technology for all Americans: A rationale and structure for the study of technology*. Reston, VA: Author.

International Technology Education Association. (2000). *Standards for technological literacy: Content for the study of technology*. Reston, VA: Author.

IPCC. (2014). Summary for policymakers. In C. B. Field, V. R. Barros, D. J. Dokken, K. J. Mach, M. D. Mastrandrea, T. E. Bilir, M. Chatterjee, K. L. Ebi, Y. O. Estrada, R. C. Genova, B. Girma, E. S. Kissel, A. N. Levy, S. MacCracken, P. R. Mastrandrea & L. L. White (Eds.), Climate change 2014: Impacts, adaptation, and vulnerability. Part A: Global and sectoral aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (pp. 1-32). Cambridge, UK: Cambridge University Press.

Irons, A. (2007). Enhancing learning through formative assessment and feedback. Florence, NY: ProQuest eLibrary.

Irving, K. E., Pape, S. J., Owens, D. T., Abrahamson, L., Silver, D., & Sanalan, V. (2010, May). *Longitudinal Study of Classroom Connectivity in Promoting Mathematics and Science Achievement: Years 1-3*. Paper presented at the 2010 AERA Annual Meeting, Denver, CO.

Irving, K. E., Sanalan, V. A., & Shirley, M. L. (2009). Physical science connected classrooms: Case studies. *Journal of Computers in Mathematics and Science Teaching*, *28*(3), 247–275.

Ito, M., Baumer, S., Bittani, M., boyd, d., Cody, R., Herr-Stephenson, B., . . . Tripp, L. (2010). Hanging out, messing around and geeking out: Kids living and learning with new media. Cambridge, MA: The MIT Press.

Jaakkola, T., & Nurmi, S. (2008). Fostering elementary school students' understanding of simple electricity by combining simulation and laboratory activities. *Journal of Computer Assisted Learning*, *24*(4), 271–283. doi:10.1111/j.1365-2729.2007.00259.x

Jaakkola, T., Nurmi, S., & Veermans, K. (2010). A comparison of students' conceptual understanding of electric circuits in simulation only and simulation-laboratory contexts. *Journal of Research in Science Teaching*, *48*(1), 71–93. doi:10.1002/tea.20386

Jackson, S., Stratford, S. J., Krajcik, J. S., & Soloway, E. (1996). Making system dynamics modeling accessible to pre-college science students. *Interactive Learning Environments*, *4*(3), 233–257. doi:10.1080/1049482940040305

Jakobson, R. (1960). Closing statement: Linguistics and poetics. In T. Sebeok (Ed.), *Style in language* (pp. 350–377). Cambridge, MA: MIT press.

Jiménez-Aleixandre, M. P., & Erduran, S. (2007). Argumentation in science education: An overview. In *Argumentation in science education* (pp. 3–27). Springer Netherlands. doi:10.1007/978-1-4020-6670-2_1

Jimoyiannis, A., & Komis, V. (2007). Examining teachers' beliefs about ICT in education: Implications of a teacher preparation programme. *Teacher Development*, *11*(2), 149–173. doi:10.1080/13664530701414779

Johnson, L., Adams, S., Cummins, M., Estrada, V., Freeman, A., & Ludgate, H. (2013). *The NMC horizon report: 2012 higher education edition.* Retrieved from http://www.nmc.org/publications/2013-horizon-report-higher-ed

Johnson, D. W., & Johnson, R. T. (1999). Making cooperative learning work. *Theory into Practice*, *38*(2), 67–73. doi:10.1080/00405849909543834

Johnson, R., DeMoss, G. S., & Sorensen, R. (2003). *Earth science with Vernier*. Beaverton, OR: Vernier Software and Technology.

Johnstone, A. H. (1993). The development of chemistry teaching: A changing response to changing demand. *Journal of Chemical Education*, *70*(9), 701–704. doi:10.1021/ed070p701

Jonassen, D. H. (1997). Instructional design models for well-structured and ill-structured problem-solving learning outcomes. *Educational Technology Research and Development*, *45*(1), 65–95. doi:10.1007/BF02299613

Jonassen, D. H. (2000). Toward a design theory of problem-solving. *Educational Technology Research and Development*, *48*(4), 63–85. doi:10.1007/BF02300500

Jonassen, D. H. (2011). Supporting problem-solving in PBL. *Interdisciplinary Journal of Problem-based Learning*, *5*(2), 95–119. doi:10.7771/1541-5015.1256

Jonassen, D. H., & Strobel, J. (2006). Modeling for meaningful learning. In D. Hung & M. S. Khine (Eds.), *Engaged learning with emerging technologies* (pp. 1–27). Dordrecht: Springer; doi:10.1007/1-4020-3669-8_1

Jonassen, D., Howland, J., Marra, R., & Crismond, D. (2008). *Meaningful learning with technology* (3rd ed.). Upper Saddle River, NJ: Pearson.

Judson, E., & Sawada, D. (2000). Examining the effects of a reformed junior high school science class on students' math achievement. *School Science and Mathematics*, *100*(8), 419–425. doi:10.1111/j.1949-8594.2000.tb17330.x

Kafai, Y. B. (2006). Playing and making games for learning instructionist and constructionist perspectives for game studies. *Games and Culture*, *1*(1), 36–40. doi:10.1177/1555412005281767

Kafai, Y. B., & Burke, Q. (2014). *Connected code: Why children need to learn programming*. Cambridge, MA: The MIT Press.

Kahle, J., Meece, J., & Scantlebury, K. (2000). Urban African-American middle school students: Does standards-based teaching make a difference? *Journal of Research in Science Teaching*, *37*(9), 1019–1041. doi:10.1002/1098-2736(200011)37:9<1019::AID-TEA9>3.0.CO;2-J

Kambouri, M. (2011). *Teachers and Children's Misconceptions inScience*. BEI's Education-line collection. Retrieved November 12, 2014 from http://www.leeds.ac.uk/bei/COLN/COLN_default.html

Kamil, M. L., Borman, G. D., Dole, J., Kral, C. C., Salinger, T., & Torgesen, J. (2008). *Improving adolescent literacy: Effective classroom and intervention practices: A practice guide (NCEE #2008-4027).* Washington, DC: U.S. Department of Education, National Center for Education Evaluation and Regional Assistance.

Karppinen, P. (2005). Meaningful learning with digital and online videos: Theoretical perspectives. *AACE Journal*, *13*(3), 233–250.

Kastberg, S., & Leatham, K. (2005). Research on graphing calculators at the secondary level: Implications for mathematics teacher education. *Contemporary Issues in Technology & Teacher Education*, *5*(1), 25–37.

Kay, A. C. (1991, September). Computers, networks and education. *Scientific American*, *265*(3), 138–148. doi:10.1038/scientificamerican0991-138

Kay, R. H., & LeSage, K. (2009). Examining the benefits and challenges of using audience response systems: A review of the literature. *Computers & Education*, *53*(3), 819–827. doi:10.1016/j.compedu.2009.05.001

Keane, W. (2000). Voice. *Journal of Linguistic Anthropology*, *9*(1-2), 271–273. doi:10.1525/jlin.1999.9.1-2.271

Kearney, M., & Schuck, S. (2005). Students in the director's seat: Teaching and learning with student-generated video. In P. Kommers & G. Richards (Eds.), Proceedings of Ed-Media 2005—World Conference on Educational Multimedia, Hypermedia, & Telecommunications. Norfolk, VA: Association for the Advancement of Computing in Education. Retrieved from http://www.editlib.org/p/20518/

Kearney, M., & Schuck, S. (2006). Spotlight on authentic learning: student developed digital video projects. *Australasian Journal of Educational Technology, 22*(2), 189-208. Retrieved from http://www.ascilite.org.au/ajet/ajet22/kearney1.html

Kearney, M. (2004). Classroom use of multimedia-supported predict-observe-explain tasks in a social constructivist-learning environment. *Research in Science Education*, *34*(1), 427–453. doi:10.1007/s11165-004-8795-y

Kearney, M. (2011). A learning design for student-generated digital storytelling. *Learning, Media and Technology*, *36*(2), 169–188. doi:10.1080/17439884.2011.553623

Keating, T., Barnett, M., Barab, S. A., & Hay, K. E. (2002). Developing conceptual understanding of scientific concepts through building three-dimensional computational models. *Journal of Science Education and Technology*, *11*(3), 261–275. doi:10.1023/A:1016024619689

Keawdang, R. (1998). *The binding of Thai Educational Article in Years 1997-1998*. Bangkok: The Institute of National Education Committee.

Kebritchi, M., Hirumi, A., & Bai, H. (2010). The effects of modern mathematics computer games on mathematics achievement and class motivation. *Computers & Education*, *55*(2), 427–443. doi:10.1016/j.compedu.2010.02.007

Keeley, P., Eberle, F., Farrin, L., & Oliver, L. (2005). Uncovering student ideas in science: Vol. 1. *25 formative assessment probes*. Alexandria, VA: NSTA Press.

Ke, F. (2009). A qualitative meta-analysis of computer games as learning tools. In R. E. Ferdig (Ed.), *Effective Electronic Gaming in Education* (Vol. 1, pp. 1–32). New York: Information Science Reference. doi:10.4018/978-1-59904-808-6.ch001

Ke, F., & Grabowski, B. (2007). Gameplaying for maths learning: Cooperative or not? *British Journal of Educational Technology*, *38*(2), 249–259. doi:10.1111/j.1467-8535.2006.00593.x

Kelleher, C., & Pausch, R. (2005). Lowering the barriers to programming: A taxonomy of programming environments and languages for novice programmers. *ACM Computing Surveys*, *37*(2), 83–137. doi:10.1145/1089733.1089734

Kelly, A. E., & Lesh, R. A. (Eds.). (2000). Handbook of Research Design in Mathematics and Science Education. Mahwah, NJ: Lawrence Erlbaum Associates.

Kelly, G. J., & Crawford, T. (1996). Students' interaction with computer representations: Analysis of discourse in laboratory groups. *Journal of Research in Science Teaching*, *33*(7), 693–707. doi:10.1002/(SICI)1098-2736(199609)33:7<693::AID-TEA1>3.0.CO;2-I

Kelly, R. M. (2014). Using variation theory with metacognitive monitoring to develop insights into how students learn from molecular visualizations. *Journal of Chemical Education*, *91*(8), 1152–1161. doi:10.1021/ed500182g

Kelly, R. M., & Jones, L. L. (2007). Exploring how different features of animations of sodium chloride dissolving affect students' explanations. *Journal of Science Education and Technology*, *16*(5), 413–429. doi:10.1007/s10956-007-9065-3

Kennewell, S., & Beauchamp, G. (2007). The features of interactive whiteboards and their influence on learning. *Learning, Media and Technology*, *32*(3), 227–241. doi:10.1080/17439880701511073

Kennewell, S., Tanner, H., Jones, S., & Beauchamp, G. (2008). Analysing the use of interactive technology to implement interactive teaching. *Journal of Computer Assisted Learning*, *24*(1), 61–73. doi:10.1111/j.1365-2729.2007.00244.x

Kerski, J. J. (2007). *The Implementation and Effectiveness of Geographic Information Systems Technology and Methods in Secondary Education*. Retrieved from http://gis.esri.com/library/userconf/proc01/professional/papers/pap191/p191.htm

Ketelhut, D. J., Dede, C., Clarke, J., & Nelson, B. (2006). *A multi-user virtual environment for building higher order inquiry skills in science*. Paper presented at the AERA Annual Meeting, San Francisco, CA. Retrieved from http://muve.gse.harvard.edu/rivercityproject/documents/rivercitysympinq1.pdf

Khalili, N., Sheridan, K., Williams, A., Clark, K., & Stegman, M. (2011). Students designing video games about immunology: Insights for science learning. *Computers in the Schools*, *28*(3), 228–240. doi:10.1080/07380569.2011.594988

Kibble, J. (2007). Use of unsupervised online quizzes as formative assessment in a medical physiology course: Effects of incentive on student participation and performance. *Advances in Physiology Education*, *31*(3), 253–260. doi:10.1152/advan.00027.2007 PMID:17848591

Kibble, J. (2011). Voluntary participation in online formative quizzes is a sensitive predictor of student success. *Advances in Physiology Education*, *35*(1), 95–96. doi:10.1152/advan.00053.2010 PMID:21386008

Kim, H. K., VanTasse-Baska, J., Bracken, B. A., Feng, A., Stanbaugh, T., & Bland, L. (2011). Project Clarion: Three years of science instruction in Title I schools among K-third grade students. *Research in Science Education*, *42*(5), 813–829. doi:10.1007/s11165-011-9218-5

Kim, M. C., Hannafin, M. J., & Bryan, L. A. (2007). Technology-enhanced inquiry tools in science education: An emerging pedagogical framework for classroom practice. *Science Education*, *91*(6), 1010–1030. doi:10.1002/sce.20219

Kirkwood, C. W. (2013). *System dynamics methods: A quick introduction*. Retrieved from http://www.public.asu.edu/~kirkwood/sysdyn/SDIntro/SDIntro.htm

Klahr, D., Triona, L. M., & Williams, C. (2007). Hands on what? The relative effectiveness of physical vs. virtual materials in an engineering design project by middle school children. *Journal of Research in Science Teaching*, *44*(1), 183–203. doi:10.1002/tea.20152

Klopfer, E. (2008). *Augmented learning: Research and design of mobile educational games*. Cambridge, MA: MIT Press. doi:10.7551/mitpress/9780262113151.001.0001

Kluger, A. N., & DeNisi, A. (1996). The effects of feedback on interventions on performance: A historical review, a meta-analysis, and a preliminary feedback intervention theory. *Psychological Bulletin*, *119*(2), 254–284. doi:10.1037/0033-2909.119.2.254

Koehler, M., & Mishra, P. (2005). What happens when teachers design educational technology? The development of technological pedagogical content knowledge. *Journal of Educational Computing Research*, *32*(2), 131–152. doi:10.2190/0EW7-01WB-BKHL-QDYV

Kogut, L. S. (1996). Critical thinking in general chemistry. *Journal of Chemical Education*, *73*(3), 218. doi:10.1021/ed073p218

Koh, J., & Divaharan, S. (2011). Developing pre-service teachers' technology integration expertise through the TPACK-developing instructional model. *Journal of Educational Computing Research*, *44*(1), 35–58. doi:10.2190/EC.44.1.c

Kohn, A. (1997). Students don't 'work' – They learn. *Education Week*, (Sept): 3.

Kolko, B., Nakamura, L., & Rodman, G. (2000). *Race in cyberspace*. New York: Routledge.

Komoroske, L. M., Hameed, S. O., Szoboszlai, A. I., Newson, A. J., & Williams, S. L. (2015). A scientist's guide to achieving broader impacts through K-12 STEM collaboration. *BioScience Advance Access.* doi:10:1093/biosci/biu222

Koster, R. (2005). *A theory of fun for game design*. Scottsdale, AZ: Paraglyph Press.

Krajcik, J., Marx, R., Blumenfeld, P., Soloway, E., & Fishman, B. (2000). Inquiry based science supported by technology: Achievement among urban middle school students. Washington, DC: National Science Education Standards. (ERIC Document Reproduction Service No. ED443676).

Kubicek, J. (2005). Inquiry-based learning, the nature of science, and computer technology: New possibilities in science education. *Canadian Journal of Learning and Technology*, *31*(1), 51–64.

Kuhn, D., & Dean, D. Jr. (2004). Metacognition: A bridge between cognitive psychology and educational practice. *Theory into Practice*, *43*(4), 268–274. doi:10.1207/s15430421tip4304_4

Kuhn, D., Schauble, L., & Garcia-Mila, M. (1992). Cross-domain development of scientific reasoning. *Cognition and Instruction*, *9*(4), 285–327. doi:10.1207/s1532690xci0904_1

Kulhavey, R. W., & Wager, W. (1993). Feedback in programmed instruction: Historical context and implications for practice. In J. Dempsey & G. Ales (Eds.), *Interactive instruction and feedback* (pp. 3–20). Englewood Cliffs, NJ: Educational Technology Publications.

Kuo-Hung, T., Chi-Cheng, C., Shi-Jer, L., & Wen-Ping, C. (2013). Attitudes towards science, technology, engineering and mathematics (STEM) in a project-based learning (PjBL) environment. *International Journal of Technology and Design Education*, *23*(1), 87–102. doi:10.1007/s10798-011-9160-x

Kurtz, P. D., Marshall, E. K., & Banspach, S. W. (1985). Interpersonal skill-training research: A 12-year review and analysis. *Counselor Education and Supervision*, *24*(3), 249–263. doi:10.1002/j.1556-6978.1985.tb00482.x

Kwon, O. N. (2002). The effect of calculator-based ranger activities on students' graphing ability. *School Science and Mathematics*, *102*(2), 57–67. doi:10.1111/j.1949-8594.2002.tb17895.x

Lages, C., & Mendez, E. (2007). Contact angle measurements under thermodynamic equilibrium conditions. *Analytical and Bioanalytical Chemistry*, *388*(8), 1689–1692. doi:10.1007/s00216-007-1373-1 PMID:17546444

Langkhapin, S. (2009, November). *Achieving educational soundness for science mathematics and technology digital resource instructional design*. Paper presented at the Third International Conference on Science and Mathematics Education (CoSMEd2009), Penang, Malaysia.

Latif, F., & Shafipoor, M. (2012). Innovative teaching methodology: Application of computer and technology in Iranian business English courses. *Theory & Practice in Language Studies*, *2*(11), 2284–2290. doi:10.4304/tpls.2.11.2284-2290

Lave, J. (1988). *Cognition in practice: Mind, mathematics, and culture in everyday life*. Cambridge, UK: Cambridge University Press. doi:10.1017/CBO9780511609268

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge University Press. doi:10.1017/CBO9780511815355

Lavonen, J., Juuti, K., & Meisalo, V. (2003). Designing MBL package for school science. In the V. Uskov (Eds.). In *Proceedings of the IASTED International Conference Computer and Advanced Technology in Education* (pp. 664-669). Anaheim: ACTA Press.

Lawson, A. (2003). The nature and development of hypothetico-predictive argumentation with implications for science teaching. *International Journal of Science Education*, *25*(11), 1387–1408. doi:10.1080/0950069032000052117

Laxman, K. (2011). A study on the adoption of clickers in higher education. *Australasian Journal of Educational Technology*, *27*(8), 1291–1303.

Lazonder, A. W., & Ehrenhard, S. (2014). Relative effectiveness of physical and virtual manipulatives for conceptual change in science: How falling objects fall. *Journal of Computer Assisted Learning*, *30*(2), 110–120. doi:10.1111/jcal.12024

Lazzaro, N. (2004). Why we play games: Four keys to more emotion without story. *Xeodesign*. Retrieved from http://www.xeodesign.com/xeodesign_whyweplaygames.pdf

Lederman, N. G. (1992). Students' and teachers' conceptions about the nature of science: A review of the research. *Journal of Research in Science Teaching*, *29*(4), 331–359. doi:10.1002/tea.3660290404

Lee, H.-S., Linn, M. C., Varma, K., & Liu, O. L. (2010). How do technology-enhanced inquiry science units impact classroom learning? *Journal of Research in Science Teaching*, *47*(1), 71–90. doi:10.1002/tea.20304

Lee, H.-S., & Songer, N. B. (2003). Making authentic science accessible to students. *International Journal of Science Education*, *25*(8), 923–948. doi:10.1080/09500690305023

Lee, O., Deaktor, R., Hart, J. E., Cuevas, P., & Enders, C. (2005). An instructional intervention's impact on the science and literacy achievement of culturally and linguistically diverse elementary students. *Journal of Research in Science Teaching*, *42*(8), 857–887. doi:10.1002/tea.20071

Lee, S. C., & Irving, K. E. (2015). Teachers' use of interactive technology to enhance students' metacognition: Awareness of student learning and feedback. *Journal of Computers in Mathematics and Science Teaching*, *35*(2), 175–198.

Lee, Y. F., Guo, Y., & Ho, H. j. (2008). Explore Effective Use of Computer Simulations for Physics Education. *Journal of Computers in Mathematics and Science Teaching*, *27*(4), 443–466.

Lekhavat, P., & Jones, L. (2009). The effect of adjunct questions emphasizing the particulate nature of matter on students' understanding of chemical concepts in multimedia lessons. *Educación en la Química*, *20*(3), 351–359.

Lemke, J. (2004). *Why study digital game worlds? Notes toward a basic research agenda for learning technologies.* Retrieved December 11, 2013, from http://www-personal.umich. edu/~jaylemke/games.htm

Lemke, J. L. (1990). *Talking science: Language, learning and values*. Norwood, NJ: Ablex.

Lepper, M. R., & Cordova, D. I. (1992). A desire to be taught: Instructional consequences of intrinsic motivation. *Motivation and Emotion*, *16*(3), 187–208. doi:10.1007/BF00991651

Lesh, R., Hover, M., Hole, B., Kelly, A., & Post, T. (2000). Principles for developing thought-revealing activities for students and teachers. In A. Kelly & R. Lesh (Eds.), Handbook of Research Design in Mathematics and Science Education (pp. 591-645). Mahwah, NJ: Lawrence Erlbaum.

Lesser, L. M. (2007). Critical values and transforming data: Teaching statistics with social justice. *Journal of Statistics Education*, *15*(1).

Lester, J. C., Spires, H. A., Nietfeld, J. L., Minogue, J., Mott, B. W., & Lobene, E. V. (2014). Designing games-based learning environments for elementary science education: A narrative-centred learning perspective. *Journal of Information Science*, *264*, 4–18. doi:10.1016/j.ins.2013.09.005

Levine, T. H., & Marcus, A. S. (2007). Closing the achievement gap through teacher collaboration: Facilitating multiple trajectories of teacher learning. *Journal of Advanced Academics*, *19*(1), 116–138.

Levine, T. H., & Marcus, A. S. (2010). How the structure and focus of teachers' collaborative activities facilitate and constrain teacher learning. *Teaching and Teacher Education: An International Journal of Research and Studies*, *26*(3), 389–398. doi:10.1016/j.tate.2009.03.001

Levin, H. (2011). Authentic doing: Student-produced web-based digital video oral histories. *The Oral History Review*, *38*(1), 6–33. doi:10.1093/ohr/ohr046

Levinson, S. C. (1983). *Pragmatics*. Cambridge, UK: Cambridge University Press.

Liao, Y. K., & Chen, Y. W. (2007). The Effect of Computer Simulation Instruction on Student Learning: A Meta-analysis of Studies in Taiwan. *Journal of Information Technology and Applications, 2*(2), 69-79.

Li, L., Lui, X., & Steckelberg, A. (2010). Assessor or assesse: How student learning improves by giving and receiving peer feedback. *British Journal of Educational Research*, *41*(3), 525–536.

Li, L., Lui, X., & Zhou, Y. (2012). A re-analysis of assessor and assesse's roles in technology-facilitated peer assessment. *British Journal of Educational Technology*, *43*(3), 376–384. doi:10.1111/j.1467-8535.2011.01180.x

Li, M. C., & Tsai, C. C. (2013). Game-based learning in science education: A review of relevant research. *Journal of Science Education and Technology*, *22*(6), 877–898. doi:10.1007/s10956-013-9436-x

Limson, M., Witzlib, C., & Desharnais, R. A. (2007). Using web-based simulations to promote inquiry. *Science Scope*, (February): 36–42.

Linn, M. (2003). Technology and science education: Starting points, research programs, and trends.'. *International Journal of Science Education*, *25*(6), 727–758. doi:10.1080/09500690305017

Little II, D. L. (2014). Defining Sustainability in Meaningful Ways for Educators. *Journal of Sustainability Education, 7*.

Locatelli, S., Ferreira, C., & Arroio, A. (2010). Metavisualization: An important skill in the learning chemistry. *Problems of Education in the 21st Century, 24*, 75-83.

López, O. S. (2010). The digital learning classroom: Improving English language learners' academic succes in mathematics and reading using interactive whiteboard technology. *Computers & Education*, *54*(4), 901–915. doi:10.1016/j.compedu.2009.09.019

Lou, S. J., Shih, R. C., Diez, C. R., & Tseng, K. H. (2011). The impact of problem-based learning strategies on STEM knowledge integration and attitudes: An exploratory study among female Taiwanese senior high school students. *International Journal of Technology & Design*, *21*(2), 195–215. doi:10.1007/s10798-010-9114-8

Lovett, M. W., Borden, S. L., DeLuca, T., Lacerenza, L., Benson, N. J., & Brackstone, D. (1994). Treating the core deficits of developmental dyslexia: Evidence of transfer of learning after phonologically and strategy-based reading training programs. *Developmental Psychology*, *30*(6), 805–822. doi:10.1037/0012-1649.30.6.805

Lowther, D. L., Ross, S. M., & Morrison, G. M. (2003). When each one has one: The influences of teaching strategies and student achievement of using laptops in the classroom. *Educational Technology Research and Development*, *51*(3), 23–44. doi:10.1007/BF02504551

Lozano, R. (2008). Envisioning sustainability three-dimensionally. *Journal of Cleaner Production*, *16*(17), 1838–1846. doi:10.1016/j.jclepro.2008.02.008

Lumpe, A. T., & Staver, J. R. (1995). Peer collaboration and concept development: Learning about photosynthesis. *Journal of Research in Science Teaching*, *32*(1), 71–98. doi:10.1002/tea.3660320108

MacArthur, J. R., & Jones, L. L. (2008). A review of literature reports of clickers applicable to college chemistry classrooms. *Chemical Education Research Practice*, *9*(3), 187–195. doi:10.1039/B812407H

Macdonald, D., Hunter, L., & Tinning, R. (2007). Curriculum construction: A critical analysis of rich tasks in the recontextualisation field. *Australian Journal of Education*, *51*(2), 112–128. doi:10.1177/000494410705100202

Maeng, J. L., Mulvey, L. K., & Bell, R. L. (2013). Preservice teachers' TPACK: Using technology to support inquiry instruction. *Journal of Science Education and Technology*, *22*(6), 838–857. doi:10.1007/s10956-013-9434-z

Malan, D. J., & Leitner, H. H. (2007). Scratch for budding computer scientists. In *Proceedings of the 38th Technical Symposium on Computer Science Education (SIGCSE '07)*. New York, NY: ACM. http://doi.org/ doi:10.1145/1227310.1227388

Malone, T. W. (2012). Collective intelligence 2012. *MIT Sloan Experts*. Retrieved from http://mitsloanexperts.mit.edu/collective-intelligence-2012-prof-tom-malone-on-how-new-technologies-are-changing-the-ways-people-and-computers-work-together/

Malone, T. W., & Lepper, M. R. (1987). Making learning fun: A taxonomy of intrinsic motivations for learning. *Aptitude. Learning and Instruction*, *3*, 223–253.

Maloney, J. H., Peppler, K., Kafai, Y., Resnick, M., & Rusk, N. (2008). Programming by choice: Urban youth learning programming with scratch. *ACM SIGCSE Bulletin*, *40*(1), 367–371. doi:10.1145/1352322.1352260

Mann, S. (2009, March 15). *Visualizing Sustainability*. Retrieved February 27, 2012, from WordPress Computing for Sustainability: http://computingforsustainability.wordpress.com/2009/03/15/visualising-sustainability

Marden, N., Ulman, L., Wilson, F., & Velan, G. (2013). Online feedback assessment in physiology: Effects on students' learning experiences and outcomes. *Advances in Physiology Education*, *37*(2), 192–200. doi:10.1152/advan.00092.2012 PMID:23728137

Margolis, J., & Fisher, A. (2003). *Unlocking the clubhouse: Women in computing*. Cambridge, MA: The MIT Press.

Marley, K. A. (2014). Eye on the Gemba: Using student-created videos and the revised Bloom's Taxonomy to teach lean management. *Journal of Education for Business*, *89*(6), 310–316. doi:10.1080/08832323.2014.903888

Marrero, M. E., & Mensah, F. M. M. (2011). Socioscientific Decision Making and the Ocean: A Case Study of 7th Grade Life Science Students. *Electronic Journal of Science Education, 14*(1).

Marrero, M. E., Schuster, G., & Bickerstaff, A. (2013). Earth System Science in Three Dimensions: Perspectives of Students and Teachers on NASA's Project 3D-VIEW. In K. Fletcher & L. Lennex (Eds.), Cases on 3D Technology Application and Integration in Education (pp. 253-280). Hershey, PA: IGI Global.

Marrero, M. E., Davey, B. T., Davis, H. B., & Schuster, G. S. (2011). Climate Change as an Integrating Context for Learning. *Journal for Activist Science and Technology Education*, *3*(1).

Marrero, M. E., & Schuster, G. (2010). Students making environmental connections to achieve scientific literacy: From local schoolyards to half a world away. In J. Hoot & J. Szente (Eds.), *The Earth is Our Home* (pp. 93–108). Olney, MD: Association for Childhood Education International.

Martinez, J. F., Borko, H., & Stecher, B. M. (2012). Measuring instructional practice in science using classroom artifacts: Lessons learned from two validation studies. *Journal of Research in Science Teaching*, *49*(1), 38–67. doi:10.1002/tea.20447

Martin, M. O., Mullis, I. V. S., Foy, P., & Stanco, G. M. (2012). *TIMSS 2011 international results in science*. Chestnut Hill, MA: TIMSS & PIRLS International Study Center, Boston College.

Marzluf, J. (2008). *Urban Ecology: An International Perspective on the Interaction Between Humans and Nature*. New York: Springer. doi:10.1007/978-0-387-73412-5

Mayo, A., Sharma, M. D., & Muller, D. A. (2009). Qualitative differences between learning environements using video in small groups and whole class discussions: A preliminary study in physics. *Research in Science Education*, *39*(4), 477–493. doi:10.1007/s11165-008-9090-0

Mayo, M. J. (2007). Games for science and engineering education. *Communications of the ACM*, *50*(7), 30–35. doi:10.1145/1272516.1272536

Mayo, M. J. (2009). Video games: A route to large-scale STEM education? *Science*, *323*(5910), 79–82. doi:10.1126/science.1166900 PMID:19119223

McElhaney, K. W., & Linn, M. C. (2011). Investigations of a Complex, Realistic Task: Intentional, Unsystematic, and Exhaustive Experimenters. *Journal of Research in Science Teaching*, *48*(7), 745–770. doi:10.1002/tea.20423

McGrath, E., Lowes, S., Lin, P., & Sayres, S. (2009). *Analysis of middle and high school student learning of science, mathematics and engineering concepts through a LEGO underwater robotics design challenge*. American Society for Engineering Education.

McKay, M., & McGrath, B. (2007). Real-world problem solving using real-time data. *International Journal of Engineering Education*, *23*(1), 36–42.

McKeachie, W. (1994). *Teaching tips: Strategies, research, and theory for college and university teachers*. Lexington, MA: D.C. Heath and Company.

McKenzie, D. L., & Padilla, M. J. (1986). The construction and validation of the test of graphing in science (TOGS). *Journal of Research in Science Teaching*, *23*(7), 571–579. doi:10.1002/tea.3660230702

McRobbie, C. M., & Thomas, G. P. (2000). Epistemological and contextual issues in the use of microcomputer-based laboratories in a Year 11 Chemistry classroom. *Journal of Computers in Mathematics and Science Teaching*, *19*(2), 137–160.

MDE (Massachusetts Department of Education). (2013). *2014 Report card - Cambridge Rindge and Latin* [data tables]. Retrieved from http://profiles.doe.mass.edu/reportcard/rc.aspx?linkid=37&orgcode=00490506&fycode=2014&orgtypecode=6

Mehan, H. (1979). *Learning lessons: Social organization in the classroom*. Cambridge, MA: Harvard University Press. doi:10.4159/harvard.9780674420106

Mendenhall, W., Beaver, R., & Beaver, B. (2006). *Introduction to probability and statistics* (12th ed.). Belmont, CA: Thompson Brooks/Cole.

Mercer, N., Warwick, P., Kershner, R., & Staarman, J. K. (2010). Can the interactive whiteboard help to provide "dialogic space" for children's collaborative activity? *Language & Education: An International Journal*, *24*(5), 367–384. doi:10.1080/09500781003642460

Merriam, S. B. (2002). Introduction to Qualitative Research. In S. B. Merriam (Ed.), *Qualitative Research in Practice: Examples for Discussion and Analysis* (pp. 3–17). San Francisco: Jossey-Bass.

Merriam, S. B. (2009). *Qualitative research and case study applications in education* (3rd ed.). San Francisco, CA: Jossey-Bass.

Merriam, S. B. (2009). *Qualitative Research: A Guide to Design and Implementation*. San Francisco, CA: Jossey-Bass.

Meskill, C., Mossop, J., & Bates, R. (1999). *Electronic text and English as a second language environment*. Albany, NY: National Research Center on English Learning and Achievement.

Meskill, C., Mossop, J., & Bates, R. (2000). Bilingualism, cognitive flexibility, and electronic texts. *Bilingual Research Journal*, *23*(2-3), 235–246. doi:10.1080/15235882.1999.10668689

Meskill, C., Oliveira, A., Gregory, K., Oliver, G., Reichen, B., & Witmer, P. (2014). Professional development in support of English learner achievement: Science and ESOL educator collaborations. In L. Minaya-Rowe (Ed.), *Effective Educational Programs, Practices, and Policies for English Learners* (pp. 83–107). Charlotte, NC: Information Age Publishing.

Messaris, P. (1998). Visual aspects of media literacy. *Journal of Communication*, *48*(1), 70–80. doi:10.1111/j.1460-2466.1998.tb02738.x

Michalchik, V., Rosenquist, A., Kozma, R., Coppola, B., Kreikemeier, P., & Schank, P. (2008). Representational resources for constructing shared understandings in the high school chemistry classroom. In J. Gilbert, M. Nakhleh, & M. Reiner (Eds.), *Visualization: Theory and practice in science education* (pp. 233–282). New York: Springer. doi:10.1007/978-1-4020-5267-5_11

Miles, A. (2007). Network literacy: The new path to knowledge. *Screen Education, 45*, 24-30. Retrieved from http://vogmae.net.au/research/thinking/Network-Literacy-The-New-Path-To-Knowledge/

Miles, M. B., & Huberman, A. M. (1994). *An Expanded Sourcebook: Qualitative Data Analysis* (2nd ed.). Thousand Oaks, CA: Sage.

Miles, M. B., & Huberman, A. M. (1994). *Qualitative data analysis* (2nd ed.). Thousand Oaks, CA: Sage Publications.

Miles, M. B., & Huberman, A. M. (1994). *Qualitative data analysis: An expanded sourcebook* (2nd ed.). Thousand Oaks, CA: Sage.

Millar, R. (2006). Twenty First Century Science: Insights from the design and implementation of a scientific literacy approach in school science. *International Journal of Science Education*, *28*(13), 1499–1521. doi:10.1080/09500690600718344

Mills, J. M., Durepos, G., & Wiebe, E. (2010). *Encyclopedia of Case Study Research*. Thousand Oaks: Sage Publications Inc. doi:10.4135/9781412957397

Ministry of Education. (2008). *The Basic core curriculum education B.E. 2551 (A.D. 2008)*. Bangkok: Kurusapa Ladprao Publishing.

Minner, D. D., Levy, A. J., & Century, J. (2010). Inquiry-based science instruction: What is it and does it matter? Results from a research synthesis years 1984 to 2002. *Journal of Research in Science Teaching*, *47*(4), 474–496. doi:10.1002/tea.20347

Minstrell, J., & Kraus, P. (2005). Guiding inquiry in the science classroom. In M. S. Donovan & J. D. Bransford (Eds.), *How students learn: History, mathematics, and science in the classroom* (pp. 475–513). Washington, DC: The National Academies Press.

Mitchelmore, M., & Cavanagh, M. (2000). Students' difficulties in operating a graphics calculator. *Mathematics Education Research Journal*, *12*(3), 254–268. doi:10.1007/BF03217088

Monterey Bay Aquarium. (n.d.). *Sardines to a Sanctuary* [Motion Picture]. Retrieved April 1 2012, from http://www.montereybayaquarium.org/videos/Video.aspx?enc=0ZZ+8rD1FkYlVUC+FOQbAQ

Moore, C., & Huber, R. (2009). Roadkill data analysis: Using spreadsheets to integrate math and science. *Science Scope*, 26–29.

Moreno-Ger, P., Burgos, D., Martínez-Ortiz, I., Sierra, J. L., & Fernández-Manjón, B. (2008). Educational game design for online education. *Computers in Human Behavior*, *24*(6), 2530–2540. doi:10.1016/j.chb.2008.03.012

Morgan, C., & Alshwaikh, J. (2012). Communicating experience of 3D space: Mathematical and everyday discourse. *Mathematical Thinking and Learning*, *14*(3), 199–225. doi:10.1080/10986065.2012.682960

Mortimer, E. F., & Scott, P. H. (2003). *Meaning making in secondary science classrooms*. Maidenhead, UK: Open University Press.

Moses, R., & Cobb, C. E. Jr. (2001). *Radical equations: Math literacy and civil rights*. Boston, MA: Beacon Press.

Mouza, C. (2002). Learning to teach with new technology: Implications for professional development. *Journal of Research on Technology in Education*, *35*(2), 272–289. doi:10.1080/15391523.2002.10782386

Muehrer, R., Jenson, J., Friedberg, J., & Husain, N. (2012). Challenges and opportunities: Using a science-based video game in secondary school settings. *Cultural Studies of Science Education*, *7*(4), 783–805. doi:10.1007/s11422-012-9409-z

Muller, D. A., Sharma, M. D., & Reimann, P. (2008). Raising cognitive load with linear multimedia to promote conceptual change. *Science Education*, *92*(2), 278–296. doi:10.1002/sce.20244

Muller, M. J., & Druin, A. (2010). *Participatory design: The third space in HCI*. Hillsdale, NJ: Lawrence Erlbaum.

Mumford, A. (Ed.). (1997). *Action learning at work*. Farnham, UK: Gower.

Mumtaz, S. (2000). Factors affecting teachers' use of information and communications technology: A review of the literature. *Journal of Information Technology for Teacher Education*, *9*(3), 319–341. doi:10.1080/14759390000200096

Murphy, K. (2012). The social pillar of sustainable development: a literature review and framework for policy analysis. *Sustainability: Science, Practice, &. Policy*, *8*(1), 15–29.

Nakhleh, M. B. (1994). A review of microcomputer-based labs: How have they affected science learning? *Journal of Computers in Mathematics and Science Teaching*, *13*(4), 368–681.

Nakhleh, M. B., & Krajcik, J. S. (1994). The effect of level of information as presented by different technologies on students' understanding of acid, base and pH concepts. *Journal of Research in Science Teaching*, *31*(10), 1077–1096. doi:10.1002/tea.3660311004

Namioka, A. H., & Rao, C. (1996). Introduction to participatory design. In *Field methods casebook for software design* (pp. 283–299). New York: John Wiley & Sons.

National Academy of Engineering & National Research Council. (2014). *STEM integration in K-12 education: Status, prospects, and an agenda for research*. Washington, DC: The National Academies Press.

National Center for Education Statistics (NCES). (2012*). National assessment of educational progress.* U.S. Department of Education, Institute of Education Sciences. Retrieved from http://nces.ed.gov/nationsreportcard/

National Council of Teachers of Mathematics. (1989). *Curriculum and evaluation standards for school mathematics*. Reston, VA: Author.

National Council of Teachers of Mathematics. (2000). *Principles and standards for school mathematics*. Reston, VA: Author.

National Governors Association Center for Best Practices & Council of Chief State School Officers. (2010). *Common core state standards*. Washington, DC: National Governors Association Center for Best Practices, Council of Chief State School Officers.

National Governors Association Center for Best Practices (NGACBP). (2010). *Common Core State Standards for mathematics.* Retrieved from: http://www.corestandards.org/ Math/

National Governors Association Center for Best Practices, Council of Chief State School Officers. (2010). *Common Core State Standards for English language arts & literacy in history/social studies, science, and technical subjects*. Washington, DC: Author.

National Governors Association Center for Best Practices, Council of Chief State School Officers. (2010). *Common Core State Standards for Mathematics*. Washington, DC: Author.

National Research Council (NRC). (2007). *Taking science to school: Learning and teaching science in grades K-8.* National Academies Press.

National Research Council (NRC). (2011). *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*. Washington, D.C.: The National Academies Press.

National Research Council (NRC). (2011). *Successful K-12 education: Identifying effective approaches in Science, Technology, Engineering and Mathematics*. Washington, DC: National Academy Press.

National Research Council (NRC). (2012). *A framework for K-12 science education*. Washington, DC: National Academies Press.

National Research Council (NRC). (2012). *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas.* Washington, DC: The National Academies Press.

National Research Council. (1989). *Everybody counts. A report to the nation on the future of mathematics education*. Washington, DC: National Academy Press.

National Research Council. (1996). *National science education standards*. Washington, DC: National Academy Press.

National Research Council. (2000). *How People Learn: Brain, Mind, Experience, and School*. Washington, DC: National Academy Press.

National Research Council. (2006). *America's lab report: Investigations in high school science*. Washington, DC: National Academy Press.

National Research Council. (2006). *Learning to think spatially: GIS as a support system in the K-12 curriculum*. Washington, DC: National Academies Press.

National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts and core ideas*. Washington, DC: National Academies Press.

National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. Washington, DC: The National Academies Press.

National Research Council. (2012). *Next generation science standards.* Retrieved from http://www.nextgenscience.org

National Science Board. (2014). *Science and engineering indicators, 2014: A broad base of quantitative information on the U.S. and international science and engineering enterprise*. Washington, DC: Author.

National Science Teachers Association. (1992). Scope, sequence and coordination of secondary school science: Vol. 1. *The content core: A guide for curriculum developers*. Washington, DC: Author.

National Science Teachers Association. (1997). *NSTA pathways to the science standards: Guidelines for moving the vision into practice, Elementary school edition*. Arlington, VA: Author.

National Science Teachers Association. (2015). *Sports teams boost STEM learning*. Retrieved from http://www.nsta.org

National Science Teachers Association. (n.d.). *The NSTA Learning Center*. Retrieved October 20, 2014, http://learningcenter.nsta.org

National Telecommunications and Information Administration. (2000). *Falling through the net: Toward digital inclusion*. Washington, DC: Author.

NCES. (2015). *Digest of education statistics* [data files]. Retrieved from http://nces.ed.gov/programs/digest/current_tables.asp

Nelson, T., & Slavit, D. (2008). Supported teacher collaborative inquiry. *Teacher Education Quarterly*, *35*(1), 99–126.

Newman, W. J. J. Jr, Abell, S. K., Hubbard, P. D., McDonald, J., Otaala, J., & Martini, M. (2004). Dilemmas of teaching inquiry in elementary science methods. *Journal of Science Teacher Education*, *15*(4), 4. doi:10.1023/B:JSTE.0000048330.07586.d6

NGSS Lead States. (2013). *Next generation science standards*. Retrieved from: http://www.nextgenscience.org/

NGSS Lead States. (2013). *Next generation science standards: For states, by states*. Washington, DC: The National Academies Press.

NGSS Lead States. (2013). *Next Generation Science Standards: For States, By States*. Washington, DC: The National Academies Press.

NGSS Lead States. (2013). *Next Generation Science Standards: For States*. Washington, DC: By States.

NGSS The Next Generation Science Standards. (2013, June). Retrieved August 2013, from Next Generation Science Standards: http://www.nextgenscience.org/next-generation-science-standards

Nickerson, R. S. (1994). The teaching of thinking and problem-solving. In R. J. Sternberg (Ed.), *Thinking and problem-solving* (pp. 121–132). San Diego, CA: Academic; doi:10.1016/B978-0-08-057299-4.50019-0

Nicolaou, C. T., Nicolaidou, I. A., Zacharia, Z. C., & Constantinou, C. P. (2007). Enhancing fourth graders' ability to interpret graphical representations through the use of microcomputer-based labs implemented within an inquiry-based activity sequence. *Journal of Computers in Mathematics and Science Teaching*, *26*, 75–99.

Nieto, S. (1994). Lessons from students on creating a chance to dream. *Harvard Educational Review*, *64*(5), 392–426. doi:10.17763/haer.64.4.4846361m306pl670

Nikolova-Houston, T. (2005). Using participatory design to improve web sites. *Computers in Libraries*, *25*(9), 20–25.

Nolet, V. (2009). Febrary). Preparing Sustainability-Literate Teachers. *Teachers College Record*, *111*(2), 409–442.

Nordine, J. C. (2011). Motivating Calculus-Based Kinematics Instruction with Super Mario Bros. *The Physics Teacher*, *49*(380), 380–382. doi:10.1119/1.3628271

Norris, S. P., & Phillips, L. M. (2003). How literacy in its fundamental sense is central to scientific literacy. *Science Education*, *87*(2), 224–240. doi:10.1002/sce.10066

NRC (National Research Council). (1996). *National Science Education Standards*. NRC.

NRC (National Research Council, Committee on a Conceptual Framework for New K-12 Science Education Standards Board on Science Education, Division of Behavioral and Social Sciences and Education). (2012). A framework for K-12 science education: Practices, crosscutting concepts, and core ideas. Washington, DC: The National Academies Press.

NSF Task Force on Cyberlearning. (2008). *Fostering Learning in the Networked World: Learning Opportunity and Challege, a 21st century agenda for the National Science Foundation*. Arlington, VA: National Science Foundation.

Nucci, J. A., Doherty, P., Lung, L., & Singhota, N. (2011). How researchers can help K–12 teachers bring materials science into the classroom. *Materials Research Society Bulletin*, *36*(04), 284–289. doi:10.1557/mrs.2011.40

Nyachwaya, J. M., Mohamed, A.-R., Roehrig, G. H., Wood, N. B., Kern, A. L., & Schneider, J. L. (2011). The development of an open-ended drawing tool: An alternative diagnostic tool for assessing students' understanding of the particulate nature of matter. *Chemistry Education Research and Practice*, *12*(2), 121–132. doi:10.1039/C1RP90017J

Nystrand, M. (1997). *Opening dialogue: Understanding the dynamics of language and learning in the English classroom*. New York: Teachers College Press.

Office of the National Education Commission. (1999). *National Education Act of B.E. 2542 (1999)*. Retrieved May 3, 2015 from http://planipolis.iiep.unesco.org/upload/Thailand/Thailand_ Education_Act_1999.pdf

Office of the National Education Commission. (2000). *Learning reform: A learner-centered approach*. Bangkok: Watana Paint Printing & Publishing Company Limited.

Oh, P. S. (2011). Characteristics of abductive inquiry in earth science: An undergraduate case study.[Case Study]. *Science Education*, *95*(3), 409–430. doi:10.1002/sce.20424

Oliveira, A. W., Meskill, C., Judson, D., Gregory, K., Rogers, P., Imperial, C. J., & Casler-Failing, S. (2015). Language repair strategies in bilingual tutoring of mathematics word problems. *Canadian Journal of Science*. *Mathematics and Technology Education*, *15*(1), 102–115. doi:10.1080/14926156.2014.990173

Olympiou, G., & Zacharia, Z. C. (2012). Blending physical and virtual manipulatives: An effort to improve students' conceptual understanding through science laboratory experimentation. *Science Education*, *96*(1), 21–47. doi:10.1002/sce.20463

Orion, N., & Kali, Y. (2005). The effect of an earth-science learning program on students' scientific thinking skills. *Journal of Geoscience Education*, *53*, 387–394.

Orpwood, G., Schmidt, B., & Jun, H. (2012). *Competing in the 21st Century Skills Race*. Ottawa: Canadian Council of Chief Executives.

Osborne, J., Simon, S., Christodoulou, A., Howell-Richardson, C., & Richardson, K. (2013). Learning to argue: A study of four schools and their attempt to develop the use of argumentation as a common instructional practice and its impact on students. *Journal of Research in Science Teaching*, *50*(3), 315–347. doi:10.1002/tea.21073

Osborne, R. J., & Cosgrove, M. M. (1982). Children's conceptions of the changes of state of water. *Journal of Research in Science Teaching*, *20*(9), 825–838. doi:10.1002/tea.3660200905

OSPI. (2008). *Report on Washington State K-12 Environmental Education and Education for Sustainability 2008 Teacher Survey*. Washington Superintendent of Public Instruction. Washington Superintendent of Public Instruction.

Palsson, G., Szerszynski, B., Sörlin, S., Marks, J., Avril, B., Crumley, C., & Weehuizen, R. et al. (2013). Reconceptualizing the 'Anthropos' in the Anthropocene: Integrating the social sciences and humanities in global environmental change research. *Environmental Science & Policy*, *28*, 3–13. doi:10.1016/j.envsci.2012.11.004

Pang, J. S., & Good, R. (2000). A review of the integration of science and mathematics: Implications for further research. *School Science and Mathematics*, *100*(2), 73–82. doi:10.1111/j.1949-8594.2000.tb17239.x

Panoff, R. (2009). Simulations deepen scientific learning. *ASCD Express, 4*(19). Retrieved on Dec., 2014, from http://www.ascd.org/ascd_express/vol4/419_panoff.aspx

Panus, P., Stewart, D., Hagemeier, N., Thigpen, J., & Brooks, L. (2014). A subgroup analysis of the impact of self-testing frequency on examination scores in a pathophysiology course. *American Journal of Pharmaceutical Education, 78*(9). *Article*, *165*, 1–8.

Pape, S. J., Bell, C. V., Owens, S. K., Bostic, J. D., Irving, K. E., Owens, D. T., . . . Silver, D. (2010, May). *Examining verbal interactions within connected mathematics classrooms.* Paper presented at the Annual Meeting of the American Educational Research Association, Denver, CO.

Papert, S. (1980). *Mindstorms: Children, computers, and powerful ideas*. New York, NY: Basic Books, Inc.

Papert, S. (1996). An exploration in the space of mathematics educations. *International Journal of Computers for Mathematical Learning*, *1*(1), 95–123. doi:10.1007/BF00191473

Papert, S., & Harel, I. (1991). Situating constructionsim. *Constructionism*, *36*, 1–11.

Pape, S. J., Irving, K. E., Bell, C. V., Shirley, M. L., Owens, D. T., Owens, S., & Lee, S. C. et al. (2011). Principles of effective pedagogy within the context of connected classroom technology: Implications for teacher knowledge. In R. N. Ronau, C. R. Rakes, & M. L. Niess (Eds.), *Educational technology, teacher knowledge, and classroom impact: A research handbook on frameworks and approaches*. Hershey, PA: IGI Global.

Pape, S. J., Irving, K. E., Owens, D. T., Boscardin, C. K., Sanalan, V. A., Abrahamson, L., & Silver, D. et al. (2013). Classroom connectivity in *Algebra 1* classrooms: Results of a randomized control trial. *Effective Education*, *4*(2), 169–189. doi:10.1080/19415532.2013.841059

Pappas, C. C., Varelas, M., Barry, A., & Rife, A. (2003). Dialogic inquiry around information texts: The role of intertextuality in constructing scientific understandings in urban primary classrooms. *Linguistics and Education*, *13*(4), 435–482. doi:10.1016/S0898-5898(03)00004-4

Parr, C. S., Jones, T., & Songer, N. B. (2004). Evaluation of a handheld data collection interface for science learning. *Journal of Science Education and Technology*, *13*(2), 233–242. doi:10.1023/B:JOST.0000031262.22712.e0

Partnership for 21st Century Skills. (2009). *21st Century Skills Map.* National Science Teachers Association.

Partnership for 21st Century Skills. (2011). *Framework for 21st century learning*. Retrieved February 10, 2015 from http://www.p21.org/our-work/p21-framework

Pashler, H., Bain, P. M., Bottge, B. A., Graesser, A., Koedinger, K., McDaniel, M., & Metcalfe, J. (2007). *Organizing instruction and study to improve student learning. IES Practice Guide (NCER 2007-2004).* Jessup, MD: National Center for Education Research.

Patton, M. Q. (2001). *Qualitative research & evaluation methods*. Thousand Oaks, CA: Sage Publications.

Pearson, P. D., Moje, E., & Greenleaf, C. (2010). Literacy and science: Each in the service of the other. *Science*, *328*(5977), 459–463. doi:10.1126/science.1182595 PMID:20413491

Peat, M., & Franklin, S. (2003). Has student learning been improved by the use of online and offline assessment opportunities? *Australasian Journal of Educational Technology*, *19*, 87–99.

Pellegrino, J. W., & Hilton, M. L. (2013). *Education for life and work: Developing transferable knowledge and skills in the 21st Century.* Washington, DC: National Academies Press.

Penuel, W. R., Fishman, B. J., Yamaguchi, R., & Gallagher, L. P. (2007). What makes professional development effective? Strategies that foster curriculum implementation. *American Educational Research Journal*, *44*(4), 921–958. doi:10.3102/0002831207308221

Perrin, M. (2004). Inquiry-based pre-engineering activities for K-4 students. *Journal of STEM Education: Innovations and Research*, *5*(3/4), 29–34.

Pickett, S. T. A., Cadenasso, M. L., Grove, J. M., Nilon, C. H., Pouyat, R. V., Zipperer, W. C., & Costanza, R. (2008). Urban Ecological Systems: Linking Terrestrial Ecological, Physical, and Socioeconomic Components of Metropolitan Areas. In J. Marzluff, E. Shulenberger, W. Endlicher, M. Alberti, G. Bradley, C. Ryan, & C. ZumBrunnen et al. (Eds.), *Urban Ecology* (pp. 99–122). Springer, US. doi:10.1007/978-0-387-73412-5_7

Pidgeon, N., & Fischhoff, B. (2011). The role of social and decision sciences in communicating uncertain climate risks. *Nature Climate Change*, *1*(1), 35–41. doi:10.1038/nclimate1080

Pilco, S. (1990). *The XO laptop in the classroom*. Puno, Peru: Sdenka Zobeida Salas Pilco.

Pillay, H. (2002). An investigation of cognitive processes engaged in by recreational computer game players: Implications for skills for the future. *Journal of Research on Technology in Education*, *34*(3), 336–350. doi:10.1080/15391523.2002.10782354

Piraksa, J., & Srisawasdi, N. (2014). Promoting students' physics motivation by blended combination of physical and virtual laboratory environment: A result on different levels of inquiry. In *Proceedings of the 22nd International Conference on Computers in Education*. Asia-Pacific Society for Computers in Education.

Plant, E. A., Baylor, A. L., Doerr, C. E., & Rosenberg-Kima, R. B. (2009). Changing middle-school students' attitudes and performance regarding engineering with computer based social models. *Computers & Education*, *53*(2), 209–215. doi:10.1016/j.compedu.2009.01.013

Plass, J. L., Milne, C., Homer, B. D., Jordan, T., Schwartz, R. N., Hayward, E. O., & Barrientos, J. et al. (2012). Investigating the effectiveness of computer simulations for chemistry Learning. *Journal of Research in Science Teaching*, *49*(3), 394–419. doi:10.1002/tea.21008

Plass, J. L., O'Keefe, P. A., Homer, B. D., Case, J., Hayward, E. O., Stein, M., & Perlin, K. (2013). The impact of individual, competitive, and collaborative mathematics game play on learning, performance, and motivation. *Journal of Educational Psychology*, *105*(4), 1050–1066. doi:10.1037/a0032688

Polman, J. L. (2004). Dialogic activity structures for project-based learning environments. *Cognition and Instruction*, *22*(4), 431–466. doi:10.1207/s1532690Xci2204_3

Polsani, P. R. (2003). Use and abuse of reusable learning objects. *Journal of Digital Information, 3*(4). Retrieved May 3, 2015, from https://journals.tdl.org/jodi/index.php/jodi/article/view/89/88

Popham, W. J. (2008). Transformative assessment. Alexandria VA: Association for Supervision and Curriculum Development (ASCD).

Potter, J. (2010). The state of media literacy. *Journal of Broadcasting & Electronic Media*, *54*(4), 675–696. doi:10.1080/08838151.2011.521462

Prensky, M. (2001). Digital natives, digital immigrants. *On the Horizon, 9*(5). The President and Fellows of Harvard College. (n.d.). *The Project MOSART (Misconceptions-Oriented Standards Based Assessment Resources for Teachers) Self-Service Website*. National Science Foundation. Retrieved October 12, 2014, from https://www.cfa.harvard.edu/smgphp/mosart/index.html

Prensky, D. (2001). *Digital game-based learning*. New York: McGraw-Hill.

Prensky, M. (2005). Listen to the natives. *Educational Leadership*, *63*(4).

Presidents Council of Advisors on Science and Technology. (2012). Engage to Excel: Producing one million additional college graduates with degrees in science, technology, engineering, and mathematics. Washington, DC: Author.

Pressley, M., & McCormick, C. (1995). *Cognition, teaching, and assessment*. New York, NY: Harper Collins.

Prestridge, S. (2009). Teachers' talk in professional development activity that supports change in their ICT pedagogical beliefs and practices. *Teacher Development*, *13*(1), 43–55. doi:10.1080/13664530902858493

Prince, M. (2004). Does active learning work? A review of the research. *The Journal of Engineering Education*, *93*(3), 223–231. doi:10.1002/j.2168-9830.2004.tb00809.x

Pringle, R. M., Brkich, K. M., Adams, T. L., West-Olatunii, C., & Archer-Banks, D. A. (2012). Factors influencing elementary teachers' positioning of African American girls as science and mathematics learners. *School Science and Mathematics*, *112*(4), 217–229. doi:10.1111/j.1949-8594.2012.00137.x

Prothero, W. A. Jr, & Kelly, G. J. (2008). Earth data, science writing, and peer review in a large general education oceanography class. *Journal of Geoscience Education*, *56*(1), 61.

Puentedura, R. (2009). *As We May Teach: Educational Technology from Theory into Practice.* Retrieved January 20, 2015, from http://www.hippasus.com/rrpweblog/archives/000025.html

Putnam, R., & Borko, H. (2000). What do new views of knowledge and thinking have to say about research on teaching? *Educational Researcher*, *29*(1), 4–15. doi:10.3102/0013189X029001004

Qian, Y. (2009). An Investigation of Current Online Educational Games. In R. E. Ferdig (Ed.), *Effective Electronic Gaming in Education* (Vol. 1, pp. 67–82). New York: Information Science Reference. doi:10.4018/978-1-59904-808-6.ch004

Ramamurthy, M. K. (2006). A new generation of cyberinfrastructure and data services for earth system science education and research. *Advances in Geosciences*, *8*, 69–78. doi:10.5194/adgeo-8-69-2006

Ramus, F. (2003). Developmental dyslexia: Specific phonological deficit or general sensorimotor dysfunction? *Current Opinion in Neurobiology*, *13*(2), 212–218. doi:10.1016/S0959-4388(03)00035-7 PMID:12744976

Ramus, F., & Szenkovits, G. (2008). What phonological deficit? *Quarterly Journal of Experimental Psychology*, *61*(1), 129–141. doi:10.1080/17470210701508822 PMID:18038344

Rapley, T. (2004). Interviews. In C. Seale, G. Gobo, J. F. Gubrium, & D. Silverman (Eds.), *Qualitative Research Practice* (pp. 15–33). Thousand Oaks, CA: Sage Publications Ltd. doi:10.4135/9781848608191.d5

Raskind, M. (2000). *Bridges to reading*. San Mateo, CA: Schwab Foundation for Learning.

Ravenscroft, A., & Matheson, M. P. (2002). Developing and evaluating dialogue games for collaborative e-learning interaction. *Journal of Computer Assisted Learning*, *18*(1), 93–102. doi:10.1046/j.0266-4909.2001.00215.x

Rees, W., & Wackernagel, M. (2008). Urban Ecological Footprints: Why Cities Cannot be Sustainable—and Why They are a Key to Sustainability. In J. Marzluff, E. Shulenberger, W. Endlicher, M. Alberti, G. Bradley, C. Ryan, & C. Zum-Brunnen et al. (Eds.), *Urban Ecology* (pp. 537–555). Springer, US. doi:10.1007/978-0-387-73412-5_35

Reeve, E. M. (2013). *Implementing Science, Technology, Mathematics, and Engineering (STEM) Education in Thailand and in ASEAN*. Retrieved fromhttp://dpst-apply.ipst.ac.th/specialproject/images/IPST_Global/document/Implementing%20STEM%20in%20ASEAN%20%20-%20IPST%20May% 207%202013%20-%20Final.pdf

Rennie, L., Venville, G., & Wallace, J. (Eds.). (2012). *Integrating science, technology, engineering, and mathematics: Issues, reflections, and ways forward*. New York, NY: Routledge.

Resnick, L. B. (1991). Shared cognition: Thinking as social practice. In L. B. Resnick, J. M. Levine, & S. D. Teasley (Eds.), *Perspectives on socially shared cognition* (pp. 1–20). Washington, DC: American Psychological Association. doi:10.1037/10096-018

Resnick, M. (2006). Computer as paintbrush: Technology, play, and the creative society. In D. Singer, R. Golikoff, & K. Hirsh-Pasek (Eds.), *Play=Learning: How play motivates and enhances, children's cognitive and social-emotional growth* (pp. 192–208). Oxford, UK: Oxford University Press. doi:10.1093/acprof:oso/9780195304381.003.0010

Resnick, M., Maloney, J., Monroy-Hernández, A., Rusk, N., Eastmond, E., Brennan, K., & Kafai, Y. et al. (2009). Scratch: Programming for all. *Communications of the ACM*, *52*(11), 60–67. doi:10.1145/1592761.1592779

Richardson, K. (2001). Risk news in the world of Internet newsgroups. *Journal of Sociolinguistics*, *5*(1), 50–72. doi:10.1111/1467-9481.00137

Richardson, U., Thomson, J. M., Scott, S. K., & Goswami, U. (2004). Auditory processing skills and phonological representation in dyslexic children. *Dyslexia (Chichester, England)*, *10*(3), 215–233. doi:10.1002/dys.276 PMID:15341199

Richardson, V. (Ed.). (1997). *Constructivist teacher education: Building new understandings*. New York: Routeledge.

Rittel, H. W., & Webber, M. M. (2000). Dilemmas in a general theory of planning. *The Science of Public Policy: Policy Analysis II, 4*, 321.

Rivard, L. P. (2004). Are language-based activities in science effective for all students, including low achievers. *Science Education*, *88*(3), 420–442. doi:10.1002/sce.10114

Rivet, A. E., & Krajcik, J. S. (2008). Contextualizing instruction: Leveraging student prior knowledge and experience to foster understanding of middle school science. *Journal of Research in Science Teaching*, *45*(1), 79–100. doi:10.1002/tea.20203

Robinson, A., Shore, B. M., & Enersen, D. L. (2007). *Best practices in gifted education: An evidence-based guide*. Waco, TX: Prufrock Press.

Rogers, L. T. (1995). The computer as an aid for exploring graphs. *The School Science Review*, *76*(276), 31–39.

Rogoff, B. (1990). *Apprenticeship in thinking: Cognitive development in social context*. New York: Oxford University Press.

Rollock, N. (2007). Why Black girls don't matter: Deconstructing gendered and racialised discourses of academic success in an inner city school. *British Journal of Learning Support*, *22*(4), 197–202. doi:10.1111/j.1467-9604.2007.00471.x

Rooney-Varga, J. N., Brisk, A. A., Shuldman, M., & Rath, K. (2015). The CAM Project: Tools for bringing student media production into climate change education. *In the Trenches, 5*(1), 4-7. Retrieved from http://nagt.org/nagt/publications/trenches/articles/v5n1-2.html

Rooney-Varga, J. N., Brisk, A. A., Adams, E., Shuldman, M., & Rath, K. (2014). Student media production to meet challenges in climate change science education. *Journal of Geoscience Education*, *62*(4), 598–608. doi:10.5408/13-050.1

Roschelle, J., Penuel, W. R., & Abrahamson, L. (2004). The networked classroom. *Educational Leadership*, *61*(5), 50–54.

Rose, D. B., van Dooren, T., Chrulew, M., Cooke, S., Kearnes, M., & O'Gorman, E. (2012). Thinking through the environment, unsettling the humanities. *Environmental Humanities, 1*(1), 1-5. Retrieved from http://environmentalhumanities.org/arch/vol1/EH1.1.pdf

Rosebery, A. S., Warren, B., & Conant, F. R. (1992). Appropriating scientific discourse: Findings from language minority classrooms. *Journal of the Learning Sciences*, *21*(1), 61–94. doi:10.1207/s15327809jls0201_2

Rosenshine, B., Meister, C., & Chapman, S. (1996). Teaching students to generate questions: A review of the intervention studies. *Review of Educational Research*, *66*(2), 181–221. doi:10.3102/00346543066002181

Rossman, A. J., & Chance, B. L. (2012). *Workshop Statistics: Discovery with Data* (4th ed.). John Wiley Publications.

Roth, W.-M. (1996). Where is the context in contextual word problems?: Mathematical practices and products in grade 8 students' answers to story problems. *Cognition and Instruction*, *14*(4), 487–527. doi:10.1207/s1532690xci1404_3

Roth, W.-M., McGinn, M. K., & Bowen, G. M. (1998). How prepared are preservice teachers to teach scientific inquiry? Levels of performance in scientific representation practices. *Journal of Science Teacher Education*, *9*(1), 25–48. doi:10.1023/A:1009465505918

Roth, W.-M., Woszczyna, C., & Smith, G. (1996). Affordances and constraints of computers in science education. *Journal of Research in Science Teaching*, *33*(9), 995–1017. doi:10.1002/(SICI)1098-2736(199611)33:9<995::AID-TEA3>3.0.CO;2-Q

Rouda, R. H. (1973). Student-produced videotapes in a physical chemistry laboratory course. *Journal of Chemical Education*, *50*(2), 126. doi:10.1021/ed050p126

Rowe, J. (2001). An experiment in the use of games in the teaching of mental arithmetic. *Philosophy of Mathematics Education, 14*.

Rowland, A. (2012). Exploring How Conversations Meet Teacher Learning Needs. In P. Resta (Ed.), *Proceedings of Society for Information Technology & Teacher Education International Conference 2012* (pp. 3043-3047). Chesapeake, VA: AACE.

Ruiz-Primo, M. A., & Furtak, E. M. (2006). Informal formative assessment and scientific inquiry: Exploring teachers' practices and student learning. *Educational Assessment*, *11*(3/4), 205–235.

Ruiz-Primo, M. A., & Furtak, E. M. (2007). Exploring teachers' informal formative assessment practices and students' understanding in the context of scientific inquiry. *Journal of Research in Science Teaching*, *44*(1), 57–84. doi:10.1002/tea.20163

Ruiz-Primo, M. A., Shavelson, R. J., Hamilton, L., & Klein, S. (2002). On the evaluation ofsystemic education reform: Searching for instructional sensitivity. *Journal of Research in Science Teaching*, *39*(5), 369–393. doi:10.1002/tea.10027

Rushton, S. P. (2000). Student teacher efficacy in inner-city schools. *The Urban Review*, *32*(4), 365–383. doi:10.1023/A:1026459809392

Russell, D. W., Lucas, K. B., & McRobbie, C. J. (2003). The role of the microcomputer-based laboratory display in supporting the construction of new understandings in kinematics. *Research in Science Education*, *33*(2), 217–243. doi:10.1023/A:1025073410522

Russell, J. W., Kozma, R. B., Jones, T., Wykoff, J., Marx, N., & Davis, J. (1997). Use of simultaneous- synchronized macroscopic, microscopic, and symbolic representations to enhance the teaching and learning of chemical concepts. *Journal of Chemical Education*, *74*(3), 330–334. doi:10.1021/ed074p330

Rutten, N., Joolingen, W. R., & Veen, J. T. (2012). The learning effects of computer simulations in science education. *Computers & Education*, *58*(1), 136–153. doi:10.1016/j.compedu.2011.07.017

Ryan, C. (2013). *Language use in the United States: 2011*. U.S. Census Bureau. Retrieved from http://www.census.gov/prod/2013pubs/acs-22.pdf

Sadler, T. D. (2004). Informal reasoning regarding socioscientific issues: A critical review of research. *Journal of Research in Science Teaching*, *41*(5), 513–536. doi:10.1002/tea.20009

Saettler, P. (1990). The Evolution of American Educational Technology. Englewood, CO: Libraries Unlimited, Inc.

Sahin, S. (2006). Computer simulations in science education: Implications for Distance Education. *Turkish Online Journal of Distance Education*, *7*(4), 132–146.

Salen, K., & Zimmerman, E. (2004). *Rules of play: Game design fundamentals*. Cambridge, MA: MIT Press.

Salvia, J., Ysseldyke, J. E., & Bolt, S. (2010). *Assessment in special and inclusion education* (11th ed.). Belmont, CA: Wadsworth, Cengage Learning.

Sanchez-Franco, M. J. (2006). Exploring the influence of gender on Web usage via partial least squares. *Behaviour & Information Technology*, *25*(1), 19–36. doi:10.1080/01449290500124536

Sánchez, J., & Olivares, R. (2011). Problem solving and collaboration using mobile serious games. *Computers & Education*, *57*(3), 1943–1952. doi:10.1016/j.compedu.2011.04.012

Sanders, M. (2009). STEM, STEM education, STEMmania. *Technology Teacher*, *68*(4), 20–26.

Sarama, J. C., Clements, D. H., & Henry, J. J. (1998). Network of influences in an implementation of a mathematics curriculum innovation. *International Journal of Computers for Mathematical Learning*, *3*(2), 113–148. doi:10.1023/A:1009768005398

Saxton, E., Burns, R., Holveck, S., Kelley, S., Prince, D., Rigelman, N., & Skinner, E. A. (2014). A common measurement system for K-12 STEM education: Adopting an educational evaluation methodology that elevates theoretical foundations and systems thinking. *Studies in Educational Evaluation*, *40*, 18–35. doi:10.1016/j.stueduc.2013.11.005

Schmidt, H. G., Loyens, S. M. M., van Gog, T., & Paas, F. (2007). Problem based learning *is* compatible with human cognitive architecture: Commentary on Sweller, Kirschner, and Clark (2007). *Educational Psychologist*, *42*(2), 91–97. doi:10.1080/00461520701263350

Schmidt, H. G., Rotgans, J. I., & Yew, E. H. (2011). The process of problem-based learning: What works and why. [PubMed]. *Medical Education*, *45*(8), 792–806. doi:10.1111/j.1365-2923.2011.04035.x

Schroyens, W. (2005). Knowledge and thought: An introduction to critical thinking. *Experimental Psychology*, *52*(2), 163–164. doi:10.1027/1618-3169.52.2.163

Schwarz, B., Eisenmenger-Sittner, C., & Steiner, H. (2008). Construction of a higher-temperature sessile drop device. *Vacuum*, *82*(2), 186–188. doi:10.1016/j.vacuum.2007.07.033

Scott-Cato, M. (2009). *Green Economics: An Introduction to Theory, Policy and Practice*. London: Earthscan.

ScratchEd. (2014). *Scratch curriculum guide*. Retrieved February 10, 2015 from http://scratched.gse.harvard.edu/resources

Searle, J. R. (1972). What is a speech act? In P. P. Giglioli (Ed.), *Language and social context* (pp. 136–154). Baltimore, MD: Penguin Books.

Seehorn, D., Carey, S., Fuschetto, B., Lee, I., Moix, D., O'Grady-Cunniff, D., & Verno, A. et al. (2011). *CSTA K-12 Computer science standards: Revised 2011*. New York, NY: Computer Science Task Force.

Seiter, L., & Foreman, B. (2013). Modeling the learning progressions of computational thinking of primary grade students. In *Proceedings of the 9th Annual International ACM Conference on International Computing Education Research (ICER '13)*. New York, NY: ACM. http://doi.org/ doi:10.1145/2493394.2493403

Serrano, A. B., & Anderson, A. Q. (2004). The evaluation of food pyramid games, a bilingual computer nutrition education program for Latino youth[Electronic version]. *Journal of Family and Consumer Sciences Education*, *22*(1), 1–16.

Servage, L. (2008). Critical and transformative practices in professional learning communities. *Teacher Education Quarterly*, *35*(1), 63–77.

Shaffer, D. W., & Gee, J. P. (2005). *Before every child is left behind: How epistemic games can solve the coming crisis in education.* (WCER Working Paper No. 2005-7). University of Wisconsin-Madison, Wisconsin Center for Education Research. Retrieved from http://www.wcer.wisc.edu/

Shanahan, T., & Shanahan, C. (2008). Teaching disciplinary literacy to adolescents: Rethinking content-area literacy. *Harvard Educational Review*, *78*(1), 40–59. doi:10.17763/haer.78.1.v62444321p602101

Shanahan, T., & Shanahan, C. (2012). What is disciplinary literacy and why does it matter? *Topics in Language Disorders*, *32*(1), 7–18. doi:10.1097/TLD.0b013e318244557a

Shaywitz, S. (1998). Dyslexia. *The New England Journal of Medicine*, *338*(5), 307–312. doi:10.1056/NEJM199801293380507 PMID:9445412

Shaywitz, S. (2003). *Overcoming dyslexia*. New York, NY: Random House.

Sheldon, L., Clare, A., & Rufo-Tepper, R. (2014). Gamification: Creating new education tools by applying games to classroom learning. *The Current.* (A. M. Tremonti, Interviewer) CBC.

Shelton, B. E. (2007). Designing educational games for activity-goal alignment. In B. E. Shelton & D. Wiley (Eds.), *The design and use of simulation computer games in education* (pp. 103–130). Rotterdam, The Netherlands: Sense Publishers.

Shih, J. L., Shih, B. J., Shih, C. C., Su, H. Y., & Chuang, C. W. (2010). The influence of collaboration styles to children's cognitive performance in digital problem-solving game ''william adventure'': A comparative case study. *Computers in the Schools*, *55*(3), 982–993. doi:10.1016/j.compedu.2010.04.009

Shimoda, T. A., White, B. Y., & Frederiksen, J. R. (2002). Students goal orientation in learning inquiry skills with modifiable software advisors. *Science Education*, *86*(2), 244–263. doi:10.1002/sce.10003

Shin, N., Sutherland, L. M., Norris, C. A., & Soloway, E. (2012). Effects of game technology on elementary student learning in mathematics. *British Journal of Educational Technology*, *43*(4), 540–560. doi:10.1111/j.1467-8535.2011.01197.x

Shirley, M. L., & Irving, K. E. (2014). Connected classroom technology facilitates multiple components of formative assessment practice. *Journal of Science Education and Technology*, (October): 1–13. doi:10.1007/s10956-014-9520-x

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher*, *15*(2), 4–14. doi:10.3102/0013189X015002004

Shulman, L. S. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review*, *57*(1), 1–22. doi:10.17763/haer.57.1.j463w79r56455411

Shute, V. J. (2008). Focus on formative feedback. *Review of Educational Research*, *78*(1), 153–189. doi:10.3102/0034654307313795

Silva, E. (2009). Measuring Skills for 21st Century Learning. *Phi Delta Kappan*, *90*(9), 630–634. doi:10.1177/003172170909000905

Silverstein, M. (1995). Shifters, linguistic categories and cultural description. In B. G. Blount (Ed.), *Language, culture and society*. Prospect Heights, IL: Waveland Press.

Simon, H. A. (2000). Observations on the sciences of science learning. *Journal of Applied Developmental Psychology*, *21*(1), 115–121. doi:10.1016/S0193-3973(99)00055-6

Simons, K. D., & Ertmer, P. A. (2006). Scaffolding disciplined inquiry in problem-based learning environments. *International Journal of Learning*, *12*(6), 297–305.

Simpson, V., & Oliver, M. (2006). *Using electronic voting systems in lectures*. Retrieved February 14, 2015 from http://www.academia.edu/274635/Using_Electronic_Voting_Systems_In_Lectures

Skadberg, Y. X., & Kimmel, J. R. (2004). Visitors' flow experience while browsing a Web site: Its measurement, contributing factors and consequences. *Computers in Human Behavior*, *20*(3), 403–422. doi:10.1016/S0747-5632(03)00050-5

Skovsmose, O. (1985). Mathematical education versus critical education. *Educational Studies in Mathematics*, *16*(4), 337–354. doi:10.1007/BF00417191

Skovsmose, O. (2011). *An Invitation to Critical Mathematics Education*. Sense Publishers. doi:10.1007/978-94-6091-442-3

Smentana, L. K., & Bell, R. L. (2012). Computer simulations to support science instruction and learning: A critical review of the literature. *International Journal of Science Education*, *34*(9), 1337–1370. doi:10.1080/09500693.2011.605182

Smith-Evans, L., & George, J. (2014). *Unlocking opportunity for African American girls: A call to action for educational equity*. New York: The NAACP Legal Defense and Educational Fund and The National Women's Law Center. Retrieved December 11, 2014 from http://www.nwlc.org/resource/unlocking-opportunity-african-american-girls-call-action-educational-equity

Smith, P., Banilower, E., McMahon, K., & Weiss, I. (2002). *The national survey of science and mathematics education*. Chapel Hill, NC: Horizon Research.

Smolleck, L., & Hershberger, V. (2011). Playing with Science: An Investigation of Young Children's Science Conceptions and Misconceptions. *Current Issues in Education, 14*(1). Retrieved from http://cie.asu.edu/ojs/index.php/cieatasu/article/view/

Songer, N. B. (2000). *Persistence of inquiry: Evidence of complex reasoning among inner city middle school students*. Paper presented at the Annual Meeting of the American Educational Research Association, San Diego, CA.

Songer, N. B., & Gotwals, A. W. (2004). What constitutes evidence of complex reasoning in science? Paper presented at the 6th International Conference on Learning Sciences, Santa Monica, California.

Songer, N. (2007). Digital resources versus cognitive tools: A discussion of learning science with technology. In S. Abell & N. Lederman (Eds.), *Handbook of Research in Science Education* (pp. 471–492). Mahwah, NJ: Erlbaum.

Songer, N. B., Kelcey, B., & Gotwals, A. W. (2009). How and when does complex reasoning occur? Empirically driven development of a learning progression focused on complex reasoning about biodiversity. *Journal of Research in Science Teaching*, *46*(6), 610–631. doi:10.1002/tea.20313

Songer, N. B., Lee, H.-S., & Kam, R. (2002). Technology-rich inquiry science in urban classrooms: What are the barriers to inquiry pedagogy? *Journal of Research in Science Teaching*, *39*(2), 128–150. doi:10.1002/tea.10013

Songer, N. B., & Linn, M. C. (1991). How do students' views of science influence knowledge integration? *Journal of Research in Science Teaching*, *28*(9), 761–784. doi:10.1002/tea.3660280905

Soydhurum, P. (2001). *Science education in Thailand*. Bangkok: The Institute for the Promotion of Teaching Science and Technology.

Spillett, M. A. (2003). Peer debriefing: Who, what, when, why, how. *Academic Exchange Quarterly*, *7*(3), 36–41.

Spires, H. (2008). 21st century skills and serious games: Preparing the N generation. In L. A. Annetta (Ed.), *Serious Educational Games* (pp. 13–23). Rotterdam, The Netherlands: Sense Publishers.

Spiropoulou, D. T. A., Kontaxaki, S., & Bouras, S. (2007). Primary teachers' literacy and attitudes on education for sustainable development. *Journal of Science Education and Technology*, *16*(5), 443–450. doi:10.1007/s10956-007-9061-7

Squire, K. (2006). From content to context: Videogames as designed experience. *Educational Researcher*, *35*(8), 19–29. doi:10.3102/0013189X035008019

Srisawasdi, N., Moonsara, R., & Panjaburee, P. (2013). Students' motivation of science learning in integrated computer-based laboratory environment. In *Proceedings of the 21st International Conference on Computers in Education*. Asia-Pacific Society for Computers in Education.

Srisawasdi, N. (2012a). Introducing students to authentic inquiry investigation by using an artificial olfactory system. In K. C. D. Tan, M. Kim, & S. W. Hwang (Eds.), *Issues and challenges in science education research: Moving forward*. Dordrecht, The Netherlands: Springer. doi:10.1007/978-94-007-3980-2_7

Srisawasdi, N. (2012b). Student teachers' perceptions of computerized laboratory practice for science teaching: A comparative analysis. *Procedia: Social and Behavioral Sciences*, *46*, 4031–4038. doi:10.1016/j.sbspro.2012.06.192

Srisawasdi, N. (2014). Developing technological pedagogical content knowledge in using computerized science laboratory environment: An arrangement for science teacher education program. *Research and Practice in Technology Enhanced Learning*, *9*(1), 123–143.

Srisawasdi, N., Kerdcharoen, T., & Suits, J. P. (2008). Turning scientific laboratory research into innovative instructional material for science education: Case studies from practical experience. *The International Journal of Learning*, *15*(5), 201–210.

Srisawasdi, N., & Kroothkeaw, S. (2014). Supporting students' conceptual learning and retention of light refraction concepts by simulation-based inquiry with dual-situated learning model. *Journal of Computers in Education.*, *1*(1), 49–79. doi:10.1007/s40692-014-0005-y

Srisawasdi, N., & Sornkhatha, P. (2014). The effect of simulation-based inquiry on students' conceptual learning and its potential applications in mobile learning. *International Journal of Mobile Learning and Organisation*, *8*(1), 24–49. doi:10.1504/IJMLO.2014.059996

St. John, K., Leckie, R. M., Pound, K., Jones, M., & Krissek, L. (2012). *Reconstructing earth's climate history: Inquiry-based exercises for lab and class*. Hoboken, NJ: Wiley-Blackwell.

Stake, R. (1995). *The art of case research*. Newbury Park, CA: Sage Publications.

Stake, R. (1995). *The art of case study research*. Thousand Oaks, CA: Sage.

Stake, R. (2000). Case Studies. In N. K. Denzin & Y. S. Lincoln (Eds.), *Handbook of Qualitative research* (pp. 435–454). Thousand Oaks, CA: Sage.

Stake, R. (2005). Qualitative case studies. In N. K. Denzin & Y. S. Lincoln (Eds.), *The Sage handbook of qualitative research* (pp. 443–466). Thousand Oaks, CA: Sage.

State Educational Technology Directors Association. (2008). *Science, technology, engineering and math*. Retrieved April 9, 2011 from http://www.setda.org/wp-content/uploads/2013/11/Science-Technology-Engineering-and-Mathematics-STEM-Report.pdf

Steinberg, L. (1996). *Beyond the classroom: Why school reforms have failed and what parents need to do*. New York: Simon and Schuster.

Steinkuehler, C., & Duncan, S. (2008). Scientific Habits of Mind in Virtual Worlds. *Journal of Science Education and Technology*, *17*(6), 530–543. doi:10.1007/s10956-008-9120-8

Stein, M. K., & Lane, S. (1996). Instructional tasks and the development of student capacity to think and reason: An analysis of the relationship between teaching and learning in a reform mathematics project, Educational Research and Evaluation. *An International Journal on Theory and Practice*, *2*(1), 50–80. doi:10.1080/1380361960020103

Stemler, S. (2001). An overview of content analysis. *Practical Assessment, Research & Evaluation*, *7*(17). Retrieved from http://PAREonline.net/getvn.asp?v=7&n=17

Sterling, S. (2001). *Sustainable Education: Re-visioning Learning and Change.* Schumacker Briefings No. 6. Green Books Ltd.

Sterman, J. D. (2006). Learning from evidence in a complex world. *American Journal of Public Health*, *96*(3), 505–514. doi:10.2105/AJPH.2005.066043 PMID:16449579

Stevens, R., Wineburg, S., Herrenkohl, L. R., & Bell, P. (2005). Comparative understanding of school subjects: Past, present, and future. *Review of Educational Research*, *75*(2), 125–157. doi:10.3102/00346543075002125

Stone, R. J., III. *(2011). Delivering STEM education through career and technical education schools and programs.* Paper prepared for the workshop of the Committee on Highly Successful Schools or Programs for K-12 STEM Education, Washington, DC. Retrieved on Dec., 2014, from http://sites.nationalacademies.org/DBASSE/BOSE/DBASSE_080128#.Uai4CcHD-Uk

Stone, L. D., & Gutierrez, K. D. (2007). Problem articulation and the process of assistance: An activity theoretic view of mediation in game play. *International Journal of Educational Research*, *46*(1-2), 43–56. doi:10.1016/j.ijer.2007.07.005

Strachan, G. (2009). Systems Thinking. In A. Stibbe (Ed.), *The Handbook of Sustainability Literacy* (pp. 84–88). Green Books Ltd.

Strauss, A. L. (1987). *Qualitative analysis for social scientists*. Cambridge, UK: Cambridge University Press; doi:10.1017/CBO9780511557842

Strauss, A. L., & Corbin, J. (1990). *Basics of qualitative research: Grounded theory procedures and techniques*. Newbury Park, CA: Sage Publications, Inc.

Strauss, R., & Kinzie, M. B. (1994). Student achievement and attitudes in a pilot study comparing an interactive videodisc simulation to conventional dissection. *The American Biology Teacher*, *56*(7), 398–402. doi:10.2307/4449869

Stroud, R., Drayton, B., Hobbs, K., & Falk, J. (2014). Interactive Whiteboard Use in High-Tech Science Classrooms: Patterns of Integration. *International Journal of Emerging Technologies in Learning*, *9*(9), 41–49. doi:10.3991/ijet.v9i9.4141

Stubbs, H. S., Fowler, K., Ball, J., Singh, N., Whitaker, D., & Hawley, B. (2007). Educational Environmental Projects, using Technology Applications, For Middle School Students in Formal and Non-Formal Settings. *Meredian: A Middle School Computer Technologies Journal*. Retrieved from http://www.ncsu.edu/meridian/sum2003/gis/3.html

Suh, J. M., Johnston, C. J., & Douds, J. (2008). Enhancing mathematical learning in a technology-rich environment. *Teaching Children Mathematics*, 235–241.

Suits, J. P., & Srisawasdi, N. (2013). Use of an interactive computer-simulated experiment to enhance students' mental models of hydrogen bonding phenomena. In J. P. Suits & M. J. Sanger (Eds.), *Pedagogic roles of animations and simulations in chemistry courses.* American Chemical Society.

Summers, M., & Childs, A. (2007, November). Student science teachers' conceptions of sustainable development: An empirical study of three postgraduate training cohorts. *Research in Science & Technological Education*, *25*(3), 307–327. doi:10.1080/02635140701535067

Summers, M., Corney, G., & Childs, A. (2004). Student teachers' conceptions of sustainable development: The starting points of geographers and scientists. *Educational Research*, *46*(2), 163–182. doi:10.1080/0013188042000222449

Sustainability of Chocolate: The cacao plant is in trouble ! (2012, January). [Motion Picture]. California Academy of Sciences. Retrieved 2012, April from http://www.calacademy.org/sciencetoday/the-sustainability-of-chocolate/

Swan, D., & Goswami, U. (1997). Phonological awareness deficits in developmental dyslexia and the phonological representations hypothesis. *Journal of Experimental Child Psychology*, *66*(1), 18–41. doi:10.1006/jecp.1997.2375 PMID:9226932

Swanson, H. L. (1999). Reading comprehension and working memory in learning-disabled readers: Is the phonological loop more important than the executive system? *Journal of Experimental Child Psychology*, *72*(1), 1–31. doi:10.1006/jecp.1998.2477 PMID:9888984

Swarat, S., Ortony, A., & Revelle, W. (2012). Activity matters: Understanding student interest in school science. *Journal of Research in Science Teaching*, *49*(4), 515–537. doi:10.1002/tea.21010

Sweller, J., Kirschner, P. A., & Clark, R. E. (2007). Why minimally guided teaching techniques do not work: A reply to commentaries. *Educational Psychologist*, *42*(2), 115–121. doi:10.1080/00461520701263426

Tabak, I., & Baumgartner, E. (2004). The teacher as partner: Exploring participant structures, symmetry, and identity work in scaffolding. *Cognition and Instruction*, *22*(4), 393–429. doi:10.1207/s1532690Xci2204_2

Taber, K. S. (2013). Revisiting the chemistry triplet: Drawing upon the nature of chemical knowledge and the psychology of learning to inform chemistry education. *Chemistry Education Research and Practice*, *14*(2), 156–168. doi:10.1039/C3RP00012E

Tai, R. H., Liu, C. Q., Maltese, A. V., & Fan, X. (2006). Planning early for careers in science. *Science*, *312*(5777), 1143–1144. doi:10.1126/science.1128690 PMID:16728620

Takeuchi, L. M., & Vaala, S. (2014). *Level up learning: A national survey on teaching with digital games*. New York: The Joan Ganz Cooney Center at Sesame Workshop.

Tallal, P., Merzenich, M. M., Miller, S., & Jenkins, W. (1998). Language learning impairments: Integrating basic science, technology, and remediation. *Experimental Brain Research*, *123*(1-2), 210–219. doi:10.1007/s002210050563 PMID:9835411

Tal, T., Krajcik, J., & Blumenfeld, P. C. (2006). Urban schools' teachers enacting project-based science. *Journal of Research in Science Teaching*, *43*(7), 722–745. doi:10.1002/tea.20102

Tams, J. (2006). Online casual games Q&A. *Minna Magazine*, 2-5. Retrieved from http://mag.casualconnect.org/MinnaMagazine_Summer2006.pdf

Tan, O. S. (2007). Using problems for e-learning environments. In O. S. Tan (Ed.), *Problem based learning in eLearning breakthrough* (pp. 1–14). Singapore: Thomson Learning.

Tashakkori, A., & Teddlie, C. (1998). *Mixed methodology: Combing qualitative and quantitative approaches* (Vol. 46). Thousand Oaks, CA: Sage.

Taylor, N., Nathan, S., & Coll, R. K. (2003). Education for sustainability in regional New South Wales, Australia: An exploratory study of som teachers' perceptions. *International Research in Geographical and Environmental Education*, *12*(4), 291–311. doi:10.1080/10382040308667543

Tella, A. (2007). The Impact of Motivation on Student's Academic and Learning Outcomes in Mathematics among Secondary School Students in Nigeria. *Eurasia Journal of Mathematics, Science, & Technology (Elmsford, N.Y.)*, *3*(2), 149–156.

Texas Instruments. (2011). *CBL 2*. Retrieved July 18, 2011 from http://education.ti.com/educationportal/sites/US/productDetail/us_cbl_2.html

The Design-Based Research Collective. (2003). Design-based research: An emerging paradigm for educational inquiry. *Educational Researcher*, *32*(1), 5–8. doi:10.3102/0013189X032001005

The Tech Museum of Innovation. (n.d.). *Tough Stuff* [Motion Picture]. Retrieved February 13, 2015, from http://thetechawards.thetech.org/the-laureates/stories/1495

Thomas, A., Jalkio, J., Gunderson, B., Schmidtbauer, M., & Johnson, S. (n.d.). *Welcome to the Squishy Circuits Website Page*. Retrieved October 20, 2014, from http://courseweb.stthomas.edu/apthomas/SquishyCircuits

Thompson, J. R., Bakken, J. P., Fulk, B. M., & Peterson-Karlan, G. (2004). *Using technology to improve the literacy skills of students with disabilities.* Retrieved from North Central Regional Educational Laboratory: http://www.learningpt.org/pdfs/literacy/disability.pdf

Thompson, A., & Mishra, P. (2007). Breaking news: TPCK becomes TPACK! *Journal of Computing in Teacher Education*, *24*, 38–39.

Thornton, R. K. (2008). Effective learning environments for computer supported instruction in the physics classroom and laboratory. In M. Vicentini & E. Sassi (Eds.), Connecting research in physics education with teacher education. International Commission on Physics Education. Retrieved December 15, 2014 from vnr.st/sb4b

Thornton, R. K. (1987). Tools for scientific thinking - microcomputer-based laboratories for physics teaching. *Physics Education*, *22*(4), 230–238. doi:10.1088/0031-9120/22/4/005

Tidball, K., & Krasny, M. E. (2010). Urban environmental education from a social-ecological perspective: Conceptual Framework for Civic Ecology Education. *Cities and the Environment, 2*(1).

Tierney, J. P., & Grossman, J. B. (2000). *Making a difference: An impact study of Big Brothers Big Sisters*. Philadelphia, PA: Public/Private Ventures.

Torrance, H., & Pryor, J. (1998). *Investigating formative assessment: Teaching, learning, and assessment in the classroom*. Philadelphia, PA: Open University Press.

Toth, E. E., Morrow, B. L., & Ludvico, L. R. (2009). Designing blended inquiry learning in a laboratory context: A study of incorporating hands-on and virtual laboratories. *Innovative Higher Education*, *33*(5), 333–344. doi:10.1007/s10755-008-9087-7

Toulmin, S. E. (1958). *The uses of argument*. Cambridge, UK: Cambridge University Press.

Toulmin, S., Rieke, R., & Janik, A. (1984). *An introduction to reasoning*. Upper Saddle Ridge, NJ: Prentice Hall.

Trautmann, N. (2009). Interactive learning through web-mediated peer review of student science reports. *Educational Technology Research and Development*, *57*(5), 685–704. doi:10.1007/s11423-007-9077-y

Trilling, B., & Fadel, C. (2009). *21st century skills: Learning for life in our times*. San Francisco, CA: Jossey-Bass.

Triona, L., & Klahr, D. (2003). Point and click or grab and heft: Comparing the influence of physical and virtual instructional materials on elementary school students' ability to design experiments. *Cognition and Instruction*, *21*(2), 149–173. doi:10.1207/S1532690XCI2102_02

Trotter, A. (2005). Despite allure, using digital games for learning seen as no easy task. *Education Week*, *25*, 1–19.

Trumper, R., & Gelbman, M. (2001). A microcomputer-based contribution to scientific and technological literacy. *Journal of Science Education and Technology*, *10*(3), 213–221. doi:10.1023/A:1016673931746

Trunfio, P., Berenfeld, B., Kreikemeier, P., Moran, J., & Moodley, S. (2003). *Molecular Modeling and Visualization Tools in Science Education*. Symposium presented at the 2003 annual meeting of the National Association of Research in Science Teaching (NARST), Philadelphia, PA.

Tuan, H. L., Chin, C. C., Tsai, C. C., & Cheng, S. F. (2005). Investigating the effectiveness of inquiry instruction on the motivation of different learning styles students. *International Journal of Science and Mathematics Education*, *3*(4), 541–566. doi:10.1007/s10763-004-6827-8

Turnbull, R., Huerta, N., & Stowe, M. (2006). *The Individuals with Disabilities Education Act as amended in 2004*. Upper Saddle River, NJ: Pearson Education.

Tuzin, H. (2007). Blending video games with learning: Issues and challenges with classroom implementations in the Turkish context. *British Journal of Educational Technology*, *38*(3), 465–477. doi:10.1111/j.1467-8535.2007.00710.x

Tytler, R., & Peterson, S. (2003). Tracing young children's scientific reasoning. *Research in Science Education*, *33*(4), 433–465. doi:10.1023/B:RISE.0000005250.04426.67

U.S. Department of Education Green Ribbon Schools. (2014). Retrieved February 13, 2015, from http://www2.ed.gov/programs/green-ribbon-schools/index.html

U.S. Department of Education, Institute of Education Sciences, What Works Clearinghouse. (2012, May). *Science intervention report: Technology Enhanced Elementary and Middle School Science (TEEMSS)*. Retrieved from http://whatworks.ed.gov

U.S. Department of Education. (2011). *Proceedings Report From the Sustainability Education Summit*. Retrieved February 13, 2015, from http://www2ed.gov/about/reports/strat/sustainability/summit-2010.doc

Ucar, S., & Trundle, K. C. (2011). Conducting guided inquiry in science classes using authentic, archived, web-based data. *Computers & Education*, *57*(2), 1571–1582. doi:10.1016/j.compedu.2011.02.007

United Nations Educational, Scientific and Cultural Organization (UNESCO). (2004). *United Nations decade of education for sustainable development: Draft international implementation scheme*. New York: United Nations Education, Scientific, and Cultural Organization.

United Nations Educational, Scientific and Cultural Organization (UNESCO). (2012). *Education for Sustainable Development Source Book: Learning and Training Tools No. 4*. Paris: UNESCO Education Sector.

United Nations. (2002). *Report of the World Summit on Sustainable Development.* New York: United Nations. Retrieved April 2013, from http://daccess-dds-ny.un.org/doc/UNDOC/GEN/N02/636/93/PDF/N0263693.pdf?OpenElement

University of Colorado Boulder. (2015). *PhET interactive simulations for science and mathematics*. Retrieved from https://phet.colorado.edu

Urtel, M., Bahamonda, R., Mikesky, A., Udry, E., & Vessely, J. (2006). On-line quizzing and its effects on student engagement and academic performance. *Journal of Scholarly Teaching and Learning*, *6*, 84–92.

van der Meij, H., van der Meij, J., & Harmsen, R. (2012). *Animated pedagogical agents: Do they advance student motivation and learning in an inquiry learning environment*? Internal report, Center for Telematics and Information Technology (CTIT), University of Twente. Retrieved May 03, 2015 from http://doc.utwente.nl/79575/1/CTIT-TR-12-02.pdf

van der Meij, J., & de Jong, T. (2006). Learning with multiple representations: Supporting students' learning with multiple representations in a dynamic simulation-based learning environment. *Learning and Instruction*, *16*(3), 199–212. doi:10.1016/j.learninstruc.2006.03.007

van Driel, J. H., Beijaard, D., & Verloop, N. (2001). Professional Development and Reform in Science Education: The Role of Teachers' Practical Knowledge. *Journal of Research in Science Teaching*, *38*(2), 137–158. doi:10.1002/1098-2736(200102)38:2<137::AID-TEA1001>3.0.CO;2-U

Van Eck, R. (2006). The effect of contextual pedagogical advisement and competition on middle school students' attitude toward mathematics and mathematics instruction using a computer based simulation game. *Journal of Computers in Mathematics and Science Teaching*, *25*(2), 165–195.

Van Langenhove, L. (2012). Global issues: Make social sciences relevant. *Nature*, *484*(7395), 442. doi:10.1038/484442a PMID:22538586

Veemans, K., van Joolingen, W., & de Jong, T. (2006). Use of heuristics to facilitate scientific discovery learning in a simulation learning environment in a physics domain. *International Journal of Science Education*, *28*(4), 341–361. doi:10.1080/09500690500277615

Venables, A., & Summit, R. (2003). Enhancing scientific essay writing using peer assessment. *Innovations in Education and Teaching International*, *40*(3), 281–290. doi:10.1080/1470329032000103816

Venville, G., Wallace, J., Rennie, L., & Malone, J. (2000). Bridging the boundaries of compartmentalized knowledge: Student learning in an integrated environment. *Research in Science & Technological Education*, *18*(1), 23–25. doi:10.1080/713694958

Vickery, J. R. (2014). The role of after-school digital media clubs in closing participation gaps and expanding social networks. *Equity & Excellence in Education*, *47*(1), 78–95. doi:10.1080/10665684.2013.866870

Vizcarra, N. (2012). Arctic sea ice extent breaks 2007 record low. *Arctic Sea Ice News & Analysis.* Retrieved February 12, 2015, from http://nsidc.org/arcticseaicenews/2012/08/arctic-sea-ice-breaks-2007-record-extent/

Vogel, J. J., Vogel, D. S., Cannon-Bowers, J., Bowers, C. A., Muse, K., & Wright, M. (2006). Computer gaming and interactive simulations for learning: A meta-analysis. *Journal of Educational Computing Research*, *34*(3), 229–243. doi:10.2190/FLHV-K4WA-WPVQ-H0YM

Voloshinov, V. N. (1995). *Marxism and the philosophy of language, Bakhtinian thought: An introductory reader*. London: Routledge.

Volz, D. L. (2000). *Middle school science with calculators: Science experiments using Vernier sensors with the LabPro or the CBL 2 interface*. Beaverton, OR: Vernier Software and Technology.

Von Aufschnaiter, C., & Rogge, C. (2010). Misconceptions or missing conceptions? *Eurasia Journal of Mathematics. Science and Technology Education*, *6*(1), 3–18.

Voogt, J., Fisser, P., Pareja Roblin, N., Tondeur, J., & van Braak, J. (2013). Technological pedagogical content knowledge: A review of the literature. *Journal of Computer Assisted Learning*, *29*(2), 109–121. doi:10.1111/j.1365-2729.2012.00487.x

Vygotsky, L. S. (1978). *Mind in society*. Cambridge, MA: Harvard University Press.

Waitayangkoon, P. (2007). ICT professional development of teachers in Thailand: The lead-teacher model. In E. Meleisea (Eds.), *ICT in Teacher Education: Case Studies from the Asia-Pacific Region*. UNESCO Thailand. Retrieved May 4, 2015 from http://unesdoc.unesco.org/images/0015/001567/156757e.pdf

Wallace, M., & Robbins, B. (Eds.). (2006). *IGDA 2006 casual games white paper*. Retrieved from http://www.igda.org/casual/IGDA_CasualGames_Whitepaper_2006.pdfWaugh, 2006

Walqui, A., & van Lier, L. (2010). *Scaffolding the academic success of adolescent English language learners*. San Francisco, CA: WestEd.

Walshe, N. (2008, October). Understanding students' conceptions of sustainability. *Environmental Education Research*, *14*(5), 537–558. doi:10.1080/13504620802345958

Wang, F., & Hannafin, M. J. (2005). Design-based research and technology-enhanced learning environments. *Educational Technology Research and Development*, *53*(4), 5–23. doi:10.1007/BF02504682

Warschauer, M., Grant, D., Del Real, G., & Rousseau, M. (2004). Promoting academic literacy with technology: Successful laptop programs in K-12 schools. *System*, *32*(4), 525–537. doi:10.1016/j.system.2004.09.010

Warschauer, M., & Matuchniak, T. (2010). New technology and digital worlds: Analyzing evidence of equity in access, use, and outcomes. *Review of Research in Education*, *34*(1), 179–225.

Watkins, S. C. (2012). Digital divide: Navigating the digital edge. *International Journal of Learning and Media*, *3*(2), 1–12. doi:10.1162/ijlm_a_00072

Waugh, E. (2006*). An introduction to casual games.* GDC: Casual Games Summit 2006. Retrieved from http://www.gamasutra.com/view/feature/131030/gdc_casual_games_summit_2006_an_.php

Webb, M. (2008). Impact of IT on science education. In J. Voogt & G. Knezek (Eds.), International handbook of information technology in primary and secondary education (pp. 133-148). Springer International Handbooks of Education, Volume 20. Springer. doi:10.1007/978-0-387-73315-9_8

Weber, E. U. (2006). Experience-based and description-based perceptions of long-term risk: Why global warming does not scare us (yet). *Climatic Change*, *77*(1), 103–120. doi:10.1007/s10584-006-9060-3

Weber, E. U. (2010). What shapes perceptions of climate change? *Wiley Interdisciplinary Reviews: Climate Change*, *1*(3), 332–342. doi:10.1002/wcc.41

Weber, R. P. (1990). *Basic Content Analysis* (2nd ed.). Newbury Park, CA.

Wegener, M., Mcintyre, T. J., McGrath, D., Savage, C. M., & Williamson, M. (2012). Developing a virtual physics world. *Australasian Journal of Educational Technology*, *28*(3), 504–521.

Wellington, J., & Osborne, J. (2001). *Language and literacy in science education*. New York, NY: McGraw-Hill International.

Wells, G. (1993). Reevaluating the IRF sequence. *Linguistics and Education*, *5*(1), 1–38. doi:10.1016/S0898-5898(05)80001-4

Wells, G. (1999). *Dialogic inquiry: Toward a sociocultural practice and theory of education*. Cambridge, UK: Cambridge University Press. doi:10.1017/CBO9780511605895

Wenglinsky, H. (2005). Technology and achievement: The bottom line. *Educational Leadership*, *63*(4), 29.

Wheeler, K. A., & Byrne, J. M. (2003). K-12 Sustainability Education: Its Status and Where Higher Education Should Intervene. *Planning for Higher Education*, *31*(3), 23–29.

White, T. (2006). Code talk: Student discourse and participation with networked handhelds. *Computer-Supported Collaborative Learning*, *1*(3), 359–382. doi:10.1007/s11412-006-9658-5

Wideman, H. H., Owston, R. D., Brown, C., Kushniruk, A., Ho, F., & Pitts, K. C. (2007). Unpacking the potential of educational gaming: A new tool for gaming research. *Simulation & Gaming*, *38*(1), 1–21. doi:10.1177/1046878106297650

Wieman, C., Adams, W., & Perkins, K. (2008). PhET: Simulations that enhance learning. *Science*, *332*(5902), 682–683. doi:10.1126/science.1161948 PMID:18974334

Wiggin, G., & McTighe, J. (2005). *Understanding by Design template*. Academic Press.

Wiggins, G., & McTighe, J. (2005). Understanding by Design (2nd ed.). Alexandria, VA: Association for Supervision and Curriculum Development.

Wiliam, D. (2006). FA: Getting the focus right. *Educational Assessment*, *11*(3/4), 283–289. doi:10.1080/10627197.2006.9652993

Wiliam, D., & Thompson, M. (2008). Integrating Assessment with Learning: What will it take to make it work? In C. A. Dwyer (Ed.), *The future of assessment: Shaping teaching and learning* (pp. 53–82). New York: Lawrence Erlbaum.

Wilson, C., Taylor, J., Kowalski, S., & Carlson, J. (2010). The relative effects and equity of inquiry-based and commonplace science teaching on students' knowledge, reasoning, and argumentation. *Journal of Research in Science Teaching*, *47*(3), 276–301.

Wilson, M. E. (2009). *Assessing the Impact of High-Fidelity Implementation of 3D-VIEW on Student Achievement*. Purdys, NY: EDU, Inc.

Wilson, S. M., & Peterson, L. C. (2002). The anthropology of online communities. *Annual Review of Anthropology*, *31*(1), 449–460. doi:10.1146/annurev.anthro.31.040402.085436

Wilson, S., Shulman, L., & Richert, A. (1987). 150 different ways of knowing": Representations of knowledge in teaching. In J. Calderhead (Ed.), *Exploring teacher's thinking* (pp. 104–123). Eastbourne, UK: Cassell.

Winberg, T. M., & Berg, R. (2007). Students' cognitive focus during a chemistry laboratory exercise: Effects of a computer-simulated prelab. *Journal of Research in Science Teaching*, *44*(8), 1108–1113. doi:10.1002/tea.20217

Windschitl, M. M. (2003). Inquiry Projects in Science Teacher Education: What Can Investigative Experiences Reveal about Teacher Thinking and Eventual Classroom Practice? *Science education*, *87*(1), 112–143. doi:10.1002/sce.10044

Windschitl, M., & Andre, T. (1998). Using computer simulations to enhance conceptual change: The roles of constructivist instruction and student epistemological beliefs. *Journal of Research in Science Teaching*, *35*(2), 145–160. doi:10.1002/(SICI)1098-2736(199802)35:2<145::AID-TEA5>3.0.CO;2-S

Wing, J. M. (2008a). Computational thinking and thinking about computing. *Philosophical Transactions of the Royal Society of London A: Mathematical, Physical and Engineering Sciences, 366*(1881), 3717–3725. http://doi.org/<ALIGNMENT.qj></ALIGNMENT>10.1098/rsta.2008.0118

Wing, J. M. (2008b). Five deep questions in computing. *Communications of the ACM*, *51*(1), 58–60. doi:10.1145/1327452.1327479

Winn, W., Stahr, F., Sarason, C., Fruland, R., Oppenheimer, P., & Lee, Y.-L. (2006). Learning oceanography from a computer simulation compared with direct experience at sea. *Journal of Research in Science Teaching*, *43*(1), 25–42. doi:10.1002/tea.20097

Winsberg, E. (2010). *Science in the age of computer simulation*. The University of Chicago Press. doi:10.7208/chicago/9780226902050.001.0001

Wolz, U., Stone, M., Pulimood, S. M., & Pearson, K. (2010, March). Computational thinking via interactive journalism in middle school. In In *Proceedings of the 41st ACM Technical Symposium on Computer Science Education* (pp. 239-243). New York, NY: ACM. http://doi.org/ doi:10.1145/1734263.1734345

Woolley, A. W., Chabris, C. F., Pentland, A., Hashmi, N., & Malone, T. W. (2010, October). Evidence for a collective intelligence factor in the performance of human groups. *Science*, *330*(6004), 686–688. doi:10.1126/science.1193147 PMID:20929725

World Commission on Environment and Development (WCED). (1987). *Our Common Future*. Geneva: United Nations.

World Economic Forum. (2011). *The Global Competitiveness Report 2010-2011*. Retrieved May, 12, 2014 from http://reports.weforum.org/global-competitiveness-2011-2012

Wright, T., & Cockburn, A. (2005). Evaluation of two textual programming notations for children. In Proceedings of the Sixth Australasian Conference on User Interface (Vol. 40, pp. 55–62). Darlinghurst, Australia: Australian Computer Society, Inc.. Retrieved from http://dl.acm.org/citation.cfm?id=1082243.1082251

Wright, W. (2007). Spore, birth of a game. *TED2007*. Retrieved from http://www.ted.com/talks/will_wright_makes_toys_that_make_worlds?language=en

Wrzesien, M., & Raya, M. A. (2010). Learning in serious virtual worlds: Evaluation of learning effectiveness and appeal to students in the E-Junior project. *Computers & Education*, *55*(1), 178–187. doi:10.1016/j.compedu.2010.01.003

Wu, H.-K., & Krajcik, J. S. (2006). Inscriptional practices in two inquiry-based classrooms: A case study of seventh graders' use of data tables and graphs. *Journal of Research in Science Teaching*, *43*(1), 63–95. doi:10.1002/tea.20092

Xin, J. F. (1999). Computer-assisted cooperative learning in integrated classrooms for students with and without disabilities. *Information Technology in Childhood Education Annual*, (1): 61–78.

Yeo, S., Loss, R., Zadnik, M., Harrison, A., & Treagust, D. (2004). What do students really learn from interactive multimedia? A physics case study. *American Journal of Physics*, *72*(10), 1351–1358. doi:10.1119/1.1748074

Yin, R. K. (2014). *Case study research: Design and methods* (5th ed.). Thousand Oaks, CA: Sage.

Yip, F., & Kwan, A. (2006). Online vocabulary games as a tool for teaching and learning English vocabulary. *Educational Media International*, *43*(3), 233–249. doi:10.1080/09523980600641445

Zacharia, Z. C. (2007). Comparing and combining real and virtual experimentation: An effort to enhance students' conceptual understanding of electric circuits. *Journal of Computer Assisted Learning*, *23*(2), 120–132. doi:10.1111/j.1365-2729.2006.00215.x

Zacharia, Z. C., & Anderson, O. R. (2003). The effects of an interactive computer-based simulations prior to performing a laboratory inquiry-based experiments on students' conceptual understanding of physics. *American Journal of Physics*, *71*(6), 618–629. doi:10.1119/1.1566427

Zacharia, Z. C., & Constantinou, C. P. (2008). Comparing the influence of physical and virtual manipulatives in the context of the physics by inquiry curriculum: The case of undergraduate students' conceptual understanding of heat and temperature. *American Journal of Physics*, *76*(4), 425–430. doi:10.1119/1.2885059

Zacharia, Z. C., & Olympiou, G. (2011). Physical versus virtual manipulative experimentation in physics learning. *Learning and Instruction*, *21*(3), 317–331. doi:10.1016/j.learninstruc.2010.03.001

Zacharia, Z. C., Olympiou, G., & Papaevripidou, M. (2008). Effects of experimenting with physical and virtual manipulatives on students' conceptual understanding in heat and temperature. *Journal of Research in Science Teaching*, *45*(9), 1021–1035. doi:10.1002/tea.20260

Zion, M. (2006). On line forums as a "rescue net" in an open inquiry process. *International Journal of Science and Mathematics Education*, *6*(2), 351–375. doi:10.1007/s10763-006-9051-x

Zion, M., & Sadeh, I. (2007). Curiosity and open inquiry learning. *Journal of Biological Education*, *41*(4), 162–168. doi:10.1080/00219266.2007.9656092

Zucker, A. A., Tinker, R., Staudt, C., Mansfiled, A., & Metcalf, S. (2008). Learning science in grades 3-8 using probeware and computers: Findings from the TEEMSS II project. *Journal of Science Education and Technology*, *17*(1), 42–48. doi:10.1007/s10956-007-9086-y

Zumbach, J., Schmitt, S., Reimann, P., & Starkloff, P. (2006). Learning life sciences: Design and development of a virtual molecular biology learning lab. *Journal of Computers in Mathematics and Science Teaching*, *25*(3), 281–300.

Zwiers, J. (2014). Building academic language: Meeting Common Core Standards across disciplines, grades 5-12 (2nd ed.). San Francisco, CA: Jossey-Bass.

About the Contributors

Michael Urban is an Associate Professor of Professional Education at Bemidji State University, in Minnesota, USA. He teaches undergraduate and graduate classes in science education, Earth and physical science, and general education. Dr. Urban earned his doctorate in Educational Technology from the University of Northern Colorado. Over the past decade he has participated in several grants related to science education and teaching with technology, developed curriculum, and written a number of articles about science education in general, and geoscience education in particular. His current research interests relate to using high altitude weather ballooning as a means for in-service teachers, pre-service teacher candidates, and K-12 students to design and conduct authentic science, technology, engineering, and mathematics (STEM) investigations in order to enhance their knowledge and skills in those disciplines. Dr. Urban began his professional career in education as a middle school science teacher.

David Falvo has recently served as a Full-Time Core Faculty Member in the Richard W. Riley College of Education and Leadership at Walden University. Prior to that appointment he served as an Associate Professor of Instructional Technology at Delaware State University. He has over 30 years of professional experience in education and now serves as a Contributing Faculty Member for Walden University, while working on an assortment of community and environmental projects at his home-town location in the Pocono Mountains of Pennsylvania. Dr. Falvo earned his doctorate in Curriculum and Instruction and Instructional Technology at West Virginia University. Since then, he has a record of published research, quality teaching, and service. Dr. Falvo served as key personnel on an NSF grant studying the use of animations for teaching chemistry, and on numerous research projects about educational technologies. His research interests include online learning systems (designs and tools), interface usability, collaborative learning, and teacher professional development. In addition to his thirty years of working in the field of education, he has experience working with teachers and students in K-12 science education settings as well as over thirteen years of experience teaching undergraduate and graduate students.

* * *

Sevil Akaygun is an assistant professor of chemical education at Bogazici University, Istanbul, Turkey. She taught high school chemistry and middle school science for 12 years. In 2000, she earned an MS in science education at Bogazici University; in 2008, an MS in chemistry and in 2009, and a Ph.D. in chemical education at the University Northern Colorado. Her research interests include dynamic computer visualizations used in learning and teaching chemistry, nanoscience education and STEM education.

Marilyn Ault is Senior Research Associate and Director of ALTEC at the University of Kansas Center for Research on Learning. Her research interests focus on the instructional use of technology, including the design and use of educational games, to affect teaching and learning.

Michael Barnett is a professor of science education and technology in the Lynch School of Education at Boston College. He is the 2012 Carnegie Foundation for the advancement of Teaching Professor of the year. Dr. Barnett has been awarded over 10 National Science Foundation awards that has supported his research and development efforts. His primary areas of interests are (1) designing learning environments that empower students to not only take charge of their own learning but to develop the capacity to become change agents in their community, and (2) designing technology rich learning environments that enable students to solve complex problems, and (3) how to improve undergraduate STEM education for pre-service teachers and non-science majors. Dr. Barnett focuses his work on students who are under-represented in STEM fields (minorities and women) and is currently examining how to develop sustainable indoor urban agricultural programs and how to communicate science to the general public.

Nicole Beeman-Cadwallader is Director of Professional Development at Project Lead The Way (PLTW). She strategizes, develops, and manages K-12 STEM teacher professional development across PLTW's national network. Seeking to narrow STEM achievement gaps for underserved and underrepresented students drives her, and her scholarly and research interests reflect this vision.

Gayle A. Buck is a Professor of Science Education at Indiana University Bloomington. Her scholarship and teaching foregrounds relationships across learner diversity and science. Her research focuses on student populations traditionally under-served by science education and neglected epistemological assumptions in science teaching and learning.

Janis Bulgren is a Research Professor in the University of Kansas Center for Research on Learning. Her research interests focus on the development of and research on instructional procedures across the content areas that help students engage in higher order reasoning.

Hsiaowei "Cristina" Chang received her MA in Science Education from San Jose State University in 2013 for her work in studying teachers' understanding of sustainability. She teaches at a public elementary school in Palo Alto, CA.

Jana Craig-Hare is an Assistant Research Professor and Associate Director of ALTEC at the University of Kansas Center for Research on Learning. Her research interests focus on the instructional use of technology, school-wide interventions, and program evaluation.

Anne Vera Cruz is a curriculum developer and doctoral student of the Curriculum and Instruction program at Boston College. Her focus is on curriculum development and science education. She obtained a pre-medical psychology degree in Ateneo de Manila University, and further studied Curriculum and Teaching at Boston University. She taught early childhood and science in the United States and abroad. She also consulted for various institutions for curriculum development. Her research interests include curriculum theory, educational change, and science learning for early childhood education.

Pradeep Maxwell Dass serves as the director of the Center for Science Teaching and Learning at Northern Arizona University, Flagstaff, AZ, USA. He is a veteran high school biology teacher and science teacher educator, with a Ph.D. in Science Education from the University of Iowa, Iowa City, IA, USA. His scholarly activities and efforts have focused on the professional development of K - 12 in-service science teachers to advance the teaching and learning of science and mathematics in the context of real life situations, questions, problems, and issues.

Dennis J. DeBay's current research interests include using technological learning environments as a mediating factor between the teaching and learning of mathematics in formal and informal learning settings. This includes utilizing geospatial technologies to explore student understanding of real-world data. His other research interest includes teaching urban high school students to use STEM related skills to explore social justice issues such as sustainability and urban planning in their own communities.

Isha DeCoito is a Faculty Member in Curriculum Studies, STEM Education at Western University. Her research interests include multi-literacies – focusing on communication and representation of meaning in different contexts to improve students' and teachers' scientific and technological literacy; promoting inquiry and STEM integration through digital games and project based learning; enhancing nature of science conceptions, exploring and promoting diversity and equity in science education; and teacher professional development.

Hilary Dwyer is a post-doctoral researcher in Education and Computer Science at UC-Santa Barbara.

James D. Ellis is an Associate Professor in the Department of Curriculum and Teaching at the University of Kansas. His research interests focus on reform in science education, science teacher education, and use of technology to enhance teaching and learning in science.

Autumn Joy Florencio-Wain is currently a full time research assistant and PhD student at the State University of New York at Albany. Prior to beginning her doctoral work, she spent over a decade teaching in ESL and foreign languages (French, Spanish and Portuguese) in pre-K through college settings both in the US and abroad. Her current interests include holistic education, socio-emotional aspects of learning, experiential learning and student centered learning. When she is not engaged in academics she enjoys spending time immersed in nature, philosophizing with friends and playing with her children.

Diana Franklin is the Director of Computer Science Education at the Center for Elementary Mathematics and Science Education at the University of Chicago.

Bruce B. Frey is an Associate Professor of psychology and research in education and is a co-author of the widely used Levels of Collaboration Scale (utilized in program evaluations) and the Spirituality Index of Well-Being. His areas of interest include classroom assessment, instrument development, and program evaluation methodology.

Anne Gatling's experience in the field of education began as an elementary teacher, then as an Einstein Fellow working on the Teacher Quality portion of the Higher Education Reauthorization with Senator Lieberman, and more recently as an educator for both pre-service and in-service teachers. She values the opportunity to engage with pre-service and in-service teachers and is passionate about working with them as they develop the STEM knowledge and skills necessary to reach each student in our classrooms today. In addition, Dr. Gatling's interest in educational research allows her to continue to investigate ways to improve pre-service elementary teacher preparation in three ways: one, self-efficacy toward science; two, content knowledge; and thirdly, pedagogical skill in improving linguistically and culturally diverse student learning. Dr. Gatling is the Director of Merrimack College's Early Childhood and Elementary STEM Education Degree.

Anne Gold is Associate Scientist and geoeducation specialist with the Cooperative Institute for Research in Environmental Sciences (CIRES)'s Education and Outreach group. She has conducted climate science research for 6 years and taught many college-level classes, including field-camps and advised M.S. students. She is serving as a lead on a summer research project for community college students in Colorado, on curriculum development projects and on research projects about the importance of spatial thinking in Geoscience education. She previously developed the CLEAN peer-review process for educational resources. She conducts program evaluation and educational research around climate topics. Her projects translate research into educational resources.

Tracy Goodson-Espy is a professor of Mathematics Education in the Department of Curriculum and Instruction at Appalachian State University in Boone, North Carolina. She also serves on the Board of Directors for the North Carolina Science, Mathematics, and Technology Center. She earned a BS and an MS in Mathematics from Middle Tennessee State University and an EdD in Mathematics Education from George Peabody College of Vanderbilt University. She has served as the principal investigator on several U.S. National Science Foundation projects, including NC NAEP: Improving Mathematics Content and Methods Courses and Project SMILE: Science and Mathematics for Literacy Enhancement.

Amanda M. Gunning earned a Bachelor's of Science in Physics and after a short time as a journalist, became a high school physics teacher. During this time, she participated in a Research Experience for Teachers, sponsored by the NSF, in electrical and mechanical engineering. This experience sparked her interest in engineering in science education, which continues today. Amanda went on to earn her PhD in Science Education from Teachers College, Columbia University doing research in elementary science education and adult learning. She completed a post-doctoral fellowship at Teachers College for two years before joining Mercy College as an assistant professor. She teaches k-12 science methods courses and interdisciplinary science content courses for teachers. Her research interests lie in k-12 science teacher education using a self-efficacy framework, the history of physics education, and professional development of science teachers.

Alexandria Hansen is a graduate student in STEM Education at UC-Santa Barbara.

Danielle Harlow is an associate professor of education at UC-Santa Barbara. She earned her Ph.D. in science education from the University of Colorado, Boulder. She also has an undergraduate degree in physics and master's degree in geophysics. Her research focuses on how elementary school students and teachers learn science, engineering, and computer science.

Charlotte Hill is a graduate student in Computer Science at UC-Santa Barbara.

Karen E. Irving is an associate professor in the Department of Teaching and Learning at The Ohio State University. She earned her BS and MS in chemistry at Bucknell University and PhD in science education at the University of Virginia. Dr. Irving received the 2004 National Technology Leadership Initiative Science Fellowship Award for her work in educational technology in science teaching and learning. Dr. Irving was co-principal investigator on the Connected Classrooms in Promoting Achievement in Mathematics and Science project supported by the Institute of Education. This project was an interdisciplinary effort focused on teaching and learning of mathematics and science at the 7th-10th grade using wireless handheld devices in a classroom setting. Currently, Dr. Irving serves as associate director for education on the The STEM-Faculty Project: Training the next generation of STEM faculty at higher education institutions in India. Her research interests include technology-assisted formative assessment in STEM classrooms and the use of science focused animations and simulations to promote strong conceptual understanding. Recently, Dr. Irving was appointed to serve on the Ohio Science Standards Review Committee by Ohio Senate President Keith Faber.

Ashley Iveland is a doctoral student at UC Santa Barbara, studying STEM education. She has a teaching credential in secondary science and taught in middle and high school classrooms. Her research includes examining K-12 student understandings of science, engineering, and computer science concepts as well as looking at prospective, preservice, and practicing teachers' knowledge in these areas. She helped in the development of a curriculum geared towards teaching programming and computer science concepts to upper elementary school children. She also works with UC Santa Barbara's CalTeach program to recruit, educate, and research highly qualified STEM teachers.

Resa Marie Kelly is an Associate Professor of Chemistry and Science Education at San José State University in San José, CA, where her research focuses on using qualitative methodologies to examine general chemistry students' understanding of chemistry concepts and how animation use affects their understanding.

Isa Kretschmer is an experienced videographer with a BS in Film from the University of Kansas. He is skilled in the development of media to support information delivery including all aspects of video production: pre-production, script writing, videography, audio recording/mixing, editing, motion graphics animation, and internet streaming.

Anne Leak is a graduate student in Education at UC-Santa Barbara.

Paul Madden is a doctoral student at Boston College, studying Curriculum and Instruction with a focus on leadership, policy, educational change, and math education. He has degrees in philosophy and management with a concentration in accounting and a masters degree in secondary math education, both from Boston College. He previously taught high school math and coached policy debate in a Boston Public High School and at an Oglala Lakota Tribally Chartered School in Kyle, South Dakota. In addition, Paul has worked as a teacher educator for the Boston Debate League, an education non-profit that works closely with the Boston Public Schools to improve teaching and learning in the district. His research interests include teacher education, out-of-school time learning, critical pedagogy, epistemology, issues of race and power, and math and debate education.

Meghan E. Marrero is an associate professor of secondary education at Mercy College, where she directs two large grant programs supporting math and science teacher education. Meghan earned a BS in biological science at Cornell University and a Master's in secondary science education from Teachers College, Columbia University, where she later earned her doctorate is science education. She taught high school biology, marine science, and earth science in New York City before moving on to leading curriculum and professional development related to incorporating authentic data into K-12 classrooms at U.S. Satellite Laboratory. Meghan joined the faculty at Mercy College in 2011 and teaches courses in elementary and secondary science teaching methods, assessment and evaluation, and oceanography. Her research interests include STEM teacher education and improving ocean literacy. She is the lead author of a high school marine science textbook that relies on authentic earth data to improve student learning.

Felicia Moore Mensah, Ph.D. is professor of science and education, and program coordinator of the science education program at Teachers College, Columbia University in New York City. Since receiving her doctoral degree, Dr. Mensah has published extensively in the area of science teacher education. Her research interests are equity, diversity and social justice education with an emphasis on improving science experiences of PreK-16 teachers and students in urban classrooms.

Ellen Metzger is Professor of Geology and Science Education at San José State University (SJSU) where she directs the Bay Area Environmental STEM Institute (BAESI), a professional development program that has served more than 2,500 teachers since 1990 with funding from the National Science Foundation, NASA, Chevron, Intel and other supporters. She served for several years as Director of SJSU's Science Education Program, was a past member of the Board of Directors for the California Science Teachers' Association, and is author of An Explorers Guide to the Earth System (Pearson 2003).

Mahnaz Moallem is a Professor of Instructional Technology and Research. She received her Ph.D. in Instructional Systems Design (Learning Sciences) and her Certificate in Program Design and Evaluation. She has served as a PI and Co-PI on a number of funded projects and has served as Program Coordinator for the Instructional Technology graduate program in the Watson College of Education at the University of North Carolina Wilmington (UNCW) for 16 years. In addition to her research interest and experience in instructional design, program design and program evaluation, she has served as Technology Project Leader at the National Science Foundation (IPA) for two years and has interest and investigative experience in STEM education with strong record of innovative and advanced teacher preparation and leadership programs.

Deb Morrison is a teacher and researcher who works at the intersection of science education, equity and teacher education. She has degrees in geography, plant sciences and environmental sciences, and science education. Deb is a Colorado secondary science certified teacher and currently teaches 8th grade Earth science. She is also a teacher educator, an ecologist, a mother and an avid hockey fan.

Shelby P. Morge is an Associate Professor of Mathematics Education in the Watson College of Education, University of North Carolina at Wilmington.

Nirmala Naresh is an associate professor of mathematics education in the Department of Mathematics at Miami University. She received her bachelors, master's and M.Phil degree in Mathematics from the University of Madras, India. She received a Ph.D. in Mathematics Education from Illinois State University. She is a recipient of the prestigious National Science Foundation (NSF) – funded Service, Teaching and Research (STaR) fellowship. Naresh's research interests lie in the domains of ethnomathematics and the teaching and learning of probability & statistics. She is an active member of the National Council of Teachers of Mathematics and the Association of Mathematics Teacher Educators. Recently, she received funds from the Ohio Department of Education to facilitate professional development partnerships between Miami faculty and local school teachers. She teaches mathematics content courses for both mathematics and mathematics education majors and advises graduate and undergraduate students and serves on masters thesis committees.

Gretchen Oliver is a doctoral student in the Department of Education Theory and Practice at the University at Albany. Her research interests include teacher education and professional development, and teaching STEM to English learner students. She is the Project Coordinator for a U.S. Department of Education grant project, the Technology-Enhanced Multimodal Observation Protocol (MOP) Project.

Alandeom W. Oliveira is an associate professor of science education at the State University of New York at Albany. He earned a Master's degree in science education at Southeast Missouri State University (2002) and a PhD degree in science education at Indiana University Bloomington (2008). He has taught science education courses to teachers in Brazil and the US and has coordinated multiple professional development programs for school teachers, including Science Modeling for Inquiring Teachers Network, and Technology-Enhanced Multimodal Instruction in Science and Math for English Language Learners. His research interests include cooperative science learning, inquiry-based teaching, and classroom discourse.

David Oonk is an associate scientist at the Cooperative Institute for Research in Environmental Sciences (CIRES) at the University of Colorado of Boulder. He has been the resident videographer for CIRES and has recently begun the Ph.D. Program at the ATLAS Institute, a center of interdisciplinary research, learning, and collaboration in engineering, creative technologies and design. David's research will explore the efficacy of using the creative process to promote sustained engagement of secondary students in the STEM disciplines.

Amie Patchen is a doctoral student at Boston College, studying Curriculum and Instruction with a focus on science education. She has a degree in biochemistry from Oberlin College, and masters degrees in secondary science education and secondary literacy. She previously taught high school chemistry and Earth science in Chicago. Her research interests include informal and community-based science learning, and youth as mediators of science learning.

Lisa Poling is an Assistant Professor of Mathematics Education in the Department of Curriculum and Instruction at Appalachian State University (ASU), Boone North Carolina. At ASU she teaches junior and senior level undergraduate, as well as graduate courses in elementary mathematic pedagogy and content. Her current research interests include the examination of teacher preparation programs, how teachers' define their sense of responsibility in educating all children in the science of mathematics and employing mathematics to critically assess social justice issues. Prior to receiving her doctorate from The Ohio State University in 2010, she taught elementary school for seven years.

Bethany M. Reichen is a doctoral student and graduate research assistant in the Educational Theory and Practice department at the State University of New York at Albany, where she also received a Master's degree in Teaching English to Speakers of Other Languages. She has taught and designed English language courses in China and the United States, with the goal of merging content, language, and culture in the classroom. Her research interests include language acquisition and education, identity and language learning, and second language writing.

Tasha Richardson holds an undergraduate degree in Biophysics, and a Masters of Arts degree in Education. She is currently in the Curriculum Studies and Teacher Development PhD program at the Ontario Institute for Studies in Education at the University of Toronto. Her research interests include: informal learning spaces, digital video games and identity development, and physics education.

Juliette Rooney-Varga directs the Climate Change Initiative at UMass Lowell and is an Associate Professor of Environmental Biology. She has more than 20 years experience as a research scientist, studying microbial ecology and biogeochemistry in diverse environments, including marine algal blooms, climate change-carbon cycle feedbacks in Arctic peatlands, and anaerobic microbial community dynamics and performance in microbial fuel cells. Her recent work, funded by NASA and NSF, is focused on climate change education, communication, and decision support.

Yushaneen Simms has a Master of Science in Science of Instruction; Bachelor of Science in Biomaterials and Tissue Engineering. Current position is Science Coordinator at YSC Academy, Wayne, PA. Yushaneen has four years of experience teaching middle school and upper school science. She also has over five years of experience working in the field as a program evaluator for two master degree programs at the University of Pennsylvania's Penn Science Teacher Institute.

Lesley K. Smith is Associate Director of CIRES Education and Outreach at the University of Colorado. Her research focused on the biogeochemistry of wetland ecosystems, and she is now an outreach scientist providing professional development opportunities for undergraduate and graduate students and science teachers. She has been director of several NSF-funded programs, such as the GK-12 and COSEE Collaborative. She co-leads two new programs with colleague, Anne Gold, one of which provides summer research internships to community college students in Colorado and the other based on the short documentary program described in our chapter. Lesley also served eight years on the Board of Education for the Boulder Valley School District.

Loraine P. Snead has a Master of Science in Chemistry (anticipated), Master of Science in Science Education. Current position is Science Department Chair and Director of Student Advocacy and Teaching and Learning at YSC Academy, Wayne, PA. She has over 14 years of experience in secondary schools.

John Spagnolo has served as Technology Specialist for Faculty Development in the Reich College of Education (RCOE), Appalachian State University (ASU) since 1998. In this role he has assisted faculty with meeting state mandated technology standards for teacher education students. He is responsible for planning and delivering programs and activities designed to raise the technology skill levels of faculty so they can increase the quality and effectiveness of the technology they integrate into their teaching. John taught high school science for ten years, served as an "educator on loan" to the NC Department of

Public Instruction, was a faculty member for the NC Legislators School for Youth Leadership Development and has taught as an adjunct at East Carolina University. His current interests included digital curb cuts for learning, virtual communities of practice, wikis, blogs, and real simple syndication (RSS) for teaching and learning. . His main goal is preparing teachers for a digitally networked world.

Niwat Srisawasdi is an assistant professor at Division of Science, Mathematics, and Technology Education, Faculty of Education, Khon Kaen University, Thailand.

Gene A. Tagliarini is a professor of Computer Science in the College of Arts and Sciences. He received his Ph.D. in Computer Science and his MA in mathematics. He has a strong interest and experience in the design, development and delivery of Squeak Etoys models and simulations and teaches an elective course in integrating computing with mathematics. Dr. Tagliarni has served as a PI and Co-PI on a number of funded projects in STEM education.

Amy Trauth-Nare is the Associate Director of Science Education in the Delaware Center for Teacher Education at the University of Delaware. In this position, Amy works alongside K-12 science teachers to examine and improve science teaching. Her research focused on classroom assessment, environmental education and teacher professional development.

Clement Vashkar Gomes, Ph.D., is an assistant adjunct professor of education at Teachers College, Columbia University in New York City, where he received his master's and doctoral degree. Dr. Gomes is also the department coordinator of middle school science and the seventh and eighth grade head teacher at the Churchill School and Center in New York City. His research interests include using technology to support marginalized students with learning differences to help them better understand science concepts and skills.

Meredith Houle Vaughn is an Associate Professor in Science Education in the School of Teacher Education at San Diego State University in Science Education and a member of the Center for Research in Mathematics and Science Education (CRMSE). Her work supports teachers and informal educators design of locally contextualized science instruction. She is also studies the the role of professional development experiences in supporting science teacher learning and leadership. She holds a Ph.D. in Curriculum and Instruction, with a focus in science education from Boston College and a B.S. in Biology from Allegheny College. She has taught high school biology and currently teaches graduate and credential courses in science education.

Karen Woodruff, M.A., is Director of Curriculum for U.S. Satellite Laboratory and the Endeavor STEM Leadership Project, a professional development opportunity for educators. She is dedicated to helping K-12 classroom teachers gain the confidence and content knowledge they need to integrate across STEM subject areas for more enriching, meaningful teaching and learning experiences. With a strong emphasis on authentic data available through NASA missions, Karen and her team of instructors emphasize and model data analysis, problem solving, and critical thinking skills that are fundamental to a successful integrated STEM classroom. Karen is a former high school science teacher and graduate of Muhlenberg College and Lehigh University. She enjoys hosting Family STEM Nights and visiting schools to work with students. At home, she enjoys tinkering and exploring with her three boys and wonderful husband.

Yang Xu is a Ph.D. student in Curriculum and Instruction in the Lynch School of Education at Boston College. He is interested in using technology to design innovative learning environments that support the learning of literacy and STEM. He also studies the role of technology in networked professional development organizations and the creative use of data to drive informed decision-making. He is working with the Center of Applied Special Technology (CAST) on online literacy platforms and the Roche Center of Education at Boston College on Two-Way Immersion Network for Catholic Schools (TWIN-CS). He has a M.Ed in English Language Learners from Vanderbilt University and a B.A in the English Language and Literature from Northeast Normal University in China.

Index

Improving K-12 STEM Education Outcomes through Technological Integration

The application of technology in classroom settings has equipped educators with innovative tools and techniques for effective teaching practice. Integrating digital technologies at the elementary and secondary levels helps to enrich the students' learning experience and maximize competency in the areas of science, technology, engineering, and mathematics.

Improving K-12 STEM Education Outcomes through Technological Integration focuses on current research surrounding the effectiveness, performance, and benefits of incorporating various technological tools within science, technology, engineering, and mathematics classrooms. Focusing on evidence-based approaches and current educational innovations, this book is an essential reference source for teachers, teacher educators, and professionals interested in how emerging technologies are benefiting teaching and/or learning efficacy.

Topics Covered:

- Distance Learning
- Educational Technology Standards
- Gaming Technologies
- Hand-Held Devices
- Internet Technologies
- Social Media
- Software Applications

Information Science Reference

An Imprint of **IGI Global**
701 E. Chocolate Avenue
Hershey, PA 17033, USA
www.igi-global.com

ISBN 978-1-4666-9616-7
90000
9 781466 696167