SSMA 2014

Jacksonville • November 6 - 8

Bridging Connections between Mathematics and Science

Proceedings — Volume 1

113th Annual Convention

November 6 — 8, 2014

Jacksonville, Florida

Margaret J. Mohr-Schroeder
Shelly S. Harkness
Editors

ISBN 978-1-4951-3401-2

PROCEEDINGS OF THE 113TH ANNUAL CONVENTION OF THE SCHOOL SCIENCE AND MATHEMATICS ASSOCIATION

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Cite Proceedings Volume as:
Mohr-Schroeder, M. J., & Harkness, S. S. (Eds.). (2014). *Proceedings of the 113th annual convention of the School Science and Mathematics Association* (Vol. 1). Jacksonville, FL: SSMA.

Cite Proceedings Chapter as:
Author. (2014). Title of chapter. In M. J. Mohr-Schroeder, & S. S. Harkness (Eds.), *Proceedings of the 113th annual convention of the School Science and Mathematics Association* (Vol. 1). Jacksonville, FL: SSMA.

Website: www.ssma.org
The proceedings are also available via http://www.ssma.org/convention-proceedings

ISBN: 978-1-4951-3401-2

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Special thanks to

Kayla Blyman and Maureen Cavalcanti, University of Kentucky Graduate Students, for all of their hard work on the proceedings.

School Science and Mathematics Association

Founded in 1901

The School Science and Mathematics Association [SSMA] is an inclusive professional community of researchers and teachers who promote research, scholarship, and practice that improves school science and mathematics and advances the integration of science and mathematics.

SSMA began in 1901 but has undergone several name changes over the years. The Association, which began in Chicago, was first named the Central Association of Physics Teachers with C. H. Smith named as President. In 1902, the Association became the Central Association of Science and Mathematics Teachers (CASMT) and C. H. Smith continued as President. July 18, 1928 marked the formal incorporation of CASMT in the State of Illinois. On December 8, 1970, the Association changed its name to School Science and Mathematics Association. Now the organizational name aligned with the title of the journal and embraced the national and international status the organization had managed for many years. Throughout its entire history, the Association has served as a sounding board and enabler for numerous related organizations (e.g., Pennsylvania Science Teachers Association and the National Council of Teachers of Mathematics).

SSMA focuses on promoting research-based innovations related to K-16 teacher preparation and continued professional enhancement in science and mathematics. Target audiences include higher education faculty members, K-16 school leaders and K-16 classroom teachers.

Four goals define the activities and products of the School Science and Mathematics Association:

- Building and sustaining a community of teachers, researchers, scientists, and mathematicians
- Advancing knowledge through research in science and mathematics education and their integration
- Informing practice through the dissemination of scholarly works in and across science and mathematics
- Influencing policy in science and mathematics education at local, state, and national levels

PREFACE

These proceedings are a written record of some of the research and instructional innovations presented at the 113th Annual Meeting of the School Science and Mathematics Association held in Jacksonville, Florida, November 6 – 8, 2014. The theme for the conference is *Bridging Connections between Mathematics and Science*.

The blinded, peer reviewed proceedings include 6 papers regarding instructional innovations, 12 research papers, 1 transdisciplinary science and mathematics lesson plan, and 2 perspectives of the teacher. The acceptance rate for the proceedings was 60%. Papers are organized by paper type and presented in alphabetical order.

We would like to thank Maureen Cavalcanti and Kayla Blyman for their dedication to the technical details of putting together this document. We are pleased to present these Proceedings as an important resource for the mathematics, science, and STEM education community.

Margaret J. Mohr-Schroeder
Shelly S. Harkness
Co-Editors

TABLE OF CONTENTS

VOLUME 1

INSTRUCTIONAL INNOVATION PAPERS

TEACHER'S CORNER

RESEARCH PAPERS

Instructional Innovations

DEPOLITICIZING THE ENVIRONMENTAL IMPACT OF ENERGY PRODUCTION: A PROFESSIONAL DEVELOPMENT EXPERIENCE FOR SCIENCE TEACHERS

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Teaching about environmental concerns and sustainability is often met with challenges such as misinformation and biased opinions among learners. Such one-sided and erroneous ideas are often derived due to highly polarized political perspectives. This article describes a professional development experience for in-service science teachers that exposed participants to multiple perspectives on a series of local energy sources (e.g., nuclear reactor, wind farm, coal power plant). Mathematical modeling was used as a lens through which the participants could consider the multiple stakeholders and myriad environmental impacts of each energy source to determine their relative sustainability.

Introduction

For decades, scientists have warned of growing environmental threats (e.g., climate change, acid rain, ozone hole) and encouraged action by individuals, corporations, and governments to mitigate and/or reverse them. For such warnings to be heeded, citizens must be educated about the environment and be able to understand the sustainability of practices that impact it. Despite efforts of science educators, individuals' understandings of such issues are often misinformed or underdeveloped due to one-sided representations provided by political pundits, pastors, news outlets, and social media (Saylan & Blumstein, 2001). Since the green movement began, there has been conflict between pro-environmentalist and corporate interests. For example, Rachel Carson (1962) met personal and professional attacks from the chemical industry in response to her book, *Silent Spring,* despite her work ultimately being deemed valid. Radical environmental groups have been as guilty of sacrificing truth in favor of pro-environmental (and often anti-corporation) objectives (Saylan & Blumstein, 2001). Continued politicization of environmental issues (from all sides) has persisted over the subsequent five decades. This leads to the public receiving simple, narrow, and inaccurate views on highly complex environmental problems (Baimbridge, 2004).

Objectives/Purpose

The present paper will describe a professional development experience (PD), which explored the environmental impacts of various energy sources. The primary objective of the PD was to expose participants (in-service science teachers) to various sides of the issues related to energy production (both pro-environmental and pro-energy) and guide them in developing the skills to evaluate and compare the sustainability of diverse energy sources. In what follows, we provide related literature, describe the general structure of the PD, detail the experiences related to one of the energy sources, and close with implications for supporting teachers in evaluating environmental issues.

Related Literature

The social and cultural perspectives that people hold regarding energy production and use are often influenced by the politicization of environmental issues (Baimbridge, 2004). In order to navigate such politicization, individuals must consider diverse factors such as ecological interdependency, relationship between social and ecological systems, relationship between local- to global-scale environmental problems, local and specific knowledge of particular ecosystems, and the implicit value of life and diversity (Parker, Wade, & Atkinson, 2004).

The importance of environmental issues to individuals' lives can best be emphasized when connections between human action and environmental impacts are emphasized (Connell, 1999; Littledyke, 2008), instruction targets cognitive and affective domains (Littledyke, 2008; Loughland et al., 2002; Loughland et al., 2003; Martin & Brouwer, 1991), and personal action/choice is presented as a potential change agent with regard to environmental concerns (Bloom & Holden, 2011). Bloom, Holden, Sawey, and Weinburgh (2010) emphasize the importance of such learning experiences happening in natural environments when the goal is to create a sense of concern for environmental issues.

Mathematical modeling serves as a link between mathematics and its use to examine real-world situations in other fields (Giordano, Weir, & Fox, 2003; Pollak, 2011). Specifically, mathematical modeling "is the process of choosing and using appropriate mathematics and statistics to analyze empirical situations, to understand them better, and to improve decisions" (NGA & CCSSO, 2010, p. 72). The practice of modeling has multiple stages: identify a problem grounded in a real-word context, make assumptions, distinguish critical variables, devise an appropriate model, apply the model to the problem, evaluate the model, and, if necessary, revise the model (Galbraith, Stillman, & Brown, 2010). Galbraith et al. describe two approaches to mathematical modeling instruction. For the first approach, *modeling as content*, the goal is to proceed through all stages of the mathematical modeling process in order to address a real-world problem. The purpose of the second approach, *modeling as vehicle*, is to use mathematical modeling as a means to learn specific content or to focus on one or more competencies of the modeling process (Maaβ, 2006).

The modeling competencies parallel the stages of the modeling process and are described by subcompetencies (Maaβ, 2006). For instance, the first competency relates to understanding the problem in order to create a model, which reflects the reality of the situation. The subcompetencies in this area include: making assumptions and simplifying the situation; identifying important quantities and variables, which affect the situation; recognizing relationships between the variables; and researching and distinguishing relevant information to the situation (Blum & Kaiser, 1991 as cited in Maaβ, 2006). Mathematical modelers dedicate a significant amount of time to the various subtasks of understanding the problem, stages of the modeling process, which pose particular challenges for students (Haines & Crouch, 2010). Hilborn and Mangel (1997) argue that the power of mathematical modeling is the development of an understanding of a real-world situation, which leads to making informed decisions about societal issues.

Professional Development

The professional development consisted of an intensive three-week summer experience followed by monthly meetings throughout the subsequent academic year. The follow-up monthly meetings were to offer an opportunity for the teachers to reflect on how the summer experience was impacting their classroom teaching. A team consisting of science educators, a mathematics educator, and content specialists conducted the PD. The present paper describes the summer portion of the PD, which consisted of three primary components: 1) introduction to mathematical modeling, 2) classroom instruction and on-site experiences at various energy production sites, and 3) group activities to synthesize the information gained from classroom and field experiences.

To prepare the participants for the on-site experiences, they were first introduced to mathematical modeling by engaging in two modeling activities. Using a modeling as vehicle approach, the first activity focused on the initial stages of the modeling process. The participants were asked to identify the variables that should be considered when determining what time one must leave one's home in order to arrive at work on time. With the guidance of the mathematics educator, the participants generated the steps to the modeling process. Over two sessions, the participants then used this process to create a model to evaluate the environmental costs of locally versus non-locally grown produce. To close this portion of the PD, the participants presented their initial models. Mathematical modeling, in particular the initial phases involving identifying variables and making assumptions, became the lens through which the participants considered what they learned during the subsequent on-site field experiences.

The general approach used in the PD involved multiple sources of instruction. For all energy sources, the participants were provided with general, non-biased, scientific background about how the energy was produced via *The Energy Report* published by the Texas Comptroller of Public Accounts [TCPA] (2008). After being exposed to the general background regarding how each energy source was used to produce electricity, a combination of information sources were used to expose participants to various (and opposing) perspectives regarding the relative economic and environmental benefit of each. Table 1 outlines the experiences for each energy source.

Table 1
Energy Sources Investigated, Location of Instruction, and Representations of Energy Sources

Energy Source	Location of Event	Representations of Energy Source
Oil	East Texas Oil Museum Kilgore, Texas	Video and tour by museum representative Film – *A Crude Awakening: The Oil Crash* News – Deepwater Horizon oil spill in the Gulf of Mexico
Coal	Oak Hill Mine Henderson, Texas Martin Creek Steam Electric Power Plant Henderson, Texas	Tour of Oak Hill and Martin Creek by energy company representatives Film – *Coal Country* Film – *Burning the Future: Coal in America*
Wind	Wolf Ridge Wind Farm Muenster, Texas	NextEra representative presentation Research ecologist presentation Bird/bat mortality sampling experience
Hydroelectric	Buchanan Dam Buchanan, Texas	Lower Colorado River Authority representative presentation and tour Film – *Deliverance* News – 2010/2011 Texas drought
Natural Gas	Classroom	XTO Energy representative presentation Film – *Gasland*
Nuclear	Comanche Peak Nuclear Power Plant Somervell, Texas	Video and tour by Comanche Peak representatives Film – *Silkwood* News – Fukushima Daiichi nuclear power plant meltdown

These information sources included presentations by energy sector representatives and environmental biologists, instructional documentaries, mainstream films, news media, and on-site energy extraction/production sites. Effort was made to ensure that divergent perspectives on each energy source were presented. Subsequent to on-site visits, participants were given the opportunity to share their own developing ideas about each energy source and the variables, which should be considered when determining their environmental impact. In the next section, a detailed description of one energy source (wind power) is given.

After the on-site visits, the participants were challenged to work in groups to develop models, which could be used to compare the energy sources with respect to their impact on the environment. The intention of the PD was not for the participants to successfully develop a complete model (i.e., a modeling as content approach). However, by using a modeling as vehicle approach and focusing on the initial stages of the modeling process, participants gained an understanding of the complex nature of making decisions about the sustainability of energy production and its effect on the environment, which was a primary goal of the PD. The cumulative product of the summer portion of the PD was a PowerPoint presentation created in groups wherein participants advocated for or against one assigned energy source. During the presentations, the other participants were able to use their new knowledge and awareness to contest or support the presenters' arguments.

Example

This section illustrates one example of how participants were exposed to multiple perspectives on an energy source, namely wind generated power. Participants were taken to Wolf Ridge Wind Farm in Muenster, Texas where they deepened their content knowledge of wind power and heard from both energy sector representatives and wildlife biologists. Before the onsite visit, participants were given textbook materials that conveyed the scientific, non-biased, background information on how wind was used to generate electricity (TCPA, 2008). Upon arrival at the wind farm, they were provided classroom instruction on wind energy and were given a model wind turbine kit. Each participant was challenged to build the most efficient wind turbine using the materials provided. Upon completion, fans were used to test the efficiency of each design.

After this activity, a representative from Wolf Ridge conducted a presentation, which depicted the construction of the wind farm and presented data regarding, the amount of energy produced annually, the environmental benefits of wind power, and the economic benefit of Wolf Ridge to the local community. Following his presentation, he took the participants on a tour of the farm and allowed them to observe, photograph, and/or videotape the turbines up close, look inside a turbine tower, and witness the powering-up and powering-down of one to hear the relative change in noise level. The participants spent the night in cabins, which overlooked the wind farm and were able to watch the turbines throughout the evening and the following morning when the experience continued.

To further develop their understanding of the environmental costs and benefits of wind generated power, a wildlife biologist shared data regarding bird and bat mortality, discussed other wildlife impacts, and conducted a question and answer period. After the discussion, the participants engaged in a simulated bird/bat mortality search at one turbine. Field researchers taught the participants the sampling protocol, assisted them in locating bird and bat mortalities, and described the relative number of casualties found throughout the migratory season.

Upon returning to the classroom, participants had the opportunity to debrief about the experience. During this time, they shared their own perspectives of wind energy and how their perceptions had (or had not) changed. Emphasis was given to identifying the variables that must be considered when making the determination regarding the sustainability and environmental costs/benefits of this form of energy.

Implications

The instructional approach helped achieve positive learning outcomes related to both academic understanding of energy production as well as deepening recognition of environmental variables affected by energy production. In their post-assessments, many demonstrated more developed understanding of energy production methods. For example, regarding how wind can be used to generate power, Participant 8 initially stated: "*Wind turns a generator directly.*" Her post-assessment description included more details and complexity: "*Windmills (propellers turned by blowing wind) can provide mechanical energy to pump water or power machine tools. This mechanical energy can be used to turn generators that generate electricity*." Her answer changed from a very vague and general explanation to one with more elements of an informed answer.

Likewise, with regard to environmental costs of each energy production method, many more were identified on the post-assessments than on the pre-assessments. For wind power, Participant 2 only referred to the space needed: "*Requires A LOT of space to give moderate* *amount of electricity*." Her post-assessment response ("*Degradation to aesthetic aspects of a landscape…disruption to migratory patterns of birds… noise…need to be a tremendous number of windmills through the windiest parts of the country to make this a viable solution to energy needs.*") related much more.

The participants also emphasized the importance the on-site, field-based experiences to their own learning process: "*Having direct contact with the places and topics we were studying really made them real to me, took them out of abstraction and paper scenarios to a life experience*" (Participant 12) The participants also related how this approach would impact instruction in their own classrooms.

> When we discuss energy sources, my resource is the textbook, so I can only give my students the advantages/disadvantages that the text provides…. Now I can factually give my students info that I personally saw and know, thus providing more info than the text. In addition, we can have better discussions and better presentations from me. Also, I can talk more knowledgeably about nuclear, hydropower, and coal plants. And with pictures taken of these sources, I can connect Texas to the students and show them what's going on in their own state. Not only am I planning to boost my lecture strategy with the additional info, I'm also going to use the windmill kit with the students to teach variable, fair testing, inquiry, etc. I'm going to let them test out blades and try to light a bulb. I'm excited!!! (Participant 13)

The PD had implications for the participants and the instructional experiences of their students.

The PD, described herein, connected science and mathematics through the use of mathematical modeling. Using a modeling as vehicle approach, the initial stages of the modeling process (gathering information, identifying variables, and making assumptions) served as means for the participants to consider the multiple stakeholders and myriad environmental impacts of each energy source to determine their relative sustainability. The PD was designed to provide the participants with multiple, diverse experiences, which provided various perspectives regarding the relative economic and environmental benefit of each energy source. The participants explored the content via onsite field trips, films, and classroom teaching; explained what they had learned through classroom discussions and their group-constructed energy presentation; elaborated on their understanding by critically analyzing the presentations of other groups; evaluated the content through their comparison of the energy sources; and made final determination of their relative sustainability and environmental impact. As a result of the PD the participants experienced modeling as a vehicle for learning, realized the educational impact of on-site experiences for learning, gained content knowledge, and recognized the complexity of environmental issues.

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Acknowledgements

The professional development described in this paper was funded through the Texas Higher Education Coordinating Board and the Teacher Quality Enhancement grants program.

K-12 STEM SUMMER INSTITUTE FOR TEACHERS

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In the summers of 2013 and 2014, a team of university and informal science educators planned and implemented four one-week K-12 STEM Summer Institute that partnered the university, local informal science providers, and businesses. With a limited budget, the institutes emphasized evidence-based inquiry techniques through the lens of environmental issues. Teachers participated in inquiry-based activities, some of which integrated technology such as iPads and Vernier probes, while they learned more about conducting scientific investigations. The teachers used what they learned to develop and publish inquiry lesson plans for K-12 classrooms.

Introduction

The STEM Institute Summer Workshop for K-12 teachers offered a total of four one-week summer workshops in 2013 and 2014 to K-12 teachers in southwest Florida. University faculty and informal science educators delivered model activities in the areas of environmental chemistry, renewable energy, environmental engineering, and forensic anthropology. Features of the workshops included a) training in evidence-based inquiry pedagogy, b) sessions on navigating CPALMS, an online state repository of information and vetted resources for Florida teachers, c) time for teachers to develop their own lessons, d) emphasis on environmental education, e) participant lunches and morning coffee, f) breakout sessions for K-5 and 6-12 where appropriate, and g) outreach training for graduate and undergraduate student assistants. The institutes were a collaborative effort among STEM and education faculty associates of the Whitaker Center for STEM Education at Florida Gulf Coast University (FGCU), informal science educators at the Conservancy of Southwest Florida (Naples, FL) and the Imaginarium Science Center (Fort Myers, FL). The institutes were held on site at the Conservancy of Southwest Florida providing relevant K-12 classroom technology in an environmentally accessible setting conducive to collaboration for good pedagogical practice. The institutes filled a need in Southwest Florida for K-12 STEM professional development that is highly desired by the school districts in a region of the country with many Title 1schools.

Objectives/Purpose of the Study

Southwest Florida is situated between the Gulf of Mexico and the western edge of the Everglades and includes many environmentally important locations, such as mangrove estuaries, swamps, and freshwater rivers. However, the opportunities for professional development in STEM for teachers have been limited, mainly due to the lack of higher education facilities. The area's first state university, Florida Gulf Coast University, opened less than 20 years ago. Although the two largest school districts, Lee and Collier Counties, host annual Saturday conferences for teacher professional development with sessions on science and STEM, no follow-up support is provided. Collier and Lee counties have advanced programming for only a few selected teachers in each district. The summer institutes endeavored to support an additional 70-75 STEM teachers in the school districts both in content, confidence, and follow-up support to sustain positive effects on teacher practice and student learning.

The goals of the institutes included

- Development and delivery of integrated STEM activities for participant classrooms through
    - focusing on the standards using the backward design process.
    - gaining familiarity with constructivist learning methods such as the 5-E model and Process Oriented Guided Inquiry Learning (POGIL).
    - integrating STEM topics into one lesson, with a focus on Conservancy themes.
    - collaborating and sharing developed resources in their own school, among teachers in their district, and via Florida's resource repository, CPALMS.
- Dissemination of an effective model for teacher training in integrative STEM instruction.
- Involving FGCU STEM graduate and undergraduate students in the training process for their own professional development.

Significance and Related Literature

Traditionally, elementary teachers have little background in STEM courses (National Research Council, 2007). Further, many middle and high school STEM teachers coming into the teaching profession through alternative certification routes have little formal training in pedagogy. The institutes encourage collaboration among K-12 teachers, university faculty, and informal science educators to share best practices by providing all participants the opportunity to teach and learn from each other. This approach has been shown to enhance teacher effectiveness because both subject matter knowledge and understanding of how people learn are critical for increased student learning (Darling-Hammond & Youngs, 2002).

We also sought to involve two graduate students and one undergraduate student in each summer institute. The literature is clear that students involved in K-12 outreach activities gain teaching skills, confidence, and enhanced communication which give these students a competitive edge when seeking employment (Rao, Shamah & Collay, 2007).

The institutes focused on STEM professional development. In 2011, Wilson reviewed and summarized the literature regarding effective STEM teacher preparation, induction, and professional development. She notes that even though there are over 15,000 school districts in the U.S. and they all have multiple professional development programs with various sponsors, the professional development of teachers has been poorly studied. In fact, Wilson characterizes the variety of professional learning opportunities as “carnivalesque” and the literature too varied and uneven to draw strong empirical claims (Wilson, 2011). Wilson’s review suggests that professional learning opportunities for teachers in STEM, when available, are often flat, disconnected, and transitory. Furthermore, they are not designed to address the specific need of individual teachers. There is a strong need for more quality professional development activities for K-12 teachers in STEM (National Research Council, 2011).

The literature also tells us there is a definite link between teacher confidence, anxiety, efficacy and the student’s ability to learn (Enochs & Riggs, 1990; Tschannen-Moran, Hoy, & Hoy, 1998). There is further evidence that when teachers are uncomfortable teaching topics, they will tend to avoid them cover these topics superficially (Bursal & Paznokas, 2006; Nadelson, Seifert, Moll, & Coats, 2012). The institutes sought to address content knowledge gaps and improve teacher comfort with STEM content as well as influence teacher self-efficacy and confidence. The intent was to provide effective and consistent content models in varied STEM areas as well as to provide resources for teachers to investigate content further after the workshop.

Practice/Innovation

For the first institute (summer 2013), the FGCU facilitators, FGCU students, and community partners met during Fall 2012 to begin planning. This planning group met every six weeks to share ideas for inquiry activities, suggest supplies needed, and assign individual tasks. After the success of the first institute, the collaborators met during the fall to de-brief and assess the previous summer’s workshops prior to the follow-up workshop. Using the survey results from summer 2013, we continued meeting on a bi-monthly basis during the spring prior to the next institute to plan workshops for the Summer 2014 Institute. All partners benefitted from this synergistic collaboration through sharing ideas and resources as we created the model for our institute.

Daily feedback in the form of a single-page reflection regarding each day's activities was collected from the workshop participants allowing the teachers to reflect on the day's information as well as provide formative assessment to the facilitators so that unclear topics could be addressed the next day. Participants were also surveyed at the end of the week regarding workshop organization and overall satisfaction. In addition, participants completed two online surveys pre-, post- and three months after of the workshop. The Inquiry Science Implementation Scale (ISIS) survey immediately after provided insight into the level of inquiry implementation in use by the teachers while the Science Teaching Efficacy Belief Instrument (STEBI) allowed measurement of teacher self-efficacy changes. Although both of these surveys were originally developed to measures changes in science pedagogy, additional research has established reliability with both instruments when the word "Science" is changed to "STEM" in the surveys (Nadelson, Seifert, Moll, & Coats, 2012).

Additionally, at the conclusion of the workshop, teachers presented an inquiry-based lesson module for their classroom. These were developed by teachers working in cooperative groups in consultation with the facilitators during the week. We strongly encouraged the teachers to submit their lessons to CPALMS, a Florida K-12 vetted repository that shares resources through their website. A Florida Gulf Coast University Whitaker Center collection was set up in CPALMS to track submissions from institute participants. This submission process provided a level of teacher confidence, assurance, and professional development that is rare but much needed among teachers.

During the institutes, K-12 teachers experienced learning through inquiry-based STEM lessons developed and modeled by FGCU faculty. Teachers were then tasked with developing their own inquiry-based lessons using a backward design (Wiggins & McTighe, 1998) template. In backward design, teachers examine the standards, then develop related student learning objectives and assessments before designing their lessons based on an inquiry model such as Engage-Explore-Explain-Elaborate-Evaluate (the 5-E model) developed by the Biological Sciences Curriculum Study in the early 1990s (Bybee, 2014). Finally, teachers posted their lessons to CPALMS, a resource for Florida's K-12 teachers, where they are reviewed first by the facilitators and then other state reviewers before sharing with science teachers throughout Florida. Our STEM institute offered seven hours of unstructured consultation and development time for the creation of the lessons. Beaudoin, Johnston, Jones, and Waggett (2013) found that the most important feature of their summer workshop was time for teachers to collaborate in lesson development with support from university faculty and their peers.

The features of the institutes include

- Model guided inquiry activities developed and introduced by FGCU faculty and community partners in STEM focusing on environmental themes of the Conservancy with lessons in soil typing, animal anatomy, water chemistry, renewable energy, and engineering for K-12 teachers and our student assistants.
- Sessions examining CPALMS, a Florida repository that holds all Next Generation Sunshine State Standards and thousands of resources for K-12 teachers.
- Time for teachers to develop their own activities based on the guided inquiry model.
- Highlighting a sense of place (SoP) for participants in daily Conservancy explorations such as engineering a filter marsh and gopher tortoise corridor with Conservancy staff.
- Break-out sessions for Engineering and Anatomy topics into elementary and secondary cohorts to better address varied needs in these areas (based on 2013 workshop feedback).
- Training of FGCU graduate and undergraduate students in facilitating K-12 outreach activities.

The week-long summer workshops included 18 hours of instruction, 7 hours of teacher activity development, 3 hours of dissemination from the teachers, 3 hours of networking and unstructured time for socializing (lunches and coffee breaks were provided) and 4 hours for Conservancy activities (i.e., boat tours through mangroves; wildlife rescue center; museum exhibits explaining habitat reclamation).

Classroom Examples

During the first STEM Institute in summer 2013, the Whitaker Center for STEM Education faculty associates collaborated with education staff from the Conservancy of Southwest Florida and education staff from the Fort Myers science museum, the Imaginarium, to develop a pilot offering institute on site at the Conservancy. There were 32 teacher participants. Results were promising as evidenced by a post-workshop survey where teachers were asked whether they gained what they were hoping from the workshop. Of the 31 respondents, 84% said yes, 16% indicated yes and no, and not a single respondent was disappointed in the workshop. Additionally we asked teachers what they thought were the top three benefits of the workshop. The top responses to this open-ended question were (in order) Resources, Activities, Inquiry Training, Technology, and CPALMS. All of these responses were cited by more than 20% of the participants.

Teachers were also asked to complete the Inquiry Science Implementation Scale (ISIS) assessment which measures the degree to which faculty implement inquiry in their classroom (Nadelson, Seifert, Moll, & Coats, 2012). These results will inform future workshop offerings. The results of the 2013 pilot offering are promising, however, with no funds, almost 2/3 of the participants were from Collier County, where the Conservancy is located. Providing reimbursement for mileage as well as incentives such as classroom technology would assist greatly in increasing representation from the five-county area.

Although teachers were encouraged to submit their lessons to CPALMS, only one team in the 2013 institute was successful in having their lesson vetted and published. That lesson, entitled “Florida Panthers and Wildlife Corridors,” was accessed on June 6, 2014, at http://www.cpalms.org/Public/PreviewResourceLesson/Preview/50971.

Implications

The institutes offer a model workshop for effective K-12 STEM professional development. The institutes were developed by FGCU STEM and Education faculty (co-PIs) in collaboration with community partners. They focus on encouraging teachers to engage students in inquiry learning instead of simply meeting benchmarks and standards. The institutes offer a unique approach to integrating constructivist learning practices throughout its STEM content. The programming is evidence-based and the practices are consistently modeled throughout the workshop by the facilitators. The Conservancy setting leverages modern technology in an environmental setting that is appealing to teachers. Formative assessment from the 2013 pilot offering indicated that teachers gained skills with technology, inquiry training, writing activities, and CPALMS. They also appreciate the resources provided and the access to FGCU faculty both during and after the institutes. During the four institutes, the partners worked to accommodate the needs of the K-12 teachers. For example, feedback during one institute indicated that teachers are unsure what “STEM” means when applied to K-

12 education, so a very informative discussion was held where university faculty and K-12 teachers shared their viewpoints.

In addition to impacting the professional development of the K-12 teacher participants, the institutes had a broader impact including:

- *Enhancement of academic/community/K-12 interaction.* Our model of involving post-secondary educators and informal science partners to deliver K-12 professional development is a win-win for the university, the community, and the school districts, all of whom have an interest in K-12 STEM education enhancement.
- *Increased participation of underrepresented schools.* In 2013, the two institutes had 32 attendees from the five-county area, with 1/3 of the teachers representing Title 1 schools.
- *Teachers sharing their activities with a larger audience.* Teachers were encouraged at the end of the workshop to upload the lessons developed in the institutes to the State repository, CPALMS which, when vetted, are made available to any K-12 educators. The lessons are identified in CPALMS as belonging to the FGCU Whitaker Center Collection. Teachers were also encouraged to present their developed activities at their local STEM events for K-12 teachers including Super Science Saturday (Lee County) and Collier County's STEM Conference. With funding, future plans include supporting teachers during their first year of implementation via a Saturday follow-up workshop/learning community where faculty will share results of their implementation.

The summer institutes continue to evolve to meet the STEM professional development needs of K-12 teachers in southwest Florida. The participating teachers have shared their enthusiasm for what they learned during the institutes informally, and in local workshops and presentations. As the professional development model is refined for future STEM summer institutes at the Conservancy, lessons learned will be shared with a larger audience including university faculty and informal science educators.

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Acknowledgements

The authors are grateful for the support of the partners including Heather Walsh-Haney, Associate Professor of Forensic Studies, Florida Gulf Coast University; David Webb, Director of Education, Conservancy of Southwest Florida; Anji McStravic, Education Manager, Imaginarium Fort Myers, FL; and Sarah Von Williamsen, STEM Program Coordinator, Imaginarium, Fort Myers, FL.

USING MULTI-DECISION SCENARIOS TO FACILITATE TEACHER KNOWLEDGE FOR MATHEMATICAL QUESTIONING

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A novel method for both examining and improving preservice teachers' knowledge for facilitating mathematical discussion is presented. The online platform LessonSketch.org was used to create comic-based representations of mathematics teaching that included multiple variations depending on user (preservice teacher) question choice. Each scenario includes three decision points in which question types are available as options for the user, allowing for 39 potential storylines generated from user choice. Preliminary data from preservice teachers is presented, along with an example scenario, to support discussion for implementation in teacher education, with the example provided focusing particularly on elementary mathematics.

Introduction

Over the last several years, approaches to mathematics teacher education have been increasingly informed by indicators of mathematical knowledge for teaching (MKT). Most widely discussed by Deborah Ball and colleagues (Ball, Thames, & Phelps, 2008; Ball & Bass, 2000; Hill, Schilling & Ball, 2004), MKT includes several sub-domains of knowledge that can be usefully distinguished into two primary groups: subject matter knowledge (SMK) and pedagogical content knowledge (PCK). These domains, and their subdomains, have been particularly useful in creating multiple-choice quantitative assessments at the elementary (Hill et al., 2004), middle (Hill, 2007), and secondary level (Herbst & Kosko, 2014), as well as assessments based on representations of practice (Kersting, 2008; Kersting, Givvin, Sotelo, & Stigler, 2010). Such assessments have aided in exploring relationships observed between teachers' actions and their level of MKT (Ball et al., 2008; Kersting et al., 2010), as well as relationships between teachers' MKT and their decision-making in hypothetical scenarios (Kosko, in review; Kosko & Herbst, 2012). Part of what makes these assessments both reliable and valid is their construction of items surrounding particular tasks of teaching (Herbst & Kosko, 2014). In the case of assessments following Ball and colleagues' approach, items are situated in a task specific to mathematics teaching and the participant reading the item is solicited to make some form of decision (is a child's mathematics correct, do they hold a certain misconception, etc.). However, such a design can be modified to not only assess, but improve conceptions of MKT.

Objectives and Purpose

Tasks of mathematics teaching provide a useful context for assessing and improving teachers' conceptions of MKT. In this paper, I describe the use of animated representations of practice via an interactive web-based platform (LessonSketch.org) to prompt preservice teachers to consider multiple scenarios of instruction, differing on the premise of pedagogical decisions made in the scenario. To facilitate this description, an example and response data are discussed. Given these objectives, the purpose of this paper to describe the initial efforts of designing these activities for preservice elementary teachers to develop their MKT for the specific task of facilitating mathematical discussions.

Related Literature

Much of the research examining teacher knowledge, in general, and MKT in particular is based on early research on teachers' decision-making in the 1970's, pioneered by Alan Bishop, Lee Shulman, and Richard Shavelson through a series of concurrent investigations (Borko, Roberts, & Shavelson, 2008). Such work considered understanding teachers' decision-making as a means of improving teacher education. Shulman's (1986) contribution to this line of research was his conceptualization of teacher knowledge, particularly PCK. MKT, developed by Ball and colleagues as an extension of Shulman's work (Ball et al., 2008; Ball & Bass, 2000), has since been shown to be a useful factor in explaining a portion of teachers' decision-making (Kosko, in review; Hill, 2010: Kosko & Herbst, 2012).However, items included in assessments of MKT are situated in tasks of teaching (Herbst & Kosko, 2014). These tasks of teaching can serve as simplistic scenarios of classroom practice, often boiled down to a very particular moment in the potential decision-making process. As such, tasks of teaching can be considered as one type of representation or practice.

Representations of practice, in general, have been used in teacher education programs for decades; mostly in the form of written cases and video vignettes. For example, Jacobs, Lamb, and Philipp (2010) describe the use of video vignettes as a means of developing elementary teachers' noticing of student thinking. However, Jacobs et al. (2010) frame their description of noticing as a part of a process of decision-making on the part of the teacher. Further, the skillset of noticing students' thinking and operationalizing it within teachers' decision-making is something that can be learned provided certain experiences. Some have suggested the use of cartoon and comic-based representations as a means of developing such skillsets (Chen, 2012; Chieu, Herbst, & Weiss, 2011; Herbst, Aaron, & Chieu, 2013). Chieu et al. (2011) found that animations provided prospective teachers with opportunities to focus on particular aspects of instruction. Rather, while videos include all events that occur in a classroom, animations allow for a filtering of certain information and events, allowing for specific features of practice to come to the fore. Chen (2012) examined preservice teachers' construction of vignettes and found that when preservice teachers created cartoon-based scenarios, they had an increased focus on student actions in lessons.

While cartoon-based scenarios have been found to be useful for facilitating mathematics teacher education, other studies have examined how cartoon-based scenarios can be used to examine teachers' decision-making (Kosko & Herbst, 2012), as well as how MKT is embedded as part of the process of decision-making (Kosko, in review). The findings from these various studies suggest that cartoon-based scenarios can be used to both improve and assess MKT. Given this background, I extended findings from the literature and applied them to the context of an elementary mathematics methods course. Within the next section, I describe the nature of the comic-based scenarios used, the manner in which they were used, and preliminary evidence for their effect on preservice teachers' MKT in the context of facilitating mathematical discussions.

Innovative Instructional Practice

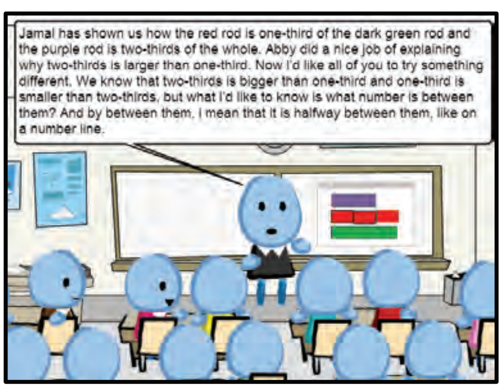
Branching Decisions as a Representation of Practice

I use the term *branching decision* to denote a particular representation of mathematics teaching that includes multiple decision points, and thus multiple branches in a decision tree for a scenario[1]. While it is possible to use various types of representations to create a branching decision (i.e., written cases, video vignettes), Herbst, Chazan, Chen, Chieu, and Weiss (2011) have argued that comic-based representations of teaching offer a more pragmatic means of developing such branching scenarios. In particular, comic-based representations contain many of the visual indicators present in video, but can include hypothetical as well as actual happenings in the classroom (Herbst et al., 2011). Herbst et al. (2011) advocate the use of LessonSketch.org for the creation and organization of such representations, and I elected to follow this recommendation.

In Spring 2014, I developed and implemented two branching decision scenarios into a preservice elementary mathematics methods course early in the semester (n = 20). The course one of two mandatory mathematics methods courses for preservice teachers, focusing on mathematics pedagogy and children's mathematical thinking. Because the course also places a large emphasis on number and operations topics, the two branching decision scenarios were designed to focus on multi-digit subtraction and fractions, respectively. Each scenario included three decision points with between three and four hypothetical actions for preservice teachers to consider. Each action depicted the teacher posing a question, structured after Boaler and Broadie's (2004) descriptions of *gather info*, *generate discussion*, and *probing questions* because of the prevalence these question types are observed in classroom practice. Further, scenarios were designed so that decision branches could be designated as *probing sequences* that included more than one probing question to solicit students' mathematical thinking (Franke et al., 2009). Preservice teachers could explore alternate decision branches using a 'back button' embedded in LessonSketch.org experiences. In this manner, preservice teachers enrolled in the course could examine the consequence of asking certain questions. Following completion of branching decision experiences, we discussed both the question practices, and students' mathematical thinking within scenarios as part of the next course meeting.

Classroom Examples

For purposes of space, I discuss the use and preliminary findings from using the fractions branching decision experience in the fifth week of the course. Preservice teachers completed the experience after one course meeting which focused on Steffe and Olive's (2010) description of children's fractional schemes, and ways in which to help students develop particular definitions of fractions. When preservice teachers opened the experience in LessonSketch.org, they were provided an overview of the class, including descriptions of the teacher, particular students, materials, and curriculum at time of the scenario. They were then presented with the initial slides of the scenario, shown in Figure 1. The scenario included use of Cuisenaire rods, which aligned with content focused on in the course meeting, as well as the readings assigned for the preceding and forthcoming week.



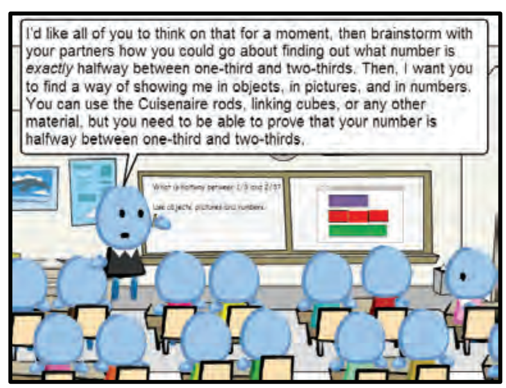


Figure 1. Initial Stem of Example Branching Decision.

After viewing the scenario in Figure 1, preservice teachers were provided with three initial options (see Figure 2). Each of these decisions, designated with a dashed border, resulted in different student responses. The first option was classified as a *gather info* question because it solicited only an answer from the depicted student Jessie. The second option was a *probing question* because it asked Jesse to describe the procedures for finding the number between one-third and two-thirds. The final option was a *generate discussion* question as it did not designate a particular student provide a response.

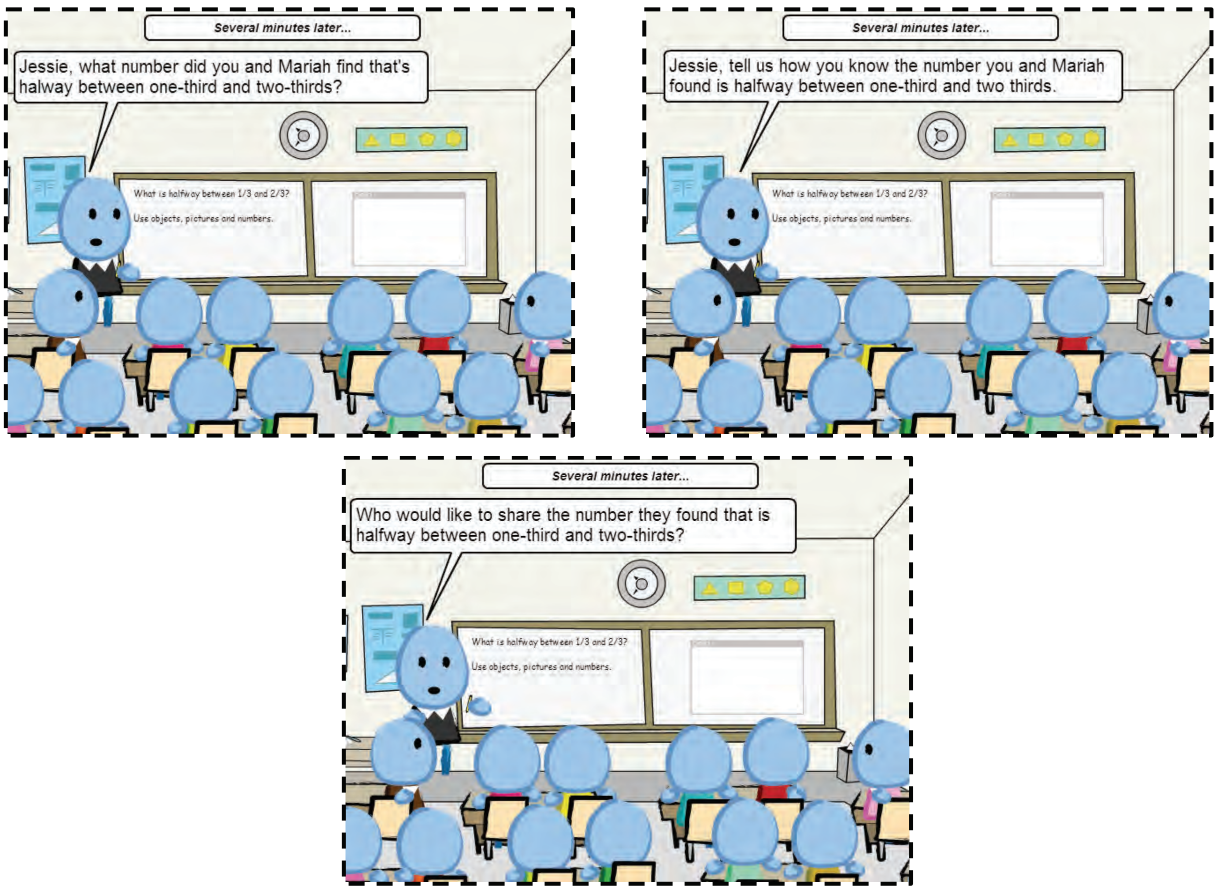


Figure 2. Optional Decisions for First Decision Point.

Selecting the second option resulted in Jesse briefly describing what she and her partner did to find a solution of three-sixths. However, another student disagrees and says that the number can also be one-half. Figure 3 presents this consequence of choosing the second action in Figure 2. Yet, Figure 3 also presents a portion of a decision path that can result; the second slide in Figure 3 presents another decision point (probing question) and the third slide presents the consequence of that decision. Should the preservice teacher completing this item continue to choose certain prompts, students will eventually present their full and correct descriptions of their mathematical strategies and solutions (as has been observed by Franke et al., 2009).

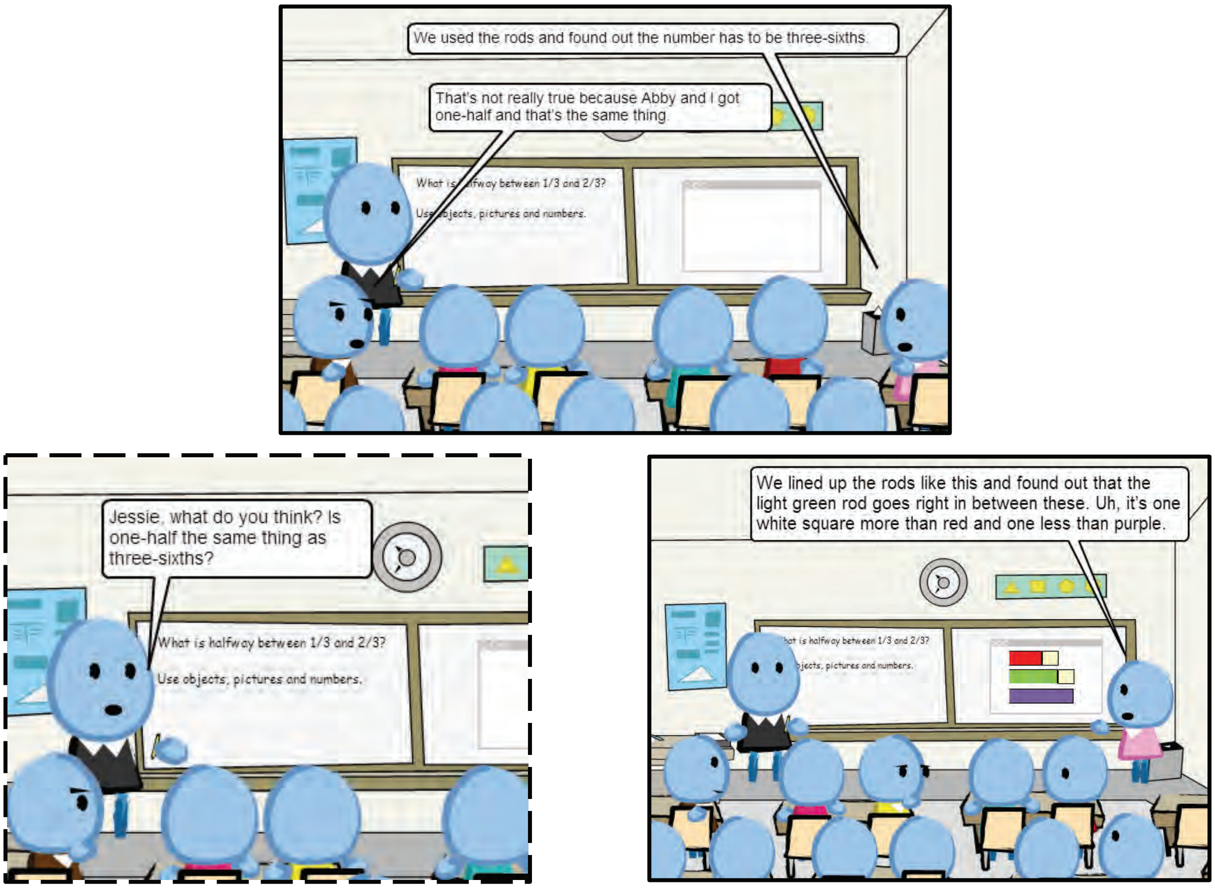


Figure 3. Potential decision branch resulting from selecting action 2 in decision point 1.

In the comments and discussion that followed, preservice teachers noted how comparing the results of different questions affected their teacher knowledge. One preservice teacher, Sarah, noted, “it was interesting to see at which point the teacher moved on the next question. I tried many different options to try and include the most discussion and explanations before moving on, while not forgetting to solve the original problem.” This echoes what many other preservice teachers noted was a tension regarding attending to students’ mathematical thinking, while also attending to demands of the curriculum (in this case the mathematical task at hand). Another preservice teacher, Megan, commented that “it’s important to dig deep and encourage children to show their thought process. Instead of moving on to the next problem, we encouraged Jesse to explain why."

What it meant for preservice teachers to have students "explain why" was a concept that evolved over the entire course. At this point in the semester, Sarah was describing this in terms of using probing sequences while Megan was referring to individual probing questions. Megan's descriptions were fairly common in the course, but they also demonstrated an improvement in how preservice teachers described facilitating mathematical discussions at the beginning of the course. In completing the first branching decision experience, approximately 60% of the class indicated that using a series of *generate discussion* prompts was appropriate; this effectively limited the depth of mathematical description in the depicted scenario in exchange for a larger number of participating students in the scenario. Rather, by examining the various branches in each depicted scenario, and being instructed to focus on how the questions helped students articulate their thinking, preservice teachers began to make more meaningful connections between the nature of a mathematical prompt and students' mathematical descriptions. Anna's description, below, helps illustrate this point.

> One thing that I learned was you really need to follow along with the story and think about the responses the students will give. When I picked what the teacher should do next, I had a scenario set up in my head, but when I reflected on my story it wasn't what I expected (Anna).

Implications

Use of the branching decision experiences showed the potential for engaging preservice teachers in reflecting on their own MKT in regards to facilitating mathematical discussions. This was in spite of only using two such experiences in the course. Future implementation will include additional experiences with a similar emphasis on focusing on how choice of prompt affects what student thinking was solicited. Additionally, branching decision experiences for other tasks of teaching could be created to help preservice teachers develop their PCK in specific instructional contexts that may not readily come about in their field experiences. However, additional study and implementation is necessary to fully realize the potential of branching decisions in mathematics teacher education. While this paper provides the mere beginnings of such work, it appears there is much promise in branching decisions as a teacher education tool.

Notes

[1]The term *branching decision* was coined by Daniel Chazan and Patricio Herbst in their work with cartoon-based representations of practice.

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CONSTRUCTIVISM-BASED "SETS" FOR LESSON PLANNING: AN EXAMPLE FROM HIGH SCHOOL CHEMISTRY

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Constructivist practice requires flexible lesson planning based on longitudinal assessment. This example document for lesson planning demonstrates a way to transfer constructivist, methodological teacher knowledge. The "SET," for "atoms-first" chemistry, covers all SAT II topics using the mental-models approach. Key components are: direct correspondence to a free text, student-performed demonstrations replacing non-constructivist teacher demonstrations, lab activities allowing more discussion, explicitly-presented mental models, simulations, and manipulatives, keyed to proven classroom methodology. This successfully used (SAT II average >650) SET is freely available.

Introduction

Today's new teachers, graduated from a program often based on constructivist theory and with a working knowledge of many valuable methods and proven activities, often move into school settings where it is very hard to apply all of their learning. Chief among the difficulties are time limitations and institutional resistance to change.

Lesson planning takes an inordinate amount of time. Young teachers following constructivist ideas must find and evaluate (for quality and appropriateness) many methodologically varied components, preferably many more than they will ever use in one year, so that they may adapt the learning environment to the needs of the students in real time. In training, pre-service teachers may have spent much time on a unit plan or other assignment, and done an excellent job, while learning how to construct and modify a good learning environment. But on the job, time constraints hinder this process greatly while real-time response too longitudinal assessment limits the applicability of the traditional unit-length plan.

Many new teachers must also immediately integrate into environments that are not optimal. Some new teachers are under state-mandated constraints associated with high-stakes tests; some have insufficient funding; many have multiple class preparations or other duties like coaching and monitoring; most do not yet fully understand the range of student abilities and backgrounds in their schools. These constraints make a high-quality learning environment with quality lessons more difficult to construct.

Older teachers like the author, especially those of us who have tried to stay abreast of educational innovations, should help new teachers adapt to today's challenging educational settings. Probably the best way for us to help is to mentor new teachers, but one-on-one

Mohr-Schroeder, M. J., & Harkness, S. S. (Eds.). (2014). *Proceedings of the 113th annual convention of the School Science and Mathematics Association.* Jacksonville, FL: SSMA.

mentoring has obvious limitations. In the most challenging situations, mentoring is not even a possibility: a new teacher may be in a school with no appropriate mentor and no time or equipment to work online with a mentor. Clearly, another means of transferring constructivist-friendly practices is needed. The purpose of the Constructivist “SET” is to provide an efficient way to pass constructivist methods and ideas to a new teacher, who may simply not have the opportunity or time for extensive mentoring, onsite observations, or consulting.

Objectives/Purpose

For three years, I have been modifying lesson plan formats with the objective of constructing a transferrable (especially to new teachers) set of information that would reduce preparation work load but still facilitate the use of constructivism-compatible practices. I have developed an example of the resulting “Constructivist Set” (or just “SET”) for the curriculum for a first-year, advanced chemistry class with high SAT II performance as a principle end-of-year goal. SAT constraints have often been used as an excuse to avoid constructivist methods, but I have included much methodology consistent with constructivist theory (although the curriculum is far from perfect in this regard) into the SET.

I have applied and developed this curriculum for three years, using it with three first-year teachers. I want to share this specific SET and the SET idea so that new chemistry teachers may benefit, and so that other long-time constructivist-based teachers might try a similar method of sharing knowledge and practice with new teachers they may not be able to mentor individually.

Instructional Framework

I decided based on my online and onsite mentoring that different information would be useful to new teachers with constructivist backgrounds, instead of the typical unit and lesson plans, which tend to limit variation based on classroom assessment. The design I developed I call a “Constructivist Set” since it is a listing of tested learning activities, classroom environment activities and characteristics, and assessment methods for determining best practices, not just a collection of dictatorial step-by-step plans.

Innovation

I use this "SET," a collection of documents, to provide a teacher with a highly varied list of proven methods from which they could choose appropriate activities based on their assessments of student learning needs. I did not want to dictate specific lessons, although I often asked a mentee to try a specific method for a while.

This particular “SET” parallels (in general) a free web text and associated ancillaries (Bishop, 2013). This text is incredibly readable, and ancillary material on the same site includes a wide range of activities, from problem solving to simulation and animation. Audio book, PowerPoint format, and portable formats are also available. This choice of text and ancillaries allows nearly any teacher to access the text, even if the school cannot purchase new texts, or has a poor or too high a level of text in hand.

The SET includes a page of tested activities for each section of the book (there are about 60 pages total) beginning with chapter 3 (the first two chapters are not taught individually; their topics are integrated into later chapters). A typical SET page begins the examples below. The activities referenced include POGIL student worksheets, on-line animations and simulations, YouTube demonstrations and helps, Khan Academy lectures, laboratory procedures, student-performed demonstrations (Laughner, 2006) and more. Obviously some of these are more helpful than others to constructivist practice. Therefore, most activities are also keyed (using a two-letter code) to a list of methodologies and classroom practices the teacher is encouraged to use and assess.

Completing the SET are supplemental documents (accessed via links or document files), for example:

- Any necessary details of activities listed on the pages
- A compendium of classroom practices
- Brief reminders of theory behind the activities and practices to be used and avoided
- Laboratory and demonstration activity procedures
- Other procedures and other documents for student and teacher use

Examples

Examples of SET components follow:

- Appendix A is An example of a SET section page (section 3.1)
- Representative excerpts from the list of classroom practices
- Representative excerpts from the theoretical background section
- A typical student-performed demonstration document, representative of the laboratory and demonstration procedures compilations

The SET section page is the basic “SET” document. It contains a list (or set) of possible activities, methods, and topics to be covered in a period of a few classes. The items on the list can be found in the text or in the other documents. Here is an example from Chapter 3 section 1 of the text (Bishop Chemistry, Atoms-First). Note particularly the letter pairs in brackets, which are used for easy reference to comments in the other documents:

Example SET Basic Document: The Section Page

SET for Chemistry 1A Deerfield Academy	Remember to use bracketed letter pairs to review theory and practice!

Text	Section #	Title of Section	Objectives location
Bishop Atoms First	3.1	Solids, Liquids, and Gases	p. 107

	Beginning of Class:
Homework possibilities [HA]	p. 110 #8,10,12,14,16,18 p. 112 #43, 45, 47, 47, 49 Read and outline 3.1 (before first class) Read and outline 3. 2(after last class in this section)
Warm Up(s) [WU]	1) Use SLG simulation 5 min. and take notes: http://preparatorychemistry.com/KMT_flash.htm
	Main Class Possibilities:
Class component	Description and/or location
Text Link [RA]	http://preparatorychemistry.com/Bishop_Book_atoms_3.pdf
Mental Model(s) [MM]	KMT (p. 76 OR model>mental>KMT)
Hands-on model(s) [MH]	27 dice SLG model (model>SLG)
Concept Map [CM]	http://preparatorychemistry.com/Bishop_Chapter_Map_3.htm
StudentPerformedDemo [SD]	LabsAndDemos>SPD>WireThroughIce
Lab [LT]	LabsAndDemos>Labs>HeatingColdIce
POGIL activity [PA]	none
Other activity	Draw KMT pictures 2-on-Whiteboard [WT] for phases, transitions, etc.
Khan Acad. lectures [KA]	https://www.khanacademy.org/science/chemistry/states-of-matter/v/phase-diagrams
Other aids	PhET animation http://phet.colorado.edu/en/simulation/states-of-matter-basics
Compatible Continuous Assessment Types [CA]	Socratic [QS] during MH, LT, SD, and MM. Multiple Choice Cards/Clicker [CC] during MH, CM, in-class HA. Random Questioning [QR] during term review, lecture
	End of Class:
End-or-class review [ER]	Draw a picture of the KMT model of a particular phase
End-of class Stretch [ES]	Consider KMT of sugar sweetened cola, other extensions
Ticket2Leave [ET]	Draw KMT showing why evaporation occurs at T<Tboiling
	Topics List:
Property contrast/compare L/S/G/P	
Phase Transitions and the KMT	
Terms	vaporization, evaporation, sublimation, etc.

The Classroom Practices list is my effort to keep constructivist methods at the forefront as the new teacher plans classes, even as the basic document allows maximum versatility to respond to student needs. Reference to this document may help the beginning teacher resist reverting to non-constructivist practice. Here is an excerpt (the letter pairs connect the document with the basic SET document above):

Excerpt from the list of classroom practices

QR: This letter pair indicates a place where the teacher should consider random questioning, seating, student selection, etc. Many teachers still allow students to raise hands, etc. even though random questioning is almost always a superior practice; the theoretical background section gives a summary of the theory behind randomness in the classroom. In short, though, remember to use some random selection process *every* time a non-Socratic question is asked during a lecture, *every* time a lab is done (do not use the same lab groups repeatedly!), *any* time a student is selected to be a "reader" or a "performer" of a student-performed demonstration, etc.

QS: This letter indicates an appropriate place for Socratic questioning. For example, dice are used in many of the hands-on models. The dice represent different things in different models. Using dice in this way is purposeful; it encourages students to think about what each model component *stands for*, rather than to concentrate on the model components themselves. So, as the students are working on a model that uses dice and you are walking around, great Socratic questions include: What does the red die represent and how is it a good thing to use a die to model this? How is it bad? What is one thing this model can help you think about? Is there anything this model might *predict* if you apply it? Is the prediction right or wrong?

For more on Socratic questions (there is a whole literature on this one topic!), try some suggested readings (Elder, 1998; Moore, 2002).

The theoretical background document, like the classroom practices document, is an attempt to connect the activity choices to constructivist ideas and enforce the theoretical ideas in the mind of the new teacher during actual practice and lesson design. Here is an excerpt:

Excerpt from the theoretical background section

QR: The job of the teacher is to construct an environment in which students can learn efficiently. This environment will change quite a bit as the students learn by constructing mental models, practicing mathematical procedures, memorizing content, applying models using multiple-step critical thinking, etc. The teacher must gather information about the students continuously in order to make decisions about the most appropriate methodology to introduce next. Statistically there are two ways to collect valid information: sample *every* student or sample *randomly.*

Since a sample must be as representative as possible, allowing students to raise hands (or *not to!)*, to pick partners, etc. guarantees that information gathered from the resulting situation is *not* valid for methodological decisions. Also, student effort is significantly increased when random elements are included (McDougall, 1993).

QS: The subject of classroom questioning in general and Socratic questions in particular is too large to go into here. For more on how to ask questions in chemistry, look at relevant articles (for example, Wenning, 2006) or the very large literature on this topic in general. Questions can be designed best after background research into student conceptualization and language are first reviewed by the teacher, for example by reading appropriate sections of *The Chemistry Classroom* (Herron, 1996).

The final part of the SET is the collection of laboratories and demonstrations. While Laboratories are often redesigned to be more constructivist in practice, the demonstration is much more radically changed. Doing demonstrations in front of passive students is neither constructivist nor productive (Crouch, 2004). The following is an example of a student-performed demonstration, which is led by a pair of randomly-chosen students. Perhaps 30 of these are done in a year. The two students are under careful classroom observation, with the teacher acting only as safety observer. Other students take notes, make sketches, and perhaps hypothesize during the first reading, then write down observations during the second reading (which is done as the second student performs the demonstration step-by-step.

One example follows; a complete collection of "SPD's" is available from the author:

Example of a Student-Performed Demonstration Procedure

STUDENT PERFORMED DEMONSTRATION

Wire through Ice

Background for this SPD: Coverage of phases of matter, particle model of matter, KMT, closeness of density of solid and liquid compared to gas, and "backwards" pressure behavior of water-to-ice transition (phase diagram).

Teacher preparation for this SPD:

1. Obtain ice cube (colder ones work better)
2. Tie loops onto ends of a mono-strand copper wire or other suitable wire.
3. Hang about 500 g mass onto wire to insure it will hold.

4. Cantilever a meter stick over the end of a bench, clamping it or weighting the end on the bench to insure stability.

Teacher SPD initiation:

Randomly select a student "reader. Then randomly select a student "performer." Have the reader begin reading immediately below the heading "Student Instructions," while ensuring that all directions are followed and everything is done safely.

Student Instructions

One student reads these directions while ALL students take notes. Then the same student reads the instructions again. This time, the "performer" follows the directions while everyone takes notes on what they observe.

Demonstration directions:

- Make sure meter stick cantilever is secure
- Center the metal wire so that its middle is on the top of the meter stick
- Hang the 500 g mass through both loops of the wire, below the meter stick
- Put an ice cube on the cantilevered meter stick and move it under the wire until the wire holds it in place.
- Everyone observe, and then go back and check on the ice after minute or so, then again after another minute. After two minutes, you may attempt to lift the wire out of the ice by lifting on each side of the wire.

Implications

This SET product will hopefully be one model for a more constructivism-compatible way to transfer practice to new teachers, who simply do not have the time both to continuously assess students to determine their needs *and* to find or construct activities, practices, and classroom environmental characteristics from scratch to fit the needs of their students and meet the requirements of good constructivist practice. Since all students, classrooms, and teachers are different, the flexibility of the SET may allow a new teacher to more efficiently improve classroom practice, when compared to current lesson planning techniques. The SET may do this by providing many good activities and methods, while still allowing (and encouraging with integrated helps) new teachers to continually assess the needs of their students and modify classroom environments and activities accordingly.

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Acknowledgements

The author would like to acknowledge his colleagues Jonathon Chittirulu, Toby Emerson, Ivory Hills, Robin Lempicki, and Asvelt Nduwumwami. He thanks Deerfield Academy for a summer support grant toward assembling of the SET.

GEOMETRIC PATTERNS: EXPLORING MODULAR ARITHMETIC AND FRACTAL DESIGNS

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Lending an artistic flare to exploring modular arithmetic makes the subject more palatable and interesting to both the math and non-math wired student. Making observations, drawing and shading patterns obtained from residual sets can range from simple to complex. Adding fractal explorations connected to the familiar Pascal's Triangle to make models of Sierpinski's Triangle by use of different modulo just increases the fun!

Introduction

An exploration of subsets of modular arithmetic residual sets provides an opportunity to blend art and mathematics together. By placing points on circles delineating congruent arc lengths for the number of non-zero elements of residual sets for a given devisor, some interesting designs can be created. Some of the patterns are trivial and some have interesting symmetries. Reciprocal modular arithmetic congruencies have identical designs; which are unexpected outcomes by the students. Nonetheless, they quickly catch on to the pattern and can thereafter describe additional reciprocals for different moduli.

Another group of interesting sketches that can be made comes from the investigation of fractals. Fractals are iterative designs where a pattern is repeated many times. We can generate the beginning of a fractal design by hand, but to see several iterations of the design we need to use a computer. We will explore some of the famous fractals like Sierpinski's triangle (sometimes referred to as Sierpinski's gasket or Sierpinski's sieve), Koch's snowflake, and the Mandelbrot Set.

Purpose of the Study

Here in the United States in the twenty-first century there has been a significant push by government, industry, and educators to improve the quality and quantity of students attracted to the STEM (Science, Technology, Engineering, and Mathematics) areas of study. In an endeavor to spark interest and to make connections between art and mathematics, I have revitalized and extended some activities published in 1984 and 2003 to promote and stimulate interest by young students to look at mathematics with a different lens. By showing students patterns created with residual sets and doing some informal work with fractals, students can see some mathematics beyond their usual course of study and potentially be inspired and stimulated to study mathematics or other related STEM fields.

These activities are not only engaging, but they provide an opportunity for the instructor to introduce students to the names of famous mathematicians and to help familiarize them with some of their work. Granted this is not a thorough or even rigorous investigation of Gauss, Sierpinski, Koch, or Mandelbrot, but it is a beginning exposure to these giants within the field. It is an opportunity to stimulate interest and direct students to find more information on these scholars. It is a chance to inspire a student into committing to the study of mathematics!

Significance and Related Literature

The first mathematician and ideas explored in the activity centered on Gauss. Karl Friedrich Gauss (1777 – 1855) launched the idea of congruences in one of his number theory books, *Disquisitiones Arithmeticae*, making Gauss the father of modular arithmetic (Eves, 1990). Congruence ideas are frequently found in our every day lives. The position of the hour hand on a clock can be determined by using mod 12, Thanksgiving on Thursday is that day mod 7, and grades are determined using mod 5 on a 4.0 scale. Manufacturers use moduli to determine the amount of product to make to fit into packaging. This activity explored the graphing patterns of the non-zero residual sets for a few different moduli (NCTM, 1984).

Students were given a rudimentary understanding of modular arithmetic congruencies and then asked to look at creating some designs mod 7 and mod 10. Reciprocal congruencies were explored and a final activity mod 65 was assigned as homework. The mod 65 residual design using 2 as a multiplier created a cardioid as shown in Figure 1. Following the modular arithmetic exercises, the activity continued with an exploration of fractals and some of the mathematicians associated with them.

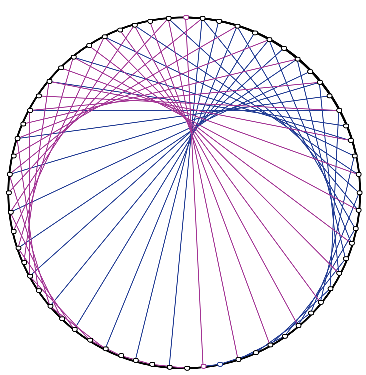

Figure 1

Waclaw Sierpinski (1882 – 1969) was a mathematician from Poland who introduced the triangular fractal named for him in 1915, although the design had been used in Italian art since the 13th century (Wolfram, 2014). The iteration is performed by connecting the medians of an equilateral triangle and then connecting the medians of each equilateral triangle formed by this iterative process. Online you can play with Sierpinski's triangle at http://www.shodor.org/interactivate/activities/SierpinskiTriangle/ as seen in Figure 2 (Shodor, 2014a).

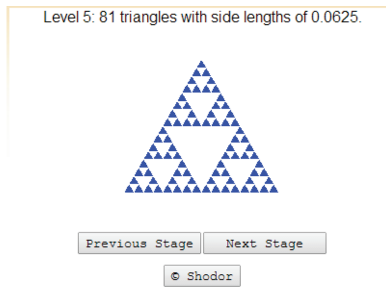

Figure 2: Level 5

O'Sullivan (2003) does a nice job of linking Pascal's triangle, Sierpinski's triangle, and the use of spreadsheets. The directions are clear, concise, and easy to follow. The time needed to complete the programming is nominal and the results are well worth the effort. Using the spreadsheet program, not only can Pascal's triangle be shown mod 2 (see Figure 3), but the instructor or student can now instantly produce Sierpinski-like designs mod 3 through mod 100 allowing for discussion of a wide variety of patterns within these patterns (see Figure 4). From here we moved on to look at another equilateral triangle fractal design.

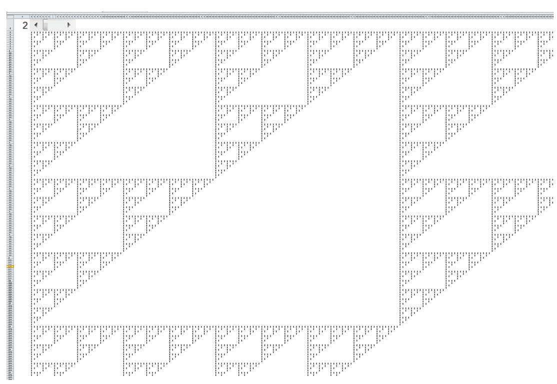

Figure 3: Pascal's triangle mod 2

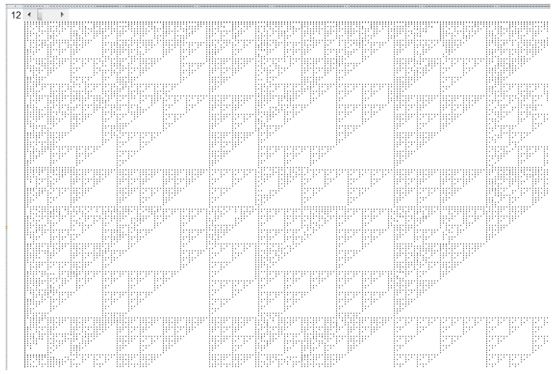

Figure 4: Pascal's triangle mod 12

Helge von Koch (1870 – 1924) was a Swedish mathematician who created a continuous polygonal curve without tangents at any point often referred to as Koch's snowflake (O'Conner & Robertson, 2000). Like Sierpinski's triangle, Koch's snowflake begins with an equilateral triangle. The length of each line segment is increased by one-third its length repeatedly as indicated in the figures below. This iterative pattern produces an infinite perimeter with a finite area! One online interactive tool exploring this pattern is found at http://www.shodor.org/interactivate/activities/koch/ seen in Figure 5 (Shodor, 2014b). The National Library of Virtual Manipulatives for Interactive Mathematics (NLVM) provides an animated simulation of many iterations of the Koch snowflake seen in progress in Figure 6 (2014a). Finally, we move to our final fractal exploration, leaving the real numbers behind and delving into the complex numbers.

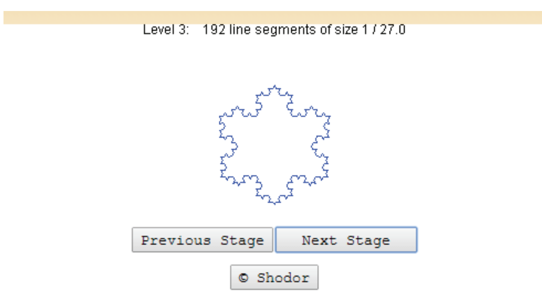

Figure 5: Koch's Snowflake Level 3

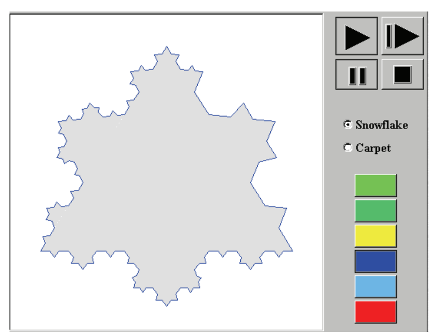

Figure 6: Koch snowflake animated

Benoit B. Mandelbrot (1924 – 2010) was born in Poland and is known for creating an infinitely complex set known as the Mandelbrot set (O'Conner & Robertson, 1999). The basic idea behind deriving the set comes from the plotting of $Z = Z^2 + C$, where Z is a complex number and C is some constant to be tested (Dewey, 2014). When colors are added to the graph, spectacular artistic shapes appear within the set. Julia sets are small subsets of the Mandelbrot set or close-ups of particular segments. The appearance of the set is dependent upon what initial values are selected for C and Z. Dr. Mandelbrot was a professor at Yale University (see his personal website at http://www.math.yale.edu/users/mandelbrot/). NLVM (2014b) provides a tool for easily exploring the Mandelbrot (see Figure 7) and Julia sets (see Figure 8).

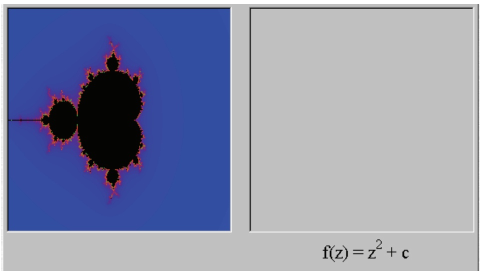

Figure 7: Mandelbrot set

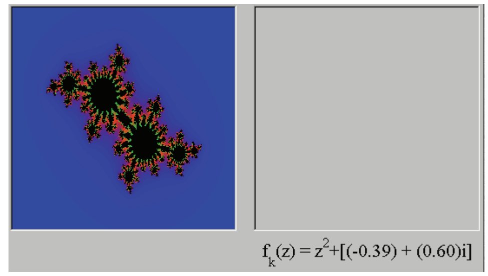

Figure 8: Julia set

Practice

The material for this workshop was put together in such a way as to be used either as a group lead whole class activity (GLA) or a standalone individual learning activity (ILA) for students with a sufficient background to handle the concepts presented. The GLA offers opportunities for robust discussions and peer assistance exploring modular arithmetic and fractal design ideas. It is important for the facilitator of the GLA to allow for natural development of ideas and side excursions into the “I wonder what would happen if…” scenarios. The facilitator should take the time to review the activity and materials in advance to determine where their students may or may not have problems and plan as much as is possible in advance for these occurrences.

The ILA offers the classroom teacher possibilities for enticing students to do some work in mathematics while exposing them to ideas and concepts they might not hear about otherwise until they were in college, if at all. Students are given the ILA when they have completed other assignments or potentially as extra credit types of explorations or projects. The activity gives the students an exposure to mathematical ideas beyond the scope of the regular classroom and helps to open the door into developing their interest and curiosity about higher levels of mathematics.

Classroom Examples

I presented this material as a workshop with sophomore to senior girls and their teachers from several different high schools in southern Georgia as part of Valdosta State University’s annual Sonya Kovalevsky Day activities. The students found the material very accessible and had few questions regarding the instructions for doing the modular arithmetic or for creating the desired figures. Some caught on to the process more quickly than others, but all were able to complete the exercises with minimal assistance from teachers or peers. Perhaps more importantly, they seemed to enjoy doing the activities and felt good about their mathematics abilities when they completed the various activities.

Additionally, I had the opportunity to present this workshop for the Valdosta State University Learning in Retirement (LIR) program. Approximately a dozen retirees attended the workshop and were energized and amazed at the connections between the residual designs and modular arithmetic as well as being able to complete some fractal designs. Even though several claimed rusty mathematics skills or outright difficulties with numbers, all were able to grasp the concepts presented and complete the work. Several attendees requested extra worksheets to take home to share with their grandchildren in an effort to spark interest into the field of mathematics.

Implications

This type of activity provides, not just an elect few individuals, but all students a chance at being exposed to non-routine mathematics at the middle grades to high school level. In a climate of high stakes testing and teaching to the test, this type of activity provides educators and their students with materials that can help to ignite interest and fuel a desire to study materials vital for a student to become successful in any of the STEM majors. The activity can be employed even if there is no whole class time available. Exposing young students to these types of materials affords them the chance to see mathematics used in a way they never thought possible. It allows them to do mathematics they never thought they would be able to get to let alone be successful at doing.

Exposure by itself is not enough. We still need to encourage young students to study hard and take as many advanced courses as they are able. Empowering students with the notion they can do and find a use for advanced mathematics is vital if we hope to inspire students to enter into the STEM fields. Dr. Peter Hilton (1923 – 2010), renowned topologist and mathematician, once told me, "If only the students could see the beauty in the numbers, the way I do, they would delight in doing their exercises!" (personal communication, 2000). By creating and delivering these types of activities, maybe, just maybe, we are on the path to opening students' eyes to seeing the beauty in the mathematics.

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Acknowledgements

Funding for the presentation of this workshop was provided by a faculty Development-Instructional Improvement Grant or the Graduate School at Valdosta State University.

STARTING FROM SCRATCH: DESIGNING AN INTEGRATED DEGREE FOR MIDDLE SCHOOL CERTIFICATION

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The State of Illinois is beginning tri-level certification, requiring a new middle level education certification degree program of each higher education institution. This paper is a discussion of the stages of development of an integrated, cross-disciplinary degree – including the political, social, and academic challenges and achievements. In particular, the program for mathematics and science has several unique aspects including assisting students through notorious university "gateway" courses and the blending of STEM Education into methods courses.

Introduction

By the fall semester of 2015, each four-year higher education institution in Illinois is to have a degree program for the newly created middle school teacher licensure certification. Illinois will begin tri-level teacher certification, namely grades 1-6, 5-8, and 9-12, by February 1, 2018 (Illinois State Board of Education, 2013). This paper is a discussion of the stages of development of an integrated, cross-disciplinary degree – including the political, social, and academic challenges and achievements.

Objective

The objective of the Northern Illinois University (NIU) Middle Level Teaching and Learning Program is to prepare teacher candidates who understand the intellectual, physical, social, emotional, ethical, and cultural needs and interests of young adolescents; who demonstrate content knowledge expertise; and who commit themselves to a developmentally responsive approach to curriculum and instruction at the middle school level.

The program fosters the following values as central to middle level teaching and learning:

- Social justice and equity for all students;
- Respect for diversity among learners and within their community;
- Developmentally responsive practices;
- In-depth content knowledge and interdisciplinary connections;
- Profound pedagogical content knowledge;
- Comprehensive pedagogical knowledge;
- Standards-based curricula;
- Data-informed instruction;

- Collaboration with colleagues, parents, and the school's community; and
- Commitment to ongoing professional development and reflective practice (NIU, 2013a).

The NIU Bachelor of Science in Education (B.S. Ed.) degree in Middle Level Teaching and Learning is an interdisciplinary program. It is designed to prepare future practitioners with the content knowledge and pedagogical approaches necessary to serve the needs of young adolescent learners in specific disciplines as required for teacher licensure in middle level education. As a condition for obtaining an initial or subsequent Illinois middle level teaching license, for grades 5-8, candidates prepare for teaching endorsements in two of four content areas: English Language Arts, Mathematics, Science, and Social Sciences.

Instructional Framework

Designing a new certification degree program is a daunting task. It is especially daunting when this task was dictated by an entity outside the university, namely the Illinois State Board of Education (ISBE). Our process began with a handpicked Middle Level Teaching and Learning (MLTL) Program Advisory Committee by the Provost. This committee was made up of faculty from each subject area in the College of Liberal Arts and Sciences and from faculty from the College of Education.

In an approach to eliminate possible academic "turf wars" the Provost deemed the new degree to be independent of either College in the charge to the MLTL Committee. Later, the degree was agreed by both College Deans to be under the College of Education for purely logistic reasons. A further charge to the committee was to design four-year degree pathways that satisfy all State Certification and University graduation requirements in the various subject areas. The ISBE mandated educational content in Education Psychology, Middle School Child Development, Assessment, ELL, Content Area Literacy, Middle School Organization, Classroom Management, and Integration of the Exceptional Student, plus Clinical Experiences and Student Teaching. In addition, ISBE also mandated that certification candidates fulfill the subject matter content requirements in two of four content areas: English Language Arts, Mathematics, Science, and Social Sciences.

The MLTL Committee researched the standards of the National Council for Accreditation of Teacher Education, Association for Middle Level Education, as well as the Specialized Professional Associations: International Reading Association, National Council of Teachers of English, National Council of Teachers of Mathematics, National Council of

Teachers of Social Studies, and National Science Teachers Association. Further, the degree certification requirements of universities that are in states that already had Middle Level certification were evaluated.

Innovation

It became immediately obvious that choosing courses to fulfill all these requirements and standards would violate the Provost charge of a four-year degree pathway. The MLTL Committee also was committed to having rigorous content course requirements in the subject areas beyond the State minimum specifications. New courses needed to be designed and existing courses need to be revised to fulfill these expectations. For example, freshman *English* was blocked with *Education as an Agent of Change* and with *Education Experience* and school visitations into a *Themed Learning Community* course package for second-semester freshmen. The blocking of courses in the freshman year should structure the undergraduate students into four-year cadres of students. Cadres can allow the students to belong to a community of learners to meet students' academic, emotional and social support needs (Zollman, Smith & Reisdorf, 2011).

Specifically for the notorious university "gateway" courses of chemistry and calculus, these courses were blocked with a University Experience course. This course goes beyond the normal introduction to college study skills. Students are guided into how to read and study mathematics and science at the college level explicit to the content study during that period of the semester. The first purpose is to teach specific content study skills, e.g., thinking of a limit in multiple perspectives – not just graphical. The second purpose is to assist students in becoming mature reflective learners and forming their own identity by fostering self determination, cultivating self regulation, and capitalizing on peer interaction in a productive learning environment (Zollman, Smith & Reisdorf, 2011).

Example

Appendix A presents the four-year degree pathway for a student going for middle school certification with mathematics as the primary content area and science as the secondary content area. Many of the courses are blocked together, disrupting the one-to-one correspondence between requirement standards and a specific course assumed by some university faculty. The primary area of mathematics has 32/33 semester hours of mathematics, beginning with calculus and includes one STEM methods course and one mathematics methods course for middle level students. The secondary area of science for this pathway has 24 hours in the natural sciences. The professional education coursework is 41 additional hours.

Implications

Usually a "top-down" administrative approach, as in this case forced by the State, does not succeed. However the top University administrators fortunately identified individual faculty members in various departments that bought into and whole-heartedly supported the objectives of the new middle school certification degree program. These faculty members shaped, swayed and coerced the established programs to develop a fresh approach to a new degree.

Will these new degrees be successful? This depends on several factors beyond the control of the university faculty:

- Will the university continue financial support of degrees that may require small class size?
- Will the administration continue to compel colleges, departments and faculty to stop turf battles over control of programs and courses?
- Will the State, as has occurred in the past, change requirements before programs can develop?

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Appendix A

Four-Year Degree Pathway: Primary Area Mathematics and Secondary Area Science

Northern Illinois University

Mathematics (primary content area) & Science (secondary content area)

Middle Level - Teacher Certification
Grades 5-8 Program
Degree Path - Catalog 2015-2016

Fall 1	Credits	To Do
COMS 100	3	
ENGL 103	3	
MATH 229	4	
UNIV 101	1	UNIV 101 specifically tied to MATH 229 & CHEM 210/212
CHEM 210 + CHEM 212 (lab)	4	
Total hours	15	

Spring 1	Credits	To Do
ENGL 104	3	ENGL 104 EPFR 201 and UEDU 101 specifically tied to Themed Learning Communities & School Visitations
EPFE 201	3	
UEDU 101	1	
CHEM 211 + CHEM 213 (lab)	4	Secondary Content Area
MATH 230	4	Primary Content Area
Total hours	15	

Fall 2	Credits	To Do
MATH 303	3	Primary Content Area
STAT 301	3	Primary Content Area
HIST 260 or 261	3	
BIOS 208 + BIOS 210 (lab)	4	Secondary Content Area
ENGL 110 or other ENGL Literature course	3	
Total hours	16	

Spring 2	Credits	To Do
MATH 302	3	Primary Content Area
BIOS 209 + BIOS 211(lab)	4	Secondary Content Area
EPS 419 (Middle Child)	3	EPS 419, MLTL Clinical #1, and EPS 300 are Blocked Courses
MLTL 301 Clincial #1 (Early Adolescent Dev. Emphasis)	1	
EPS 300 (ED PSY)	3	
PSYC 102	3	
Total hours	17	

Fall 3	Credits	To Do
MATH ELECTIVE #1*	3	Primary Content Area
MLTL 302 Clincial #2 (Special Ed. & Content Area Lit.	1	
TLSE 457 (Sp ED - Exceptional Child)	3	choose special Middle School section
PHYS 210	4	Secondary Content Area
LTR 311 (LIT in the STEM Area)	3	Cross-listed course
ARTH 282 or MUSC 220 or THEA 203	3	
Total hours	17	

Spring 3	Credits	To Do
TLCI 422 (M.S. Organization)	3	
MLTL 404/MATH 404X (STEM ED METHODS)	3	Cross-listed inter-discipline methods course
MATH ELECTIVE #2*	3	Primary Content Area
POLS 100 or Appropriate Social Studies Elective	3	
PHYS 211	4	Secondary Content Area
MLTL 303 Clincial #3 (Multi-Culture & Middle Sch. Phil.	1	
Total hours	17	

Fall 4	Credits	To Do
LTIC 420 METHODS for ELL	3	
MLTL 304 Clincial #4 (Co-Teaching & ED TPA	2	
MLTL 410/MATH 410 (MIDDLE SCHOOL MATH METHODS)	3	Cross-listed course
MATH ELECTIVE #3*	3	Primary Content Area
TLCI 450/EPS 450X (Classroo	2	
ETR 422 Assessment & Technology	4	
Total hours	17	

Spring 4	Credits	To Do
MLTL 485 STUDENT TEACHIN	11	
MLTL 461 Seminar (ED TPA Emphasis)	1	
Total hours	12	

Notes: 130/131 Total Hours with 32/33 Hours in Mathematics (includes two methods courses) and 24 Hours in Science Content
April **1, 2014** red: CORE COMPENTCY, orange: IDS), purple: Social Sciences, green:Humanities & the Arts, blue:Science & Math: GENERAL EDU REQUIREMENTS

* Math Elective Options (Choose three): MATH 206; MATH 210; MATH 304; MATH 360; MATH 415; MATH 416

Teacher's Corner

Mohr-Schroeder, M. J., & Harkness, S. S. (Eds.). (2014). *Proceedings of the 113th annual convention of the School Science and Mathematics Association.* Jacksonville, FL: SSMA.

LESSON PLANNING THROUGH A TRANSDISCIPLINARY STEM LENS

Variations to a transdisciplinary unit of study

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The purpose of this plan is to present a way to engage students in a complex real-world problem and in doing so facilitate learning within and across STEM related content areas using inquiry-based standards-driven methods. This document can serve as a guide for developing a transdisciplinary unit of study. The unit here relates to the biodiversity of forests and the influence of human intervention through harvesting natural resources. The unit can progress along a number of different paths, depending of the scope and time constraints in the classroom.

Identify relevant content standards and look for commonalities. Identify applicable mathematical practices, science and engineering practices, and potential connections to literacy standards.		
Mathematics	**Science**	**Engineering**
CCSS-M F-IF-3 Understand the concept of a function and use function notation 3. Recognize that sequences are functions, sometimes defined recursively, whose domain is a subset of the integers. F-BF-1a Build a function that models a relationship between two quantities 1. Write a function that describes a relationship between two quantities. a. Determine an explicit expression, a recursive process, or steps for calculation from a context.	NGSS Performance Objectives, HS-ESS3-1. Construct an explanation based on evidence for how the availability of natural resources, occurrence of natural hazards, and changes in climate have influenced human activity. HS-ESS3-4. Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.* HS-LS2-2.Use mathematical representations to support and revise explanations based on evidence about factors affecting biodiversity and populations in ecosystems of different scales. HS-LS2-6.Evaluate the claims, evidence, and reasoning that the complex interactions in ecosystems maintain relatively consistent numbers and types of organisms in stable conditions, but changing conditions may result in a new ecosystem. HS-LS2-7. Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity.	HS-ETS1-3. Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, and reliability, and aesthetics as well as possible social, cultural, and environmental impacts.

Mathematical Practices 4. Model with mathematics. 8. Look for and express regularity in repeated reasoning.	**Science and Engineering Practices** 5. Using mathematics and computational thinking 6. Constructing explanations (for science) and designing solutions (for engineering) 7. Engaging in argument from evidence
Common Core State Standards Connections-ELA/Literacy	
RST.11-12.8 Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text, verifying the data when possible and corroborating or challenging conclusions with other sources of information.	
WHST.9-12.2 Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes.	
The big idea, driving question for the unit of study, potential sub-driving/investigative questions, and end product	
The Big Idea: Functions and modeling can be used to solve complex real-world problems related to natural resources and the purpose and impact of human intervention.	
Unit Driving Question: Should we stop cutting down trees? **Possible sub-driving/investigative questions:** 1. What happens to the trees that are cut down? (Science) 2. Investigate the impact on animal species in areas of logging. (Science, Math) 3. To what extent can we predict the future of trees? Develop an appropriate mathematical model (Math, Engineering) 4. Consider alternatives to tree and logging (e.g. fuel, construction, paper products, etc.) (Math, Science, Engineering) **End Product** • Build a structure using material other than wood OR build a “before and after” model of a geographic area • Create a campaign for or against advocacy of conservation efforts (options could include newsletters, wiki page, blog, infomercials, create and conduct a survey and report the results)	

Instructional Methods and Assessment

General instructional methods appropriate for the unit of study:

Text driven Socratic seminar (potential readings below)

- Purdue University. (2009, December 9). Logging effects vary based on a forest's history, climate. ScienceDaily. Retrieved November 3, 2014 from www.sciencedaily.com/releases/2009/12/091202114046.htm
- USDA Forest Service - Pacific Southwest Research Station. (2014, January 6). 79 years of monitoring demonstrates dramatic forest change. Science Daily. Retrieved from www.sciencedaily.com/releases/2014/01/140106133257.htm
- University of Washington. (2010, December 8). Bringing the green back. Conservation. http://conservationmagazine.org/2010/12/bringing-the-greenback/

Guest Speakers-experts in the field

- Field trip to local arboretum, with geocaching component and landscape analysis
- Use of popular television to develop narrative of experiences of loggers such as AxMen and SwampLoggers
- Connections to technology
- Role playing activities-what if you needed to leave your environment?
- Brainstorming (e.g. alternative resources)
- Reflective Journal (e.g. daily journal of uses of wood)

Assessment:

Sample General Rubric appropriate for the unit end product:

SLA Standard Rubric

	Design 20	Knowledge 20	Application 20	Presentation 20	Process 20
Exceeds Expectations 20 - 19					
Meets Expectations 18 - 15					
Approaches Expectations 14 - 13					
Does Not Meet Expectations 12 - 0					
Totals:					

Source: https://www.scienceleadership.org/pages/Assessment_at_SLA

For additional resources check out Pinterest-

- PBL-Project Based Learning http://www.pinterest.com/MrsMacsMusic/pbl-project-based-learning/
- STEM Education and Play http://www.pinterest.com/resseguie/stem-education-and-play/
- National Academies Press-STEM Education http://www.pinterest.com/napress/stem-education/

Sample Mathematics Benchmark Lesson
Sub-driving/Investigative Question: To what extent can we predict the future of trees? Develop an appropriate mathematical model.

Learning Objectives

- Students will be able to write an explicit formula using recursive methods.
- Students will determine the limiting value of a function and interpret in the context of the problem.

Instructional Methods

Engage/Explore

The Problem: You are a forest ranger in charge of a national forest that currently has 1000 trees. A new policy of cutting and planting has just been approved: At the end of each year, 20% of the trees in the forest will be cut down and 100 new, fast-growing trees will be planted. In this lab, you will discover the long-term effects on the number of trees in a forest of a cutting and planting process in which 20% of the trees are cut down at the end of each year and 100 new trees are planted. Figure out the long-term effects of this environmental policy; that is, whether all the trees will eventually disappear from the forest, the forest will be overwhelmed with trees, or something between these two extremes.

Source: Goldberg, K. (2007). Using technology for problem solving in middle and high school mathematics. Upper Saddle River, NJ: Pearson Education

Work to dissect the problem will be accomplished using mixed teacher guided and student directed methods. The teacher will guide students through a KWL for the problem. Then students will move into groups using a method appropriate for the given class and work to solve the problem.

Explain

Discussion of results and explanation of mathematical procedures. The following terminology will be discussed in the context of the tree problem (examples will be provided as needed, connections to prior learning will be consistently made):

- Function
- Recursively defined functions
- Closed form or an equation (incl. linear functions)
- Input and output (revisit domain and range)
- Conjecture and hypothesis

Elaborate

Students explore the Ecology Global Network website
http://www.ecology.com/2011/09/10/paper-chase/

Students use the site http://www.bugwood.org/intensive/forest_tree_planting.html or other similar to identify the cutting and planting values for a geographic location. Determine an equation to model and explain the long-term outcome for the trees. Represent the model graphically and include a table of at least 10 values.

Additional Resource:

NCTM Illuminations-Rainforest Deforestation Problem or Myth?
http://illuminations.nctm.org/Lesson.aspx?id=3820

Assessment:
Student work from the elaborate phase will be assessed to determine student understanding of recursively defined functions and using multiple representations (tabular, graphical, algebraic) to present results. Students' appropriate use of content-specific language will additionally be assessed, feedback will be provided, and opportunities to make revisions using feedback will be available.

Sample Science Benchmark Lesson
Sub-driving/Investigative Question: Investigate the impact on animal species in areas of logging.
Learning Objectives • Students will investigate the impact on the human activity of logging on biodiversity of a geographic location. • Students will create an alternative habitat for a species misplaced by the practice of logging.

Instructional Methods

Engage

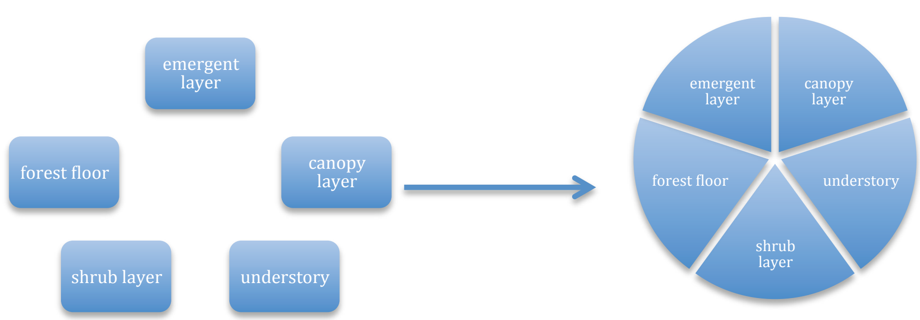
Ask students to share what they know about forests/wooded areas and the plants and animals that live there. Generate a list of geographic locations that are classified as forests.
Teacher reads Dr. Seuss' The Lorax to the class (or show select movie clips); Video clips from Avatar, Fern Gully, Planet Earth-Rainforests or The Inconvenient Truth could be used in place of The Lorax. Debrief the selected reading or video clip.

Explore

Students are assigned to a group characterized by various layers of the rainforest: Emergent layer, Canopy layer, Understory, Shrub layer, Forest floor. These are the expert groups. At each station students explore the environment, including plant and animal life, for the given layer. The goal is for each student to become an expert of a single rainforest layer. Possible guiding questions include:

1. Describe the layer-amount of sunlight, climate, available resources
2. Identify plants and animals that would thrive in a given layer, including identifying animals that could move between layers. Consider various aspects of animals and relationships such as nutrition, adaptive behaviors, predation, movement, growth and reproduction.

Now that the individual layers have been explored (below left), new groups are formed that consist of one member from each of the expert groups (below right).



Experts share out their understanding of their respective rainforest layer. The group compares and contrasts the various rainforest layers. Individuals record "take-aways" for each layer using a selected graphic organizer.

Explain

- Check in with groups and share out "take-aways." This work can be displayed using Google Drive or other tool for document sharing for students to use as a reference.
- Vocabulary will be explicitly addressed including-biodiversity, habitat, ecosystem, and other terms identified as needing clarification

Explore/Elaborate

Once students have completed group discussions of the five layers, the teacher probes them with a follow-up scenario:

- Find a New Home Activity-Imagine trees are being harvested in a rainforest of your choice. Find a new home for an animal of your group's choice using your knowledge of your understanding of the animal and its habitat. Compare the new habitat to the rainforest and identify long-term impact on the species (e.g. was it a good move? can the species survive? advantages? disadvantage? adaptive behaviors?)

Explain

Students present a visual and narrative of the animal and its new habitat

Additional Resources

- Student Activities related to forests: https://www.plt.org/focus-on-forests
- Background information on Logging, Rainforests, Deforestation: http://kids.mongabay.com/lesson_plans/
- FOSS Kit-Animals Two by Two (for younger students)
- Environmental Education: http://ee.wfpa.org/ee/

Assessment:

"Find a New Home" assignment can be evaluated using a holistic rubric.

- 1 points- An animal and brief description of a new home is described.
- 2 points- all of the above and the description contains many details.
- 3 points- all of the above and both animal and habitat are described in many detail.
- 4 points- all of the above and comparisons are clearly made to the rainforest ecosystem
- 5 points- all of the above and long-term impact is explored and discussed
- *Work that is not presented in a clear and fluid manner will be returned for revisions.

Additional skills including collaboration and critical thinking will be supported and assessed throughout this multi-day lesson. Students will have an opportunity to submit a summary of individual contributions and new learning of how animal species are impacted by harvesting in their environment.

WARM-UPS TRANSFORMED MY CLASSROOM

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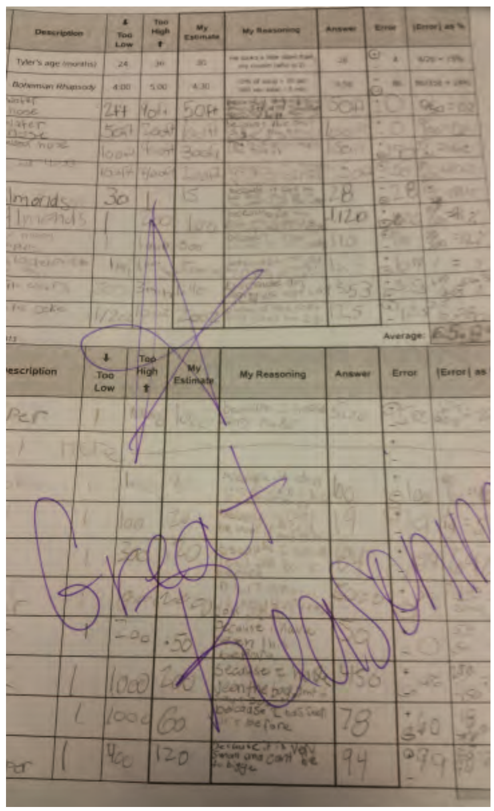
http://powersfulmath.wordpress.com/

I have always had a love/hate relationship with warm-ups and flashbacks. At the school where I teach they are required and I truly to get the "why" behind using them to start class. After all, I honestly need that 5 minutes to take attendance, answer questions, and deal with whatever 7th grade crisis just transpired in the hall. However, I have always struggled with what that warm-up or flashback should look like. So I have done what many teachers do, that good old skill and drill warm-up. You know the process, you give the kids the five questions, they pretend to do them, you go over the answers, they write the answers down and pretend they got them all correct. Great learning going on there right? (Side note, sometimes I think about the ways I have taught kids in the past and cry a little on the inside).

Time to Change

Enter this year's teacher led TMC conference. No I didn't attend the conference but I felt like I did. I anxiously awaited every tweet, read every blog post that came out of it, and resolved that even if I wasn't there I could certainly still use it to make myself a better teacher. Of course, I quickly became overwhelmed with so many amazing ideas at once so I decided I needed to focus my efforts and energies so I started working on my warm-up dilemma. I started by reading this blog post and then that quickly led to others and as I read post after post about teachers who had leveraged their warm-ups in the classroom to really improve student learning. I knew this change was needed for me and was doable so I created this Warm-Up to use this year in my class.

Each day we do Estimation 180. I know some only incorporate it once or twice a week but due to the fact that I love it and the kids love it I knew I needed to do it every day. The kids fill out the hand-out provided on the website and also send their estimate in on their clicker. This allows me to provide an incentive to our best estimator (using our team money system) and once I display the live results it gives us some great talking points. We talk a lot about the estimates, what we know was too high or low, why some answers were more popular than others, etc. Besides just the reasoning and number sense provided by the activity I love the focus that we have been able to place on finding the percent of error. Percent error is such a big 7th grade Common Core Standard and is so valuable in students being able to reason with percentages. I have been amazed by the results so far. In a class that is about 30% English Language Learners and 45% students with disabilities, 92% of students turned in an Estimation 180 sheet for the first 20 days of school that was filled with beautiful reasoning strategies and high quality percent of error work. I can't begin to tell you how rare it is for students to put that much effort into a warm-up sheet. And to date, 84% of students in that class have currently mastered finding the percent of error with no formal instruction only the focus we have placed on it during our Estimation 180 time.



The rest of our warm-up time changes based on the day of the week as follows:

- Math Talk Monday
- Counting Circle Tuesday (There are tons of great resources out there for this, just google Counting Circle!)
- Would You Rather Wednesday
- Tough Pattern Thursday
- Find the Flub Friday (I just write a problem on the board and purposefully work it out incorrectly.)

Love

I love the focus this has allowed us to place on mathematical reasoning and processing and not skill and drill. I love that the kids have a few minutes to share their ideas and just talk about math. I love that kids the used to pretend to do their warm-ups and then just wrote down the answers have bought in and work diligently so that they have something to share with the class. I love that we are focusing less on the right answer and more on the right reason. I love that when I read their warm-ups at the end of the week that I can see the effort they have put in. I love that warm-ups have went from my least favorite part of class to the most valuable time we spend.

CREATING HIGH-QUALITY STANDARDS-BASED EXTENDED RESPONSE QUESTIONS (ERQS)

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As we continue to move towards changing standards and classroom expectations, we must continue to find ways to prepare our students not only for mandated standardized tests, but also for real-life mathematical challenges they will face. Writing exceptional Extended Response Questions (ERQs) is not an easy task. If you are like me, tested or not, these questions are the summative assessment tool that incorporates the application of targeted standards. Whatever your reason for creating and using, I have outlined below some tips and ideas as you create these ERQs.

1. Read the standard, carefully.

If you want to assess a standard, make sure you have read it and understand its scope and magnitude. Check standards that are similar in both the grade prior and grade after your targeted grade to verify you are covering the scope of the standard at your grade level.

2. Stick with one standard.

If you try to assess too many standards in one ERQ, your ability to determine your student's knowledge of each standard will become muddied. The standards are complex on their own, so try not to mix in multiple standards.

3. Pick a standard that is hard to assess with multiple-choice items.

There are certain standards that lend themselves to ERQs and more importantly cannot be assessed with multiple-choice accurately. For instance if you want to find out if a student can solve a system of equations using the substitution method, this is much better left to a short answer or ERQ. A multiple-choice question for this standard would allow for guess and check or any other method to be used. If you used a multiple-choice question that asked for a step in substitution you would only be assessing part of the process. While writing your standards-based tests, these standards that can only be assessed with ERQs will be evident to you.

4. Ask an open-ended question, but keep the parts as independent as possible.

That may be a little blurry. What I'm trying to say is that if a student doesn't understand part A of a three part question, he should still be able to share his knowledge or complete parts

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B and C. If the answer to part A has to be correct in order to get part B or part C, then you might get a lot of false negatives on parts B and C.

5. Start from scratch.

We all have our favorite older open response questions that we want to keep using. Please don't. The curriculum has changed and so has the expectations for the question. It is much better to be creative and generate a new question that is focused solely on the standard you wish to assess. Modifying old questions often results in assessing multiple standards or maybe even one that isn't on grade level.

6. Pick something that students can relate to.

The bane of my existence was a flour barrel question we used for an open response question at my school. I'm not even sure I've ever seen a flour barrel and I know my students haven't. Make it something common and culturally relevant to your area and socially relevant to your students. I've seen some recently with Napoleon Dynamite, but even that is old. Try to include Psy, Lady Gaga, or Lebron James and your students will think you're ERQ is more relevant and interesting. (I just felt old trying to be cool there.)

7. Run it by a colleague.

Some of us are fortunate enough to have other teachers that teach the same grade level, but many of you may not. Have another teacher look it over (post it on a blog or Twitter #edchat if there is no one in your building) for feedback before you use it. Ask them what standard they think it addresses. Sometimes this other vantage point will allow you to catch an error in wording or content.

8. Grade with a fine-tooth comb.

I always grade extremely difficult on my own ERQs. Whatever you allow during the year and give credit for, you should expect when it comes state testing time. Don't slack on the grading thinking they will do it perfectly next time. You will get what you demand.

I hope these suggestions will help you in developing quality ERQs for your students. Find a real-life problem they can relate to, one that assesses one standard, and one that helps your students apply their knowledge. Good luck to everyone!

Research Papers

THE USE OF HANDS-ON ACTIVITIES TO EXPLORE DIRECTLY AND INVERSELY PROPORTIONAL RELATIONSHIPS

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In mathematics education literature, preservice teachers' reasoning about and comprehension of proportional and inversely proportional relationships is not well-explored. In this explanatory multiple-case study, hands-on and real-world problems were used to investigate the reasoning of four middle and secondary grades teachers' when determining whether two quantities are in a directly or inversely proportional relationship. This study makes use of the coordination classes construct to analyze teachers' responses. Although teachers considered proportionality to explain relationships, they determined directly and inversely proportional relationships by comparing given quantities qualitatively and had trouble in recognizing the reciprocal multiplicative relationships between those quantities.

Introduction

Understanding ratios, proportions, and proportional reasoning has been a central focus of school mathematics, and these topics are critical for students to learn, but difficult for teachers to teach (Lobato, Ellis, & Zbiek, 2010). One of the problems of teaching and learning proportional relationships is that traditional proportion instruction puts an emphasis on rule memorization and rote computations (Izsák & Jacobson, 2013). Hence, the most common strategy for solving a missing-value problem is the cross-multiplication strategy (Fisher, 1988), which requires setting a proportion and cross-multiplying numbers within the proportion. Even though this strategy has been mentioned in textbooks as a general strategy and widely used in classrooms, many students apply this strategy without a meaningful understanding of it (Lobato et al., 2010). In fact, simply knowing how to apply the cross-multiplication strategy to these types of problems does not mean that students really understand the proportional relationships. A second problem is that mathematics education research has overlooked teachers' proportional reasoning (Izsák & Jacobson, 2013). In particular, only a few researchers (e.g., Fisher, 1988; Izsák & Jacobson, 2013; Lim, 2009; Riley, 2010) studied teachers' proportional reasoning regarding inverse proportions. Similarly, the concept of multiple proportions has been explored by only a few researchers such as Vergnaud (1983, 1988). Therefore, the preservice teachers' reasoning about and comprehension of inversely proportional relationships are not well-explored.

Objectives of the Study

My main goal in conducting this study is to explore how preservice secondary grade mathematics teachers identify directly and inversely proportional relationships and distinguish them from each other. Additionally, the types of strategies that prospective teachers use to solve single and multiple proportion problems, their ability to represent direct and inverse proportional relationships in given problems, and the difficulties that they encounter while solving these problems are explored. Thus, the following research questions guide this study.

1. How do preservice middle school mathematics teachers determine directly and inversely proportional relationships in given problems, and what types of reasoning strategies do they use in detecting and explaining directly and inversely proportional relationships?
2. What types of strategies do preservice teachers use to solve given problems, and what kinds of difficulties do they encounter in the process of detecting and explaining directly and inversely proportional relationships?

Theoretical Framework and Related Literature

This study makes use of the construct of coordination classes (diSessa & Sherin, 1998), a concept established in science education as part of the knowledge-in-pieces epistemological perspective (diSessa, 1988), to analyze teachers' facility with precise identification of directly and inversely proportional relationships and multiplicative relationships. A coordination class contains two essential tools: readout strategies and the causal net. Readout strategies "deal with the diversity of presentations of information to determine, for example, characteristic attributes of a concept exemplar in different situations" (diSessa & Sherin, 1998, p. 1171), or more simply, they are strategies for acquiring information about the physical world. The causal net, is "The general class of knowledge and reasoning strategies that determines when and how some observations are related to the information at issue" (diSessa & Sherin, 1998, p. 1176).

Most recently, Izsàk and Jacobson (2014) investigated preservice middle and secondary grades teachers' facility with multiplicative relationships and the identification of directly and inversely proportional relationships by utilizing coordination classes. However, the missing-value problems used by Izsàk and Jacobson (2014) involved either a single proportional or nonproportional relationship. As Izsàk and Jacobson (2014) stated, this was a limitation of their study, and they suggest that future research should involve more complex cognitive structures to analyze teachers' responses to the proportion problems (Izsàk & Jacobson, 2014). In order to examine complex cognitive structures Izsàk and Jacobson (2014) recommend using problem tasks that involve physical devices and other contexts with which teachers have less experience. Since this study uses hands-on problem tasks and multiple proportion problems to examine teachers' proportional reasoning, it extends and strengthens the knowledge-in-pieces perspective by applying core components of this perspective to understand the more complex cognitive structures used by teachers to identify directly and inversely proportional relationships and multiplicative relationships.

Methodology

An explanatory multiple-case study methodology (e.g., Yin, 1993, 2009) was used in designing this study. Because the purpose of this study was to explore preservice teachers' reasoning, each individual participant constituted a case. Since there was more than one case, a multiple-case study methodology best suited the scope of this study. The data was collected through semi-structured clinical interviews (e.g., Bernard, 1994). In Spring 2013, one female and two male students from the secondary grade program (8-12 grades) and in Fall 2013, one female student from the middle grade program (4-8 grades) at one large public university in the Southeast participated in the study. The following pseudonyms were used for the students from middle and secondary grade programs, respectively: Abby, Robert, Sally, and Jason. All participants were in the third year of their programs. Robert, Jason, and Sally were interviewed for three hours each; Abby was interviewed for approximately 80 minutes.

This study presents participants' responses to the three hands-on—Gear I, Gear II, and Balance—, and three real-world problem—Speed, Fence, and Apartment—tasks. Abby worked on the Balance and Speed tasks; Robert worked on the Gear I, Gear II, Fence, and Apartment tasks; and Sally and Jason both worked on Gear I, Gear II, Speed, Fence, and Apartment tasks. I developed the Gear, Balance, and Apartment tasks and adopted the Speed and Fence tasks from Dr. Sybilla Beckman's mathematics textbook, *Mathematics for Elementary Teachers* (2013). In the Gear and Balance tasks, participants were provided with plastic gears and with a mini number balance system, which was a simple version of an equal-arm beam balance scale, respectively. The Gear I task involved determining a directly proportional relationship between the size of a gear and the number of notches it possessed. The Gear II task involved determining an inversely proportional relationship between the number of revolutions that a gear makes and its radius as well as an inversely proportional relationship between the number of revolutions and the number of notches. The Balance task involved determining an inversely proportional relationship between the distance (how far from the center a weight was placed) and the number of weights. The Fence, Apartment, and Speed tasks involved multiple directly and/or inversely proportional relationships.

Results and Discussion

Abby's Case

Abby successfully explained the directly and inversely proportional relationships between quantities in the Balance and Speed tasks. In both tasks, she determined directly and inversely proportional relationships by describing qualitative relationships between quantities. However, except in one instance, she did not explain the multiplicative reciprocal relationships. Hence, her read out of the relationships was based on appropriate qualitative relationships, not on the multiplicative relationships between quantities. Her difficulty with forming appropriate multiplicative relationships seemed to be an important constraint in her causal net. Additionally, she did not recognize the constancy of the products in the inversely proportional relationships and the constancy of the quotients in the directly proportional relationships. For instance, in the Balance task, although she suspected the product of the distance from center and the number of weights to be something constant, she did not recognize that the same constant could be obtained from the rate table that she generated to explain the inversely proportional relationship.

Since, in her causal net, Abby knew that the quantities in a directly proportional relationship were increasing and decreasing at a single constant rate, she initially endorsed a single constant rate in the inversely proportional relationship between the number of weights hung and the distance from center. Later, as a result of examining the values in her rate table, she recognized that there was not a single constant rate. However, she had two inconsistent meanings of the term rate. She used the term to indicate the multiplicative within and between measure factors. Later, she associated between measure factors with the slopes of the directly proportional graphs. Her usages of the term rate was evidence that she understood the rate to be a constant factor that can be used to get from one value to another. She did not recognize that the rate was showing the multiplicative relationship between quantities compared. Thus, Abby's initial endorsement of a single rate in the inversely proportional relationship and the use of rate to indicate within and between multiplicative factors were two significant constraints in her causal net. On the other hand, as she worked out the questions, she appeared to make adjustments in her causal net that provoked to more complete coordination with directly and inversely proportional relationships. To solve the problems in the Balance task, she used the balance formula and considered constancy of the place values. In the Speed task, she used the unit ratio, coordinated multiplication and division, and scale factor strategies. She also obtained the distance formula correctly but did not have time to use it solve the given problems. She expressed relationships with ratio and rate tables, balance and distance formulas, and directly and inversely proportional graphs.

Sarah's Case

Similar to Abby, Sally recognized the directly and inversely proportional relationships by attending to the qualitative relationships between quantities. For example, in the Gear 2 task, she described the inversely proportional relationship between the size of a gear and its revolutions by saying, "so, as your radius gets bigger you do less turns, and then [as] the radius gets smaller your revolutions increase." She sometimes recognized and described multiplicative relationships between those quantities. For instance, in the Gear I task, one of the problems involved investigating the number of notches around a gear with a 4-cm radius, given that it was meshed to another gear with a 3-cm radius and 18 notches. She explained the reciprocal multiplicative relationship between the size of a gear and its number of notches by saying, "I know that Gear 1 is always going to have three-fourths the amount of little notches that Gear 2 has. And so if I know how many notches Gear 2 has, [then] I can multiply this by $\frac{3}{4}$ and get the amounts of notches that gear 1 has." Her read out of the relationships was mainly based on appropriate qualitative relationships since she did not always recognize the appropriate multiplicative relationships between quantities.

Sally seemed to be comfortable while she was working on the tasks. She set up direct and inverse proportions and used other proportional reasoning strategies to solve given problems. If the tasks involved a single relationship such as in the Gear tasks, she set up direct and inverse proportions to solve problems. However, the Fence, Apartment, and Speed tasks involved multiple relationships, so her main strategy for solving the problems in those tasks was that she fixed one quantity as constant and used either the coordinated multiplications (or divisions) strategy or the coordinated multiplication and division strategy. She used the coordinated multiplications (or divisions) strategy if there was a directly proportional relationship between the remaining two quantities. On the contrary, if the relationship was inversely proportional, then she used the coordinated multiplication and division strategy. She expressed the relationships between quantities with proportions, ratio and rate tables, directly and inversely proportional graphs, and/or algebraic formulas. While depicting the inversely proportional relationship between the number of revolutions and the number of notches, she stated that she initially did not know what the graph of an inversely proportional relationship would look like. She obtained the correct graph by marking the values, which she already calculated. In the Gear I and Fence tasks, she drew the directly proportional graphs as if the lines were intercepting the y-axis at $y \neq 0$. It is likely that she did not know that if the line intercepts the y-axis at $y \neq 0$, then the graph expresses a non-proportional relationship. In addition, if there was a directly proportional relationship, she recognized the constancy of the quotients. However, in the inversely proportional relationships, she did not recognize the constancy of the products.

Jason's Case

Similar to Abby and Sally, Jason initially recognized the directly and inversely proportional relationships by attending to the qualitative relationships between quantities. He also sometimes recognized and described multiplicative relationships between those quantities. Similar to Sally, if problems involved more than two quantities, he fixed value of one quantity as constant to discuss the relationship between the other two quantities. For example, in the Fence task, he fixed the number of fences and explained that there was an inversely proportional relationship between the number of painters and the number of days to paint those fences.

Although he reasoned proportionally and used proportional reasoning strategies to solve problems, he sometimes had difficulties to distinguish directly and inversely proportional relationships. For instance, in the Gear II task, he initially endorsed a directly proportional relationship between the radius and the number of revolutions. To determine the number of revolutions that a gear with a 3-cm radius made given that another gear with a 4-cm radius revolved six times, he set up the direct proportion $\frac{3\ cm}{4\ cm} = \frac{x\ revolutions}{6\ revolutions}$, and so he obtained an incorrect answer. Later, although he obtained the correct answer, his initial endorsement of a directly proportional relationship was a sign of a significant constraint in his causal net. In addition, in the Fence task, he initially endorsed an inversely proportional relationship between the number of days and the number of fences painted. He immediately realized that it was a directly proportional relationship, so he corrected his initial endorsement. Similarly, when he was obtaining the speed of a car that was driving two miles in 100 seconds he assumed the relationship between the time and the distance to be inversely proportional. As a result of assuming an inversely proportional relationship, he obtained an incorrect answer.

Robert's Case

Robert appeared to be looking for numerical relationships to generate algebraic equations and formulas during the interview on each task. This strategy allowed him to correctly solve the given problems but prevented him from the use of proportional reasoning strategies. He also used a proportion formula strategy in which he usually cross multiplied values to get the missing one. Similar to the other three preservice teachers, he determined the directly and inversely proportional relationships between quantities by describing the qualitative relationships. For instance, in the Gear II task, he determined that a small gear was making more revolutions than a larger gear, and he explored that the increment in the size of a gear was resulting in fewer revolutions. Therefore, he easily determined the inverse relationship between the size of a gear and the number of revolutions it made. However, he focused on qualitative relationships between quantities instead of multiplicative relationships.

Because Robert depended on the algebraic equations and formulas to solve given problems, he had more difficulties than the other participants in explaining and making sense of his solutions. For example, he had difficulty with using correct units, explaining the meaning of the units, and the unit conversions. When the numbers were not presented, he had trouble in generating algebraic equations and formulas. He also had difficulty with fractions and fraction operations and solving problems that involved multiple relationships. In addition, in some cases, he could not explain the meanings of his operations, equations, or formulas. In the Fence and Apartment tasks, he explored the relationships between quantities by fixing one quantity at a time and explaining the relationship between unfixed quantities. In the Gear II and Apartment tasks, even though he used the idea of constancy of the products, he did not recognize and explain that the products were constant because of the inversely proportional relationships between quantities. For example, in the Gear II task, he determined the total number of notches moved on a gear for each revolution multiplying the number of notches by the number of revolutions. Similarly, in the Apartment task, he obtained a constant 1,152 man-hours by multiplying the values of the inversely proportional quantities.

Implications

In earlier research, researchers investigated teachers' proportional reasoning mostly using missing-value word problems, which usually involved a single directly or inversely proportional relationship. In this study, a combination of hands-on and real-world missing-value problems, which involved either single or multiple directly and inversely proportional relationships, were used. Because multiple proportion problems cannot be solved by simply constituting a single proportion and applying the cross-multiplication strategy, preservice teachers did not prefer using the cross-multiplication and the additive strategies in those problems. Likewise, the use of hands-on tasks generated a checking mechanism for teachers and helped me in observing teachers' application of different strategies to determine directly and inversely proportional relationships and to solve given problems.

Thus, this study makes three contributions to the current research base: First, very little research has been conducted on preservice teachers' proportional reasoning. In particular, only a few researchers (e.g., Fisher, 1988; Izsák & Jacobson, 2013; Lim, 2009; Riley, 2010) have studied teachers' proportional reasoning regarding inverse proportions, and even fewer researchers have studied multiple proportions (e.g., Vergnaud, 1983, 1988). Second, the use of hands-on tasks and real-world missing-value problems together precipitate the gathering of relevant information regarding preservice teachers' proportional reasoning. Third, the study examines the construct of coordination classes for analyzing teachers' capability of detecting and explaining directly and inversely proportional relationships.

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Acknowledgements

I thank Dr. Andrew Izsàk for helpful comments on earlier drafts of this paper.

GRAPHING CALCULATOR QUANDARY: AT WHAT POINT SHOULD GRAPHING CALCULATORS BE INTRODUCED WHEN GRAPHING QUADRATICS?

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High stakes testing is driving the decision for when and where teachers use technology in the mathematics classroom. This study examined two sequences for using graphing calculators to teach quadratic functions in four sections of advanced Algebra 2 (n=40) in a large Midwestern high school. While each class received both types of instruction, initial instruction for two classes incorporated the graphing calculator while the other two classes used pencil and paper. Data from pre and post-tests suggest that students can learn to graph quadratics by either sequence.

Introduction

High stakes testing is driving the use of technology in core mathematics' classrooms (Robelen, 2013). Wording such as "studies have shown" or "research shows" resonating in the jargon of the proponents for technology in high stakes testing seems to have minimal actual classroom research backing their claims. Graphing calculators are currently allowed and also included in dropdown windows on the computerized versions of some Algebra end of course exams (Robelen, 2013). However, teachers fear that allowing the use of graphing calculators on these exams skew the scores by allowing students to correctly answer questions even when they lack meaningful understanding. Because of wide attention to the test scores by various stakeholders, we are being "strongly encouraged" by administrators to use graphing calculators in Algebra classes simply because they are allowed on the end of course exams. Although graphing calculators allow students (and teachers) to explore real world data and functions in ways that they otherwise could not, conceptual cognizance is essential for building a mathematical foundation for future coursework.

The use of graphing calculators has redefined the mathematical content that can be explored and mastered in the secondary mathematics classroom. Graphing calculators used as instructional resources "provide opportunities for students to learn about the connections between algebraic and graphing representations, an important skill in the visualization process" (Smith & Shotsberger, 1997, p. 368). Furthermore, "Anyone who has seen trained teachers use calculators knows that they can be used to teach 'thinking'," (Martin, 2008), and it is this "thinking" that the rigor of mathematics requires. However, as Smith and Shotsberger (1997) discovered and Martin (2008) confirms, teachers do need training to be able to use them appropriately. When used properly in the mathematics classroom, graphing calculators encourage students to ask “more thoughtful, higher-order questions in class” and allow teachers and students to “model the use of multiple approaches – numerical, graphical, symbolic, and verbal – to help students learn a variety of techniques for problem solving” (Martin, 2008, p. 23).

Objectives of the Study

Graphing calculators certainly have a place in the Algebra classroom, as backed by multiple studies yielding convincing evidence (Martin, 2008; Kastberg & Leatham, 2005; Smith & Shotsberger, 1997, e.g.). However, studies have been inconclusive concerning how and when to implement graphing calculators into the classroom (Kastberg & Leatham, 2005). A driving purpose for this study was urged on by other studies such as Martin (2008) who recognized that there are multiple articles that “give wonderful advice on how to use the graphing calculator to teach a specific concept, but significantly fewer articles report studies which compare the success rates of the traditional (paper-pencil) approach to teaching algebra versus the graphing-calculator-based approach to teaching algebra” (Martin, 2008, p. 20). One of the reasons for a lack of studies in this area is because researchers must take great care to not knowingly withhold a possibly better pedagogy from select groups of students (Herman, 2007, p. 28). The focus of this study was to determine whether or not the timing of the use of graphing calculators when teaching the graphing of quadratics affects the learning outcome of the students. In this study, all students were instructed both with the graphing calculator and by traditional paper-pencil lecture (without the graphing calculator). The purpose of this study was to determine if calculator or traditional paper-pencil based instruction should come first. This study used pre-test and post-test during the quadratics unit to assess the effectiveness of the two different sequences of instruction. Two questions guided this study. First, does the sequence of instruction, graphing calculator exploration or traditional paper-pencil lecture, have a greater impact on the student’s overall success on the end of unit quadratics exam? And second, do students develop a deeper understanding of graphing quadratics if first introduced to the topic by traditional paper-pencil lecture or by graphing calculator exploration?

Related Literature

Attitudes of teachers toward the use of graphing calculators in their classrooms greatly affect the students’ achievement in those classes. Lee and McDougall (2010) found that “Teachers who are proficient in using the graphing calculators can in turn teach their students to effectively and efficiently use their graphing calculators" and that calculator use freed up "mundane pencil and paper mechanics" making more classroom time for meaningful discussions about mathematics. They add, "When graphing calculators are effectively used in the mathematics classroom, they are a powerful tool to assist teachers in providing their students with an environment to help them construct their mathematical knowledge and understanding" (Lee, 2010, p. 871).

Nonetheless, many are concerned with equity issues surrounding the implementation of the graphing calculator in all Algebra classes. Special needs students, control groups, access to personal technology, and teacher assignment are all equity issues that must be considered. Although some believe that teachers are making positive strides when they "encourage graphing-calculator use in high school, particularly among lower-achieving students" (Robelen, 2013), others do not share that optimism. Steele (2006) states "Although graphing calculators are clearly useful resources for both teachers and students, the calculators frequently present challenges for students with learning problems" (Steele, 2006, p. 32). Equity in research, secondly, becomes an issue because to determine whether or not the graphing calculator helps or hinders, control groups prevent some students from receiving the benefits of the technology that other groups receive (Herman, 2007, p. 28). Third, equity is an issue when it comes to high-stakes testing, because not all students have access to graphing calculators for personal use during their learning. Therefore, even though the tests may all have "dropdown" graphing calculators, students who have not had hands-on access to comparable calculators during their learning are at a great disadvantage when it comes time to take the exams (Robelen, 2013). The fourth equity issue involves the teacher to whom a student is assigned. The attitudes of teachers, not only toward graphing calculators, but also toward mathematics in general, greatly affects calculator usage and the teaching that occurs with (or without) them. (Dewey, Singletary, & Kinzel, 2009, p. 383)

However, beyond equity issues, many others are concerned about the usage of the graphing calculators in Algebra. Robelen (2013) believes that the debate over calculator use in the classroom should not be a matter of whether we use them, but over when to strategically use them, how to appropriately use them, and why their capabilities may modify how you teach. Dewey (2009) adds to the discussion that even with the interpretation of the standards and existing supporting research, the calculator use in the mathematics classroom is debated and it “is most controversial when it is introduced before students master the equivalent pencil-and-paper algorithms without the technology” (Dewey et al., 2009, p. 383).

Methodology

The study was conducted in school district located in the Midwest with approximately 10,000 students and is located within thirty minutes from a major city. The four-year suburban high school has a student population of just over 2800 students. Mr. Thomas (pseudonym) has taught the advanced classes for several years and routinely uses technology while teaching. He prefers to teach in a blended combination of teaching methods or “hybrid classroom” (Slavit, 1996, p. 13), using traditional *tried and true* methods along with the graphing calculator for exploration. Mr. Thomas attends College Board Advanced Placement summer institutes and conferences and uses the *Rule of Four* in all of his classes. The *Rule of Four* states, “Where appropriate, topics should be presented geometrically, numerically, analytically, and verbally”(Harvard Consortium, n.d.).

Mr. Thomas’ teaches four sections of advanced Algebra 2. Students, mostly sophomores, were invited to participate in the study. Two of the sections, A and B, were in the morning while C and D were in the afternoon. Further, sections A and D were both small classes containing fewer than 15 students each, but sections B and C were large with more than 25 students each.

Mr. Thomas invited the students to participate in the study, assuring them that there would be no change in their instruction or grade regardless of their decision. Students who participated in the study did not receive any extra or bonus points and students who did not participate did not lose any points. He explained both orally and in writing that the only difference would be that those participating in the study would have their testing data examined by the researchers. Eighty-nine students were invited to participate in the study and forty-three brought back signed forms (n=6, 15, 11, 8 respectively). Mr. Thomas noted that students had two weeks to return the forms, but he did not compel them. He said that students often failed to return items not affecting their grades. Of the forty-three, three of the students missed one or more days when the tests were administered, thus data from the remaining forty students were used in this study.

A pre-test designed by the researcher was given to all students to test for prior knowledge and identify differences between treatment groups. Sections A and B received graphing calculator instruction first, followed by a more traditional paper-pencil instruction;

while sections C and D received the traditional paper-pencil instruction first, followed by the graphing calculator instruction. The quadratic unit test was created by the teacher to ensure alignment with his overall teaching philosophy and to minimize the researcher impact on the student exam. For purposes of data analysis, students' scores across both sections receiving the same treatment were combined for a total of two groups, CT for sections A and B which received calculator instruction first and TC for sections C and D which received traditional paper-pencil lecture first. Students were tested at two points: prior to any instruction and following the end of the second treatment. The purpose of the study was to examine the timing of the usage of graphing calculators in the Algebra classroom when learning to graph and identify key components of quadratic functions. The data from the tests were analyzed using an independent sample t-test in SPSS.

In addition to the exams, open dialogue focused on pedagogies of research and practice in the classroom occurred throughout the overall study and was documented via instructor notes to be included in analysis. During the graphing calculator instruction, basic graphing calculator usage preceded the lessons. After they were familiar with the calculators, Mr. Thomas led the students to explore how changes to a quadratic function affected its graph. The students were then able to use the calculators' technology to determine intercepts and extrema. During the traditional paper-pencil led instruction, Mr. Thomas spent more time with tables of values and plotting points to graph the functions. In all of his lectures he made use of a standard dry erase board and markers to write functions, draw tables, and create graphs with the students.

Results and Discussion

While the pre/post test scores of both groups do suggest an increase in overall knowledge of quadratic equations, neither group significantly outperformed the other on the post-test (t = 1.473, df = 38, p =.159). Since the data suggest the groups were also the same prior to instruction (t = .410, df=38, p=.684), it can be suggested that it does not matter if students first receive instruction with the calculator or traditional pencil-paper instruction.

Table 1

Independent Samples t-test on Student Pre/Post Exam Scores

Sequence	Sections	N	Pre-test M (SD)	Post-test M (SD)
Calculator first/then traditional (CT)	AB	21	55.2381 (14.70342)	92.8571 (13.3682)
Traditional first/then calculator (TC)	CD	19	53.1579 (17.33738)	86.8316 (13.09432)

The qualitative analysis of both the student responses as well as test development highlighted an interesting phenomenon for both treatment groups. Students' pre-test knowledge of extrema seemed to be greater than their post-test knowledge. This unexpected finding may be attributed to differences in question format due to different test developers. This prompted further analysis into the types of questions asked on the post-test. It was found that the exam created by Mr. Thomas seemed to lack the depth of knowledge (DOK) questions needed for deeper analysis of what students did and didn't know and understand about quadratics. The results of both treatment groups indicate that students can benefit from both teaching methods, but that some students may learn more effectively by using graphing calculators in the introduction of new topics followed by traditional lecture in the synthesis phase.

Conversations with Mr. Thomas about his thoughts on the implementation focused mainly on time-frame feasibility. Although he presented the same material to both groups simultaneously, the calculator-first classes required a day longer than the traditional paper-pencil lecture classes. He also said that even though the calculator-first classes were able to do some tasks on the calculator, other tasks were so time consuming that he went to the board and made T-charts to explain the concepts. He tried the table feature on the calculators with the students, but found it frustrating and time consuming. Mr. Thomas reported that students in the graphing calculator-first sections were quite engaged with the graphing calculators. However, they were so absorbed in the technology that all questions related to that technology aspect of the lesson, rather than to quadratic functions. He also commented that his students did not question the results found on the graphing calculator, but instead accepted whatever they saw on the screen. The group that received traditional paper-pencil lecture method first, had more higher-order synthesis and analysis questions than the calculator-first group. Mr. Thomas recognized that his students were advanced Algebra 2 students and questioned whether the results would be the same with regular Algebra 2 students. Mr. Thomas did enjoy the research and shared that based on the experience, he planned to introduce the material using the traditional paper-pencil lecture method and supplement the learning with the graphing calculator in the future.

Implications

Based on the findings of this study, it can be suggested that students are able to learn about quadratic functions when provided both calculator and paper-pencil lecture based opportunities. However, there is no difference in student performance determined by which method the student receives first. Thus, similar to the findings of Kastberg and Leatham (2005), there is continued need to study when to introduce the calculator in mathematics instruction, especially in regards to the overall depth of knowledge developed by the student.

High stakes testing drives the use of technology in mathematics instruction. Best teacher practice is desirable for all students and teachers, but regarding technology, there are many conflicting claims for how and when it should be used. The hope of this study was to open the door to provide direction for calculator implementation in the secondary mathematics classroom. Based on the student exam scores, this study suggests the need for additional studies to understand when it is best to integrate calculators into quadratics instruction. Further, based on the conversation with Mr. Thomas, appropriate teacher training is necessary to help teachers understand how to use graphing calculators as a powerful tool for meaningful sense-making activities. Lastly, classroom teachers enjoy research and are in the position to make changes that truly make a difference in student learning.

Those who teach mathematics need to be on the front-line for decision making about calculator use on exams while also making sure students from multiple groups are included in research. In addition to understanding the importance of the two previous suggestions, future research should explore what mathematical knowledge is better learned with graphing calculators or other forms of technology along with knowing how to monitor student engagement with the technology to determine if the calculator excites meaningful exploration by the students. Lastly, how can teachers know whether their students will learn more effectively with traditional introductions to new topics and how can teachers recognize the value of using a new technology if their students are excelling without it?

This study suggests that the order of instruction type, graphing calculator versus traditional paper-pencil, does not impact student performance on an end-of-unit teacher created exam. Further, it is important to continue exploring how and when to integrate graphing calculators into instruction, including a “hybrid” method that integrates the calculator along with the more traditional paper-pencil lectures that are both more comfortable and more familiar to most secondary teachers. The graphing calculator, if used appropriately, is a remarkable tool for the classroom. Unfortunately, on the other hand, when used simply as an expensive summation tool, it is a waste. As we continue to develop as a technology rich society, it is imperative to take both the teacher’s and the student’s knowledge and experiences into consideration to continue exploring best approaches for integrating calculator use.

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EXPLORING STUDENTS' UNDERSTANDING OF POLYNOMIAL FUNCTIONS

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This paper reports on a study of College Algebra students that examined their understanding of polynomial functions with a degree of three or more. Students were interviewed as they solved polynomial function problems individually while 'thinking aloud.' Unlike studies of understanding that rely on quantitative assessments, the study included interviews with students as they completed mathematical tasks, enabling a focus on the students' on-going cognitive actions. The results reported here summarize the students' conceptions of the shapes of the graphs of polynomial function.

Introduction

This paper is the first in a series of studies we will conduct with College Algebra (CA) students, addressing their understanding of non-linear functions. The current study examines the students' understanding of polynomial functions, $f(x)=a_nx^n + a_{n-1}x^{n-1} + \dots + a_1x^1 + a_0,\ n \geq 3$.

Objectives of the Study

While studies of non-linear functions have mostly focused on quadratic functions (Zaslavsky, 1997; Schwarz & Hershowitz, 1999, Ellis & Grinstead, 2008), there are few studies involving polynomial functions. Our research questions are:

1. What is the essence of students' understanding of polynomial function?
2. How do students express their understandings in mathematical situations?

Theoretical Framework and Related Literature

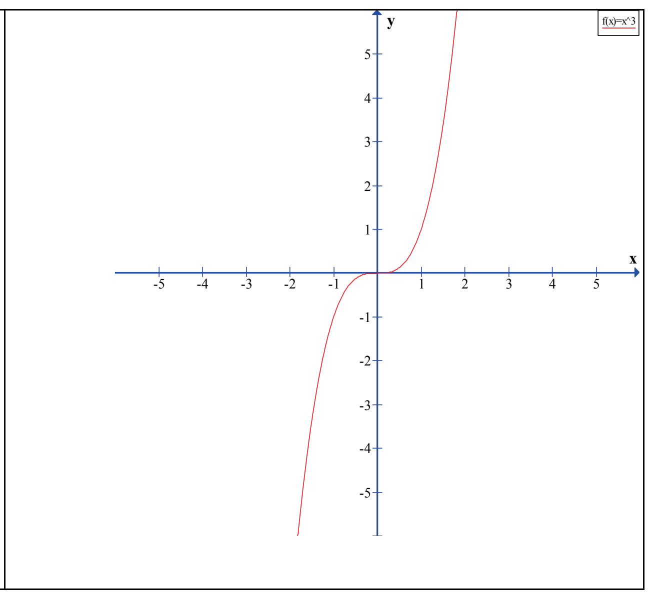
We incorporate a constructivist view of learning (Piaget, 1970, von Glasersfeld 1991, Wheatley, 2004), which views mathematics learning as building up of knowledge that is problem-based; and we draw from the work of Steffe (2002) in developing our theoretical interpretations. Specifically, we are interested in goal-directed action patterns of learners, and, in our analyses, we look to explain how goal-directed sensori-motor actions are transformed (or *interiorized*) into mental action patterns, or operations.

Though studies of learners' general knowledge of functions (Vinner & Dreyfus, 1989; Moschkovich, Schoenfeld & Arcavi, 1993) proved useful to our analysis, we noted some limitations. First, the majority of studies incorporate a multiple representation view of functions, i.e., that the learners' function knowledge can be specified in terms of different representations such as tables, graphs and formal rules. We agree with Thompson's (1994) concern that the multiple representations view may not be the best way to characterize the learner's knowledge of functions:

> …the core concept of "function" is not represented by any of what are commonly called the multiple representations of function, but instead our making connections among representational activities produces a subjective sense of invariance. … We should instead focus on them as representations of something that, from the students' perspective, is representable, such as aspects of a specific situation. (p. 24)

A major question then is how to describe and characterize the essence of students' conceptual structure of polynomial functions as problems are encountered and solved. Second, we noted that the majority of studies about non-linear functions focus on quadratic functions (Zaslavsky, 1997; Ellis & Grinstead, 2008) and do not generalize their findings to polynomial functions. Zaslavsky (1997) described a range of difficulties that students often experience with quadratic functions; however, polynomial functions introduce still more challenges that students must address. Since quadratic functions have graphs that are parabolas, they have a conceptual "sameness" to them as a class that polynomial functions do not possess. For example, note the differences in the graphs of the cubic functions in Figure 1. Polynomial functions have a much greater set of conditions to examine.

$$y = x^3$$



$$y = x^3 - x$$

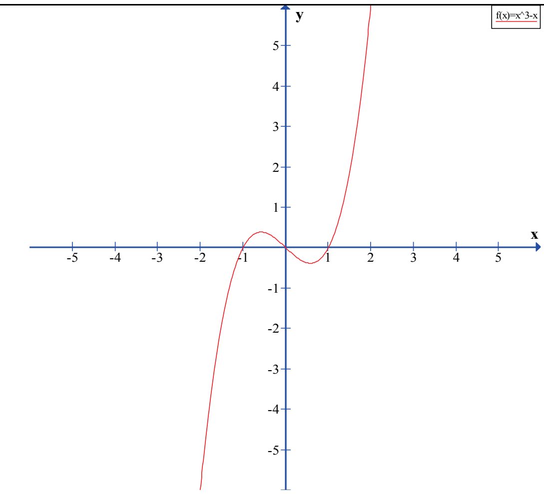


Figure 1: Possible Graphs for Cubic Functions

Methodology

A total of 20 College Algebra students participated in the study. Observing college students solving mathematics problems has proven to be an effective way of modeling the processes of problem solving (Carlson, 1997; Eizenberg & Zaslavsky, 2004; Schoenfeld, 1992).

Students were interviewed as they solved problems individually while ‘thinking aloud.’ Interviews were videotaped; the interviews followed principles of interviewing for clinical teaching experiments (Cobb & Steffe, 1983).

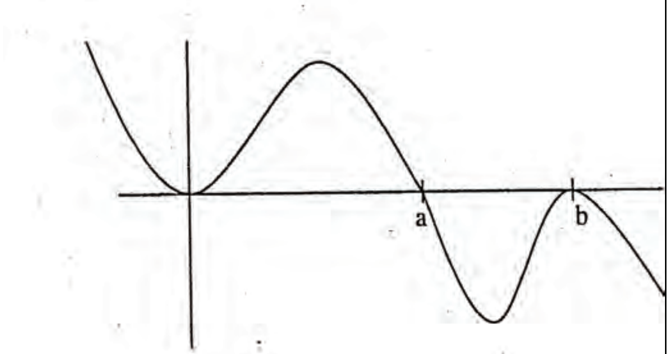
The paper will discuss the solution activity of the students as each solved a pair of polynomial problems (Table 1).

Results and Discussion

We have completed the first phase of the analysis by classifying the students in terms of how they develop their views of the shapes of the graphs of polynomial functions. Students revealed contrasting and sometimes contradictory ways to perceive the shape of the graph of polynomial functions. All students related the graph of polynomial functions to parabolas in some way. We report results from two students, BD and SE, to summarize some of their differences in solving polynomial problems.

BD appeared to have a more general way of describing polynomial functions compared to other students. When asked to explain polynomial functions, BD compared them to quadratic functions and stated that polynomial functions with higher degrees, such as cubic functions, had more than two roots and that they were “parabolic with an unknown middle” (Figure 2).

Table 1: Selected Tasks Used in the Study

Task 1: Without using the graphing functions of your calculator, sketch the graph of the function.	$f(x) = x^3 - 4x^2 - 7x + 10$
Task 2: Which of the following polynomial functions might have the graph shown here: (a) $y = x^4(x-a)^2(x-b)^3$ (b) $y = -x^3(x-a)^3(x-b)^3$ (c) $y = x^2(x-a)^2(x-b)^2$ (d) $y = x(x-a)(x-b)$ (e) $y = -x^2(x-a)(x-b)^4$	

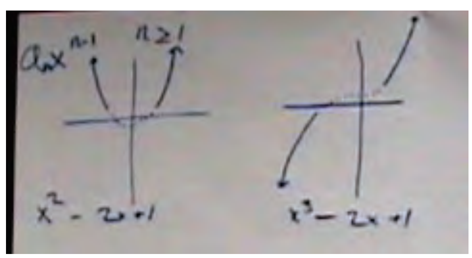


Figure 2: BD’s Diagram About Quadratic and Polynomial Functions

Interviewer: What are polynomial functions about?

BD: It’s all described by either a cubic function or a quadratic function, it’s parabolic with an unknown middle or cubic with unknown middle. Every quadratic will go like this (*he points to left graph in Figure 2*). These 2 parts I’m certain are either up positive or negative down. But I’m not sure about when it crosses or touches. Cubic here is going to go like that, so that’s what I mean by unknown middle (*he points to right graph in Figure 2*).

BD’s comment about “unknown middle” suggests he had a rough general idea of polynomial functions, which he could relate to his ideas about quadratics. He elaborated that the end behaviors of cubic functions were determined by the leading coefficients of the function equations, but the “middle parts” of the graphs varied depending on the specific functions.

In solving Task 1, $f(x) = x^3 - 4x^2 - 7x + 10$, BD used synthetic division to find a zero, x=1, found other zeros using the quadratic formula and then sketched the graph (Figure 3) stating “even’s touch and odd’s cross.” Although his graph looks very accurate and he did locate the y-intercept, he only estimated the max and min points on the graph.

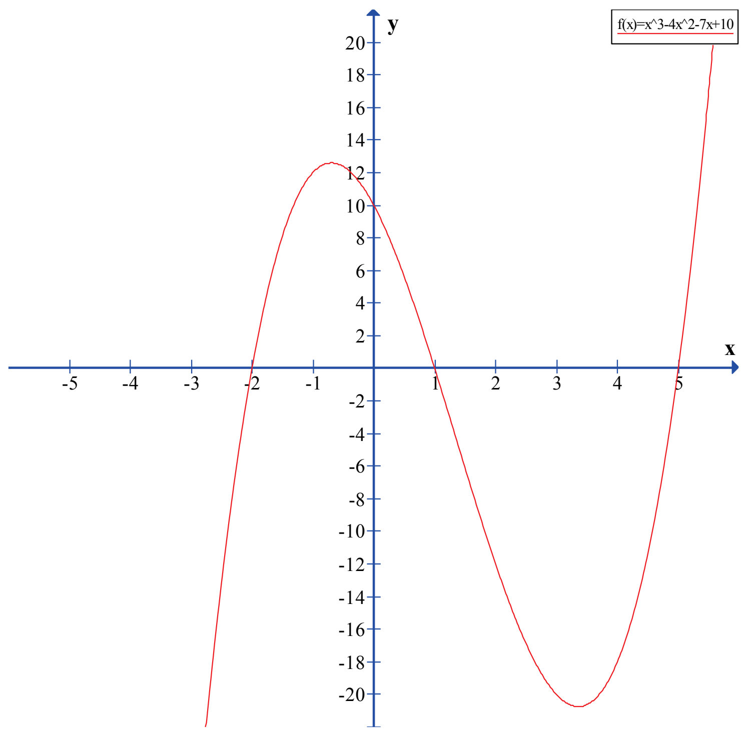


Figure 3: BD’s Graph of $f(x) = x^3 - 4x^2 - 7x + 10$

So, BD could: 1) See some differences between quadratics and polynomials in terms of the zeros, and 2) Sketch the graphs by finding the zeros. However, the students, including BD, experienced more difficulty trying to develop the functional equation from a particular graph. These findings are consistent with research findings indicating that students can easily develop graphs from function equations, but have difficulty generating equations from graphs (Zaslavsky, 1997).

In solving Task 2 (Table 1), other students looked to “dissect” graphs into conjoined parabolas. For example, student SE viewed the graph as a series of parabolas and recalled properties of quadratic functions in a process of elimination to make her selection.

SE: These are the ones I usually have trouble with. Where it touches the x-axis at 3 points. Usually these I'll see which one makes most logical sense to me.

Interviewer: What's hard about this problem?

SE: I think it's one of those that looks very difficult but actually you can dissect it and see which one, see how it works. Yes. I'll just start from right to left and see which one. Obviously the first curve right here (*she points at choice A*), so my choices are x^4. It's positive because it's going upwards so it can't be B or E. So it leaves me with $x^4,\ x^2 and\ x$.

In her analysis of the portion of the graph that includes the point (0, 0), SE ruled out the correct answer, E, reasoning that the graph "opens up" and thus the formula cannot have a term with a negative sign such as $-x^2$.

SE: B, in that problem it was a negative and it's also a parabola which means something in there had to be squared. And then there's another parabola here.

Interviewer: So you're thinking of breaking that picture up into parabolas?

SE: Yes. Looking at this parabola, B is going down making it negative. These are what go through my head. But we have to pay attention to points a and b because that's what are given. I'd probably rule out D because this is a parabola right here. There's got to be a reason it goes down and comes up right here (*she points at the portion of the graph from x=a to x=b*). It can't be D because there's no squared, so it's just a line. I'd rule out D also and would be left with A and C.

Episodes from BD's interview suggest that he has a more unified view of polynomial functions than that of SE, which appears to be compatible with the idea of a conceptual prototype as hypothesized by Schwarz and Hershowitz (1999). On the other hand, SE's structure appears somewhat more fragmented and instrumental (Skemp, 1976) in the sense that she sees polynomial graphs as collections of parabolas and seeks to match the graph with quadratic expressions.

While the analysis is still in progress, we believe that the episodes of BD and SE illustrate some important ways that our students view polynomial functions. The remainder of the analysis will focus on identifying additional categories and sub-categories of the classifications discussed above.

Implications

This study contributes to the literature on students' understanding of functions by addressing how some CA students view polynomial functions. The findings provide a dynamic account of knowledge of polynomial functions developed by college students as they solve mathematical problems.

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Acknowledgements

Research reported in this paper was made possible by a Faculty Research Grant from the University of North Carolina at Charlotte.

PROSPECTIVE TEACHERS' CONSIDERATIONS DURING THE LESSON PLANNING PROCESS

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This paper presents an action research project completed in a mathematics methods course for prospective elementary school teachers. The goal was to determine if instructional practices were effective at preparing teachers to use students' thinking to inform instructional decisions. The teachers' ability to predict students' strategies and the teachers' considerations during the planning process were investigated. The teachers selected a task involving the comparison of ratios, anticipated students' strategies for completing the task, and explained their rationale. The prospective teachers effectively predicted students' strategies; however, those student strategies were not a consideration during the task selection process for the majority.

Introduction

When reflecting on a concluded semester, I began thinking about the link between my research and teaching. My research focuses on cognitively guided instruction (CGI) and inquiry-based instruction (IBI). When instructional decisions are based off of analyses of one's students' thinking, in combination with knowledge of the ways students typically develop and interact with the content, the instruction is said to be cognitively guided. Inquiry-based instruction refers to teaching practices that involve placing students in a carefully constructed, and sequenced, series of problems or project scenarios from which they can construct their own understanding of complex concepts. I can be relatively sure, from reading my prospective teachers' lesson plans, that they grasped the constructivist nature of IBI. However, I began to wonder how successful I was at preparing them to use CGI. To successfully plan CGI, my prospective teachers needed to be able to analyze task characteristics and anticipate elementary students' approaches to those tasks to determine if the task was appropriately aligned with the lesson goal.

Objectives of the Study

The purpose of this study was to determine how effective the methods used were at preparing future teachers to plan lessons in a cognitively guided fashion. The objective was to investigate: (a) the extent to which prospective elementary school teachers consider the link between numerical structure and student thinking when selecting proportional reasoning tasks in the lesson planning process and (b) the prospective teachers' ability to anticipate students' thinking.

Theoretical Framework

An underlying assumption connects the objective to the purpose of the study; my successful demonstration of the importance of task considerations and their influence on student generated strategies would increase the likelihood that, during the task selection process, the prospective teachers: first, consider the instructional goal; and, second, simultaneously consider the task characteristics (e.g. context, numerical structure) and likely student strategies.

The framework guiding the initial memoing and coding was derived from de la Cruz' (2013) delineation of proportion problem types (distinguished by context or numerical structure), students' proportional reasoning strategies (e.g. unit rate, factor of change), and the link between the two.

Kemmis, McTaggart, and Nixon's (2013) action research methods were employed: (a) develop a plan and research questions, (b) observe effects by evaluating data, (c) reflect, (d) incorporate new effects or themes to develop a plan for the future. This paper presents the first steps in my action research, and scholarship of teaching and learning. Future steps will involve utilizing the results of this investigation to develop a new plan and to continue with action research.

The data collected consists of an observation journal, documents, and an open-ended questionnaire, all related to a single activity taking place over two class meetings. While the prospective teachers completed this activity, the researcher recorded observations regarding their dialog and regarding when students' strategies were considered in the selection process. Each group was asked to create a poster presenting the comparison task and the student generated strategies they anticipated. The purpose of collecting the posters was to document the types of comparisons chosen and types of strategies anticipated. Finally, the prospective teachers were asked to complete an open-ended questionnaire to further document their considerations when selecting the comparison. Answers to the questionnaire could then be triangulated with the researcher's observation notes.

Miles and Huberman's (1994) systematic data analysis was used to derive causal descriptions and lawful relationships among the data by using data reduction, data display, and conclusion drawing and verifying. The questions that guided the qualitative analysis of this data are: (a) What did the prospective teachers consider when selecting the comparison task? More specifically, did they consider the numerical structure of the ratios within the comparison, the goal of the lesson, and the likely strategies that such a comparison would elicit from fifth graders? (b) Did the prospective teachers accurately predict strategies fifth graders would use to solve their chosen comparison problem? (c) What types of comparisons did the prospective teachers choose?

Practices Used

Several steps were taken to promote CGI and develop the ability to predict the ways elementary students will interact with the content. First, there was a persistent focus on problem solving and student generated strategies. Across all concepts, the need for students to construct their own strategies prior to the introduction to formal procedures was discussed. The prospective teachers predicted strategies students would invent for operating with single-digit and multi-digit numbers, for estimating, for representing and adding fractions, and for several other concepts.

Second, we specifically studied CGI as it relates to addition and subtraction word problems. The research findings of Carpenter, Fennema, Franke, Levi, and Empson (1999) that explicitly linked problem characteristics to certain student-constructed strategies were shared. The prospective teachers learned how to: analyze addition and subtraction story problems and categorize problems into the 11 types defined by Carpenter et al. Next, they predicted the strategies students would use to solve each of the 11 problem types, analyzed videos of pupils solving addition and subtraction story problems, and linked strategies to problem types.

Third, the prospective teachers completed two video analyses assignments. Each of the videos illustrated an authentic classroom scenario and provided a solid example of CGI in practice. To help the prospective teachers notice the classroom teacher's cognitively guided actions, they were asked to answer a series of questions which required them to analyze: (a) the link between task characteristics (e.g. context, numerical structure) and the classroom teacher's instructional goal, (b) students' strategies for solving the task, and (c) the classroom teacher's rationale for selecting and ordering the student strategies to be shared.

An activity was designed to assess the effectiveness of the three aforementioned methods in encouraging considerations that are consistent with CGI when planning lessons. The activity required pairs of prospective teachers to begin planning a lesson involving comparing ratios. The directions stated,

You are charged with the responsibility to design a lesson for a fifth grade class that involves comparing ratios. To make the lesson meaningful, we will be planning a lesson that involves comparing prices found in grocery circulars. Complete the following in the order that you feel is most appropriate:

- Select at least two similar items found in the provided grocery circulars that you would like students to compare (your lesson would be focused around this task);
- Anticipate the strategies fifth graders might employ to compare the prices you chose;
- Determine the goal of your lesson.

The pairs were asked to create a poster to share with the class and to answer the following reflection questions: (a) Of all the comparisons that could have been chosen, explain in detail why you chose these two items. (b) What did you consider when selecting the comparison? (c) What is the goal of the lesson?

Results and Discussion

Four main findings emerged from the analyses:

1. All of the prospective teachers considered the quantities involved in the rates when selecting a comparison. However, 50% of the prospective teachers considered the quantities in a significant way.
2. The majority of the prospective teachers did not consider their instructional goal, or the strategies students would likely use to complete the comparison, until *after* they had selected the comparison task.
3. When the prospective teachers considered their instructional goal or student strategies during the task selection process, they did not do so independently. Instead, they simultaneously considered the lesson goal, student strategies, and the relationship between the quantities involved.
4. The prospective teachers were able to effectively predict the strategies that students would most likely implement. Their predictions were consistent with those found to be most likely by existing research, due to numerical structure.

These findings indicate the success of the practices used to prepare prospective teachers to anticipate students' thinking. However, they also indicate the need for further steps to emphasize the interplay between instructional goals, task choices, and anticipated strategies.

When selecting items to compare, all of the prospective teachers were observed selecting items that would be familiar to fifth grade students; 75% indicated it was a specific consideration in their responses on the questionnaire. Group F said, “We chose to have Capri-Sun as our item to compare because many students drink it, so it is relevant to their lives. …” Similarly, Group B expressed, “We chose these two items because the students would be familiar with the item and would be able to visualize the 48 oz. carton [of ice cream]. …” According to Heller, Ahlegren, Post, Behr, and Lesh (1989), choosing a familiar item is a significant consideration because students tend to be more successful with proportional reasoning strategies when the context is familiar.

Although all of the prospective teachers considered the numerical structure involved in the comparisons during the selection process, only five of the eight pairs examined the numerical structure in a significant way, by discussing the type of quantities or the relationship between the quantities involved. To this effect, Group D wrote, “We wanted to set up a simple problem so we looked for an easy comparison using the same units and easy numbers.” In their problem, students were asked to determine the better deal for toilet paper, 12 rolls for $6.99 or 24 rolls for $11. They explained that the numbers were easy because “to get from 12 rolls to 24 rolls, you just need to multiply by two.” Three groups explained that they chose two ads with varying quantities, prices, and/or sizes, which was categorized as a numerical structure consideration. However, this reflection on numerical structure in absence of further thought regarding the relationship between the quantities was deemed insignificant. For instance, Group C said, “We chose to compare these two items because they are the same product but at varying sizes and different prices. This allows the students to be able to compare price and size and determine which deal is the better buy.” Similarly, Group H said, “We made sure there was a difference in price.” This type of rationale was not considered significant, because without some variation in price or quantity, the comparison would be trivial.

Though the majority of the class considered the numerical structure present when determining which items to include within their comparison task, neither the instructional goal nor students’ thinking generally factored into the decision making process. Only three of eight groups mentioned a strategy students would use to compare rates in their expressed rationale for their task decision. The same three groups were the only ones to link their rationale to their instructional goal. For instance, Group B stated, “We chose the Breyer’s ice cream that had a price for one of the item [unit rate]. The price for the Hood ice cream is presented as a ratio [$5 for 2 cartons]. The students will have to determine the price of one carton." Thus, Group B selected this comparison to encourage their students to find a single unit rate, which they also stated as their goal: "Students can compare prices of cartons of ice cream by dividing a fraction." Similarly, Group A aimed for a unit rate with their choices. They communicated, "We considered the students' prior knowledge in relation to division and fractions," which was closely aligned with their goal, "for students to relate the problem to division." All of the considerations of the prospective teachers are summarized in Table 1.

According to the existing literature, we can predict the proportional reasoning strategies students are likely to use by examining the numerical structure of the proportion (e.g. Cramer, Post, & Currier, 1993; Miller & Fey, 2000; Singh, 2000; Weinberg, 2002). In all cases, the prospective teachers anticipated the strategy that is most consistent with the research findings. Table 2 illustrates the problems selected by the prospective teachers, identifies their numerical structure, and names the most likely strategy corresponding to the present numerical structure according to the literature.

Implications

The purpose of this research was to examine and improve instruction, as it relates to CGI. I wondered whether or not prospective teachers, at the end of the course in methods for teaching elementary mathematics, would plan lessons in a manner that is consistent with CGI. That meant that the prospective teachers would make instructional decisions based upon their students' thinking. More specifically, the prospective teachers needed to be able to predict students' strategies and analyze aspects of tasks that would influence those strategies.

Many studies have shown that prospective teachers and new teachers struggle to identify the ways in which students will approach problems. According to Kastberg, D'Ambrosio, and Lynch-Davis (2012), "The thinking of teachers is shaped by an adult understanding of the problem and an algorithmic approach they have mastered often does not resemble the way in which the students approach the problem." The results of this study imply that the methods employed to practice and develop this skill in the prospective teachers was effective. A concerted effort was aimed to provide several varied opportunities for the prospective teachers to think like a student: anticipating, interpreting and explaining students' thinking.

Table 1

The Prospective Teachers' Considerations during the Task Selection Process

Pairs	Familiar Item	Numerical Structure: Varying Quantities or Sizes*	Numerical Structure: Relationship between the quantities	Strategies	Goal
A	✓		✓	✓	✓
B	✓		✓	✓	✓
C	✓	✓			
D	✓		✓		
E		✓			
F	✓	✓			
G			✓	✓	✓
H	✓		✓		

Table 2

Numerical Structure and Strategy Predictions by the Prospective Teachers

	Comparison	Ratios	Numerical Structure: Unit rate provided	Integer FOC - within	Integer FOC - across	No Integer FOC	Strategy corresponding to numerical structure	Strategy Predicted
A	String Cheese: 1 pkg for \$3.99 2 pkgs for \$7	$\frac{\$3.99}{1}$ or $\frac{\$7}{2}$	✓	✓	✓		Unit rate	✓
B	Ice cream: 1 carton for \$3.99 2 cartons for \$5	$\frac{\$3.99}{1}$ or $\frac{\$5}{2}$	✓	✓	✓		Unit rate	✓
C	Cookies: 20oz for \$3.99 2-13oz for \$4	$\frac{\$3.99}{20}$ or $\frac{\$4}{26}$				✓	Comparison is obvious	✓
D	Toilet Paper: 12 rolls for \$6.99 24 rolls for \$11	$\frac{\$6.99}{12}$ or $\frac{\$11}{24}$			✓		FOC-across	✓
E	Soda cans 3-12 packs for \$10 24 pack for \$4.99	$\frac{\$10}{36}$ or $\frac{\$4.99}{24}$				✓	Common denominator (12 cans)	✓
F	Juice boxes: 1 box for \$1.77 2 boxes for \$4	$\frac{\$1.77}{1}$ or $\frac{\$4}{2}$	✓	✓	✓		Unit rate	✓
G	Yogurt: 10 for \$10 4 for \$3.89	$\frac{\$10}{10}$ or $\frac{\$3.89}{4}$		✓			Unit rate	✓
H	Soup cans: 5 for \$5 2 for \$4 10 for \$10	$\frac{\$5}{5}$ or $\frac{\$4}{2}$ or $\frac{\$10}{10}$		✓	✓		Unit rate or FOC - across	✓

Note. FOC-within = factor of change within a single ratio, numerator to denominator; FOC-across = factor of change across ratios, numerator to numerator or denominator to denominator.

On the other hand, this study demonstrates the need for further clarification related to lesson planning and considerations while planning. Reflection revealed that, although much time was dedicated to writing lesson plans (e.g. writing clear and measureable objectives, incorporating transition statements, linking assessments to objectives, etc.) and completing lesson analyses, the process of developing a plan (e.g. selecting the major task or activity) was given less attention. On the topic of developing a plan, a few steps to planning, prior to writing a lesson plan, which included determining the instructional goal, selecting a task or activity, anticipating students' strategies and difficulties, and identifying requisite knowledge were outlined. More attention could have been given to explicate that selecting a task should not be done without consideration given to the ways students may approach the task and the link between those approaches and the instructional goal. Additionally, practice could be improved by modeling the planning process in the methods course. For instance, we could complete a task selection activity similar to the comparison activity, where the instructional goal, tasks, and students' strategies are considered simultaneously.

Due to the cyclical nature of action research, this project will continue in subsequent iterations of my elementary mathematics methods course. I am currently using the results of this study to develop a new plan to improve and study my own teaching, which incorporates the aforementioned ideas. Although this research is not generalizable, the hope is that the results may encourage others to reflect on their own practice.

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ELEMENTARY MATHEMATICS TEACHER BELIEFS

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The purpose of this study was to understand teacher beliefs about teaching mathematics over the course of an elementary mathematics teaching methods course. The participants came from three groups of in-service and preservice teachers in master's degrees programs at a university in New York: New York City Teaching Fellows, Teacher Education Assessment and Management program, and traditional preservice teachers. Findings revealed an increase in positive beliefs about teaching mathematics over the semester, but there were no differences in participants' beliefs between the three programs.

Introduction

The purpose of this study was to understand teacher beliefs over the course of an elementary mathematics teaching methods course that emphasized problem solving and constructivism for teachers and to determine teacher beliefs. The participants in the study came from three unique groups of in-service and preservice teachers in master's degrees programs at a medium-size university in New York: New York City Teaching Fellows (NYCTF) program, Teacher Education Assessment and Management (TEAM) program, and traditional preservice teachers enrolled in a graduate program at the university. The two-year graduate program for all three was designed to prepare teachers for work in urban schools with certification in childhood and special education.

Background for Study

The NYCTF program is an alternative certification program developed in 2000 by the New Teacher Project and the New York City Department of Education (Boyd, Lankford, Loeb, Rockoff, & Wyckoff, 2007). NYCTF's goal was to bring career changers into education to fill the large teacher shortages in New York public schools. The TEAM program is a partnership between the TEAM organization and the partnering university. TEAM is an organization that facilitates partnerships with universities for its student members who receive a tuition discount due to the negotiated tuition rate (TEAM, 2012). Cohorts generally consist of 12 to 20 Orthodox Jewish teachers. Traditional preservice teachers were enrolled in the university's graduate program that required extensive fieldwork. Participants in the program were required to participate in 10 hours of fieldwork for each three-credit class in which they were enrolled.

Research Questions

1. Were there differences in beliefs about teaching mathematics over the course of a semester in a reformed-based mathematics methods course?
2. Were there differences in beliefs about teaching mathematics between the NYCTF, TEAM, and traditionally prepared teachers?

Theoretical Framework

This study is grounded in sociocultural theory (Vygotsky, 1987), which proposes individual learning is framed by experiences in learning socially among others. In the classroom context this interaction occurs between instructor and student and also among the students. The methods course was framed by teaching mathematics from a problem solving perspective, as proposed by the National Council of Supervisors of Mathematics (NCSM) (1978) and National Council of Teachers of Mathematics (NCTM) (2000). NCTM (2000) said, “Problem solving is not only a goal of learning mathematics but also a major means of doing so” (p. 52). Mathematics should be taught in a manner so that students are solving unfamiliar problems using their previously acquired knowledge, skills, and understanding to satisfy the demands of unfamiliar situations (Krulik & Rudnick, 1989).

Methodology

The methodology for this study was quantitative and the sample consisted of 115 preservice and new in-service teachers in which NYCTF teachers were all in-service teachers and TEAM and traditional teachers were preservice teachers, with several TEAM participants teaching in Yeshiva and Hebrew Academies. There were 84 NYCTF teachers, 16 TEAM teachers, and 15 traditional preservice teachers. Participants were enrolled in an inquiry- and reformed-based elementary mathematics methods course in the 2011/2012 academic year that involved both pedagogical and content instruction and was aligned with the NCTM *Principles and Standards for School Mathematics* (2000).

Teachers were given the Mathematics Beliefs Instrument (MBI) at the beginning and end of the semester, which was created by Hart (2002) and measured participants’ beliefs about teaching mathematics. The MBI is a 30-item 5-point Likert scale instrument that solicits participant beliefs about reformed-based methods of mathematics instruction such as problem solving, conceptual understanding, and student-centered teaching including active student participation.

Results

Paired-samples *t*-test was conducted to answer research question one in order to determine differences in the MBI scores over the course of the semester. A statistically significant difference was found at the 0.05 level between the pretest (M = 3.56, SD = 0.333) and the posttest (M = 3.66, SD = 0.350) with $t(114) = -3.970$, $p < 0.001$, $d = 0.29$, two-tailed. This indicated an increase in positive beliefs about teaching mathematics with a small effect size.

Descriptive statistics were also used to answer research question one. Results indicated teachers felt most positively about the study of mathematics including opportunities of using mathematics in other curriculum areas; mathematics must be an active process; and mathematics can be thought of as a language that must be meaningful, if students are to communicate and apply mathematics productively. Teachers felt positively about beliefs generally considered negative by reform-oriented mathematics educators, such as emphasizing clue words (key words) to determine which operation to use in problem solving; some people being good at mathematics and some people not being good at mathematics; and mathematics as a process in which students absorb information, storing it in easily retrievable fragments as a result of repeated practice and reinforcement.

One-way ANOVA was conducted to answer research question two in order to determine differences in MBI scores between NYCTF, TEAM, and traditional teachers. No statistically significant differences were found between NYCTF, TEAM, and traditional teachers.

Discussion

Findings revealed an increase in positive beliefs about teaching mathematics, but there were no differences in participants' beliefs between the three programs. Teacher beliefs included using mathematics in other curriculum areas, mathematics as an active process, and the communication aspects of mathematics as a language.

It was found teachers felt most positively about the study of mathematics including opportunities of using mathematics in other curriculum areas; mathematics must be an active process; and mathematics can be thought of as a language that must be meaningful, if students are to communicate and apply mathematics productively. While it is important teacher educators continue to encourage teachers in these areas, it is more important that teacher educators work with teachers in areas in which they felt less positively. Teachers believed in emphasizing clue words (key words) to determine which operation to use in problem solving; some people being good at mathematics and some people not being good at mathematics; and mathematics as a process in which students absorb information, storing it in easily retrievable fragments as a result of repeated practice and reinforcement.

The emphasis of clue words for finding solutions to word problems does not lead to true conceptual understanding that students need to solve unfamiliar problems, which is the primary component of authentic mathematical problem solving. Teachers who emphasize clue words are assisting students to rely on procedures demonstrated by the teacher without actual student understanding. Teacher educators must help their preservice and in-service teachers foster an environment of true understanding by instead assisting their students to use their previously obtained skills, knowledge, and understanding to satisfy the demands of an unfamiliar situation (Krulik & Rudnick, 1989). This can be modeled through problem solving in teacher preparation classes using multiple types of problems and unfamiliar situations for the teachers, which they can bring into the classroom.

Teacher beliefs are an important component of teacher quality, and teacher educators can influence teacher beliefs to help them become better teachers; which leads to higher student achievement and success. It is not enough for teacher educators to focus only on content knowledge and pedagogical skills. They are certainly important variables for student achievement and success, but there must be emphasis on understanding teacher beliefs and challenging and shaping those beliefs. This will consequently lead to higher student achievement and success.

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MEGAN'S GROWTH IN MATHEMATICS TPACK DEVELOPING LEVEL: A CASE STUDY OF ONE EARLY CHILDHOOD PRE-SERVICE TEACHER

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The components of Mathematics Teacher TPACK Development Level has been successful in helping pre-service teachers by identifying them as teachers of mathematics instead of learners of mathematics, but there are few of evidences about what the better approaches are for enhancing pre-service teachers' Mathematics TPACK Development Level. Based on the result of this study, the ASSURE Model (a model that leads educators to plan systematically for effective use of technology and media) is recommended as an effective approach to enhance pre-service teachers' Mathematics TPACK Development Level (a developmental framework that examines mathematics teachers' levels toward the integration between technological, pedagogical, and content knowledge).

Introduction

Driscoll (2002) suggests that the impact of technology in mathematical classrooms depends on teachers' ability to integrate technological, pedagogical, and content knowledge into mathematics curriculum. Although there have been increasing numbers of studies investigating the importance of technological integration, few studies have clearly uncovered how pre-service teachers (PSTs) acquire this capacity to integrate technology when designing curriculum; there are also not many studies that demonstrate what teaching models serve to promote pre-service teachers' design ability with technological integration. This study represents an effort to discern how pre-service teachers increase their TPACK and effectively integrate technology into their math teaching by looking at a case study of one pre-service teachers' experience using the ASSURE Model.

Objectives of the Study

This research is part of a larger study investigating how PSTs increase in their ability to integrate TPACK, especially when lesson designing. This study investigates how the ASSURE model (Baran, 2010; Russell, 1994) influences the PST's development of TPACK integration. The data and findings presented in this article answer the following questions through a case study of a PST, Megan:(a) What was the status of Megan's level of Mathematics TPACK Development before she received the ASSURE model intervention? (b) What was the status of Megan's level of Mathematics TPACK Development after she received the ASSURE model intervention?

Theoretical Framework

Technological pedagogical content knowledge (TPACK) refers to focusing on instructors' ability to integrate technological knowledge, pedagogical knowledge, and content knowledge, matching students' needs and preferences (Harris & Hofer, 2011; Koehler & Mishra, 2009). TPACK was systematically introduced to mathematics education to help clarify what knowledge was needed to specifically teach mathematics with technology (Holmes, 2009; Landry, 2010; Mitchell & Laski, 2013). This resulted in Mathematics Teacher TPACK Standards, which were developed to guide teachers in thinking about the interconnection and intersection of technology, pedagogy, and content knowledge related to math teaching and learning. The standards also provide a framework that support teacher educators preparing mathematics teachers to incorporate technology into their instruction (Niess, Ronau, Shafer, Driskell, Harper, Johnston, Browning, Özgün-Koca, & Kersaint, 2009).

The framework includes two main components, which combine together to help teachers in their mathematical teaching. The first component is the Mathematics Teacher TPACK Model, which includes curriculum & assessment, learning, teaching, and access (Niess et al., 2009). The second component is a five-stage developmental process for integrating technology in teaching and learning mathematics. The five-stage developmental process is used for describing and examining how a person makes a decision to adopt or reject a new technology in mathematical teaching and learning. The five stages include the following processes (Niess et al., 2009, p.9):

- *Recognizing* (Knowledge), where teachers are able to use the tech and recognize the alignment of the technology with mathematics content yet do not integrate the technology in teaching and learning of mathematics.
- *Accepting* (persuasion), where teachers form a favorable or unfavorable attitude toward teaching and learning mathematics with an appropriate technology.
- *Adapting* (decision), where teachers engage in activities that lead to a choice to adopt or reject teaching and learning mathematics with an appropriate technology.
- *Exploring* (implementation), where teachers actively integrate teaching and learning of mathematics with an appropriate technology.
- *Advancing* (confirmation), where teachers evaluate the results of the decision to integrate teaching and learning mathematics with an appropriate technology.

Although Mathematics Teacher TPACK has set goals for the use of technology in math instruction, the standards do not provide strategic directions about how pre-service teachers integrate technology into their mathematical instruction (Landry, 2010). In order to help mathematics pre-service teachers adequately implement TPACK integration, the ASSURE model was introduced (Russell, 1994). This model has been verified to have the potential to help pre-service teachers think and plan for effective instruction with technology (Lim & Chai, 2008), as it acts as a procedural guide for planning and conducting instruction that incorporate technological media (Heinich, Moldena, Russell, & Samldino, 1999). In other words, the ASSURE model is like a road map to guide pre-service teachers in how to use media and technology in classroom teaching (Xu, 2011). The model includes six systematic processes outlined in its acronym (Heinich et al., 1999; Smaldino, Lowther, & Russell, 2012): (a) **A**nalyze learners; (b) **S**tate the standards and objectives; (c) **S**elect strategies, technology, media, and materials; (d) **U**tilize technology, media, and materials; (e) **R**equire learner participation; and (f) **E**valuate and revise.

Methodology

The Participant

Ninety-seven participants all of whom were pre-service teachers (PSTs) enrolled in a four-year teacher education program at a public university in the northwest taking an educational technology course across five semesters, this study focuses on the experience of one student, Megan. Megan was an undergraduate student in Early Childhood Education. She was admitted to the College of Education in fall 2011. She was a senior while taking the course in which this study is set (Foundations of Education Technology). Megan was chosen for this case study because her views of her abilities with technology and the understandings she had about technological integration in curriculum design initially appeared to be unrelated, isolated ideas.

The Context

The context in which this study was conducted was during an educational technology course, Foundations of Educational Technology, which emphasized applying the ASSURE model to foster the PSTs' ability in TPACK integration. The PSTs wrote a reflection about the application of educational technology based on the assigned subject at the beginning of the course. Then, they followed the steps of the ASSURE model to design a lesson with TPACK integration after they decided on a teaching topic or concept. During the process of designing the TPACK lesson, the PSTs learned technological knowledge and how to manipulate technological tools, so that they knew what things should be integrated and what ways could be more effective in the integration. At the end of the course, the PSTs used an electronic poster (e.g., Glogster) to share their work and write a post-reflection paper to assess their learning.

Sources of Data

Each PST's work in the Educational Technology class, including Megan's, was collected and placed into a personal, individualized folder. The first work sample was a pre-reflection, which was collected at the beginning of the course. The second work sample was the PSTs TPACK lesson plan, which became a crucial document for the researchers to examine participants' capacity of TPACK integration. Third, each PST submitted a class review, which helped the teacher-researcher understand the students' perspectives about TPACK integration. Fourth, in order to understand the effects of the course activities, the PSTs wrote post-reflections. Finally, the PSTs shared their final multimedia learning presentations, which were electronic posters (e.g., Glogster).

Data Analysis

Analysis of the data followed the constant comparative method (Lincoln & Guba, 1985). The raw materials were read and reread by the researchers. The researches independently noted emergent categories. Researchers then compared the categories and developed agreement for the possible themes. Based on the agreement, the researchers reread and coded the data. All coded data were read by another person to verify the accuracy of coding.

Results and Discussion

Reviewing Megan's pre-reflection paper, it showed that she has some basic knowledge in mathematical content, instructional strategies, and technological capability. Megan's levels of mathematics TPACK development, the descriptions in her pre-reflection showed that her thoughts about technological integration toward mathematics teaching fell into the level of recognizing and accepting (See Table 1). Simply put, she was a novice in integrating technology into mathematical instruction.

After passing the intervention ASSURE Model, Megan's mathematics TPACK development expressed growing. Her perspectives toward themes of "Curriculum & Assessment" and "Teaching" changed from the recognizing and accepting level to the level of covering recognizing, accepting, adapting, exploring, and advancing. At the themes of

“Learning” and “Access” her perspectives moved from just covering the level of recognizing and accepting to covering recognizing, accepting, and adapting (See Table 2). The results imply that the ASSURE model has been impacting Megan’s TPACK implementation on her curriculum design and has been extending her mathematic TPACK development.

Table 1.

Megan’s TPACK Development: Themes, Levels, & Examples (before intervention)

	Curriculum and Assessment	Learning	Teaching	Access
Recognizing	o Tech can be a great resource for teachers	o Tech will impact their thinking skills. o Age may impact learning effectiveness.	o Tech can offer many creative and fun ways for children to get involvement.	N/A
Accepting	o Curriculum could be centered completely around technology o Worksheets and tests to the students by way of technology o Tech will be in almost all lesson plans and activities.		o Use tech to keep in contact with families and other faculty. o Slowly introduce technology o Integrate tech in classroom for short periods of time	o Would like to have computers or I-Pads in my classroom that the children are free to access o Access the technology will be based on how student treat it and what age group I am working with o Barriers: Students are not familiar with tech or students mistreat Tech. o Young children could learn tech as well. •
Adapting	N/A	N/A	N/A	N/A
Exploring	N/A	N/A	N/A	N/A
Advancing	N/A	N/A	N/A	N/A

Implications

This study’s goal was to demonstrate one PST’s Mathematic TPACK Development Level before she received instruction in the ASSURE Model and to also show the effects of what this instructional practice had on her beliefs. Based on the results, it does appear that the ASSURE Model elevated her ability to think critically about TPACK. In the beginning of the

Table 2.

Megan's TPACK Development: Themes, Levels, & Examples (After intervention)

	Curriculum and Assessment	Learning	Teaching	Access
Recognizing	o Some barriers for using technology in curriculum: a program might not work or something shuts down.	o Tech can help engage students. o This generation has adapted to using technology and finds it engaging.	o Realizes there are many ways to implement technology in a classroom.	o Doesn't know how to use a specific program properly.
Accepting	N/A	o Integrates different types of technology curriculum that would be beneficial to the student's learning.	o Tech allows teachers to create lessons with various approaches to meet every student's needs.	o Technology should be monitored and kept to a minimum.
Adapting	o Knows different technologies o Decides to find new and creative ways to integrate tech when designing a math lesson	o Glogster is useful in creating things to engage students.	o Uses a Promethean Board for teaching fractions.	o Availability will depend on how my students treat technology in the classroom.
Exploring	o Setting up a timer for managing students' performances when using computer programs	N/A	o Take away or put back pieces and ask them to write on the interactive white board to show what fraction the pizza is at.	N/A
Advancing	o Will have a backup plan for when unable to use technology during the class.	N/A	o Decided that using an interactive whiteboard is a sufficient want to teach fractions.	N/A

study, her reflections indicated that she was in the "recognizing" and "accepting" phases but later progressed to phases of "adapting", "exploring", and "advancing". This is especially helpful for math teacher educators, who are looking for a systematic approach to foster TPACK in their students. For future study, implementing experimental study would be particularly revealing how ASSURE model impact pre-service teachers' Mathematics TPACK Development Level. In addition, conducting more in-depth case studies at various grade levels and within different contexts (schools, regions, urban/rural) would enable this study to provide more insight on necessity of TPACK and effectiveness of the ASSURE model.

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QUALITATIVE POLICY DISCOURSE ANALYSIS: A REPRODUCIBLE RESEARCH APPROACH

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Reproducible Research methodologies have become popular in the analysis of quantitative data. However, these methodologies are not much used in the field of qualitative data analysis. Recent advances in analysis software offer social science researchers computing tools for the processing and analysis of this type of data. These resources enable us to implement reproducible research protocols for qualitative data. As an additional benefit, we are able to analyze large amounts of textual data by restricting our reading to procedurally preselected portions of the texts. We present our adaptation of these tools to the qualitative analysis of STEM education policy.

Introduction

The concept of *reproducible research* (RR) is related to the ideas of reproducibility and replication, that is the repetition or the reproduction of an experiment or a study either over time and place (reproduction) or in parallel (replication). This principle is, of course, one of the cornerstones of the scientific method. An experimental result that cannot be replicated is not considered to be valid. This is especially important in the fields of medicine and pharmacology for obvious reasons, but the principle holds for all sciences.

One of the prerequisites for the reproduction or replication of an experiment is the control of the experimental conditions (see e.g. Shadish, Cook, & Campbell, 2002, pp. 7-9), the uniformity of the experimental subjects and, ideally, randomization and the presence of a suitable control sample. Such control of the experimental conditions is only possible in the strict sense in physics and chemistry and, in a more relaxed sense, in biology.

Replication of a tightly controlled experiment with randomization of a sufficiently large sample of identical subjects is considered to be necessary to consider a study to be *generalizable*. Hence, the results are considered valid and applicable to all cases where similar conditions exist. A study that is not applicable beyond the confines of its experimental subjects has little utility and thus is of limited interest. In the social sciences, such as educational research where human beings are the subjects of study, it is impossible to control the experimental environment, to have uniform subjects, or to have complete randomization. Hence, strictly speaking, no study in the social sciences is generalizable. Indeed, a more appropriate term for an experimental study in the social sciences is a quasi-experiment (Shadish et al., 2002).

We have thus seen that even though replicability is central to the scientific method and thus an integral part of the process of increasing scientific knowledge, it is often difficult to implement due to the conditions of the experimental subjects and environment. To this situation we have to add more "mundane" issues such as the availability of funding and logistic constraints.

Objectives of the Study

The authors intended to address an imbalance in the field of educational research between the clear benefits of reproducible research, as we will show here below, and the paucity of examples of its use in this field. We intended to investigate whether RR would allow us to (1) significantly increase the amount of textual research data that we could analyze; (2) introduce procedures by which we could, at least partially, bracket our subjective approach to qualitative research, and (3) improve the presentation of qualitative research data and the results of its analysis through descriptive statistics and graphics. At the same time we would evaluative the limitations of RR.

Theoretical Framework

The first mention of reproducible research as a concept is in Schwab, Karrenbach, & Claerbout (2000) even though the term itself was coined later (Fomel & Claerbout, 2009). In educational research this concept has not been widespread and there are only a few examples of this kind of research, e.g. Wessa (2009). There are a few mentions of reproducible research in the social sciences, though mainly methodological papers such as Miguel et al. (2014). Thus, there is still very little actual work published in the social sciences even though there are initiatives such as the Berkeley Initiative for Transparency in the Social Sciences (http://bitss.org) that are promoting this methodology.

Partly based on the above discussed constraints of the methodology of the scientific enterprise, as well as the advances in scientific computations, data gathering and their storage in electronic form, the concept of *reproducibility* rather than *replicability* has become popular especially in the "hard" sciences (Fomel & Claerbout, 2009). Reproducible research is implemented by making available all research data and code used to manipulate and analyze the data in addition to the traditional publication of the results of the study. This availability allows the research community to independently look at the research data and re-run the analyses. Even though reproducible research does not reach the high standard of independent replication of the study it has several remarkable positive aspects:

- The research data are released and thus increasing transparency whereby confidence in the raw data is increased.
- The cost of re-running the analyses is usually negligible.
- Mistakes in the gathering and analysis of the data can be detected.
- The use of sub-optimal data analysis tools such as spreadsheets and point-and-click statistical analysis is discouraged in favor of script-based analyses.
- Opening and searching the data and code files is easy.
- Faster computation is possible.

Regarding the first point we would like to remark that other researchers can, besides verifying the analyses performed by the original researchers, use these data to apply different analyses and discover additional knowledge. The availability of the code for analyses likewise accelerates discovery by allowing other researchers to use, adapt, and extend existing code without the need to "re-invent the wheel." Recently, there have been significant efforts to make research data available (Pampel et al., 2013), especially by libraries of research universities. For a large listing of online data repositories see http://databib.org and, specifically for the social sciences, http://thedata.org. Research data that are placed online will also generally be vetted for accuracy and documented, unlike spreadsheets stored on a hard drives or flash drives.

Having access to the raw data is only half of what is necessary to implement RR. Researchers need also to share their analysis code. A popular way to do so is to use repositories that provide revision control such as Google Code, BitBucket, and GitHub. These services are free and provide a safe and secure way to not only make code available to the research community, but also allow to track revisions and to establish worldwide research groups.

Finding errors is usually easier because the researcher can check the code by use of debugging tools. Code can, and should be, documented using comments. Point-and-click statistical analysis is much harder to check, even by the same researcher. Statistical analysis scripts can be easily read to see their "inner workings," but spreadsheets hide their calculations in cryptic formulas that operate on data ranges.

Another reason that RR code and data are easier to understand and check is that usually the file format is plain text that is easily searched and loaded in various applications. Proprietary software applications such as SAS, SPSS and Excel save their files in closed, undocumented, or poorly documented formats. On the contrary, RR utilizes open software that usually saves data in a plain text format called "comma separated values" (csv extension) and the code itself also in plain text format. This allows researchers that do not have funding to purchase expensive software to use free software that is just as capable. Collaboration is easier by using scripts because by reading the code it is relatively easy to understand what a team member has done, unlike a series of right-clicks and left-clicks in menus and lists.

A fairly dramatic illustration of the importance of reproducible research is an influential study published in 2010 by Harvard economists Carmen Reinhart and Kenneth Rogoff (2010). Other researchers tried to replicate the study, but were not able to obtain the same results. When the spreadsheets used by Reinhart and Rogoff were examined it was discovered that a calculation excluded values that should instead have been included (Konkzal, 2013).

There are technical and organizational drawbacks to the use of RR. Obviously it requires more sophisticated knowledge of computing. It necessitates web and file servers and safe storage, which are expensive unless a public service is used. There are also issues of confidentiality of the data and copyright of computer code. The data need to be checked for confidential information such as personal names and social security numbers. Computer code may contain proprietary code that needs to be released appropriately or kept confidential. Qualitative data may contain information that should be kept private.

An apparent drawback is that use of scripted statistical analysis is more difficult than by using point-and-click statistical applications such as SPSS. However, the greater difficulty involved in writing statistical analysis code forces the researcher to better understand his or her analysis. Nowadays it is easy to generate vast amounts of statistical results, but the software itself is not able to check whether these results are appropriate and applicable to the specific research situation.

Methodology

We developed a procedure for analyzing large amounts of textual data based on the confluence of theory and trial runs. This procedure consisted of several steps where the data were obtained and processed by using UNIX and R scripts that were constructed so that the output of an "upstream" script was the input of its "downstream" one.

The data sources for the study consisted of the transcripts of 127 Congressional Hearings and 87 Presidential speeches on the topic of math and science education, from the years 1997 - 2011. These transcripts were available for free public access from FDsys, the Federal Digital System of the U.S. Government Printing Office, and were selected using relevant keywords in the search function of the website. The search created a web page with a listing of relevant governmental documents with embedded URLs for HTML pages containing the transcripts of Presidential speeches or Congressional Hearings. A series of UNIX scripts isolated the URLs and then created a script that downloaded the HTML files from the governmental repository and converted them into plain text. Some downstream UNIX scripts then "scrubbed" the files to remove extraneous information and divided the texts into paragraphs. At this point an R script loaded the scrubbed files into a SQLite database. Each file was a row (record) in a database table and the text was contained in one of the columns (fields). Then we added meta-data that specified the composition dates, authorship, political or institutional affiliation of the author, audience such as Senate or House Committee, and so on. The meta-data were contained in text files that were read by R scripts and used to populate additional fields in the SQLite database tables.

At this point we performed the Qualitative Data Analysis according to Creswell (2007). The core of the qualitative analysis is the application of qualitative data analysis (QDA) codes to the paragraphs (2007, pp. 150-155), which traditionally has been a labor intensive and slow process. We developed, based on theory and pilot studies, a series of 39 QDA codes. We designed these QDA codes to correspond to answers to our research questions and to be as orthogonal as possible, i.e. with minimal semantic overlap. Based on QDA codes that were narrowly and precisely specified, we created an extensive list of words and word patterns for each of these QDA codes. The QDA code application function created several false positives and a few false negatives, thus a reading of all text was still necessary. However, this process was greatly speeded up because most of the work was to remove codes, which was much quicker than applying missing ones.

The next stage of the analysis was text mining where the unit of analysis were the words of the text themselves. Text mining has been used in the analysis of policy texts by Monroe & Schrodt (2008). We wrote scripts that selected all the coded paragraphs and then "distilled" from them words that possessed "high content." The distillation was done by removing punctuation, numbers and "stopwords" such as "a(n)", "the", "that", and "and" that provide little if any information. We also performed trial runs of the distillation to supplement the list of stopwords. We wrote scripts that would convert synonyms of words that were of interest to a single term and converted terms composed of two words separated by a space or hyphen to a single composite term. We also changed all letters to lowercase and finally "stemmed" the words. The process of stemming converts related words to their base semantic value. For example, the words *achievement*, *achieve*, and *achieving* were all reduced to *achiev*. We decided to perform text mining only on the text of the coded paragraphs to isolate the texts that we found relevant to our research. The selected presidential speeches and congressional hearings often contained a preponderance of text not relevant to the study.

The R software is able to calculate descriptive statistics of the paragraph codings and the high-content words. We also wrote scripts that generated time plots and other types of graphs. In the next section we provide some details. However, these descriptive statistics were secondary to the most important product of the data analysis. We queried the data based on the theory and the research questions. We structured our questions based on set theory operations of union, intersect and negation, which we translated into SQL and incorporated into R scripts that queried the database and generated lists of relevant paragraphs arranged in chronological order. Then we wove those paragraphs into narratives.

Discussion

Our semi-automated procedures processed 214 files and generated 23,292 codings over 6,605 coded paragraphs and 13,977 significant words. In addition, the scripts produced several dozens of tables, timeline graphs, word clouds, dendrograms, and correlation plots. Our scripts generated tabulations of (1) number of codings for each code, (2) average number of characters in codings for each code, (3) number of files coded for each code, and (4) number of codings for each document. We created frequency tables where we show for each QDA code the number of codings, rank and proportion. A high rank indicated the importance of a concept in the discourse. Also, closeness in rank is relevant. These ranks allowed us to perform the Wilcoxon signed rank test and thus have an inferential test for differences between collections (Glass & Hopkins, 1996, pp. 303–304). Similarly, we compiled frequency tables for the high-content words for both stemmed and unstemmed words. A more interesting descriptive statistic was the cross-code frequency, which is an upper triangular matrix where the columns and rows correspond to the QDA codes and the cells to the number of times that the two codes are applied to the same paragraph. A high number is a sign that in our research context certain QDA codes are closely related.

Based on the research questions we prepared a list of terms and found the words in the documents with the highest correlation based on the Spearman's rank correlation coefficients (Glass & Hopkins, 1996, pp. 129–130). A visual representation of these correlations is done with dendrograms, treelike graphs. A different type of plot that we prepared was a correlation plot. The last type of plot that we prepared was a timeline plot where we show the number of codings over time. This type of plot shows how over time a certain type of discourse has changed.

Implications

In our study we have shown how the use of scripting enabled us to retrieve and analyze a large amount of textual data. Qualitative analysis of textual data is usually very time consuming, but the use of computer automation allowed us to download and process more than 200 files, code more than 6,600 paragraphs, most of them with multiple codes, and tabulate about 14,000 significant words. Such a volume of textual data, even with the assistance of QDA software such as NVivo would have taken a sizable team or considerable time. An additional consideration is the high cost of such commercial software.

The R software has sophisticated graphical capabilities where scripts take the output of the statistical analyses and produce plots and other types of graphs of publication quality without the need to spend a long time manually creating them. The ease of generating all these tables, plots and graphs created an embarrassment of riches that forced us to make choices and reduce our output.

Since we performed our research RR has kept on growing in popularity and new more powerful tools have been developed. With the use of markdown, an easy to use formatting language, and the utility pandoc it is possible to quickly generate docx, odt, and html documents. Alternatively, one can generate sophisticated publication quality pdf documents using markdown with pandoc and LaTeX.

Even considering all the benefits for the researcher him- or herself as outlined previously, one may still wonder why to share practically all details of one's efforts. However Piworar (2007) found that in a specific field of cancer research when data was made available with the publications those were significantly more cited. A recent metastudy of metastudies done by Swan (2010) showed that out of 31 metastudies that compared publications with and without openly available source data, 27 metastudies found that there was a statistically significant citation advantage. In the field of political science the increase of citations was 86% and in philosophy 45%.

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ENGINEERING IS EVERYWHERE: ENGAGING ENGINEERS IN ELEMENTARY PRESERVICE TEACHER TRAINING

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The engineering practices of the Next Generation Science Standards add a new layer of expertise for many elementary teachers. This study investigated the effect of an engineering education curriculum on elementary preservice teachers' (PSTs; N = 40) (a) knowledge and perceptions of engineering and (b) self-efficacy of teaching engineering. Two sections of elementary science methods at a Midwestern university received training; however, the engineer led part of the curriculum and interacted with one section (n = 20). Findings indicated that the curriculum had positive impacts on the PSTs. The authors present the curriculum as a broader impacts model for researchers.

Introduction

Historically, researchers have found that elementary teachers are inadequately prepared to teach science and elementary science education programs are sparse and of low quality (e.g., Czerniak & Haney, 1998; Duschl, 1983; Hone, 1970; Westerback, 1982). A national 2013 survey indicated that elementary teachers still perceive that they are not well prepared to teach science (Trygstad, Smith, Banilower, & Nelson, 2013). The arrival of the Next Generation Science Standards ([NGSS], NGSS Lead States, 2013), with the included engineering practices, add a new layer of required expertise to the elementary classroom that many teachers may not know how to address. Although the National Science Teachers Association (2003) recommends that elementary teachers establish proficiency in life science, physical science, and Earth science, only one-third of elementary teachers have completed coursework in all three of these content areas (Trygstad et al., 2013).

In addition to science content and processes, the NGSS and many state science standards (i.e., Oklahoma) incorporate the engineering design process throughout the grade levels. With fewer than five percent of elementary teachers reporting completion of college coursework in engineering (Trygstad et al., 2013), professional development for science teachers will be greatly needed to address the NGSS and to train teachers on how to incorporate engineering practices into the classroom (Wilson, 2013). Further, elementary teacher preparation must adjust in order to prepare elementary teachers to teach engineering practices in the classroom.

At the K-12 level, engineering has been defined as a “body of knowledge about the design and creation of human-made products and a process for solving problems” (National Research Council, 2009, p. 17). Further, Brophy, Klein, Portsmore, and Rogers (2008) emphasized that “engineering requires applying content knowledge and cognitive processes to design, analyze and troubleshoot complex systems in order to meet society’s needs” (p. 371). Therefore, teachers will need a firm grasp of science and mathematics content in addition to a working knowledge of the engineering design process to be effective at implementing engineering practices in the classroom.

Objectives of the Study

Engineering is Everywhere (E^2): STEM Career Outreach, is a collaborative enterprise between engineering and STEM education faculty. The faculty members developed E^2 curricula to supplement 5th grade science curriculum and to encourage student-driven explorations of engineering in their everyday lives. The developed curricula kit coupled career awareness videos led by an engineer, hand-held microscopes, and an activity guide based on the 5E model for teachers.

Measures of success for video lessons and scientist outreach efforts requires asking questions about what is beneficial about these learning experiences, and for whom and when. This article reviews the training of preservice teachers (PSTs) in the E^2 curriculum, one component of the broader research project efforts to understand how 5th grade students and teachers come to know about engineering as a potential STEM career. Our goal for this research study was to understand how these E^2 kits enhance PSTs (1) self-efficacy of teaching engineering and (2) knowledge and perceptions regarding the work of engineers. Further, this study also asks if the level of interaction (expert visit or virtual) made an impact on these outcomes.

Related Literature

This research aims to contribute to the newly emerging dialogue about best practices for preservice teachers (PSTs) in engineering education, as well as efforts to maximize the broader impacts of engineer engagements in K-12 education contexts (Katzenmeyer & Lawrenz, 2006). This section synthesizes literature on the need to increase elementary STEM career explorations and theorizes the implications for such efforts on PST professional development.

Engineering Teaching Self-Efficacy

Personal teaching self-efficacy is understood as a person's belief in ability to effectively teach (Bandura, 1977). Teaching self-efficacy scales focus on teaching and learning outcomes associated within specific contexts (e.g. the Science Teaching Efficacy Belief Instrument) and theorize that self-efficacy influences teacher level of classroom engagement (Enochs, Scharmann, & Riggs, 1995; Riggs & Enochs, 1990). Exploratory work in the motivations of elementary teachers to engage in engineering education suggests that individual understanding is a mediator of teacher engagement (Hsu, Purzer, & Cardella, 2011). One study by Woolfolk, Rosoff, and Hoy (1990) provided evidence that self-efficacy beliefs could be changed during PST training to improve teacher attitudes and anxieties about science. An instrument has been developed and validated to measure engineering teaching efficacy (Yoon, Evans, & Strobel, 2014). Engineering teacher training has the potential to increase a teacher's confidence to teach science while increasing their interest in and knowledge of engineering practices (Nugent, Kunz, Rilett, & Jones, 2010).

Elementary Engineering Career Awareness

While a great deal on literature exists on career awareness, very little addresses the emerging need for elementary STEM career awareness. Dispelling long-held career theories suggesting that young children are developmentally limited in identifying career aspirations (Hartung, Profeli, & Vondracek, 2005), contemporary research in career development strongly supports the need to introduce career exploration activities in elementary and middle school (Auger, Blackhurst, & Wahl, 2005; Clewell & Campbell, 2002). The introduction of elementary initiatives will require the preparation of teachers to guide students in exploring career interests and workforce skills (Sun & Strobel, 2013). Designed-based learning is increasingly promoted as a tool for raising student interest in engineering careers (Reynolds, Mehalik, Lovell, & Schunn, 2009; Yilmaz, Ren, Custer, & Coleman, 2010). In terms of engineering career awareness, the abilities of teachers to recognize, understand, and communicate *engineering ideas* are considered to be crucial to the developmental career experiences of students (Duncan, Diefes-dux, & Gentry, 2011).

Methodology

During the elementary science methods course, 40 preservice teachers (PST) received training on the E^2 curriculum (http://www.engineeringiseverywhere.com/) as part of their normal course work. The curriculum consists of three lessons that begin with a video featuring the engineer who provides an engineering context for each lesson. There were two classes, each with 20 PST. Both classes received similar training on the curriculum; however, one group (Expert Visit) received a visit from the engineer who led them through the first lesson in the series. The second group (Virtual) only experienced the engineer through the lesson videos. For both groups, the lesson sequence included (a) an exploratory activity to guide student thinking, (b) a video segment featuring the engineer, and (c) a challenge activity to encourage student-led exploration of the concepts explored in the video.

A variety of measures assessed changes in PST's self-efficacy of teaching engineering and knowledge and perceptions regarding the work of engineers. This study focuses on the instruments that measured treatment effect by the end of the curriculum training. First, researchers administered the *What is Technology?* Instrument (Lachapelle, Hertel, Jocz, & Cunningham, 2013) to measure changes in the participants' understanding of the human-designed world. Researchers also used the *What is an Engineer?* (Capobianco, Diefes-dux, Mena, & Weller, 2011) instrument to gauge changes in participants understanding of the work of engineers. Researchers scored both of these instruments for the percentage of correct responses. Additionally, administration of the Teaching Engineering Self-efficacy Scale (TESS) (Yoon et al., 2014) measured changes in the PSTs levels self-efficacy regarding the teaching of engineering. The TESS is a 23-item, 6-point Likert-scale instrument that consists of four factors: (1) *Engineering content knowledge self-efficacy (KS; 9 items)* – personal belief in knowledge of engineering to be used in a teaching context; (2) *Engagement self-efficacy (ES; 4 items)* – personal belief in ability to engage students during the teaching of engineering, (3) *Disciplinary self-efficacy (DS; 5 items)* – personal belief in ability to address student behavior while teaching engineering, and (4) *Outcome expectancy* (OE; 5 items) – personal belief on effect of teaching students' learning of engineering. The TESS has an overall reliability of Cronbach's $\alpha = 0.98$. Scores for each subscale are the average of responses. Although most self-efficacy instruments do not provide an overall score, the test developers prescribe an overall self-efficacy in teaching engineering (TES) score that is the sum of the subscales.

Data was deidentified, coded, and entered in to SPSS version 21.0 for statistical analysis. Researchers used the nonparametric Wilcoxon Signed-Ranks Tests (Siegel, 1956) due to the small sample size of the subgroups and the heteroscedasticity of the data. All analyses were considered significant at $p < .05$.

Results and Discussion

Teaching Engineering Self-Efficacy

Analysis for all PSTs ($N = 40$) indicates that overall teaching engineering self-efficacy ($z = -3.441$, $p = .001$) increased after training and participation in engineering activities. Furthermore, analysis of test subscales revealed that PSTs made significant gains in their pedagogical knowledge self-efficacy (z= -4,708, $p < .001$) and their engineering outcome expectancies ($z = -3.359$, $p = .001$). These findings suggest that the curriculum made positive impacts on PST self-efficacy with regard to teaching engineering (see Table 1).

Additionally, PST in both treatments made significant gains in these same areas: overall, pedagogical knowledge self-efficacy, and engineering outcome expectancies. However, the PSTS in the expert visit subgroup also made significant gains in their engagement self-efficacy ($z = -2.066$, $p = .039$). Thus, having an engineer involved with the delivery of the curriculum appears to have made an impact on PST beliefs in their ability to engage students in engineering activities.

Table 1

Changes in preservice teachers' scores on the Teaching Engineering Self Efficacy Scales

	Pre			Post				
Measures	Min	Max	Mdn	Min	Max	Mdn	z	p
All Preservice Teachers (N=40)								
Overall	4.78	23.29	18.68	4.00	24.00	20.20	-3.441	.001
KS	1.78	5.89	4.11	1.00	6.00	5.06	-4.708	<.001
ES	1.00	6.00	5.00	1.00	6.00	5.50	-1.580	.114
DS	1.00	6.00	4.90	1.00	6.00	5.10	-0.895	.371
OE	1.00	6.00	4.40	1.00	6.00	5.00	-3.359	.001
Virtual (n=20)								
Overall	13.18	23.29	19.28	15.33	24.00	20.06	-2.539	.011
KS	1.78	5.89	4.06	3.33	6.00	4.78	-3.456	.001
ES	3.00	6.00	5.63	4.00	6.00	5.38	-0.211	.833
DS	3.40	6.00	5.40	3.60	6.00	5.00	-0.601	.548
OE	2.80	5.40	4.40	3.80	6.00	4.80	-2.738	.006
Expert Visit (n=20)								
Overall	4.78	23.04	18.11	4.00	24.00	20.06	-2.539	.011
KS	1.77	5.44	4.17	1.00	6.00	5.22	-3.269	.001
ES	1.00	6.00	4.50	1.00	6.00	5.63	-2.066	.039
DS	1.00	6.00	4.70	1.00	6.00	5.20	-1.600	.110
OE	1.00	6.00	4.30	1.00	6.00	5.00	-2.023	.043

Note: KS – Engineering content knowledge self-efficacy; ES – Engagement self-efficacy; DS—Disciplinary self-efficacy; and OE--Outcome expectancy

Indicators of PST Understanding of Engineering

Researchers analyzed responses to the *What is Technology?* and *What is an Engineer?* surveys to gain an understanding of their knowledge of the human designed world and the work of engineers, respectively. Overall, the PSTs (*N*=40) made significant gains on their scores on the *What is Technology?* instrument (z = -3.009, p = .003); however, no significant gains were made on the *What is an Engineer?* measure (see Table 2). These findings suggest that PSTs gained a better understanding of what constitutes a technology after learning from the engineer with the E^2 curriculum regardless if the treatment used only the videos or a combination of the videos and a personal visit from the engineer. However, as a whole, the teachers did not make gains on their understanding of the work of engineers.

An examination of findings by the different treatment groups indicates that an expert visit with the engineer had a positive influence on PST understanding of the work of an engineer (What is an Engineer?) (z= -2.362, p = .018) and the human-designed world (What is Technology?) (z = -2.698, p = .007). Again, having an engineer participate in the delivery of the curriculum appears to have made an impact on PST's understanding of technology and the work of engineers.

Table 2

Changes in preservice teachers' scores on the What is Technology? and What is Engineering?

	Pre			Post				
Measures	Min	Max	Mdn	Min	Max	Mdn	z	p
What is Technology? (N=40)	45.00	100.00	70.00	45.00	100.00	80.00	-3.009	.003
Virtual (n=20)	45.00	100.00	70.00	45.00	100.00	77.50	-1.657	.098
Expert Visit (n=20)	45.00	100.00	70.00	45.00	100.00	80.00	-2.698	.007
What is an Engineer? (N=40)	52.63	100.00	68.42	57.89	100.00	68.42	-1.424	.154
Virtual (n=20)	52.63	100.00	71.05	57.89	100.00	65.79	-.673	.501
Expert Visit (n=20)	52.63	89.47	65.79	57.59	100.00	71.05	-2.362	.018

Implications

The findings of this study suggest several important implications for PST training in engineering curriculum. First, education-engaged engineers should seek PST audiences for broader impacts initiatives. These groups are concentrated and available on university campuses and can be easily arranged with science education faculty. Preservice teachers can be agents of change as we begin reforms to normalize NGSS engineering practices in elementary classrooms. Additionally, helping to educate PST on the work of engineers has the potential to indirectly reach more elementary students. Further, visits by engineers to PST university classrooms may be more feasible than visits to individual elementary schools. Second, in the case of this research, face-to-face interactions with the engineer increased PST understanding of engineering and the designed world. Indeed, it is the ubiquity of engineering—that it is everywhere—which makes transparent the immense importance of engineers to society (Brophy et al., 2008). A visit from a local engineer adds a distal and socio-cultural layer to teacher understanding of engineering and its importance to a 21st century workforce (Bybee & Fuchs, 2006). Finally, a virtual format (i.e., videos) allows for a novel approach for researchers to share their research and passion for engineering with many individuals. Whereas the strains of academia do not encourage researchers to visit countless classrooms, a virtual experience can be distributed to a broader audience with minimum time to be invested by the researcher. Thus, this model of engaging engineers in PST education has potential to make broad impacts for dissemination of the work of engineers into the elementary classroom.

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Acknowledgements

This study was funded in part by an Oklahoma State University (OSU) Grant for Establishing an Interdisciplinary Program and the OSU Center for Research on STEM Teaching and Learning. The ideas expressed in this paper are those of the authors and do not necessarily reflect the views of OSU.

CONNECTING PRE-SERVICE STEM TEACHING FROM COLLEGE TO FIELD EXPERIENCE: CASE STUDIES USING PROFESSIONAL DEVELOPMENT IN AN AUTHENTIC, SITUATED CONTEXT

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This mixed-methods study investigates elementary and secondary preservice teachers' (PSTs) (n=4) science content knowledge and conceptions of nature of science (NOS) following the first year implementation of a STEM site-based professional development (PD) program. The VNOS-C instrument was utilized to collect data regarding participants' perceptions of NOS before and after the intervention. Pre- and post-test data from a science content exam was used to assess changes in content knowledge. Findings in this study may offer insight into how to foster and develop PSTs content knowledge and understanding of NOS in future PD programs.

Introduction

The shortage of STEM middle school teachers, especially those in low income and high minority schools, is exacerbated by the fact that many of the teachers are not adequately prepared or supported to foster success and interest in science, technology, engineering, and mathematics (STEM) (Boyd, Lankford, Loeb, Ronfeldt, & Wyckoff, 2011; Stronge, 2007). While generalist elementary education degrees are among the most completed in the U.S. (NCES, 2012), many of these teachers have limited preparation for effectively teaching mathematics and science as they have usually completed only 1-3 content courses in generalist education programs (CMBS, 2012). A possible solution to this challenge is to use the pool of grades 4-8 STEM teachers who are elementary generalist to recruit STEM elementary STEM teachers, assisting them with the certification process by augmenting their STEM content knowledge. South Texas University (STU - pseudonym) is testing an unconventional preservice strategy for bolstering the elementary to middle levels STEM certification and teaching pathway. The TEX (pseudonym) initiative is supported by a 3-year $1.5 million grant from a national funding agency. As a research-based effort, a team of investigators are studying the impact of the TEX initiative by using a mixed methods matched-group research design addressing students, pre- and inservice-teachers in relation to views on the nature of science (NOS), as well as self-efficacy, interest, and achievement in STEM as indicators of the quantity, quality, and diversity of grades 4-8 mathematics and science teachers. This report outlines a pilot study using case based studies to investigate preservice teachers' (PSTs) changes in science knowledge and views of the NOS through the use of site-based professional development (PD) programs.

Objectives of the Study

Starting in Fall 2013, the 30-year teacher preparation partnership consisting of the largest school district and university in a mid-sized U.S. southern city, began implementing the new TEX program at three participating schools, including one middle school and two elementary feeder schools serving a combined 1,900 students annually. Given the deficits identified in the effectiveness of traditional, externally designed PD and the lack of authenticity in college preservice field-based experiences, STU investigators created a new model for science and mathematics content instruction by incorporating site- and content-specific PD with field-based experiences, using inquiry and other tools to increase authenticity. Questions arose during the planning phases of this grant such as: What do we really know about PD and verifiable improvements in student learning? How can more connections be made in the PSTs' field-based experiences to increase content knowledge and self-efficacy in science and mathematics, and cause changes in perceptions in NOS?

Theoretical Framework

Teachers, both experienced and novice, often complain that the learning experiences that take place outside of the classroom are too removed from the authentic context of day-to-day teaching to have real impact (Putnam & Borko, 2000). A problem that often arises within traditional teacher education programs is the lack of connections between university-based teacher education courses and K-12 field experiences (Zeichner, 2007). Student teachers usually do not have opportunities to observe, try out and receive focused feedback about their teaching of methods learned in college courses. Darling-Hammond (2009) identified this lack of connection as the Achilles' heel of teacher education. PSTs typically are left to work alone with little if any guidance in relating what they are doing to coursework. Furthermore, it is often assumed that good teaching practices are personally identified as they occur, rather than taught in an authentic, situated context (Darling-Hammond, 2009; Valencia, Martin, Place, & Grossman, 2009).

Investigators determined that workshops would implement research-based instructional practices incorporating active-learning experiences for participants, using strategies specific for each classroom situation. Large national teacher education studies have revealed that carefully coordinated field experiences that connect with college courses are more influential in supporting teacher learning then the typical disconnected field experiences that dominate American teacher education (Darling-Hammond, 2006). Engaging PSTs in authentic, situated practices of science and science teaching is also important because it provides a productive context to learn about NOS (Schwartz, Lederman, & Crawford, 2004).

Methodology

To create more authentic experiences and address Darling-Hammond's (2009) Achilles' heel in teacher education, authentic activities were developed that fostered different kinds of thinking and problem-solving skills that are important outside of the classroom (Putnam & Borko, 2000). The PD efforts centered directly on enhancing PSTs' content knowledge and their pedagogic content knowledge (Shulman, 1986). In addition, because educators struggle to adapt new curricula and new instructional techniques in their unique classroom contexts, just-in-time, job-embedded assistance was identified as crucial (Guskey & Yoon, 2009). Student teachers are generally not provided with the kind of preparation and support they need to practice teaching (Darling-Hammond et al., 2005; Valencia et al., 2009). Therefore, the science and math education faculty remained on-site to provide lesson planning and follow-up activities before and after the teaching experience. These efforts created what has been called a third space, or a "hybrid" space where PST education programs bring together school and university-based teacher educators and practitioner and academic knowledge in new ways to enhance the learning of prospective teachers (Ziechner, 2009).

The nature of scientific knowledge refers to the understanding of science as a way of knowing. Past studies have revealed that many teachers do not hold adequate views of NOS (Abd-El-Khalick, Bell, & Lederman, 1998). Studies highlighted the need for well-designed PD to engage PSTs in inquiry-based experiences and provide support for them in articulating their views regarding inquiry and the NOS (Capps & Crawford, 2013). Therefore, the researchers used a combination of methods and instruments to analyze PSTs' conceptions of NOS and content knowledge in science after participating in a STEM site-based PD program. This pilot study addressed the following research questions:

1. To what extent did preservice teachers' views of NOS change over the program period (from October 2013 through May 2014)?
2. To what extent did preservice teachers' science content knowledge change over the program period (from October 2013 through May 2014)?

Participants and Setting

For the purposes of this case study approach, 4 out of 12 PSTs, all female, were randomly selected as a representative sample of the original PST (also referred to as TEX Fellows) study population participating in the TEX program. Two participants were prospective elementary teachers seeking an EC-6 generalist teaching certification, and two were prospective secondary teachers seeking a 4-8 math teaching certification. The PSTs were enrolled in an undergraduate teacher preparation program at STU and participated in this research study during their required year-long field experience.

This study centered on two of the three TEX program partner schools. The experiences of PSTs at the middle school campus (Grades 6-8), where the site-based PD took place (treatment group), were compared to the experiences of PSTs at one of the elementary school campuses that serve grades K-5 students (control group).

Control group: The control group was representative of PSTs at the elementary school. The PSTs did not receive explicit teachings on NOS or the 5-E inquiry-based instructional model. In preparation for STEM Thursday activities: (a) science lessons were given to PSTs, (b) PSTs taught lessons once in 4th and 5th grade classrooms, (c) TEX program staff developed and led the lesson lessons, and (d) PSTs acted more in a supporting role.

Intervention Group: The treatment group was representative of PSTs at the middle school. The site-based PD consisted of: monthly planning meetings, enhanced STEM Thursdays, onsite support, and materials and resources. PSTs received explicit teachings on science content, NOS and 5-E inquiry-based instructional models. In preparation for STEM Thursday activities: (a) PSTs and TEX program staff collaboratively planned and created 5-E science lessons, (b) PSTs led lessons and TEX program staff acted in supporting role, (c) PSTs taught lessons in consecutive periods in 6th and 7th grade classrooms, (d) PSTs and the TEX program staff met 3-4 weeks every month, (e) There were multiple email exchanges between PSTs and TEX program staff, sharing resources, as well as, components of instructional materials, and (f) PSTs practiced teaching their lessons prior to STEM Thursday, and reflected afterwards. An additional advantage to the treatment group was that on-site support from a science education professor was available twice per week.

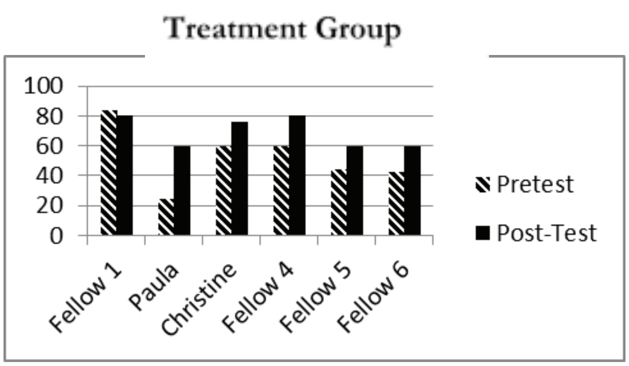
Data Collection and Instruments

Two instruments were utilized as sources of data: (a) VNOS-C questionnaire, and (b) Content test. To assess PSTs' conceptions of NOS, we administered the 10-item, open-ended

VNOS-C questionnaire (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002) before and after the TEX program. Analysis of the VNOS-C results entailed utilizing a rubric design based on previous research (Bargmann & McCollough, 2011). In addition, a pre/post multiple-choice content test was administered to measure PSTs changes in content knowledge by using an exam (Wynne, 2008) that was devised and tested to establish validity and reliability (Miles & Huberman, 1994).

Results and Discussion

Paula. Paula is a non-traditional student, pursuing teaching as a second career. English was not her native language and she lacked the cognitive academic language of science.



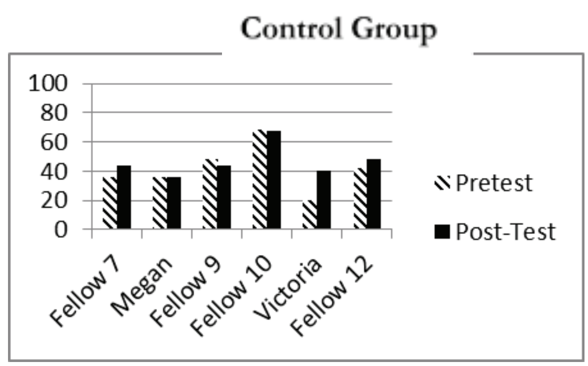


Figure 1. Schematic of the treatment group and control group's pre-test and post-test scores on the content exam.

As Figure 1 shows, Paula's content test post-score increased 150%. Paula's VNOS-C responses showed growth in two out of the five questions that were analyzed, as shown in Table 1.

Paula's post-test response, as shown in Table 1, depicted an increased understanding that science was based on experimentation and the collection of data. In her pre-test, Paula held common misconceptions about theories and laws including the belief that a theory can be proved true; once it does, it turns into a law. In her post-test, Paula was able to provide an example using Mendel.

Christine. Christine demonstrated strong leadership abilities and was extremely enthusiastic about teaching both math and science. Christine's multiple choice question score increased 27%. Her VNOS-C scores also increased in two of the five questions. Christine had similar misconceptions as Paula when she began the program. In her post-test, Christine showed a more developed understanding and was able to give Newton's Laws as a concrete example of a scientific law (see Table 1).

Table 1 Pre and Post Responses on the VNOS-C

Question	Participant	Pre-test response	Post-test response
Q1.What, in your view, is science? What makes science (or a scientific discipline such as physics, biology, etc.) different from other disciplines of inquiry (e.g., religion, philosophy)? (NOS aspect: empirically based)	Paula	Q1: Science is the study of nature (how things grow and form), human development, why individuals act the way they do. Science is different from religion in the way that science is what we see in our environment including our community, people, grow, or develop. Religion is what people think, how they create rules or beliefs to believe in something. Science=development; Religion=belief	Q1: Science is the study of nature, how we evolve as humans how living things evolve on earth. Science is the study of the universe. The difference from religion and philosophy is that science is based on experiments data and studies from the results of the experiment.
Q2. Is there a difference between a scientific theory and law? (NOS aspect: Theory versus law)	Christine	Q2: Scientific theory is based on ideas but have not been proven with 100% certainty. Scientific law has been proven or at least have (sic) not yet been disproved.	Q2: Yes, scientific law has more evidence and support. A scientific law is considered more absolute. Newton laws in the scientific world are considered proved beyond a reasonable doubt not just a theory.
	Paula	Q2: Scientific theory is was (sic) a person has prove to be true (sic) by his experiments. Scientific law is when many individuals (sic) scientists have proved the same theory they prove (sic) such theory. Then the theory becomes a law.	Scientific Theory- The study of Gregory Mandel is an example of scientific theory-We inherited 2 traits from our parents.
Question	Participant	Pre-test response	Post-test response
Q4. Do scientists use their creativity and imagination during their investigations? (NOS aspect: Creative and imaginative)	Megan	Q4: I am not sure.	Q4: I think they use little creativity in coming up with hypothesis.
Q5. Do social, cultural, and political issues influence science? (NOS aspect: Culturally and socially embedded)	Christine	Q5: Science is universal because regardless of political, social, or philosophical values, nature and life remain the same. Ex: stars do not change regardless of location animals behave equally	Q5: Our culture impacts everything we do. Scientists are also influenced by their culture and that is why I believe that one is a reflection of the other a culture that believes in religion will have different explanations to the same event as a culture who does not believe in religion at all.

Megan. Megan is an EC-6 major who was pursuing an add-on certificate in both math and science. She student taught in a self-contained fourth grade classroom. Her scores on the content exam remained the same for both administrations. As shown in Table 1, her VNOS-C response showed growth in only one NOS aspect, understanding of the role of creativity.

Victoria. Victoria was assigned to a fifth grade Language Arts classroom for student teaching. She did participate in the planning and delivery of five STEM lessons during her experience. Her prior content knowledge measured 20% on the pre-test and grew to 40% during the year. Her VNOS-C scores did not show any growth in understandings of NOS.

Table 2. Summaries of Scores on the Content Exam

	Pretest		Posttest		Normalized gains (%)		Raw gains (points)		Raw gains (%)	
	Control	Treatment	Control	Treatment	Control	Treatment	Control	Treatment	Control	Treatment
Mean	0.42	0.52	0.47	0.69	0.07	0.29	0.05	0.17	0.22	0.47
Median	0.39	0.52	0.44	0.68	0.05	0.36	0.03	0.17	0.07	0.35
St. Dev.	0.16	0.20	0.11	0.10	0.12	0.28	0.09	0.13	0.40	0.53
Min	0.20	0.24	0.36	0.60	-0.08	-0.25	-0.04	-0.04	-0.08	-0.05
Max	0.68	0.84	0.68	0.80	0.25	0.50	0.20	0.36	1.00	1.50
N	6	6	6	6	6	6	6	6	6	6

Overall, according to the pre-test results the six middle school students in TEX came into the PD program with greater science knowledge (*M* = 0.52, *SD* = .20) than the elementary group (*M* = 0.42, *SD* = .16). The post-test scores show a significant difference in gains between the two groups. As Table 2 shows, the treatment group increased showed normalized gains of 29% while the control group showed normalized gains of 7%. A Mann-Whitney test revealed a significant difference exists in the distribution of the post-test scores (*p* = .015). For normalized gains, Cohen's *d* = .71, producing a large effect size. Hence, it appears that the PD model used at the middle school had a significantly strong impact on the acquisition of content knowledge.

The two groups had similar initial responses to the VNOS-C. Despite the PD experience, all the students spent the majority of their student teaching time with traditional Cooperating Teachers. The middle school group did show some modest gains in their understanding of NOS, but none of them responded with fully informed answers to any of the questions.

Implications

Preservice teachers benefit from having site-based PD and experts available to support them as they merge theory with practice in developing and implementing research-based science lessons. The TEX faculty needs to expand the PD model to engage PSTs in longer instructional units that integrate understandings of NOS as they experience the essential elements of the scientific discipline including: building theories and models, collecting and analyzing data, constructing arguments and using specialized ways of representing ideas (Duschl & Grandy, 2013). Involving recent graduates of the program to serve as mentors for PSTs as well as training Cooperating Teachers within the schools would strengthen the TEX initiative. This may lead to a transformation of the way that 4th-8th grade students, their teachers, and the PSTs understand NOS and are able to deepen their scientific knowledge.

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Acknowledgements

This work was supported by the National Science Foundation under Grant No. 1321319. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation or the authors' institutions.

THE INFLUENCE OF VIDEO GAMES ON MIDDLE SCHOOL STUDENTS' MATH ABILITY

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There is a lot of negative advocacy that has caused a negative connotation towards the influence of video games on children's cognitive, psychological, and social development, regardless of the type of video game. Multiple studies have been conducted on the influence of video games on children's behavior, but not a lot of research exists to show connections between game playing and children's cognitive development. In this study the effects of video games on middle school students' math ability were investigated.

Introduction

Technology (this term refers to devices such as televisions, computers, tablets, phones, gaming consoles, and video games) is prevalent everywhere. Children grow up exposed to technology. Children's environment influences their learning, Technology is part of their environment. With technology the new generation will learn and develop in a different way. One aspect of technology under scrutiny is video games. Though research on this topic is scarce, some research investigated a relationship between the skills needed to do math, and the skills gamers (individuals that play video- and computer games) use when playing video games (Temple University, 2012). Discovering a relationship between doing math and playing video games might provide insights into using gaming during the learning process.

Related Literature

Games are part of children's development. The benefits of both board games and video games lie in the mental stimulation they provide either through social engagements, or the enhancement of memory (Miller, et al., 2012). Video games improve and promote problem solving, hand-eye coordination (Chuang & Chen, 2009), visual attention, (Chen, Liao, Cheng, Yeh, and Chan, 2011), reasoning and working memory (Baniqued, Lee, Voss, Basak, Cosman, Desouza, . . . and Kramer, 2012), social interaction, physical activity (Lieberman, Fisk, and Biely, 2009), imagination and creativity (Ball and Ball, 1979), fast reaction times, deeper thinking (Ip, Jacobs, and Watkins, 2008), accuracy (Dye, Green, and Bavelier, 2009), memory formation, and strategic planning (Max-Planck-Gesellschaft, 2013). In addition to the aforementioned skills, one specific cognitive skill enhanced by video game playing is spatial cognition (Max-Planck-Gesellschaft, 2013). This particular skill will be discussed in more detail and with more support in a later section.

Adverse effects of video games on behavior including addiction, aggression, violence (Ip, et al., 2008), and impulsiveness (Gentile, Swing, Lim, and Khoo, 2012) dominate the media, and provide a dissenting view of video games. Studies interested in negative implications usually look at action and/or violent video games in particular (Ewoldsen, Eno, Okdie, Velez, Guadagno, and DeCoster, 2012). Many researchers failed to establish a link between violent or non-violent video games and the diminishing of pro-social behavior (Ferguson et al., 2013; Tear and Nielsen, 2013). Other negative influences of video games include attention disorders such as attention deficit hyperactivity disorder (ADHD) (Gentile et al., 2012), lower academic grades (Ip et al., 2008), and even being numb to real-life experiences (Springer Science & Business Media, 2013). However, these effects were based on gaming frequency, and not the effect of the gaming experience itself.

". . .they are here to stay. Let us use them wisely." Those are words from Ball and Ball (1979) about the future of video games. In their article they promoted the use of video games in the classroom, even more than 30 years ago! The use of computers at an early age influence the connections formed in the brain, and therefore young children who use computers will learn differently than their counterparts (Vawter, 2010). Eow et al.(2009) stated that it will be unrealistic to try to stop the expansion of video games, and the education system should try to incorporate computer games into the teaching and learning process. Since many students are interested in technology, it can motivate and engage students in learning (Chen et al., 2011), and it can help build skills, knowledge, and habits that cannot be provided in traditional classrooms (Buschang, Chung, & Kim, 2011). The digital era requires new ways of teaching and learning (Battro and Fischer, 2012).

There has been a lot of interest lately in the potential effects of video games on perceptual and cognitive skills (Dye et al., 2009). A recent study by Green and Bavelier (Spence & Feng, 2010) found that spatial skills could be modified by playing action video games. Spatial reasoning is an essential field of study in mathematics, science, engineering (Temple University, 2012), meteorology, and architecture (Cherney, 2008.), and medicine, dentistry, and chemistry (Cherney, 2008). Math tasks and math performance have been positively correlated with spatial thinking and ability (Van Garderen, 2006).

Spatial thinking refers to the ability to mentally generate, rotate, and transform visual images (Park, Lubinski, and Benbow, 2010), and includes capacities such as contrast sensitivity (ability to distinguish between an object and its background), spatial resolution (recognizing small details), visualization, tracking multiple objects, visuomotor coordination, and speed (Spence and Feng, 2010).

Geometry involves spatial sense when comparing proportions and figures, matching disproportional pictures, and understanding relationships between objects (Boytchev, et al., 2007). Mental rotation is an important element of spatial activities (Liesefeld and Zimmer, 2013). Mental rotation involves rotating a visual object to indicate the original position of the object before it was rotated in space. Van Garderen (2006) conducted a study with students from varying abilities—students with learning disabilities, average achievers, and gifted students. The gifted students performed better on spatial visualization and visual imagery tasks than their lower and average ability counterparts.

Purpose of this Study

This study was not to determine if video games cause academic failure or success, but our goal was to see if gamers performed better in certain cognitive tasks than their non-gamer counterparts. Spatial activities were used to determine students' spatial abilities which are prevalent in both math and computer games. We compared the results to student's gaming ability.

We wanted to compare the spatial ability of gamers playing any type of video games, and that of non-gamers in this study. The hypothesis for this study is that gamers will outperform non-gamers on spatial reasoning tests. If that is the case, the benefits of using video games in educational settings for the purpose of developing mathematical skills can be investigated more.

Methodology

Middle school students from a private- and public school in Central Oklahoma participated in this study. The demographics for the participants vary and are unknown. During the initial survey 22 gamers, 1 non-gamer and 8 "tablet gamers" were identified. Participants were categorized in three groups based on the results of the initial survey.

Data Sources

The data were collected through two surveys and random interviews. The surveys were conducted through an online tool, Surveymonkey, in a controlled environment where teachers were present to supervise. The goal of the first survey was to gather data about students' gaming habits: what type of games they play, how often, what platforms they use to play games, and how serious they take their game playing. In this survey students also state their grades they achieve in math. The second survey had students do four spatial activities categorized as logical reasoning, visualization, paper folding, and perception. Each activity had four possible answers and students had to choose the correct one.

Students were randomly identified to be interviewed. The interviews were conducted to get a more in depth view of students' exposure to spatial activities throughout their lives. Examples of such questions were, "Did you build puzzles growing up?," "What type of board games did you play when you were younger?," "Did you play with blocks/Lego's when you were little?," "Have you played Connect 4 or Sudoku before?" Some questions were slightly different depending on how students identified themselves in the initial survey (e.g. To a gamer, "Why do you play video games?" and to a tablet gamer, "Why do you not play video games?").

Results

From 43 responses, only 31 were completed correctly and could be used towards the results and data analysis. Initially the researchers planned on having two groups of participants: students who play video games (gamers) and students who do not play video games (non-gamers). After receiving the data for the surveys, it was evident that there were three groups: video gamers, tablet gamers, and non-gamers. Students who only play games on tablets did not consider themselves as gamers, thus a third category emerged, tablet gamers. Since only 1 participant responded as non-gamer our data analysis will focus on two categories, gamers and tablet gamers.

Survey results indicated that students either play video games (71%) and/or games on tablets (25%). From the gamer group, 72% usually achieves an A in math, and 22% achieves a B. All tablet gamers achieve As in math.

Participants completed 4 spatial activities. Results are displayed in Table 1 below.

Analysis

Twenty five percent of participants who played video games scored 4 out of 4 when completing spatial activities whereas only 15 % of tablet gamers scored 4 out 4 when completing the spatial activities. Approximately 21% of tablet gamers completed 3 out of the 4 activities correct compared to approximately 19% of video gamers. Approximately 31% of tablet gamers completed half of the activities correct, whereas approximately 30% of video gamers completed half of the activities correctly. Eleven percent of video gamers did not complete any of the 4 activities correctly whereas only 9% of the tablet gamers did not complete any of the activities correctly. Since only one participant was a non-gamer the researchers could not adequately address the original hypothesis.

Table 1

Results of Spatial Activities

Answers correct	Play video games	No video games, but phone/tablet games
4	25.0%	15.6%
3	19.3%	21.9%
2	29.6%	31.3%
1	14.8%	21.9%
0	11.4%	9.4%

From the data collected a different category than what was expected emerged. Thus the analysis of data and conclusions are based on a small sample size and the emergence of "tablet gamers" category. The data indicates that gaming, whether video, tablet, or board, may enhance spatial abilities.

Even though the researchers' conclusion regarding the initial hypothesis is inconclusive, some other results emerged from the study. These results can possibly be used in a supplemental study regarding spatial abilities and gaming. As discussed previously, the level of a student's spatial abilities plays a role in his/her math performance. Games, either video games or board games, can enhance these abilities. Some research specifically focused on first person shooter (FPS) and action games as games that can help students develop their spatial skills. However, upon analysis of the specific gaming genres (FPS and action games) in comparison to the answers correct for the spatial activities, no relationship could be found. For example, a few students who indicated playing FPS- and action games received high scores on the activities, but there were also some who played these games (individually or as a combination) who received poor scores on the spatial activities. The same was true for those who only played one type of genre (for example simulations) who received excellent scores on the spatial activities. The time students spent on video games did not have an effect on their scores either. More time spent on video games did not necessarily provide a higher score, or vice versa, which could support the research stating that playing games for only a few minutes can enhance certain skills.

Implications

As noted previously, a bigger sample size will make the results more significant, and will give this type of research a bigger impact in how parents and teachers perceive children's development. If the results indicate that children understand spatial activities better when they are active video gamers, this change in how children learn can be incorporated in the classroom. It can completely change the way technology are utilized in schools from how it is currently done. This of course is not an easy change that can happen overnight. The transition will be time consuming and costly due to many variables that need to be investigated before implementing games in classrooms. Therefore a lot of research still needs to be done on the different aspects of this change before it can even be considered.

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PRESERVICE MATHEMATICS TEACHERS' EFFECTIVENESS IN ADDRESSING MISCONCEPTIONS IN ALGEBRA

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The purpose of this study was to examine to what extent two groups of preservice mathematics teachers (PSTs) were engaged addressing middle grade students' misconceptions in algebra. The engagement of the PSTs was defined as an effective answer that could assist students to correct existing misconceptions. On a posttest, four open-ended problems were presented to 32 (treatment) and 27(comparison) PSTs, requesting them to assist middle grade students with a misconception. There was no statistically significant difference between the treatment and comparison groups. However, the proportion of engaged PSTs in the treatment group was two to four times greater than the comparison group.

Introduction

An important goal for teachers is to help students form mathematical understandings of concepts and procedures. However, during their learning of arithmetic, students may develop misconceptions about key concepts and procedures. These misconceptions are usually resistant to change and affect students' success and progress in algebra. It is, therefore, essential that teachers be able to recognize specific misconceptions and know strategies to address them. Unfortunately, some teachers themselves have some of the same misconceptions as their students, or have not learned effective approaches to assist their students, resulting in the students' misconception becoming more robust and difficult to correct. Thus, it is very important in preservice mathematics education to address the issues of students' misconceptions and to provide future teachers with strategies for correcting their own misconceptions and support their students' learning with deeper understanding.

Objectives of the Study

The purpose of this study was to explore the effectiveness of activities designed to develop preservice teachers' abilities to recognize and address student misconceptions in algebra. The activities were a part of a required problem solving course for middle grades certification. A second purpose was to compare the participants' knowledge and strategies in addressing misconceptions with a group who only studied problem solving. In this study, the key measure of the participants' knowledge of how to address misconceptions was whether they engaged the student in thinking about the concept or procedure. The research questions were: (1) how well do preservice teachers, who have studied student misconceptions in the context of problem solving, engage students in thinking about mathematics? (2) How do preservice teachers who have studied student misconceptions compare with a group who only studied problem solving strategies?

Related Literature

Algebra is one of the critical mathematical subjects and often serves as either a gateway or barrier to more advanced courses (West, 2013). From the early grades the importance of algebra is recognized and, even if the students do not specifically know it as "algebra", the introduction of algebra is expected to be taught at preK-2 (NCTM, 2000). Thus, algebra is very crucial mathematics content because it provides a generalization of arithmetic, helps students to understand relationships and formulate rules, besides being a foundation for other mathematical content (Usiskin, 1995). Middle school students' proficiency in algebra concepts and procedures including ratios, proportions, equations, and functions is critical for later academic success and career growth (Bush & Karp, 2013; Capraro & Joffrion, 2006; Edwards, 2000; Powell, 2012; Stephens, 2005; Welder, 2012).

Even though algebra is taught beginning in the early grades, it is not an easy subject for students and they often develop misconceptions. Algebraic misconceptions have long been widespread among students and even their teachers (Davis, 1995; Huang & Kulm, 2012). Researchers have found typical mistakes committed by students in solving problems of algebra or linear equations (e.g., Powell, 2012; Welder, 2012). Based on studies about misconceptions, we found that students were unable to correctly represent an equation with a graph, or confused the differences between equations and expressions (Bush & Karp, 2013). They did not have accurate knowledge of direct and inverse proportions (Dogan & Cetin, 2009). For the students writing a ratio and finding the proportion was problematic (Kaplan, Isleyen, & Ozturk, 2011). They also had difficulty understanding the concepts of function and equation (Li, 2006), variables, constants, and unknowns (Kocakaya Baysal, 2010; Li, 2006).

Assisting students effectively is important and depends on teachers' knowledge. Students' misconceptions can be persistent if the teachers themselves have misconceptions and it was found that preservice teachers have difficulties determining students' misconceptions (Şandir & Aztekin, 2013). Studies have revealed that preservice teachers could not properly define functions with one-to-one and onto properties (Dede & Soybas, 2011), had difficulties with linear equations (Li, 2007), were not very successful in worded multi-step ratio questions (Livy & Vale, 2011), did not have full understanding of the conditions of functions and of multiple representations of functions (Dede & Soybas, 2011), and had problems in differentiating functions and equations (Aydin & Kogce, 2008).

In order to better assist students, teachers should have deep understanding of mathematical concepts and should not have misconceptions about these concepts. If teachers are well-prepared, they should be more successful in correcting students' misconceptions. It has been known for decades that there is a direct correlation between teacher quality and student outcomes. Shulman (1987) included pedagogical content knowledge (PCK) and knowing students in the categories of teachers' knowledge base. He identified PCK as a decisive category to distinguish experts from their colleagues. With PCK teachers can tailor content and pedagogy to meet diverse learners' needs for understanding mathematics content. An, Kulm and Wu (2004) further proposed that the major part of PCK is the knowledge of students' thinking, which includes their understanding of mathematical conceptions and possible underlying misconceptions.

Bush and Karp (2013) suggested that teacher education should equip preservice teachers with knowledge of strategies to address students' misconceptions. The instructional technique of erroneous examples was employed by McLaren et al. (2012) to target students' misconceptions. In the study, mathematical mistakes were intentionally imbedded in the detailed solution of the problems to challenge students to find, explain, and fix. Another proposed strategy to foster knowledge of students' thinking by An and Wu (2004) was to examine students' homework. Teachers needed to go through a 4-step process: detecting mistakes, analyzing reasons, creating solutions, and correcting them.

Methodology

Sample

There were 33 participants in the experimental and 28 participants in the comparison group. The demographics of the participants reflected the overall population of the preservice teachers at the university. There were 55 females, 51 White, 8 Hispanic, one African American, and one Asian preservice mathematics teachers. Both groups were enrolled in a required three-credit Mathematics Problem Solving course. The treatment group consisted of PSTs who attended the treatment course where as control group was comprised of PSTs who were willing to take the test from other instructors' course.

Procedure

The experimental group was taught by the first author and the comparison group by an experienced clinical professor. The experimental course included problem solving heuristics (Polya, 2004), strategies for teaching diverse students (Ellis, 2008), presentations by experts on diversity and algebra misconceptions, and the opportunity to tutor and teach middle grade students in a virtual environment. Problem solving heuristics were developed in the context of three Problem Solving Equity Challenge assignments on the topics of proportions, linear graphs, and percents (Kulm, Merchant, Ma, Oner, Davis, & Lewis, under review). These Challenges presented a culturally relevant (Ladson-Billings, 1995) problem to solve, followed by activities in which the participants developed a similar problem for students, responded to possible student misconceptions about the algebraic concepts and procedures in the problem, planned a problem solving lesson, and answered questions about the algebra concepts and procedures that students might ask. The presentation by the fifth author on algebra misconceptions included the meaning of misconception, how to correct misconceptions, what to do and what not to do while assisting students, and examples of student misconception from previous studies. The comparison group studied mathematical problem solving heuristics, completed assigned problem sets, and discussed and presented problem solutions in class.

Instrument

Participants completed a posttest of the Knowledge for Algebra Teaching for Equity (KATE) test developed by the authors. The KATE test contained 19 open-ended mathematics problems to assess algebra content and teaching knowledge. Four of the 19 problems asked how to assist a middle grade student who had a misconception. The first problem required finding a linear equation, given a table of values; the second problem required using information from a linear graph to draw another graph; the third problem required simplifying a linear expression; and the fourth problem required finding and solving a system of two linear equations, given a table of data.

Analysis

For the first problem, 32 experiment and 27 comparison group PSTs' answers were completed. Problems two, three, and four were answered by 31 experiment and 27 comparison group PSTs. The participants' answers to the four problems were independently coded for engagement by the first and third authors. We defined engagement as assisting students by asking questions to guide students, providing broad definitions of the concept, or giving examples that help students' understanding of the concept rather than just explaining or telling how to do the procedure or solve the problem. Engagement was coded as one (engaged) or zero (not engaged). The inter-rater reliability of the coding was 81%. An examples of a PST who was effective in engaging a student on problem two was the following:

> I would ask the child to pick two numbers to represent the slope, m, and the y-intercept, b. Once he/she did so I would ask them to plug those numbers into each equation and then try to graph them. They would hopefully see that their answer is incorrect. I would point out to them that the y=mx+b line is graphed so that the y-intercept equals zero, and then I would ask them which two numbers would make that line true. Once we found that out, we would move on to the next equation with the same numbers and see what happens.

On the other hand, the following answer was typical of a participant who did not engage the student:

> The original intercept is 0 so if you place that before x the line will always have a slope of zero and be a straight line.

Results and Discussion

We classified the treatment and comparison groups for engagement for each of the four problems. Then we performed a Chi-square (χ^2) 2-sample test for equality of proportions with continuity correction for each of the four responses. The results for the first problem are shown in

Table 1

The First Problem 2×2 Contingency Table

	Treatment	Comparison
Engaged	6	3
Not engaged	26	24
Total students	32	27
Proportion	0.1875	0.1111

The value of the χ^2 statistic was 0.2022 with one degree of freedom and a probability value of 0.653. Hence we concluded that there was no statistically significant difference in engagement between the treatment and comparison groups. Because of the number of participants it was unlikely to get statistical significance. Thus, we calculated effect size. The effect size was estimated by the odds ratio, which is “a measure of how many times greater the odds are that a member of a certain population will fall into a certain category than the odds are that a number of another population will fall into that category" (Grissom & Kim, 2005, p. 188). This ratio showed the odds of being engaged in the treatment group was 1.68 times higher than being in control group.

For the second problem, there was not a statistically significant difference in engagement between treatment and comparison group PSTs at the 5% significance level (p=.063). The χ^2 statistic was 3.433. However, as shown in Table 2, the odds of being engaged was 2.05 times higher in the treatment group than in comparison group.

Table 2

The Second Problem 2×2 Contingency Table

	Treatment	Comparison
Engaged	17	7
Not engaged	15	20
Total students	32	27
Proportion	0.532	0.259

For both problems three and four, the number of engaged PSTs' was the same: 9 in the treatment group and 2 in the comparison group (see Table 3). There was no statistically significant difference between the groups (p=.089, χ^2=2.89) at the 5% significance level. The odds were 3.79 times higher if PSTs received instruction and practice in dealing with misconceptions.

Table 3

The Third and Fourth Problems 2×2 Contingency Table

	Treatment	Control
Engaged	9	2
Not engaged	23	25
Total students	32	27
Proportion	0.282	0.074

Implications

It is important in preservice education to provide as much authentic practice as possible before the PSTs start to teach. A high-quality teacher education program should include an integration of content and pedagogy aimed at teaching in today's diverse classrooms. If teachers have deep knowledge of the mathematics that they will teach, it is more likely they will be able to help their students to understand and solve mathematics problems.

We have previously identified misconceptions as one of the key factors in PSTs' development of teaching diverse students (Kulm et al., under review). If preservice teachers are exposed to instruction on how to identify and address misconceptions, they can learn how to assist students and correct their own misconceptions. In this study, we showed how important and difficult it is for PSTs to learn how to engage students in thinking about typical mathematics misconceptions. The results for the first research question indicate that even given extensive instruction and practice, most of these PSTs did not do well in engaging students. Only one of the four problems had a majority of the participants able to ask students to think about the problem. We are continuing to explore our data to find explanations and intervening variables that might account for this finding. One obvious possibility is the heavy cognitive challenge of simultaneously learning problem solving, strategies for teaching diverse students, and approaches to dealing with student misconceptions.

For the second research question, we found some evidence that the treatment was effective due to the effect size estimate. Even though the differences between treatment and comparison groups in three of the four math problems were not statistically significant, the results showed large effect sizes. Hence, we believe that there was indeed evidence of the benefit of being introduced to misconceptions in the context of culturally relevant math problem solving. The proper balance of learning problem solving heuristics and learning about how diverse students think and solve problems is an ongoing challenge in preservice mathematics education. We believe, however, that the activities that we have developed are a reasonable first step in addressing this challenge.

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Acknowledgements

This project is funded by the National Science Foundation grant #1020132. Any opinions, findings, and conclusions or recommendations expressed in these materials are those of the authors and do not necessarily reflect the views of the National Science Foundation.

QUESTIONING ELEMENTARY STUDENTS IN AN INTERDISCIPLINARY LESSON IN SCIENCE AND MATHEMATICS

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Creating integrative approaches and fostering connections between science, technology, engineering and mathematics (STEM) continues to be a challenge for educators. Whole class discussion might be a way to bridge these disciplines subjects. In this session, we explore the questions two elementary school teachers asked while they orchestrated a whole class discussion during an interdisciplinary lesson. More specifically, we investigated the kinds of questions that students were asked in terms of their cognitive demand and explored whether these questions lead to convergent or divergent answers. We were also interested to know the kinds of knowledge and processes that these questions elicited.

Introduction

Many studies underline the challenges faced by educators to maintain students' interest and achievement in mathematics (M), science (S) and technology (T) courses (Davis, 2003; Gibson & Chase, 2002). It is therefore important to develop MS&T teaching practices that connect to the students' daily reality. As mentioned by the *Conseil de la science et de la technologie* (CST, 2004), when teaching science courses, it is important to use approaches that are based on "discovery and production pedagogy, experimental and contextualized learning situations" (p. 68). Making sense of the different concepts presented in a complex contextualized learning situation might contribute to develop the disciplinary content for more than one disciplinary (Fourez, 1997; Savard, 2011). Thus, an interdisciplinary approach may improve the integration of M in S&T courses and vice versa. These approaches support the Ministry of Education of Québec's (MEQ, 2004; MELS, 2007) current expectations to promote contextualized teaching methods as well as open and integrated situations, but the Ministry does not indicate how to implement these teaching strategies.

New MS&T programs in elementary and secondary schools promote an interdisciplinary approach while Quebec universities offer teachers a monodisciplinary approach (Samson, 2013). Moreover, some teachers of MS&T seem to experience difficulty with the changes brought about by educational reform, especially regarding new approaches to support students' learning. The complexity of these approaches and their relevance in students' lives are both factors to consider in MS&T integration. We consider that complex interdisciplinary learning situations provide a context for tasks of high cognitive demand. As Stein, Schwan Smith, Henningsen, & Silver (2009) pointed out, a mathematical task might have four levels of cognitive demand. Memorization tasks and activities without connections tasks are considered low cognitive demand tasks. By contrast, activities with connection tasks and doing mathematics tasks are considered high cognitive demand tasks. These tasks involve developing a deeper understanding of mathematics by making connections or by exploring some concepts or processes. The level of cognitive demand is higher. Thus, it is a great opportunity to develop mathematical and scientific/technical understanding.

Objectives of the study

The objectives of this study are to examine the questions two elementary school teachers used in an interdisciplinary learning situation that they created. More specifically, we wanted to know the kinds of questions that were asked of elementary students in term of cognitive demand. We were interested to know the kinds of knowledge and processes were required of the students as a result of these questions and whether the questions were closed or open. We were also interested to find out whether the questions lead to convergent or divergent answers by the students.

Theoretical Framework and Related Literature

Whole class discussions are seen as a productive tool for learning mathematics (Ball, 2009; Lampert, 2010) and science & technology (Thompson, 2013). Thus, discussing important ideas in mathematics might get students to understand them (Lampert, 2012). Teachers facilitate a whole class discussion by eliciting students' thinking in order to construct knowledge:

> In the back-and-forth routine dialogue among students and teacher that occurs in these kinds of routine interactions, the work of the teacher is to deliberately maintain focus and coherence as key mathematical concepts get 'explained' in a way that is co-constructed rather than produced by the teacher alone. (Lampert et al., 2012, p. 131)

Eliciting students' thinking is mainly done by questioning them, by asking them to voice what they think. When a student tells his/her ideas or solution, the teacher may consider pressing the student to get him/her and other students to think deeper about an idea or unpack it further (Ghousseini, 2009). The teacher might also want to have more students participate in the discussion and might ask another student to restate an important contribution or add onto what was said (Stein, 2009). A teacher's actions in order to orient a student's thinking to support the construction of new mathematical ideas has been termed, *ambitious teaching practices* (Ball, 2009; Kazemi, 2009). Four keys ambitious practices have been identified in science & technology (Thompson, 2009; Thompson, 2013). The first practice, selecting big ideas/models, refers to a teacher's ability to identify and select concepts instead of topics in the curriculum. This practice is important, because it creates clear instructional goals focused on specific concepts and thus teachers will be able to guide students learning. The second practice, working with science ideas, refers to a teacher's ability to support his/her students in understanding that science is constructed with models and theories instead of a set of facts. The third practice, pressing students for evidence-based explanations, refers to a teacher's ability to guide his/her students on connecting causes of events and processes instead of only looking for trends and patterns in the data. Thus, the teacher supports students to use observation to give causal explanations (Windschitl, 2011). The fourth practice, working on students' ideas, refers to a teacher's ability to elicit students' thinking and use of this information to make decision about his/her interventions.

Methodology

For this study, we used a multiple case studies method (Merriam, 1998; Stake, 2000). Two elementary school teachers agreed to be video-recorded when teaching an interdisciplinary learning situation that they individually created. Both teachers were aware of our research focus of teacher questioning. The teachers were not at the same school and chose the concepts to be learnt by students independently. We conducted interviews before and after each learning situation. However, in this paper, we will not present the data from these interviews. Rather, we will focus on the video data. Our first case, Helen, taught a Grade 5/6 split classroom. She had 7 students in Grade 5 and 17 students in Grade 6. Helen wanted students to learn about capacity in science, because she was disappointed with her students' performance on a math test on volume. Our second case, Marta, taught a Grade 3/4 split classroom. She had 12 students in Grade 3 and 9 students in Grade 4. Marta wanted students to learn scientific concepts (e.g., reproduction, abiotic and biotic factors and mass) through a unit investigation on a clementine. Marta also wanted her students to use mathematics concepts in investigating the clementine (e.g., circumference, volume, fraction and statistics).

We watched the videos many times and studied the accompanying transcripts by analyzing the teachers' questions and whole class discussions. We started first by identifying which kind of knowledge the questions were aimed for: declarative, procedural or conditional knowledge (Samson, 2004). According to many authors (e.g., Tardif, 1997; Samson, 2004), the learning process implies linking declarative knowledge (What?), procedural knowledge (How?) and conditional knowledge (Where? When? and Why?). Often, it is declarative knowledge that is taught in schools at the expense of conditional knowledge. Yet it is the latter that promotes the transfer of learning between home and school or between disciplines as is the case here with mathematics and science and technology. A reflection is needed on the type of question and the expected conditional knowledge to promote particular responses. Knowing the different kinds of knowledge helped us to identify the cognitive demand of the question. Then, we looked at their degree of openness (Maulini, 2005) and we determined whether each question was open or closed. A closed question (e.g., In which town was the scientist who…born?) has a limited number of answers, whereas an open question (e.g., Which method can you use to find the density of this object?) is aimed more at reasoning and often has many possible answers. Open questions also require students to reflect and mobilize a variety of resources. Finally, we examined whether the questions asked for a convergent or divergent answer (Maulini, 2005).

Results and Discussion

At the beginning of the whole class discussion, Helen was standing in front of the classroom holding a transparent bag filled with water. Swimming in the water were two goldfish. She then explained to the students that she bought the fish to put in the class' aquarium where two turtles already lived. Helen told her students that she had bought the fish to be eaten by the turtles, but she did not know how many fish to buy given the amount of water in the aquarium. Helen then asked the students to calculate how many fish she could put in the aquarium. She started the discussion with a leading question that connected with topics in the science curriculum: "How many fish can we put in the classroom's aquarium?" One student responded: "One fish per 1 cubic decimeter". The teacher then continued to question the student by focusing on her mathematical knowledge: "What is a cubic decimeter?" The student replied that it was 10 centimeters. Helen then asked the rest of the class if someone might help complete the student's answer. The teacher led a whole class discussion on how to find the volume of the aquarium. Thus, in this episode, the students had to estimate the capacity of the aquarium, measure the aquarium, multiply the measurements (which were in decimal numbers) and then round the answer to the nearest whole number. The kinds of questions that Helen asked her students required a combination of low and high cognitive demand. Questions requiring low cognitive demand focused on students' declarative knowledge, which were based on memorization. Conversely, questions requiring high cognitive demand focused on students' procedural knowledge. Table 1 presents examples of questions asked by Helen and the kinds of answers expected based on the kind of questions that she posed.

Table 1

Some examples of Helen's questions

Cognitive Demand	Cognitive Process Dimension	Kind of question	Examples of questions asked by the teacher	Lead to convergent or divergent answers
Low: Memorization	Declarative knowledge	Closed question on previous knowledge She launched the task	What is a dm^3?	Convergent
Low: Procedures without connections	Procedural knowledge	Closed question on previous knowledge She guided students process	Is there something you learned that you could use?	Convergent
High: Procedures with connections	Procedural knowledge	Open question on procedure She elicited students thinking	You think that with a ruler we can know it? How can we do that?	Convergent with some room of divergence on the procedures

Helen did not ask questions that allowed students to explore volume on their own. Given the fact that this lesson was presented in the last third of the year, students had already covered the concept. Thus, she was able to ask mathematics question that required a higher cognitive demand. However, Helen pressed the students by asking clarification questions (*Is this what you meant?*) and by orienting students to each other (*Do you agree with Ellie?*) (*Can you rectify what we are going to write?*). After finding the answer 30 dm^3, Helen came back to the initial answer 2 fish /dm^3 and asked if they could put 60 goldfish in the aquarium. She then brought the students back to the context of science by guiding the students to think about living space for their turtles and the oxygen needed. Helen asked her students to make a hypothesis on the number of fish that could live in the aquarium. She used the fourth ambitious teaching practice on working on students' ideas to elicit students thinking and used this information to make a decision about her intervention. In the case of Helen, we noticed that she pressed on some hypotheses, but she did not come with a final conclusion on her leading question. She ended the lesson without having a common understanding on what correct answers might be for the initial problem that she posed. In general, the questions Helen asked her students were mostly open according to the typology of Maulini (1995). These are reasoning questions (requiring observation, the mobilisation of different resources, etc.), open questions (many possible answers, eliciting reflexion, stimulating research, expressing ideas, judgments, etc.) and guided questions (connected to the learners approach and process, etc.). Furthermore, she asked very few open or divergent questions that would allow analogies, syntheses, deductions and evaluations (allowing the implementation of inference operations, of high conceptualization, etc.) or even less questions based on the four high cognitive levels; apply, analyse, synthetize and evaluate. The only time she asked high cognitive demand questions was in the context of science. Marta, on the other hand, based her activity on a document call *Opération Clémentine* (in French). Each student had this document, which contains different tasks in mathematics and science. Marta launched the task with a leading question on how to calculate the cost of clementine. Then, she gave one clementine to each pair of students. Students were asked to observe and sketch their fruit using words on the handout. Then, still working in pairs, the students were asked to answer the written questions on their sheet on mass and volume using circumference. Different materials were available for students to use, such as a ruler, a scale, and bowls. Students were also asked to peel the fruit and count the slices. They had to record this data on a table and record other students' answers as well. As the students were working, Marta walked around in the classroom and asked open and closed questions to make students think (Do you have the right measurement tool?) and make sure they were using a correct procedure (Which problem do you have with the bowl?). After a while, Marta led a whole class discussion on how to find the circumference of the clementine. While some students calculated the volume with a bowl, others completed their calculations by using a ruler. The kinds of questions Marta asked her students might be considered as low and high cognitive demands. Marta used questions that required low cognitive demand and elicited on students' declarative knowledge, which were based on memorization, as well as questions that required a high cognitive demand and elicited on students' procedural knowledge. Table 2 of questions asked by Marta and the kinds of answers expected based on the kind of question that she posed.

In the case of Marta, she ran out of time thus did not conclude properly the lesson. She pressed on some hypotheses, but she did not come with a final conclusion on her leading question. Marta ended the lesson without having a common understanding on what correct answers on defining mass and volume and on procedures about mass and volume using circumference. In general, Marta asked more closed questions (Maulini, 1995) than Helen. But these closed questions were in fact guiding questions for students to find the answers using the resources provided, including their peers. The whole class worked as a community of learners.

Table 2

Some examples of Marta's questions

Cognitive Demand	Cognitive Process Dimension	Kind of question	Examples of questions asked by the teacher	Lead to convergent or divergent answers
Low: Memorization	Declarative knowledge	Closed question on previous knowledge She launched the task	Does your answer will be in meters?	Convergent
Low: Procedures without connections	Procedural knowledge	Closed question on previous knowledge She guided students process	What did you want to do at the beginning?	Convergent
High: Procedures with connections	Procedural knowledge	Open question on procedure She elicited students thinking	How can you share your clementine in two if you have 11 slices?	Convergent with some room of divergence on the procedures

Like Helen, Marta asked very few open or divergent questions that would allow analogies, syntheses, deductions and evaluations (allowing the implementation of inference operations, of high conceptualization, etc.) or even less questions based on the four high cognitive levels; apply, analyse, synthetize and evaluate. The only time she asked high cognitive demand questions was within the context of mathematics. In both cases, the teachers mainly asked questions on declarative or procedural knowledge. Helen and Marta asked very few questions requiring conditional knowledge, mainly by asking why to students. It is interesting to observe that because both teachers were teaching two grades of students in one classroom: Helen (Grades 5 & 6) and Marta (Grades 3 & 4), they used their questioning in a way such that the older students might support younger students in the same classroom. Thus, the questions were asked to support students, not for the purpose of summative assessment.

Implications

This study will support future professional development initiatives for teachers. Our participants were interested in developing their questioning skills. They wanted to know if they asked good questions and whether they asked too many or not enough questions. Teaching science and mathematics concepts within the same lesson also concerned them. The teachers appreciated an interdisciplinary approach to teaching and wanted to do more of it. This was even true for the teacher who felt insecure about her knowledge of science. The continued interest by our teachers and the need for additional professional development and support points to a need to continue our work in researching, developing or adapting a framework on questioning in an interdisciplinary context. As our results suggest that the “weight” of the discipline could influence the type of questioning, we want to find out if one discipline dominates the other and why.

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