AC 2008-2054: ATTITUDE SHIFTS IN HIGH SCHOOL MATH AND SCIENCE TEACHER PRACTICE THROUGH CONNECTING MATH, SCIENCE, AND ENGINEERING IN A MATH SCIENCE PARTNERSHIP: PROJECT PATHWAYS

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Attitude Shift in High School Math and Science Teacher Practice Through Connecting Math, Science, and Engineering in a Math Science Partnership: Project Pathways

Abstract

Project Pathways is a Math Science Partnership (MSP) providing professional development to high school math and science teachers in Phoenix metropolitan area school districts. The NSF funded project is using four semester-long courses and professional learning communities to enhance teacher pedagogy for improving mathematics and science learning and achievement in grades 9-12. Mathematics, science, engineering and education faculty are teaming with community college master teachers in using the understanding of mathematical function as a unifying concept applied throughout the courses. Conceptual competence in core content subjects and problem solving process behaviors in scientific inquiry, mathematical problem solving, and engineering design is promoted using team-based, inquiry learning pedagogy with contextualized content in MSP-created modules. The unifying concept of function, developed in the initial Functions and Modeling course, is integrated into science and engineering topics in the subsequent science and engineering courses. For example, the functional nature of the mathematical concept of proportionality is applied in the second course on Connecting Math with Physics and Chemistry for understanding the Universal Gas Law. Subsequently, in the course on Connecting Engineering with Science and Math, the conceptual knowledge of proportionality and the Universal Gas Law is applied as a predictive tool in the design process for the Hot Air Balloon Project. Here we report on, from qualitative analysis of teacher reflections, the research question, "What is the effect of an integrated math-science-engineering professional development project on high school math and science teachers' classroom practice using the core concept of function that is integrated into the delivery of contextualized content by team-based inquiry learning."

Introduction

Project Pathways is an NSF Math Science Partnership professional development project which targets mathematics and science learning and achievement in grades 9-12 by connecting mathematics with context-rich content and problem solving processes in science and engineering. Teams of mathematics, science, engineering and education faculty are partnering with community college master teachers to generate instructional sequences of modules for four courses for secondary mathematics and science teachers and their students. The courses are promoting conceptual competence in core content subjects and key problem solving process behaviors in mathematical problem solving, scientific inquiry, and engineering design. The understanding of mathematical function as a unifying concept is applied throughout the courses. Conceptual competence in core content subjects and problem solving process behaviors in scientific inquiry, mathematical problem solving, and engineering design is promoted using team-based, inquiry learning pedagogy with contextualized content in MSP-created modules. The unifying concept of function, developed in the initial Functions and Modeling course, is integrated into science and engineering topics in the subsequent courses. Professional learning communities are supporting teachers in adapting their new knowledge and instructional approaches to their own classroom practice by engaging them in deep reflections on their instruction and their students' learning. Math, science and engineering are connected by knowledge and use of function. The concept of function is developed in the Functions and Modeling course and then integrated into fundamental science topics in the courses, Connecting Physics, Chemistry and Mathematics (CPCM) and Connecting Biology, Geology and Mathematics (CBGM). The concept of function integrated into the understanding of science to mathematically describe phenomena. It is then applied to design projects as predictive tools about phenomena in the Connecting Engineering with Science and Math (CESM) course. Examples of these connections include utilizing function in the Universal Gas Law and also Newton's Laws for application to the design process in the Hot Air Balloon Project.

The structure of Project Pathways offers the unique opportunity for high school math and science teachers to team together in professional development activities. In so doing teachers from the math and science disciplines are able to experience quality modeling of math pedagogy and of science pedagogy, not only by course instructional leaders, but also by their own team members. Implementation of enhanced knowledge, understanding, and skills will differ in math and science classroom practice, but there will be an underlying understanding of the complementary nature of math and science implicit in the pedagogy modeled in the project's courses. This linkage and integration of math and science has the potential for synergistic impact on student learning in both math and science and should be reflected in their performance. The project's four courses are intended to facilitate connections between math and science and engineering. These connections address three of the project's thrusts which are embedded in the courses and include the following. One thrust is the deepening conceptual understanding of mathematical function and its utilization in problem solving processes in math, science and engineering. Another is the application of inquiry learning techniques in both classroom practice and laboratory practice. The third thrust is the integration of math and science both through the contextualization of math content and processes and also through enhancing mathematization of science phenomena and use in predictive design tools in engineering design processes. These thrusts of function, inquiry, and context are the categories that this paper reports and assesses with qualitative analysis of teacher responses from a final reflection in the second course in the project, Connecting Math with Chemistry and Physics. It followed the mathematics conceptual development of concept in the first course, Functions and Modeling, and is a foundation for a subsequent course that will use the math and science, Connecting Engineering with Science and Math. The research question for this work is, "What is the effect of an integrated math-science-engineering professional development project on high school math and science teachers' classroom practice with respect to use of function, inquiry, and context."

Background

The project approach for improving high school student math and science performance has been to use inquiry learning for promoting teachers' deep understanding of foundational STEM (science, technology, engineering, and math) concepts and the processes and the connections between them. Research shows that STEM teachers in U. S. schools lack content knowledge and mastery of subject-related pedagogy that enables them to teach content most effectively[1]. They also lack a sense of the connections among concepts that reveal mathematics as an internally logical and coherent system of knowledge[2]. This forces teachers to use lectures to deliver content, which emphasizes procedure over engagement. This deters hard-thinking explorations that help develop critical minds with the capability to deeply understanding mathematical, scientific and engineering concepts[3]. In a high minority-population state like Arizona, superficial teaching of STEM subjects disproportionately undermines STEM learning of minority and low-income students[4].

The first facet of the project, mathematical function, is the unifying concept of the courses and is often used by scientists and engineers as a mathematical model of change. Teachers are exploring the concept vertically across grade levels and horizontally across science applications (biology, geology, physics, and chemistry) and engineering design. Understanding function is essential for students' future success in calculus[5] and is critical for retaining minority and female students, whose progress in math and science often founders at the precalculus level. The function concept is so complex that even high-performing students exhibit weak and disconnected understanding of it[6], the primary cause of which is that teachers also have weak understandings of function[7]. This weak understanding of function forces teachers to take a procedural approach to teaching functions to their students[8]. Carlson, et al.[9] have developed guiding frameworks for defining and assessing students' function knowledge and emerging understanding. The modules in each course feature examples of function as mathematical models of change that scientists and engineers use to quantify reproducible patterns of phenomena in natural and physical science and to then apply them as predictive phenomenological tools for engineering design. For example, in biology a problem solver might model the impact of an invasive plant in an ecosystem as a function of its average rate of growth per year. In engineering design, a problem solver could link function in rate of velocity change in Newton's Laws to help describe upward acceleration in the Hot Air Balloon Design Project. These science and engineering projects not only provide opportunities for mathematization of phenomena for science teachers, but also provide math teachers opportunities to learn of rich, new contexts for framing mathematical inquiry activities. Sharing instructional approaches between mathematics, the sciences, and engineering is yielding new ways of making these foundational ideas relevant and accessible to students. Student accessibility is also enhanced by contextualized content delivery with team-based, inquiry learning, which is discussed next.

Inquiry-based learning uses strategies that engage students in contextually relevant problems that are related to real-life experiences and situations. Incorporating inquiry-based learning skills into laboratory activities or classroom discussions can have significant educational benefits. In inquiry learning asking questions, hypothesizing, formulating ideas together and explaining are important aspects of discussion in a team based environment[10]. For example: using the inquiry-based method by practicing teachers improves teaching skills[11]; collaborative problem-solving changes the roles of teachers to facilitators and students to problem solvers[12]; and team-based activities and discussion lead to critical question posing and creative thinking[13]. Patrick and Middleton[14] have stated that success in inquiry learning "requires cognitive, metacognitive, motivational and collaborative engagement that comprises self-regulated learning." Such learning is a key aspect in developing the ability to achieve "far transfer" of problem solving knowledge and skills to new and unfamiliar contexts and situations[15]. This is particularly important when using the mathematical description of physical phenomena as predictive tools to design engineering processes and systems.

Providing appropriate contextualization of mathematical problems promotes motivation and access because of relevance and usefulness to the learner[16]. Recognition and valuing of prior experience demonstrates usefulness and importance of math and helps the learner recognize what they can do and how to build on it[17]. Examples of mathematics in the workplace, in financial planning, and observed phenomena of daily life can connect with the students' meaning and social environment[18]. It can also change a person's views of the nature of mathematics. Rogers[19] says that contextualization "demystified the doing of mathematics . . . calling attention to mathematics as a creation of the human mind, making visible the means by which mathematical ideas come into being . . . and engaged students within the classroom in purposeful, meaningful activity."

Procedures

The results presented here examine the effect of professional development which connects math with science and engineering through a prior course in Functions and Modeling and the second course Connecting Math with Chemistry and Physics taught in spring 2007. It was desired to summatively assess the impact of these two courses and associated learning communities on teachers' classroom practice with respect to function, inquiry, context (as earlier described). To do so, written reflections of teachers from three school districts (Scottsdale, Tempe, and Mesa) were qualitatively analyzed in response to the following question:

> *Think back on all the lessons in this course. What, from the things you learned, have you incorporated into your own teaching? Include the following categories in your answer: concepts from the opposite discipline (math teachers should state what science concept they are using, and vice versa), teaching methods, and reasoning strategies ("speaking with meaning").*

The analysis of the changes in classroom attitude and practice with respect to impact on student learning and attitude is not presently available, but is being assessed in terms of students': course grades; performance on high stakes state mathematics tests; and on future interest and enrollment in advanced science and mathematics classes. The processes and procedures for obtaining, assessing, and analyzing the appropriate data has been cumbersome because of the lack of uniformity of data acquisition, recording, and extraction procedures across different school districts but should become available in the future.

Results and Discussion

The data shown here is a summarization of the qualitative reflections about attitude shift and change in classroom practice in connecting math and science for the 27 final reflections from Mesa, Tempe and Scottsdale. The results are organized two major sections for 10 math teachers and for 17 science teachers. Each section starts with an overview and then summarizes the teachers' responses for the categories of function, inquiry, and context. After the summaries, excerpts of the teachers' responses are presented with comments on the how each of the categories of math-science integration, function, inquiry, and context were addressed. All teachers' responses were reported under pseudonyms.

Generally speaking, of the 27 teachers, the 10 math teachers all had a positive attitude shift about connecting and integrating math and science in classroom practice, mainly though science contextualization of the math through motion concepts, through energy concepts, through periodic motion with spring oscillations and wave phenomena (and one with the guitars) and through the Gas Laws. Some were even developing their own hands-on labs to demonstrate the connections between the math and the science phenomena. Of the 17 science teachers attitudes about connecting math and science, 13 had a positive shift, 1 was mixed and 3 showed little or limited shift. Function and context were shown since most of the teachers were incorporating more math to show functional relationships in science phenomena, which sometimes even simplified and made more clear the science or was the only way to understand the science. Some were also modifying or developing new inquiry-based science lessons or labs that would incorporate more mathematics.

Mathematics Teacher Responses

The 10 math teachers' final reflections showed that all had a positive shift in attitude toward integrating math and science in their classrooms. The shifts were substantial and actually represented changes in their practice of teaching. That is to say that their explanations in the final reflections showed either an active change or intent to change practice. This is revealed in the ten math teachers' excerpts described below, which are more fully described by each excerpt.

In the first three excerpts by Charlie, Sandy, and Hannah, they all describe how they are contextualizing math with real-life examples, with the physics of motion, and using graphs to tell a story. The next four teachers, Dan, May, Tanya, and Mary, will contextualize the math they are teaching by using "math" labs which use science activities. These labs will use activities such as guitars to link wavelength and proportions, ball tossing to link time and position, and two labs using spring oscillations to contextualize harmonics and wave motion. Don will provide science context in using deductive and inductive reasoning and Paula will provide context by showing how the same functions are used in science and math. Thus, the math teachers are building new contexts with real world examples and by developing new labs which represents a significant shift in how they think about and carry out their classroom practice. The students will have better access to learning math since it will be contextualized with phenomena and examples from their own world experience.

Many of the math teachers are promoting inquiry by mathematicizing physical phenomena through labs which include: playing a guitar; tossing a ball; examining the harmonics of a spring; and examining the physics of motion. They also have promoted inquiry through discussion about contexts of: the physics of motion; storytelling of Archimedes taking a bath; and deductive versus inductive reasoning. Both labs and discussions can promote inquiry and engage the student to enhance his/her learning.

Teachers have taken advantage of context and inquiry to foster understanding of the concept of function with: the physics of motion (distance, time, velocity, acceleration); water filling a tub (speed, average speed, velocity, average velocity, acceleration, and distance, and displacement); physics of a guitar (harmonic motion); and spring oscillation trigonometric functions (sine and cosine curves used to describe period, amplitude and phase shift). One teacher also promotes understanding by the use multiple representations of function by showing what a linear function is and how to illustrate it graphically, algebraically and verbally (words). Although the concept of function is difficult to understand, the teachers' classroom practice using inquiry and science context will certainly foster the development of that understanding. It will also promote linking classroom activities, language, and discussions between science and mathematics.

The positive shift in the teachers' classroom practice has been discussed above through analysis of the excerpts presented below. In order to preserve the richness of individual adaptation of contextualization and inquiry learning, specific quotes from each teacher are provided. It should be noted that the excerpts have been reproduced in the exact form as reported by the teachers, which includes a variety of possible semantic, grammatical, and spelling errors. Authentic qualitative analysis requires exact reproduction of data as gathered so as to not shift meaning or expression.

Charlie, a Mesa math teacher, contextualizes his math with real-life examples and hands-on inquiry activities to teach function. He says, "I always use science examples when I use real life examples. I try to use more hands on activities when I can to reinforce or to teach the math concepts."

Sandy, a Scottsdale math teacher, is contextualizing her math with the physics of motion. She has facilitated understanding the function concept with a scientific context and uses inquiry to develop strategy building skills in student discussions. She says, "As far as concepts go, I use more scientific applications in my pre-calc class and I am much better at explaining the motion involved in the problem rather than just the strategy that would best get to the answer. We talk about distance, velocity and acceleration quite a bit and I have added simple harmonic motion as well."

Hannah, a Tempe special education math teacher, contextualizes her math with science by using graphs to tell a story, in particular, the graph and math of the realistic story of Archimedes taking a bath. She has effectively engaged the special education students by contextualizing and, by having inquiry discussions; she has provided access and improved understanding of functions concepts. She says, "We did this without setting up a scale, so that students could just draw a line showing increase, constant, and decreasing volume of water in the tub, as we filled the tub with water, turned off the water, put man in and out of tub, and the water level decreasing when we pulled the plug over a period of time.... In doing this lesson, students were able to speak in meaning with terms of speed, average speed, velocity, average velocity, acceleration, and distance, and displacement."

Dan, a Mesa math teacher, wants to implement a "math" lab into his classes in the future. Dan plans on using a guitar context for developing an inquiry lab that would provide a physical representation of a proportion function. He says, "One lesson that I found to be very interesting was the wavelength of a guitar string. I would love to implement this lesson in my math classroom when I am teaching about waves or proportions. The students can discover physically what is happening to the wavelength and see a physical representation of a proportion."

May, a Tempe math teacher, developed an engaging, hands-on, inquiry "math" lab with graphing calculators to develop a mathematical expression for describing the function for position-time relationship for the context of a vertically tossed ball. She says, "I was able to incorporate the use of vertical motion as a real world phenomenon represented mathematically by a quadratic function. Students conducted experiments and collected data to find how high a ball was thrown into the air. This provided motivation for the students and they were actively engaged in the lesson."

Tanya, a Tempe math teacher, is going to use an inquiry "math" lab with spring oscillations to contextualize trigonometric functions. Sue says, "One concept that I did not use, but plan to use next year (it was just at the wrong timing) is the use of a spring and looking at the change in the sine, and cosine curve to describe period, amplitude and phase shift. This was a great way to incorporate science and math together in a concept that I feel would help my students better understand graphs of trig functions."

Mary, a Scottsdale math teacher, is connecting with her students in having opened up a dialogue about mathematics in science between her and those students who are taking physics and chemistry classes. This has inspired her to develop an inquiry "math" lab to contextualize a harmonic motion function with the spring oscillation activity. She says, "Knowing these concepts has made me a better math teacher because it has given me some real world connections to the math concepts that I teach. It opens up the dialogue between students that are taking physics and chemistry and me. The class has also inspired me to do some experimental activities to teach math concepts. The next time I teach sinusoids, I want to do the spring (harmonic motion) activity."

Paula, a Mesa math teacher, has deepened her conceptual understanding of the physics of motion and associated functions. She plans to develop inquiry labs for her classes and says, "Overall, I feel that I have gained so much deeper understanding of the concepts covered in this course that I truly am a better teacher. With the physics background I gained from this course I am planning to incorporate "labs" into my math classes. I have found that actually seeing how ideas of distance, time, and rate were related and discovering those relationships helped me understand so much more."

Don, a Scottsdale math teacher, will connect math to science by with inquiry discussions using a balance of deductive reasoning from math and as well as discovery with inductive reasoning from science contexts which is another path to understanding function by determining mathematical relationships. He says, "I saw the value that is brought to the table having an approach to lessons using inductive reasoning, where the students discover the concepts and relationships that exist and that we want to enforce in their learning. A good balance of deductive and inductive reasoning I have seen from this class and functions goes a long way and students will have a deeper conceptual understanding of the concepts using both approaches and in balance."

Peggy, a Mesa math teacher, is connecting math and science with inquiry discussions by showing how the same functions are used in math and contexts in science. She says, "In teaching slope and linear functions I have related it to what and how students use this in science as well as math. We discussed what a linear function is and how to illustrate it graphically, algebraically and verbally (words)."

As can be seen, both attitudes about classroom practice as well as ongoing classroom practice of the math teachers have benefitted positively from the combination of classroom/laboratory data collection, assessment, and analysis. Some of the math teachers had never collected and analyzed data, but they developed the skills and self confidence not only to work with the "dirtier, real-world" data, but to design and implement real-world science contextualization activities in their own classrooms. For the MSP classes, the hands-on activities of equipment set up, experimentation, data collection, data analysis, and connecting phenomena to functional mathematical parameterization, are providing a strong foundation with the predictive design tools used for designing, building, and characterizing behavior of hot-air balloons in the CESM course. Far transfer of conceptual knowledge and practice from the CPCM class and the CESM class will be promoted by the inquiry based development of the Universal Gas Law and Laws of Motion in the CPCM course.

Science Teacher Responses

The final reflections of 13 of 17 science teachers' showed a positive shift in attitude toward more closely integrating math and science in their classrooms. The other four science teachers showed no shift and saw little or no value in the class taken. As with the math teachers, the shifts of the 13 science teachers were substantial and actually reflected changes in their practice of teaching. The science teachers did not discuss context since the math is already embedded in the science they are teaching. Although all 13 teachers talk about using additional math in their courses, only four discuss inquiry in terms of student interactions. This may be so because about 2/3 of the science teachers are biologists and will be using more familiar contexts for a later CBGM science course, Connecting Biology and Geology to Math. At this time there does not appear to be any reference to contextualizing the science in terms of students' everyday lives nor for projects in the subsequent engineering course. This may be because the final reflection question did not request such information. The general changes in their practice involve using, revealing, applying, and framing more math in their science. Two teachers even discuss how they will develop functional relationships in order to create equations to represent phenomena. Additional comments are presented in the 13 science teacher excerpts described below.

In the first four excerpts by Fred, Barbara, Christine, and Rhonda, they all describe how they are integrating math and science by using proportional reasoning to understand the Gas Laws. Another science teacher also uses proportional reasoning in his science. The next two teachers, Jim and Hilda, are integrating math and science by using math to explain components of energy and the physical phenomena in earth science. Larry, Stephanie, Frieda and Bonnie are integrating math and science by using math in formula development, in creating a framework to understand science, to understand what mathematics of the data are saying about an experiment, and to modify a science unit to incorporate more math and graphing. Meanwhile, Gilda is integrating math and science by using her science classes to connect to math standards and Chip has a positive attitude about math in science but does not give specific examples. In all of these cases the greater integration of math and science indicates that teachers have increased their conceptual understanding of mathematical function and are now able to apply it more broadly and effectively in their classroom practice in science.

Fred, a Tempe science teacher, is integrating math and science through the process of function development as was done for the Gas Laws in the CPCM course. He says, "Instead of just giving students the function, I feel better equipped to help them first establish a proportion then develop other relationships. From a reasoning standpoint I feel this will empower students to feel a sense of ownership of the relationship. I also feel this will create more of a conceptual understanding versus just a cursory understanding."

Barbara, a Scottsdale science teacher, is enhancing math-science integration because she sees new ways to connect mathematical relationships with science phenomena through inquiry about proportionality in Gas Laws and a holistic approach of using periodic functions to describe wave behavior of water, seismic, and electromagnetic waves.... "In my Earth Science class we talk about water waves, seismic waves and electromagnetic waves when studying solar radiation and light from stars. I can now include that the velocity of a wave is the frequency times the wavelength and that the wavelength is inversely proportional to the frequency."

Christine, a Scottsdale science teacher, is integrating math and science by using inquiry to study proportionality concepts to mathematicize the Gas Laws. She says, "Now that I am teaching the Gas Laws, I will require my students to show proportional reasoning as well as the gas law equation approach to solving the problems. I really like the fact that setting up the various ratios will help me confirm whether or not they have grasped the relationship between the different variables (volume, temperature, pressure, and amount) for a gas."

Rhonda, a Scottsdale science teacher, by shifting teaching of Gas Laws from formulaic approach to deeper conceptual approach using the proportionality concept will better describe and explain molecular behavior of gasses. She says, "I try to show them what they learn in math has practical applications in science. I also plan on trying to teach gas laws differently next year. I have always taught gas laws by talking about the proportions between the variables in Boyle's and Charles' law. We also graph the data so that they can see why one of the gas laws is a direct relationship and the other is an inverse."

Bill, a Tempe science teacher, is integrating new math concepts into science classes and probing students to better develop proportional reasoning and conceptual reasoning to connect math with science. He says, "I have been probing the students more and more to develop proportional reasoning as well as conceptual reasoning. I have done this by asking them to verbally and graphically describe what they are thinking."

Jim, a Scottsdale science teacher, gives a couple of examples of integrating math and science by using mathematics to model physical phenomena which he has incorporated into his classes. He says, he is "Using the slope of lines created from data gathered from actual experiments to compare results between different groups of students and using energy bar charts to evaluate a system of reactions"

Hilda, a Scottsdale science teacher, sees many opportunities to integrate mathematics into her earth science classes through students' discovery of relationships related to contextualization of math for "real situations". She says, "I have already incorporated several things from this class into my own teaching. I now see more opportunities to incorporate math into my earth science class especially.... I help to facilitate and guide their thinking, but let them discover the relationships. This aids in their understanding and helps them to make the content knowledge their own."

Larry, a Tempe science teacher, is integrating math and science by using mathematics to describe a physical situation by development of an appropriate formula that models phenomena. He says, "I enjoyed the process of taking a given situation and translating this into a mathematical formula. I will need practice at this, but I feel the process is very important for student's understanding mathematically and seeing how things are related in their environment."

Stephanie, a Tempe science teacher, has changed the way she integrates math and science and now introduces mathematical concepts early in a science lesson for more effective understanding of science phenomena. She says, "I also learned how effective it is when you introduce the math concepts involved in a lesson before you teach the science behind the lesson. The students make the transitions much easier and understand how to better apply algebra and/or trigonometry to a science lesson."

Frieda, a Scottsdale science teacher, will further integrate math and science in emphasizing what the data are saying about the mathematics of the science in classroom experiments. She says, "As a science teacher, the concepts I have tried to use more often in my class include: truly understanding what the mathematical data is saying about the experiments conducted in class, knowing that there is more that one way to solve an equation and allowing the students to know all ways to "attack" a problem, and finally using the mathematical calculations to support or not support the hypotheses (where applicable)."

Bonnie, a Mesa science teacher, is now able to support mathematics standards through contextualization in the science she teaches. She says, "I would like to develop a more comprehensive unit that would include more math, graphing, and experimentation."

Gilda, a Mesa science teacher, can integrate math and science well enough to address math standards in her science classes in saying, "As a result of taking this course I feel more confident in the classes I teach. I also feel more comfortable teaching the mathematics behind the science. I can also now connect my science classes to math standards and the student will have a more enriched, well rounded experience."

Chip, a Tempe science teacher, has a positive attitude about integrating math and science although he is not specific about the application. He says, "Even though I only had one shot at doing the lesson, because I teach the only physics course as Tolleson H.S., I will be able to make the improvements and adjustments for next years course."

As can be seen above, the science teachers are generally using greater depth and breadth of the concept of function in mathematicizing physical phenomena. Some are using functional relationships to develop controlling equations to generalize parameters that describe physical relationships. For both math and science teachers, using multiple relationships to represent data collected as graphs, tables, and as well approximated by functions and equations. In so doing the functional dependence of the physical phenomena is revealed which then provides the opportunity to analytically understand phenomena and provide a means to explain and predict it. Thus, the understanding and explanation of phenomena mathematically generates the predictive tools used to design hot air balloons in the CESM course will also provide a model for conducting more authentic inquiry based science in teachers' own classrooms.

Summary and Conclusions

Overall, the data provide evidence that the course, Connecting Chemistry and Physics with Mathematics, has promoted a strong shift toward tighter integration of science and math in all of the math teachers' classrooms and most of the science teachers' classrooms. All of the math teachers described contextualization of the mathematics they were teaching and all showed use to inquiry learning in their description of student interactions. Their understanding of function deepened with the broader diversity of contexts in which function was used. None of the science teachers explicitly described contextualization of the mathematics they were teaching since it was already used as the context for learning. Only four teachers indicated the use to inquiry learning in their classes because they were the ones who described their interactions with students. However, it is likely that inquiry learning was being carried out in the laboratories of all of the teachers, but this was not explicitly requested in the question. It is likely that their understanding of the concept of function deepened since they were using math in more ways and new ways in their teaching of science. Overall the shifts toward greater integration of math and science were substantial and actually represented changes, or intent to change, in the classroom practice of the 10 math teachers and of 13 of 17 science teachers. Inquiry learning and content contextualization was being used by all of the math teachers. Understanding of the concept of function deepened for both math and science teachers. For almost all teachers it could be claimed that a shift was observed away from an image of good teaching as "explain and telling" toward an image of good teaching as "creating learning environments that promote meaning making, inquiry, and construction." This promotes the deep understanding of content and process necessary to achieve far transfer of mathematicized phenomena for application as predictive tools used in the engineering design process.

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References

1. Monk, S., & Nemirovsky, R. (1994). The case of Dan: Student construction of a functional situation through visual attributes. *CBMS Issues in Mathematics Education, 4.*

2. Cooney, T., & Wilson, M. (1996). Teachers' thinking about functions: Historical and research perspectives. In T. A. Romberg & E. Fennema (Eds.), *Integrating research on the graphical representation of functions* (pp. 131–158). Hillside, NJ: Lawrence Erlbaum.

3. Stigler, J., and Hiebert, J. (1999). *The teaching gap: Best ideas from the world's teachers for improving education in the classroom.* New York: The Free Press.

4. Borman, G., Stringfield, S., & Rachuba, L. (2000). *Advancing Minority High Achievement: National Trends and Promising Programs and Practices*. New York: College Entrance and Examination Board.

5. Carlson, M.; Jacobs, S. Larsen, E. (2001a). An Investigation of Covariational Reasoning and Its Role in Learning the Concepts of Limit and Accumulation. *North American Chapter of the International Group for the Psychology of Mathematics Education Conference Proceedings*, 2, 517-523.

6. Carlson, M. (1995). *A Cross-Sectional investigation of the development of the function concept,* unpublished Ph.D. Dissertation, Department of Mathematics, University of Kansas.

7. Thompson, P. W. (1994). Students, functions, and the undergraduate curriculum. In E. Dubinsky, A. H. Schoenfeld, & J. J. Kaput (Eds.), *Research in Collegiate Mathematics Education, 1. Issues in Mathematics Education, 4.*

8. Carlson, M. (2000). A Study of the Problem Solving Behaviors of Mathematicians: Metacognition and Mathematical Intimacy in Expert Problem Solvers. *Proceedings of the 24th Conference of the International Group for the Psychology of Mathematics Education*, 2, 137-144. Columbus, Ohio: Eric Clearinghouse.

9. Carlson, M.; Jacobs, S.; Coe, E., Larsen, S.; Hsu, E. (2002). Applying Covariational Reasoning While Modeling Dynamic Events: A Framework and a Study. *Journal for Research in Mathematics Education*, 33, 352-378.

10. Rivard, L., & Straw, S. (2000). The effect of talk and writing on learning science: An exploratory study. *Science Education, 84,* 566-593.

11. Blanton, W. E., Simmons, E., & Warner, M. (2001). Fifth dimension: Application of cultural-historical activity theory, inquiry-based learning, computers, and telecommunications to change prospective teachers' preconceptions. *Journal of Educational Computing Research*, 24, 435-463.

12. Crawford, B. (2000). Embracing the essence of inquiry: New roles for science teachers. *Journal of Research in Science Teaching*, 37, 916-937.

13. Russaw, E. (1997). Personally perceived problem technique: Enhancing clinical instruction. Nurse Educator, 22, 36-41.

14. Patrick, H., & Middleton, M.J. (2002). Turning the kaleidoscope: What we see when self-regulated learning is viewed with a qualitative lens. *Educational Psychologist*, 37, 27-39

15. Donovan, M. S., Bransford, J. D. & Pellegrino, J. W. (Eds.) (1999). *How people learn: Bridging research and practice.* National Academy Press, Washington, DC.

16. Miller-Reilly, B. (2007) 'Three different teaching approaches in pre-calculus bridging mathematics', *International Journal of Mathematical Education in Science and Technology*, 38:7, 891 – 905

17. Coben, D. (1996) Putting adults into the equation: an agenda for adult learning in mathematics for the new Millennium. Mathematics for the New Millennium – What Needs to be Changed and Why? (London: University of London).

18. Boaler, J. (1993) Encouraging the transfer of 'school' mathematics to the 'real world' through the integration of process and content, context and culture. *Educational Studies in Mathematics*, 25, 341–373.

19. Rogers, P. (1995) Putting theory into practice. In: P. Rogers and G. Kaiser (Eds) *Equity in Mathematics Education: Influences of Feminism and Culture* (London: The Falmer Press), pp. 175–185.