Curriculum, Instruction, and Foundational Studies Faculty Publications and Presentations

Department of Curriculum, Instruction, and Foundational Studies

6-26-2011

Connecting Science with Engineering: Using Inquiry and Design in a Teacher Professional Development Course

Louis S. Nadelson
Boise State University

Patricia Pyke
Boise State University

Janet Callahan
Boise State University

Anne Hay
Boise State University

Joshua Pfiester
Boise State University

See next page for additional authors

Authors

Louis S. Nadelson, Patricia Pyke, Janet Callahan, Anne Hay, Joshua Pfiester, and Mark A. Emmet

AC 2011-441: CONNECTING SCIENCE WITH ENGINEERING: USING INQUIRY AND DESIGN IN A TEACHER PROFESSIONAL DEVELOPMENT COURSE

Louis S. Nadelson, Boise State University

Louis S. Nadelson is an Assistant Professor in the College of Education at Boise State University. His research agenda is conducted within the context of STEM education and includes aspects of conceptual change, inquiry, and pre-service and in-service teacher education. He has published research ranging from teacher professional development to the impact of inquiry on STEM learning. Dr. Nadelson earned a B.S. degree in Biological and Physics Science from Colorado State University, a B.A. with concentrations in computing, mathematics and physics from The Evergreen State University, a Secondary Teaching Certificate from University of Puget Sound, an M. Ed. in Instructional Technology Leadership from Western Washington University and a Ph.D. (research-based, not theoretical) in Educational Psychology from the University of Nevada, Las Vegas.

Patricia Pyke, Boise State University

Patricia A. Pyke is the Director of the STEM Station at Boise State University. The STEM Station in a university-level initiative to build a STEM community where students and faculty are connected to the resources and support they need to achieve their individual goals in education, career, teaching and research. Her role as director for the STEM Station builds on previous work managing research projects and initiatives in STEM student success, K-12 engineering and integrated STEM programs. She earned a B.S.E. degree in Mechanical Engineering from Duke University and a master's degree in journalism from the University of California, Berkeley.

Janet Callahan, Boise State University

Janet Callahan is the Associate Dean for Academic Affairs at the College of Engineering at Boise State University and a Professor in the Materials Science and Engineering Department. Dr. Callahan received her Ph.D. in Materials Science, her M.S. in Metallurgy and her B.S. in Chemical Engineering from the University of Connecticut. Her educational research interests include freshmen engineering programs, math success, K-12 STEM curriculum and accreditation, and retention and recruitment of STEM majors.

Anne Hay, Boise State University

Anne Hay is the Coordinator of the Idaho SySTEMic Solution, a K-12 research project at Boise State University funded by the U.S. Department of Education. Ms. Hay has more than 25 years of teaching experience in K-12 through college programs, teaching German, English as a foreign language, biology, general science, life science, ecology and music. She received a B.A. and an M.S. in biology from Stanford University and a Teaching Credential from the University of California, Berkeley.

Joshua Pfiester, Boise State University

Joshua Pfiester is a Doctoral Student in Curriculum & Instruction and Graduate Research Assistant. His relevant research interests include understanding the obstacles STEM teachers face in collaboration and disseminating best instructional practices. He completed a M.A. in Elementary Science Education from Fairleigh Dickinson University and a B.S. in Natural Resources Management from Rutgers University.

Mark A. Emmet, Boise State University

Mark A, Emmet is currently the Associate Research Project Coordinator for Idaho SySTEMic Solution, a project funded by the United States Department of Education and administered jointly by the Colleges of Engineering and Education at Boise State University. Mr. Emmet has worked previously as the Professional Development Coordinator for the North Cascades and Olympic Science Partnership, and as Project Manager for the GK-12 'Catalysts for Reform,' two NSF funded projects at Western Washington University in Bellingham, WA. Mr. Emmet also worked as a peer instructor for the 'Physics by Inquiry' Academy in the Physics Education Group at the University of Washington in Seattle, WA. He taught elementary school in the Seattle School District for over a decade.

Connecting Science with Engineering: Using Inquiry and Design in a Teacher Professional Development Course

Abstract

The engineering design process has evolved over time to be the central and effective framework that engineers use to conduct their work. Logically, K-12 STEM professional development efforts have then attempted to incorporate the design process into their work. There has been little in the STEM literature, though, of the explicit measurement of the growth in design process knowledge. Our study presents findings of significant improvements in knowledge of the design process that resulted over the course of a recent summer STEM institute and professional development program among K-5 teachers.

As more emphasis is placed on integrating STEM into the curriculum [1] there is a need to enhance the capacity for K-12 teachers. Responding to this call the Colleges of Engineering and Education at Boise State University collaborated to offer an intensive three-day summer institute to address the preparation of elementary school teachers (grades K-5) to teach STEM curriculum. The focus of our institute was on the use of both inquiry and design as approaches for integrating STEM content. In particular we explicitly stressed the link between science and inquiry and engineering and design, how these processes differ, how they can complement each other and how they can be used instructionally to teach a wide range of STEM content. The instructional materials used in the workshop included Lego®-like bricks called PCS BrickLab® (supplied by PCS Edventures! an educational products company) and other common classroom items such as paper, tape, string, and cardboard.. Each participant received a classroom set of the materials at the close of the workshop. The BrickLab® kit contains over 5,000 bricks which is sufficient to simultaneously engage up to about 30 students in hands-on activities, which makes these instructional materials particularly suitable to facilitate classroom instruction using inquiry and design. We engaged the participants in a series of hands-on activities focused on the inquiry process of manipulating variables to gather data to explain phenomena or design processes that focus on creating and refining the best solution given constraints.

To determine the effectiveness of our workshop we gathered pre and post data to assess our 58 participants' comfort for teaching STEM, their STEM pedagogical discontentment, their implementation of inquiry curriculum, and their knowledge of the design process. Our initial results indicate significant increases in comfort teaching STEM ($t = 12.761$, $p < .01$), decreases in STEM pedagogical discontentment ($t = 7.281$, $p < .01$), and increases in design process knowledge ($t = 6.072$, $p < .01$). Delayed post data collection for the implementation of inquiry took place in Fall 2010, which allowed time for the participating teachers to apply their learned knowledge and develop a post conference context for their instructional practice with students. All instruments used for data collection were extant and had established reliability and validity.

Our results indicate that our three-day summer institute and follow-up support increased our participants' knowledge of design along with comfort for teaching STEM. Also, the institute decreased the teachers' pedagogical discontentment for teaching STEM.

Introduction

According to the President's Council of Advisors on Science and Technology, "STEM education will determine whether the United States will remain a leader among nations and whether we will be able to solve immense challenges in such areas as energy, health, environmental protection, and national security." The increasing commitment by American industry and the Obama Administration to Science, Technology, Engineering, and Mathematics (STEM) is further illustrated by the *Change the Equation* initiative (http://www.changetheequation.org). Key to achieving the goals of comprehensive STEM education initiatives is attending to the essential variables that contribute to developing highly capable and inspirational STEM teachers. Using the extant literature, our experience, and the needs communicated by the K-5 teacher community, we identified a number of these essential cognitive, affective and pedagogical variables and used them as a guide to refine the SySTEMic Solution, a professional development program designed to enhance the STEM teaching capacity of teachers grades K-5.

The Idaho SySTEMic Solution program is a multifaceted STEM education professional development endeavor that has focused on implementing best practices, inquiry, and design, in the context of hands-on activities to teach STEM content. The professional development provided opportunities for the participating K-5 teachers to enhance their use of scientific inquiry and the engineering design process as instructional approaches to teach a wide range of STEM content. We are in the third year of our research and development of this teacher education program. The strength of our K-5 teacher professional development offering comes from using the joint perspectives of educators and engineers to create and implement the program.

Our professional development project is unique because it specifically addresses the needs of K-5 teachers, a population under-represented in the STEM professional development literature. Further, we provide a unique contribution in our exploration of how K-5 teachers develop an understanding of scientific inquiry and the engineering design process. There is a dearth of literature investigating how K-5 teachers develop understanding of engineering design and scientific inquiry, and their subsequent abilities to utilize these processes in instruction.

The purpose of this paper is to share our research findings related to teacher understanding and intellectual growth in engineering design process and scientific inquiry, two fundamental instructional approaches in STEM education. Before we present our findings we will explore the relevant literature, and following the presentation of our results we will discuss their implications and suggest directions for future research. We conclude with study limitations and frame our findings in the larger context of enhancing K-12 teacher preparation in STEM education.

Teacher Professional Development in STEM Education

Teaching and Learning Scientific Inquiry

A significant conceptual hurdle that should be addressed in STEM education professional development is the perception that science is a rigid and linear process.[1,2] In spite of nearly two decades of efforts to increase awareness of how science takes place,[3,4] many educational publishers continue to offer products (e.g. text books, lab books) that promote a five-step scientific method. Conceiving the processes of science and engineering as following a set of linear prescriptive steps is a common misconception that teachers may hold due to their educational experiences.[5] The report of Buck and colleagues provides support for suggesting that teachers may enter the profession having been taught in a manner that leads them to perceive that teaching and learning science and engineering primarily involves confirming what is already known. Thus, there is warrant to predict that teachers may perceive the processes of science and engineering education as following prescriptive steps that lead toward known conclusions and consequently teach to this approach.

The current implementation of science education frequently involves teaching inquiry as the complex interactions between exploring and testing ideas, feedback and analysis from the community, and the benefits and outcomes of research.[6] The work of Herried is reflective of the attempts to align the processes of science taught in K-12 to the processes taken by professional scientists as they engage in scientific inquiry. However, the wide variety of ways that inquiry is presented in K-12 educational materials[7] and the perception of inquiry as synonymous with doing "good science"[8] may prompt teachers to think that engaging students in any experience that is labeled as inquiry is sufficient to claim they are providing their students with authentic science learning experiences. Teachers perceiving scientific inquiry as a strict linear process could potentially be prompted to, "discount, ignore, or de-value students' existing knowledge, derived from their everyday experience".[9] By not embracing student existing knowledge teachers possibly forego opportunities to address misconceptions, ground new content in student experience, or enhance student appreciation for science. Thus, student learning and engagement in science may be hampered by the potential lack of teacher understanding of processes of authentic scientific inquiry.

The probable constraint of teacher knowledge of scientific inquiry and the reinforcement of their conceptions by instructional materials provide motivation for offering professional development to K-12 teachers designed to expand their knowledge of scientific inquiry. Further, the substantial influence of teachers on their students' conceptions and appreciation of science provides justification for assuring educators are well prepared to teach scientific inquiry and have been exposed to authentic inquiry activities. We posit that professional development for K-12 teachers designed to explicitly present the authentic process of scientific inquiry will enhance their understanding of the process and their perceptions of how to teach inquiry.

Teaching and Learning Engineering Design

Seldom do K-12 STEM professional development efforts include engineering as a focus. Further, in their review of K-12 engineering curricula, the National Academy of Sciences found that engineering was often presented at the service of science or mathematics concepts.[10] While the STEM acronym may suggest fluidity in curriculum and instruction among the four disciplines, "it is more often used as shorthand for science and mathematics education".[10] The

lack of focus on engineering in K-12 teacher preparation and professional development suggests that there may be multiple justifications for providing continuing education opportunities designed to enhance teacher knowledge within this domain. We speculate that the increase in teacher knowledge and instructional implementation of engineering concepts happens most effectively through an explicit presentation and interaction with engineering content and processes.

The K-12 teacher professional development STEM efforts that have focused on the engineering design process have been predominantly designed and targeted toward secondary teachers.[11,12,13] Yet, we argue that the increased awareness and consideration of a more holistic approach to STEM necessitates the preparation of a wider range of K-12 teachers. Further, the engineering design process is an excellent context for engaging young learners in problem solving, project based learning, and collaboration. Thus, there is benefit to preparing K-5 teachers to teach using engineering design though immersing them in activities that simulate authentic engineering processes and require the application of engineering design for completion.

Determining the influence of professional development activities on teacher development of understanding and perceptions of engineering design requires an assessment strategy. While there have been attempts to measure design process knowledge among university students[14], there appears to be a deficit of extant instruments or reported techniques to assess the construct among K-12 teachers. Although the basic concepts of engineering design are well established, knowledge of the applications of these processes is contextual and dependent on experience, leading to wide variations in perceptions of engineering design. Thus, the assessment of various populations' knowledge and perceptions of engineering design should coincide with their anticipated level of knowledge and experience with engineering design. The need to find appropriate methods and instruments for assessing K-12 teacher knowledge of engineering design is of particular interest as the emphasis on engineering in the K-12 curriculum increases. These tools and methods are essential for determining the effectiveness and extent of influence of teacher professional development designed to enhance educators' knowledge of the engineering design process.

Similarities and Differences of Inquiry and Design

The benefits of using scientific inquiry and engineering design for teaching include providing an instructional context for project based learning, affording students the opportunity to elaborate on prior knowledge, and engaging students in learning experiences that parallel the work of experts. While there are certainly similarities between inquiry and the design process, such as testing hypotheses and utilizing research as a foundation to guide exploration, there are also significant differences. The differences are important considerations with regard to how teachers may use these two processes to teach STEM concepts. For example, the focus of the design process on specifications and constraints lends itself well to assignments that require students to create some sort of project, such as a bridge or a tower. Constraints include physical, environmental, and financial factors that limit design options. Trade-offs between sometimes conflicting factors must be resolved during the optimization portion of the design process. Also, unlike inquiry, the results of design processes rest in part on personal values and may vary depending on the perspective of the individual or group.

In contrast scientific inquiry focuses on gathering empirical evidence to support a hypothesis and further develop an explanation of a natural phenomenon. Constraints and specifications are not a consideration other than the limitations imposed by nature or the instruments and processes that are used for investigation that bound the possibilities. As an instructional method scientific inquiry is effective because it is aligned with how people naturally explore their environment and it provides a lot of opportunity for exploration of related facets of targeted phenomena. In instruction scientific inquiry may be utilized to explore situations such as the growth of plants, friction between surfaces, and heating and cooling of liquids. Scientific inquiry as an instructional method provides teachers a means of structuring student approaches to learning and investigating natural phenomena.

Scientific inquiry and engineering design are symbiotic in STEM fields that complement each other. For example, scientific inquiry may be implored investigate the properties of materials may then be used to inform engineering design specifications. We can capitalize on this symbiosis in STEM education anticipating that there are a number of potential benefits along with the ability to attend to a broad diversity of instructional goals and learning outcomes when scientific inquiry and engineering design are utilized for teaching STEM. Further, the overlap and divergence in the kinds of learning activities that can be attended to by scientific inquiry and engineering design suggest teachers' knowledge of these approaches and their ability to effectively use them can substantially enhance their students' STEM learning. The anticipated constrained knowledge by teachers of scientific inquiry and engineering design and the likely benefits to student learning from engagement in these processes provide the justification for assuring that teachers understand inquiry and design and are prepared to apply them effectively and appropriately as instructional approaches.

The parallels and differences between scientific inquiry and engineering design as applied to instructional methods are summarized in Table 1. The process flow of "Planning," "Observation and Testing," and "Reflection and Communication" build on the work by Bedward and colleagues who explored the integration of design into elementary curriculum.[15]

Table 1: *Comparing Inquiry Based Science and Engineering Design*

Inquiry Based Science	Engineering Design
Planning	
1. Describe the questions 2. Research the question 3. Justify data collection approach 4. Make predictions 5. Explain predictions 6. Design an experiment	1. Define the need/problem 2. Research problem & related designs 3. Define constraints 4. Brainstorm design alternatives 5. Justify optimal design 6. Create a prototype
Observation and Testing	

1. Describe materials and methods 2. Record observations 3. Replicate and seeks sources of error/variation in results	1. Test and evaluate prototype of design 2. Make modifications and redesign 3. Replicate and identify potential failure modes and scaling considerations
Reflection and Communication	
1. Does the data answer the research questions 2. Pose hypothesis 3. Explain, compare, and present findings 4. Consider ethical and broader impacts	1. Determine if design meets needs and/or solves the problem 2. Communicate with "customer" 3. Explain, compare, and present findings 4. Consider ethical and broader impacts

Teacher Implementation of Innovation

There are multiple potential influences on teachers' effective implementation of the innovative practices associated with teaching scientific inquiry and engineering design. Because most K-5 teachers have received minimal education and preparation in STEM[16] there is reason to anticipate they need significant assistance to orient their instructional practice around inquiry and the processes inherent in engineering design.[17] Perhaps one of the most revealing gauges of preparation for implementation is the level at which teachers are comfortable with their pedagogy.[18] Teachers' implementation of innovation may be hindered by their knowledge of STEM content, scientific inquiry, assessment, understanding of the Nature of Science, and working with a wide range of learners. We posit that well orchestrated teacher professional development should be designed to address the potential barriers to effective instruction of scientific inquiry and engineering design. Further, an assessment of teacher contentment with their practice (in the context of STEM) is an effective means of determining the extent to which such professional development offerings influence teacher preparedness in teaching STEM.

Methods

We designed and implemented a three-day summer institute to enhance the participating K-5 teachers' knowledge and capacity to teach scientific inquiry and engineering design. To determine the effectiveness of the combination of interactive lectures, small group workshops, and team planning on the participants' knowledge and preparation to teach using inquiry and design we utilized a variety of instruments. Using a pre-test, post-test and delayed (four months) post-test approach to data collection, we sought to quantify and qualify the influence of the summer institute. We used the following questions to direct our research:

- *Were there changes in participants' levels of comfort with teaching STEM and in their pedagogical discontentment over the course of the institute?*
- *Did the participants knowledge of the design process change over the course of the summer institute?*
- *Did the participants' perceptions of their inquiry implementation as an instructional process shift over time?*

- *Did the participants' comfort for teaching STEM, knowledge of the design process, and pedagogical discontentment shift over time?*

We anticipated that the summer institute and subsequent expectations and support of teacher implementation of content would substantially increase our participants' knowledge of and preparation for teaching STEM content using scientific inquiry and engineering design. Further, the increased knowledge and preparation would remain relatively static from the immediate post-test to the delayed post-test.

Participants

The participants in our research were recruited from the teachers engaged in our 2010 summer institute. The institute participants were K-5 teachers who work in six elementary schools in the Meridian Joint School District, the largest school district in Idaho, and one representing socioeconomic diversity. The mean age for teachers was 41.7 ($S = 10.4$) years old with 11.5 ($S = 7.8$) years of teaching experience. Ninety percent were female. The majority (87%) taught at a K-5 school with a smaller proportion working in K-8 schools (10%) or PreK-5 schools (3%). The participants had completed an average of 3.6 college level mathematics classes and 3.2 college level science classes. Eighty-four percent declared a major endorsement in elementary education with other relevant major endorsements including biology or life science (3%), physical science (1%), and mathematics (1%). The school principals attended relevant portions of the institute as their schedules allowed. Although 63 teachers participated in the summer institute, we were only able to match the pre, post, and delayed post on all of our measures for 47 of our participants using their phone code and demographics.

Institute Structure and Content

The curriculum on scientific inquiry and engineering design for the summer institute was jointly developed by personnel from the College of Engineering and College of Education at Boise State University. Using our prior experience with K-5 teacher professional development and the literature as a guide, we focused the content of the institute on enhancing teacher capacity to use scientific inquiry and engineering design to teach STEM content. To teach the processes we utilized a combination of interactive lecture, hands-on STEM activities, and grade-associated breakout sessions. Each of these activities integrated STEM content and engaged the participants in some level of scientific inquiry or engineering design, which allowed us to model integrated content and pedagogy.

An example of a hands-on STEM activity that incorporated the engineering design process was the Mars Lander Challenge, adapted from a lesson in the NSF sponsored Teach Engineering program.[19] In this activity teacher cooperative groups were challenged to design a landing craft from paperclips, construction paper, adhesive tape, and plastic building bricks. The challenge was to create a "planetary lander" that, when dropped from a two story height, had the flight stability to land at a specified target region. The relative success of the lander was determined by a mathematical formula which included variables representing flight time, proximity to the target, and payload. The activity was structured to engage the teachers in a process of optimization, as the participants were encouraged to make modifications to their

landers and test the results. Other design activities included using finite materials maximizing the height of a tower built on an inclined plane, and the construction of a bridge that could span the greatest distance and support the maximum mass.

We also engaged the participants in a variety of activities to enhance their knowledge and understanding of the use of scientific inquiry for teaching STEM. For example, we had the participants create simple paper helicopters to explore elements of gravity, air resistance and pressure differentials. To help them gain an understanding of the associated concepts we had them make modifications to their copters (e.g. shorten wings, reverse wing folds, make a larger copter). Participants made observations, then, based on their knowledge and experience, developed and tested explanations to develop hypotheses to explain the phenomena. Our goal with these activities was to model inquiry instruction and increase teacher curiosity about natural phenomena, inspiring them to explore these events with their students. Interestingly, the teachers engaged in this activity the day before the planetary lander activity, and they used their observations about physical phenomena to inform their lander designs.

The summer institute was followed by continuing support throughout the school year. During the academic year, the participating teachers are expected to teach inquiry STEM lessons they develop themselves or adapt from a depository of lessons developed by their peers. The teachers are observed twice by research personnel, who also act as coaches for the teacher participants and provide them with written feedback for each of the observed lessons. Mentor teachers in each school provide day-to-day support for the teachers and also organize lesson writing workshops and other forums in their schools, with support from university researchers and educational consultants.

To determine the impact of our summer institute curriculum on the participants' perceptions of inquiry instruction, knowledge of engineering design, and pedagogical development we pre-tested, post-tested, and delayed post-tested them using a spectrum of measures.

Measures

Demographics. Each teacher completed a pre- and post-test and the statistical outcomes resulted from matched scores. In our demographics survey we included a single item in which we asked participants to rate their comfort with teaching STEM curriculum on a scale of 1 "Very Uncomfortable" to 10 "Very Comfortable." Items similar to these have been used in prior research and have generated data that were highly correlated with the outcomes of instruments with established reliability and validity gathering data to measure the same construct or variable.[20]

Pedagogical discontentment. To assess our participants' pedagogical discontentment for teaching STEM we modified the 21 item Science Teachers' Pedagogical Discontentment Scale (STPDS).[18] Each teacher completed a pre- and post-test and the statistical outcomes resulted from matched scores. The intended use of this instrument is to determine the effectiveness of professional development on pedagogical discontentment. The STPDS asks teachers to rate their level of pedagogical discontentment on a five point Likert scale to statements such as "Teaching

science to students of lower ability levels." The scale ranges from "1" presenting "no discontentment" to "5" representing "very high discontentment." The STPDS does have six subscales, which can be examined separately or in the aggregate. We modified the scale by replacing the word "science" with "STEM" to create items such as, "Teaching STEM to students of lower ability levels." Many of the items, such as "Monitoring student understanding through alternative forms of assessment" required no modification. Southerland and colleagues established the validity of the instrument through interviews with science teachers and feedback from teacher professional development experts. The reliability of the instrument was established to have a .95 Cronbach's alpha with the subscales Cronbach's alphas ranging from .77 to .89, which indicates a good to high level of instrument reliability.

Inquiry implementation. To assess our participants' instructional practices with inquiry implementation we used a modified version of the Inquiry Science Implementation Scale (ISIS).[21] This instrument instructs users to respond to the prompt, "When you teach science, how frequently do you:" to each of the 22 items. The items include statements such as, "demonstrate the use of a new instrument?" and "ask students to make predictions about an experiment?" Participants rate their perception of their implementation on a five point Likert scale ranging from "1" representing "never" to "5" representing "always." We modified this scale by adjusting the prompt to read "When you teach STEM, how frequently do you:" but did not change the item questions. The instrument has established validity and a Cronbach's alpha reliability of .80.

Perceptions and practices of STEM teaching. To determine the participants' perceptions and practices of STEM teaching we utilized the *Perceptions and Practices in STEM Education,* an extant instrument that contained a six item free response section.[22] We wanted to collect data that would allow us to establish how the participants defined STEM, collaborated to teach STEM, their motivation to teach STEM, engagement in STEM professional development, the nature of their implementation of STEM curriculum, and how access to resources influenced their decisions to teach STEM. The survey items were generated by Nadelson and colleagues to assess the potential barriers to teaching STEM and the influence of professional development on teacher knowledge and practices in STEM education. Instructions asked participants to respond to questions such as, "How do you define STEM?" and "How do you collaborate with others when teaching STEM content?" and "What kind of social/professional networking do you engage in to gain support for teaching STEM content?" The participants are instructed to answer by providing the detail necessary to allow a reader to fully understand their perspectives.

Design Process Knowledge. To assess our participants' knowledge of engineering design we adapted and adopted items from an extant instrument, *Design Process Knowledge Test*, validated for undergraduate engineering majors.[23] The original instrument used a selected response format to assess engineering design knowledge across a range of related concepts. Because of the difference in our study population, K-5 teachers, we determined it necessary to screen the items in the instrument and select only those that were aligned with general knowledge of engineering design and remove idiosyncratic definitions or engineering education process. The resulting instrument contained 18 items such as, "Which of these is the best definition of engineering design?" and "Which is not a benefit of preliminary design or prototype?" and alternatives that represented a range of possible views, from naïve or misconceived to informed. Our version of the instrument also included several items such as, "Successful design involves breaking a problem down into smaller problems" which required

responses along a Likert type scale ranging from "1" which represented "Almost always true" to 5 which represented "Almost always false" and included "I don't know." The authors of the original instrument report a Cronbach's alpha of .84 indicating a good level of instrument reliability.

Procedure

We utilized a web-based survey site to administer our surveys. We emailed a request to the participants to complete the surveys prior to attending the summer institute. Each participant was instructed to create and consistently use a 5-digit identification code for each of the surveys as a unique identifier which allowed us to track responses. However, we took into consideration the possibility that some of the participants might not recall the same code over time and therefore collected demographics with each round of data collection to provide an additional means of tracking responses. Post-testing happened immediately following the summer institute on site. The delayed post-test took place four months later using the same process we used to pretest, by sending emails to the participants, requesting their involvement and effort to complete the surveys.

Results

Instrument reliability. Prior to our analysis to address our research questions we calculated the reliability for each of our study instruments. Our reliability analysis revealed the Inquiry Implementation Scale to have a Cronbach's Alpha of .94, the Design Process Knowledge Test had a Cronbach's Alpha of .78, and the Pedagogical Discontent measure had a Cronbach's Alpha of .95. Our reliability analysis confirms that the instruments had good to excellent reliability, allowing us to proceed with our analysis with confidence that our instruments performed consistently and as expected.

Comfort and pedagogical discontentment. Our first research question asked: *Were there changes in participants' levels of comfort with teaching STEM and in their pedagogical discontentment over the course of the institute?* To address this question we conducted a paired samples t-test using the pre- and post-institute scores for comfort and pedagogical discontentment. Our results revealed a significant increase in comfort, $t(46) = 11.17$, $p < .01$ from a pre-test mean of 3.88 ($S = 2.48$) to the post-test average of 7.11 ($S = 1.92$), an effect size of .74 partial eta squared. Our results suggest that the teachers gained in their comfort level for teaching STEM as a result of their participation in the summer institute.

Our analysis of the teachers' pedagogical discontentment revealed a significant shift from pre- to post-institute as well, $t(46) = 6.31$, $p < .01$. The pre institute composite score was 42.93 ($S = 15.15$) while the post-institute score was 35.07 ($S = 12.16$), an effect size of .47 partial eta squared. Our results indicate a substantial decrease in discontentment with teaching STEM after attending the summer institute.

Design process knowledge. Our second research question asked: *Did the participants knowledge of the design process change over the course of the summer institute?* To answer this question we examined the participants' composite scores on our modified Design Process Knowledge Test. Our paired samples t-test analysis revealed a significant increase in design knowledge $t(46) = 4.94$, $p < .01$, with the pre-institute composite scores 10.17 ($S = 3.60$) shifting

upward post-institute to 12.91 ($S = 2.07$), a .35 partial eta squared effect size. Our results indicate that participation in the institute substantially increased the participants' knowledge of the design process.

Inquiry implementation. Our third research question asked: *Did the participants' perceptions of their inquiry implementation as an instructional process shift over time?* To answer this question we examined the participants' composite scores for inquiry implementation for pre-institute and delayed-post, as the immediate post scores would not have allowed the participants time to actually implement inquiry as an instructional strategy. Our paired samples t-test analysis revealed a significant increase in inquiry implementation, $t(46) = 4.43$, $p < .01$, with the pre-institute composite scores 61.02 ($S = 31.45$) shifting upward post-institute to 82.26 ($S = 14.85$), an effect size of .32 (partial eta squared). Our results indicate that our participants perceive that they are engaging in the processes associated with inquiry instruction to a much higher degree post-institute than they did prior to the summer institute.

Change over time. Our fourth research question asked: *Did the participants' comfort for teaching STEM, knowledge of the design process, and pedagogical discontentment shift over time?* To answer this question we conducted a paired-t test analysis using the immediate post-institute scores and the delayed post-institute scores. Our results revealed no significant differences which indicates that the detected shifts in comfort teaching STEM, knowledge of the design process, and pedagogical discontentment were sustained and did not trend back toward the pre-institute levels. Thus, the change in our measures were lasting and with indications of permanent change.

Perceptions of STEM teaching. Our final research question asked: *What were the participants' perceptions of STEM education and their implementation of STEM in their educational settings, and did these perceptions change from pre- to post-institute?* To answer this question we scored responses to the *Perceptions and Practices in STEM Education* instrument according to the instrument developers.[22] Seeking to expose shifts in knowledge and perceptions over the long term, we utilized the researchers' scoring rubric to rank and categorize the responses for the pre- and delayed post-surveys.

The guidelines for scoring the *Perceptions and Practices in STEM Education* provided by Nadelson and colleagues[22] (under review) instruct users to segregate the responses into two general categories, one with responses to ordinal items and the other with responses to nominal responses. Both groups contain items reflective of participant knowledge and practice of STEM education.

Ordinal response group. The outcomes of this analysis are presented graphically along with examples of responses in figure 1. Our analysis revealed trends indicating shifts toward greater knowledge of STEM and implementation of STEM in their curriculum. Our analysis also suggests that the participants' motivation to teaching STEM and perceptions of the influence of resources on teaching STEM remained relatively static.
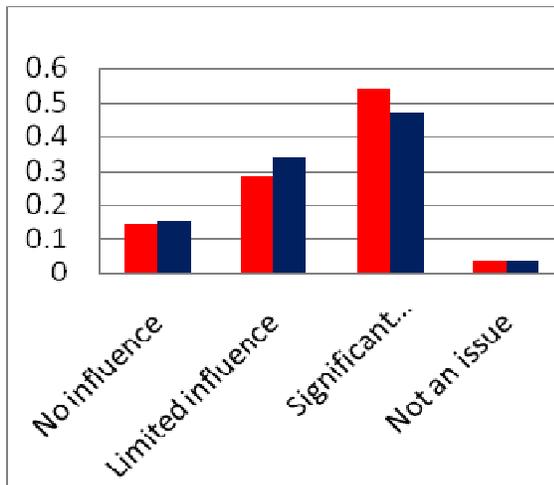
How would you define - STEM?
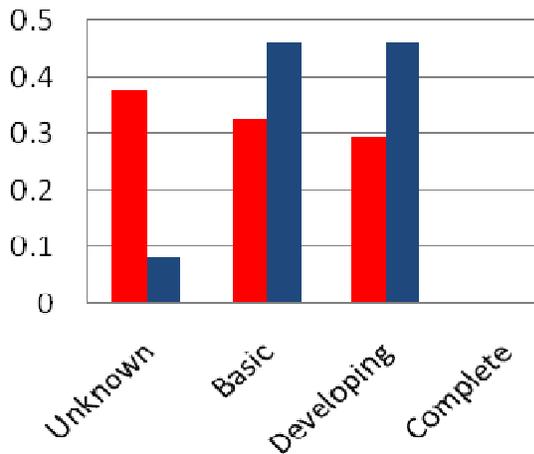
Unknown	*I have not been introduced to this term before.*
Basic	*Science, technology, engineering, and math. That is about all I know.*
Developing	*Teaching students how science, technology, engineering, and mathematics are useful in life using the inquiry method.*
Complete	*N/A*

Describe your implementation of STEM curriculum.
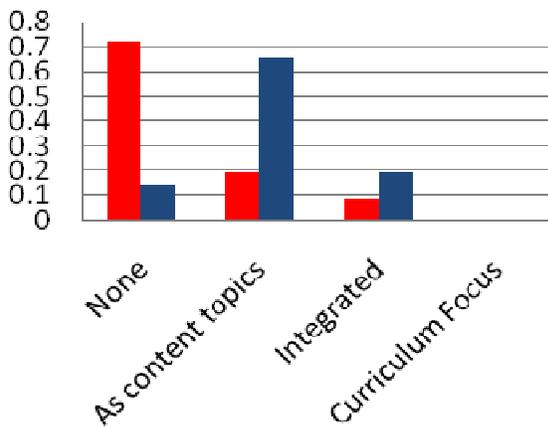
None	*I have not implemented it yet because I am just taking the class.*
As content topics	*First I introduce the concept, then let students explore, finally complete a project or take a test to show understanding.*
Integrated	*I usually emphasize STEM problem solving as it relates to the outside world.*
Curriculum Focus	*N/A*

How does access to education/instructional resources influence your teaching of STEM?

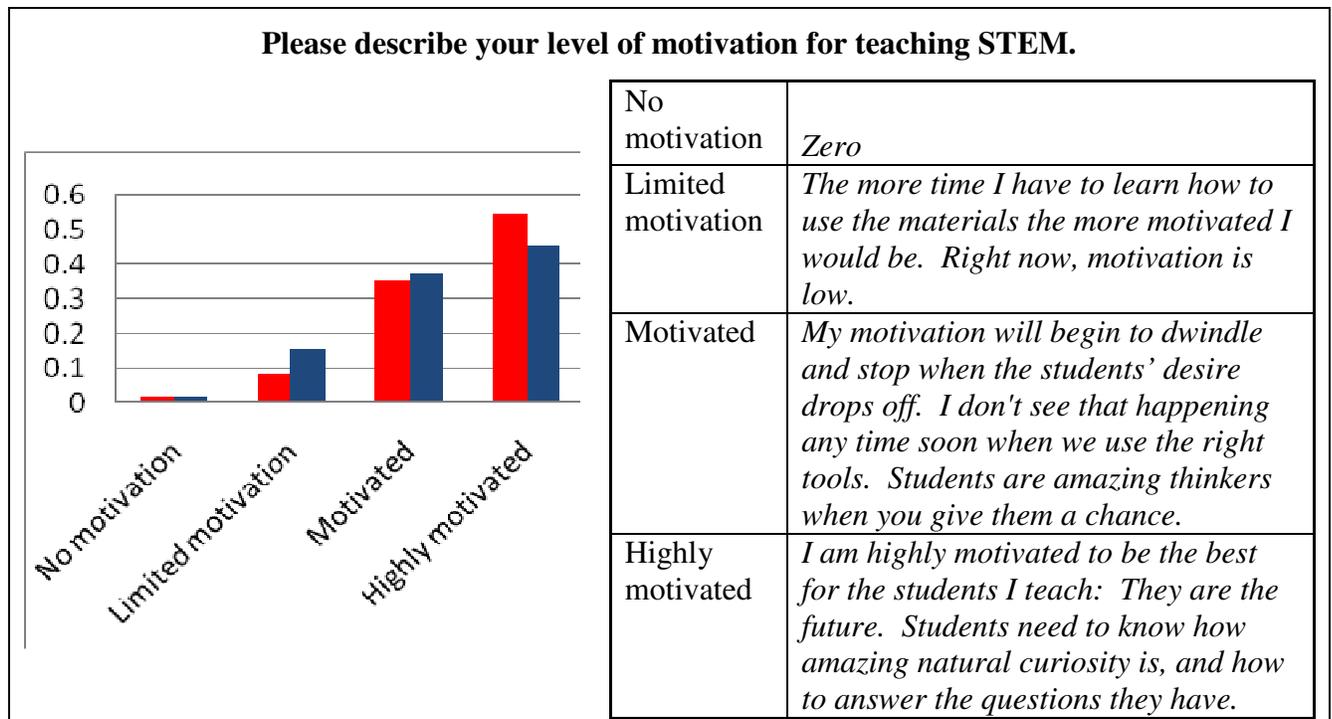| No influence	*I feel like I need many more resources to integrate STEM teaching.*
Limited influence	*Sometimes it is difficult to find the right materials if they are not in your building. It has been nice having the BrickLab® in my room, being able to use it weekly. I like to look online to find some good lessons for both brick lab and other science lessons.*
Significant influence	*Access to these resources can really make or break a curriculum of STEM learning. The more real world connections and real life application and hands on learning we can create, the greater and longer lasting the learning and problem solving skills that students will develop.*
Not an issue	*I have enough of the materials to be effective in my classroom with STEM.*

Please describe your level of motivation for teaching STEM.

|	
No motivation	*Zero*
Limited motivation	*The more time I have to learn how to use the materials the more motivated I would be. Right now, motivation is low.*
Motivated	*My motivation will begin to dwindle and stop when the students' desire drops off. I don't see that happening any time soon when we use the right tools. Students are amazing thinkers when you give them a chance.*
Highly motivated	*I am highly motivated to be the best for the students I teach: They are the future. Students need to know how amazing natural curiosity is, and how to answer the questions they have.*

Figure 1. The distribution and example responses to four (of the six) free response items ranked according to the quality for both pre-(red) and post (blue) institute.

Although we were able to detect trends in increased quality of explanation of STEM, knowledge of STEM, and engagement in STEM in two of the four items, the post-test responses tended to remain predominantly at the low to middle part of the spectrum. For example, the responses to the items assessing how the participants' defined STEM were revealed to essentially shift from unknown to basic and from basic to developing .We were not able to observe a substantial shift into the highest levels of the ordinal spectrum for these items.

Nominal response group. The two items that we classified to be associated with nominal responses assessed the nature of our participants' collaboration and networking practices as they engage in STEM teaching. The classification groupings, corresponding examples, and the categorization result pre- and post-institute are presented in Figure 2.

How do you collaborate with others when teaching STEM content?
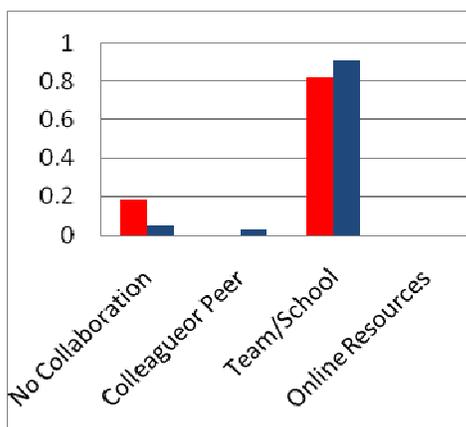
No Collaboration	*There is none as I have no knowledge of this program.*
Colleague or Peer	*The fifth grade teacher and I take time to review what has been taught and the needs of the students.*
Team/School	*We develop inquiry-based ways of approaching the material, most specifically in math.*
Online Resources	*N/A*

What kind of social/professional networking do you engage in to gain support for teaching STEM content?
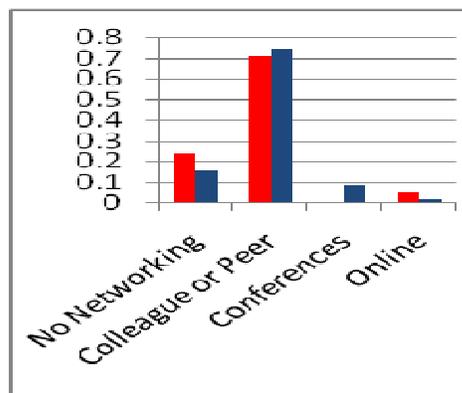
No Networking	*I am not engaged in a support network to teach STEM right now.*
Colleague or Peer	*Lots of discussion with grade-level colleagues, along with other teachers who have implemented this in their classrooms.*
Conferences & Classes	*My networking is mostly from training institutes such as the Idaho SySTEMic initiatives.*
Online	*Interactive websites, professional development (e.g., Web 2.0).*

Figure 2. The distribution and example responses to our items assessing collaboration and networking practices to prepare and implement STEM curriculum pre- (red) and post-(blue) institute.

Our analysis of our participants' responses to the items in the nominal response item group revealed rather consistent pre and post distributions for collaboration to teach STEM. The majority of the participants indicated that they collaborated as teams or schools when teaching STEM. Further, the majority indicated that they engaged with peers or colleagues when networking to gain support for teaching STEM. There was essentially no change in the collaboration and networking activities of the participants in relation to their teaching STEM.

Discussion

Recognizing the need for teachers to be prepared to teach a wide range of STEM content using appropriate STEM methods,[24,25] we created, implemented and assessed a STEM education professional development intervention for K-5 teachers. As the NRC reports, this population is usually in high need of professional development due to their constrained preparation in STEM

and expectations of a broad breadth of knowledge. Of particular interest to us was enhancing the participants' knowledge of scientific inquiry and the engineering design process so that they may use these to teach STEM content. We support the position that teacher knowledge of inquiry and design are critical to assuring their effectiveness for using these approaches to provide authentic STEM learning experiences for their students.

Specifically, the goal of this research project was to increase the participants' comfort for teaching STEM, their knowledge of the design process, and the use of inquiry in their instructional practice, resulting in a decrease in their pedagogical discontentment. Further, we sought to modify the participants' knowledge and perception of their STEM education practice. To determine the influence of the professional development we pre-tested, post-tested and delayed post-tested our participants.

Our results revealed significant and sustained shifts in comfort teaching STEM, knowledge of the design process, pedagogical discontentment teaching STEM, inquiry implementation, and perceptions and practice of STEM education. We attribute the initial shifts and sustained changes to the structure of the summer institute and the intensive post-institute follow-up activities and support. The group interactions, the authentic engaging activities, the modeling of best practices, and the discussions and seminars on the issues related to STEM education combined to provide an educational and influential experience for the participating teachers. We suspect that the effective combination of institute content, format, and focus on grade level appropriateness and expectations provided the ideal conditions to motivate participant learning, and to sustain the changes in their perception.

As Nadelson and colleagues[26] have previously reported, a relatively brief professional development intervention (three days) can have significant impact on a wide range of teacher cognitive and affective variables. Apparently, knowledge of STEM process, specifically scientific inquiry and design knowledge, along with perceptions and practice in STEM education can be added to the list of factors significantly influenced by appropriately structured teacher professional development.

Limitations

The results of our research should be considered in the context of any investigation using self-report research, however, the significant and sustained shifts in our measures suggest that the participants are certainly reporting different perspectives post institute than prior to the institute. We are in the process of following up with classroom observations which will allow us to determine if the actual practice of the participations is reflective of their self-report. Preliminary evaluation suggests a high degree of consistency is likely to be exposed. Further, the consistency in the post and delayed post tests (four months apart) suggest that there were sustained shifts in perceptions, and knowledge of STEM education, which we assume influences practice.

As with any longitudinal study, particularly those relying on participants to provide codes to mask identity, we were not able to track all of our original participants. The lack of tracking was further influenced by the volunteer nature of human subject research. We were able to post-test all of our participants. However, in our delayed post-test we were not able to engage the entire original participant population in the data collection. Further, the five-digit phone code they used was not always consistent throughout the study, and although we were able to make matches using demographic data (collected in each round) not all could be matched. Regardless, our final sample of 47 participants was likely to be representative of the participant population and is certainly sufficient to indicate that the summer institute had substantial influence on the participants.

Conclusion

As new STEM education programs are developed and promoted, such as the *Change the Equation* initiative (http://www.changetheequation.org), there is a need to assure teachers are prepared to meet the goals of STEM endeavors. Professional development is critical for assuring that teachers have the content and pedagogical knowledge to effectively teach STEM curriculum in a manner that leads to the accomplishment of STEM learning goals. We responded to the need for continuing education for teachers by developing and offering a three-day summer institute. Our assessment of the participants revealed the institute had significant and lasting impact on the scientific inquiry and design process content and instructional practices of those involved. Thus, our project reveals attending to the call for increased teacher preparation in STEM may be achieved through condensed and well crafted interventions. We hope that the benefits of our program to K-5 teachers may be an inspiration to others to seek additional *SySTEMic Solutions.*

Acknowledgements

Bibliography

1. McComas, W. F. (1996). Ten myths of science: Reexamining what we think we know about the nature of science. *School Science and Mathematics, 96*, 10-16.

2. Weinburgh, M. (2003). Confronting and changing Middle School teachers' perceptions of scientific methodology. *School Science and Mathematics, 103,* 222-232.

3. American Association for the Advancement of Science (1993*). Benchmarks for science literacy*. Oxford Press: New York.

4. National Research Council (1996). *National science education standards*. Washington, DC: National Academy Press.

5. Buck, L. B., Bretz, S. L. & Towns, M. H. (2008) Characterizing the level of inquiry in the undergraduate laboratory. Journal of College Science Teaching, 38(1), 52-58.

6. Herreid, C.F. (2010). The scientific method ain't what is used to be. *Journal of College Science Teaching, 39*(6), 68-72.

7. Chinn, C.A., & Malhotra, B.A. (2002). Epistemologically authentic inquiry in schools: A theoretical framework for evaluating inquiry tasks. *Science Education, 86*(2), 175-218.

8. Abd-El-Khalick, F., BouJaoude, S., Duschl, R.A., Hofstein, A., Lederman, N.G., Mamlok, R., Niaz, M., Treagust, D., & Tuan, H. (2004). Inquiry in science education: International perspectives. *Science Education*, *88*(3), 397-419.

9.Welch, M. & Lim, H. (2000). The strategic thinking of novice designers: Discontinuity between theory and practice. *The Journal of Technology Studies, 26*(2).

10. National Academy of Sciences. (2010). Rising Above the Gathering Storm, Revisited: Rapidly Approaching Category 5. Retrieved from http://www.nap.edu/catalog/ 12999.html

11. Burghardt, D., & Hacker, M. (2007). *Engineering professional development*. Paper presented at the National Symposium to Explore Effective Practices for Professional Development of K-12 Engineering and Technology Teachers, Dallas, TX.

12. Fontenot, D., Talkmitt, S., Morse, A., Marcy, B., Chandler, J., & Stennett, B. (2009, October). *Providing an engineering design model for secondary teachers*. Paper presented at the Frontiers in Education meeting, San Antonio, TX. Retrieved from http://www.fie-conference.org/fie2009/papers/1491.pdf

13.Tufenkjian, M,. & Lipton, E. (2007). *A professional development model to infuse engineering design content into the high school curriculum*. Paper presented at the American Association of Engineering Education Conference. Retrieved from http://soa.asee.org/paper/conference/paper-view.cfm?id=5780

14. Bailey, R., & Szabo, Z. (2006). Assessing engineering design process knowledge*. International. Journal of Engineering Education, 22*, 508-18.

15. Bedward, J., Wiebe, E., Madden, L., Minogue, J. and Carter, M. (2010). *Modeling in support of the engineering design process: Experiences in the elementary classroom. Proceedings of the American Society for Engineering Education Annual Conference & Exhibition*,: Louisville, KY.

16. Fulp, S. L. (2002). *The 2000 national survey of science and mathematics education: Status of elementary school science teaching.* Chapel Hill, NC: Horizon Research, Inc.

17. Hill, R. B. (2006). New perspectives: Technology teacher education and engineering design. *Journal of Industrial Teacher Education, 43*(3), 45-63.

18. Southerland, S. A., Nadelson, L. S., Sowell, S., Kahveci, M., Saka, Y., & Granger, D. E. (Under Review). Measuring one aspect of teachers' affective states: development of the Science Teachers' Pedagogical Discontentment Scale. *Journal of Math and Science Education.*

19. Carpinelli, J., Kimmel, H., Rockland, R. (2006). *Paper Drop Design Competition*. Washington, D.C: National Science Foundation. Retrieved from http://www.teachengineering.org /collection/cub/activities/cub_paper/ cub_paper_activity1.xml

20. Nadelson, L. S. & Sinatra, G. M. (2010). National Academy of Sciences (2009). *Engineering in K-12 education*. Washington, DC: National Academies Press.

21.Brandon, P. R., Young, D. B., Pottenger, F. M., & Taum, A. K. (2009)The inquiry science implementation scale: Development and applications. *International Journal of Science and Mathematics Education, 7*(6), 1135-1147.

22. Nadelson, Seifert, Moll, & Coats, (Under Review). i-STEM summer institute: An integrated approach to teacher professional development in STEM. *Journal of STEM Education: Innovations and Research.*

23. Sims-Knight, J., Upchurch, R., & Fortier, P. (2006). Design process knowledge test. Paper presented at the National STEM Assessment Conference, October 19-21, 2006. Washington, D.C.

24. National Academy of Engineering and National Research Council: Committee on K-12 Engineering Education. (2009). *Engineering in K-12 Education: Understanding the Status and Improving the Prospects.* Washington, D.C., National Academies Press.

25. National Research Council (2007). *Taking science to school: Learning and teaching science in grades K-8*. R. A. Duschl, H. A. Schweingruber, A. W. Shouse (Eds.). Washington, D.C.: The National Academies Press.

26. Nadelson, L.S., Callahan, J, Pyke, P. Hay, A. & Schrader, C. (2009). A Systemic Solution: Elementary-teacher preparation in STEM expertise and engineering awareness. *Proceedings of the American Society for Engineering Education Annual Conference & Exhibition*, Austin, TX.