SySTEMically Improving Student Academic Achievement in Mathematics and Science

Kevin Mason, Charles Bomar, and Petre Ghenciu
University of Wisconsin-Stout
Mike LeDocq and Carolyn Chapel
Western Technical College
Jerrilyn Brewer
Sparta Area School District
Jerry Redman
Redman & Associates

ABSTRACT

The Western Wisconsin STEM Consortia project – SySTEMically Improving Student Academic Achievement in Mathematics and Science – provided professional development for 60 K-12 teachers from 9 different school districts in Western Wisconsin. The project was funded by a Math and Science Partnership Grant from the Wisconsin Department of Public of Instruction. The purpose of the project was to increase the academic achievement of students in mathematics and science by enhancing the content knowledge and teaching skills of classroom teachers. The 2010 Summer STEM Academy focused on ecosystems and the interdependence of organisms (Wisconsin Model Academic Standards F.12.7 and F.12.8), scientific inquiry (Wisconsin Model Academic Standard C), and statistics and probability (Common Core Standards S-CP and S-MD). It also addressed effective pedagogical strategies in mathematics and science, including contextual teaching, problem-based learning, project-based learning, and inquiry-based learning. Data analysis revealed that of the 60 teacher participants, 83% demonstrated significant gains in mathematics content knowledge and 62% demonstrated significant gains in science content knowledge.

Keywords: STEM, Teaching Quality, and Training

INTRODUCTION

The need for high quality professional development programs in mathematics and science has become increasingly important in the current climate of educational reform (Blank, Alas, & Smith, 2007). According to Blank, Alas, and Smith, the success of standards-based reforms in education "requires teachers to have deep knowledge of their subject and the pedagogy that is most effective for teaching the subject" (2007, p. 3). The Western Wisconsin STEM Consortia project – SySTEMically Improving Student Academic Achievement in Mathematics and Science – provided professional development for 60 K-12 teachers from 9 different school districts in Western Wisconsin. The project was funded by a Math and Science Partnership Grant from the Wisconsin Department of Public of Instruction.

The purpose of the project was to increase the academic achievement of students in mathematics and science by enhancing the content knowledge and teaching skills of classroom teachers. The 2010 Summer STEM Academy focused on ecosystems and the interdependence of organisms (Wisconsin Model Academic Standards F.12.7 and F.12.8), scientific inquiry (Wisconsin Model Academic Standard C), and statistics and probability (Common Core Standards S-CP and S-MD). It also addressed effective pedagogical strategies in mathematics and science, including contextual teaching, problem-based learning, project-based learning, and inquiry-based learning. This paper discusses the 2010 Summer STEM Academy and the development of the integrated STEM curriculum by K-12 teachers.

LITERATURE REVIEW

This project was grounded in the belief that "teacher professional development is not an event, it's a process" (Harwell, 2003). Teachers were provided time, experiences, resources, and guidance to develop their knowledge of mathematics, science, curriculum, and instruction. In a study of professional development for teachers, Gamoran, et al (2002) found that "most teachers considered time spent planning and learning with other teachers as most valuable" and that teachers "noted that this activity was vital to their growth and development as they worked to change their teaching practice."

Using a framework designed by the National Staff Development Council (2001), this project involved three basic components of high-quality teacher professional development programs: context, content, and process. The context or setting facilitated learning as a "communal activity" where participants could "interact, study together, discuss teaching, and help one another put into practice new skills and strategies" (Joyce & Showers, 2002). A sense of community and the "supportive coaching" that it provides is necessary not only to bring about changes in beliefs but to help teachers develop and maintain a sense of efficacy regarding new teaching strategies (Showers, Joyce, & Bennett, 1987).

The content of the professional development experience was designed to deepen teachers' knowledge of the subjects being taught, sharpen teaching skills, keep up with the developments in the field, and contribute new knowledge to the profession (The National Commission on Mathematics and Science Teaching for the 21st Century, 2000). The 2010 Summer Academy employed a learning for understanding framework that included four related forms of mental activity from which mathematical and scientific understanding emerges: (a) constructing relationships, (b) extending and applying mathematical and scientific knowledge, (c) justifying and explaining generalizations and procedures, and (d) developing a sense of identity related to taking responsibility for making sense of mathematical and scientific knowledge" (Carpenter, et al, 2004).

The process of professional development was based on sound educational practice that presents information and learning activities in familiar and useful contexts (Harwell, 2003). The Career Pathways Framework (Hull, 2005) provided a real-world context that was useful for the development of the STEM (Science, Technology, Engineering, and Mathematics) integrated curriculum projects. According to Harwell, professional development should also support interaction among master teachers, take place over an extended period of time, and provide opportunities for teachers to try new behaviors in safe environments and receive feedback from peers (2003). This professional development project met each of these criteria.

Research has shown that "teachers, like students, best learn science and mathematics by doing science and mathematics, by investigating for themselves and building their own understanding" (Loucks-Horsley, et al 1996). Teachers were immersed in asking and investigating mathematics and science questions in the classroom, at outdoor locations, and at a variety of business sites. Mathematics and science concepts and skills were taught and experienced by the teachers in the context of how math and science are applied by scientists, researchers, and others in business and industry. At the same time, the teachers were given instruction in pedagogical strategies in mathematics and science and considerable time in groups arranged by grade levels to discuss how these concepts and experiences in math and science related to the K-12 curriculum and the students they teach. This led to the successful development of the integrated curriculum projects, which were taught in the K-12 classrooms the following school year.

CONTENT KNOWLEDGE IN MATHEMATICS AND SCIENCE

The 2010 Summer STEM Academy focused on ecosystems and the interdependence of organisms (Wisconsin Model Academic Standards F.12.7 and F.12.8), scientific inquiry (Wisconsin Model Academic Standard C), and statistics and probability (Common Core Standards S-CP and S-MD). To address these standards, a number of activities were utilized. For example, the Karner Blue butterfly (*Lycaeides melissa samuelis*), a federally listed endangered species (http://dnr.wi.gov/forestry/karner/), was studied as a model organism. This species is dependent on the wild lupine (*Lupinus perennis*) as a host plant, and has a mutualistic relationship with two species of mound building ants. This concept was discussed in the classroom and then further presented by a wildlife specialist in a field setting. Teachers garnered firsthand knowledge from the "expert" and then simulated the experience of monitoring this endangered butterfly. Teachers were able to identify the habitat limitations upon this species, and further apply them to their grade band projects.

Teachers also engaged in habitat assessment at a local vineyard, identifying the soil and water conditions necessary for wine grapes. Teachers were provided soil kits to analyze soil nutrients and were provided assays to test for soil texture (ribbon test) and particle size (Whiting, Card, Wilson, & Reader, 2009). These tests allow teachers to explore a variety of soil types and hypothesize to the successfulness of each for producing wine grapes.

The instruction in mathematics focused on concepts in probability and statistics, including tree diagrams, independent events, conditional probability, mean, median, mode, range, and standard deviation (Common Core Standards S-CP and S-MD). Rather than being introduced as separate topics, the probability and statistics concepts were introduced as a way to provide solutions to the questions that emerged from the participants' scientific inquiry activities. All participants do not learn in the same manner, and projects that focused on specific learning objectives provided a modality for some to discover statistical concepts that may not have been grasped within the formal classroom setting. Other participants, while they grasped the concepts, expanded their understanding of statistical concepts through the use of projects. Excel was used to summarize the collected data, run the statistical analysis, and present data in graphical form, including histograms and bar graphs. In addition to learning basic skills, the teachers learned how Excel can be used to investigate questions in a real world context with K-12 students.

PEDAGOGICAL CONTENT KNOWLEDGE IN MATHEMATICS AND SCIENCE

Teachers received instruction and guidance in the use of effective pedagogical strategies in mathematics and science, including contextual teaching, problem-based learning, project-based learning, and inquiry-based learning. The REACT model of contextual teaching emphasizes: **R**elating, **E**xperiencing, **A**pplying, **C**ooperating, and **T**ransferring (CORD, 1999). Problem-based learning helps students to "build their knowledge and skills as they solve a real problem or answer an important question – not through abstract exercises" (Delisle, 1997). Similarly, project-based learning often begins with a question or problem to solve. Project-based learning then engages students in designing and creating a "final product that addresses the driving question" (Blumenfeld, Soloway, Marx, Krajcik, Guzdial, & Palincsar, 1991). Inquiry-based learning provides students with the opportunity to "develop the ability to think and act in ways associated with inquiry" (NSES, 1996). According to the National Science Education Standards (1996), the process of scientific inquiry involves: asking questions, designing investigations, gathering data using scientific tools and techniques, analyzing and representing data, constructing explanations and conclusions, and communicating and defending findings. These theories of learning were taught and modeled throughout the summer academy and later applied by the teachers in the development of the integrated curriculum projects.

EVALUATION

The overall evaluation of this project was based on Guskey's Five-Level Model for evaluating professional development (2000). The project selected numerous evaluation tools to collect qualitative and quantitative data to establish baselines, to monitor progress, to provide feedback, and to determine overall program quality and effectiveness. The participant reaction was measured using journals and critical incident questionnaires (CIQ). Participant learning was measured using the Diagnostic Teacher Assessment in Mathematics (DTAM) test in mathematics, Assessing the Impact of Math-Science Partnerships (AIM) test for science, and a survey of contextual learning. The organization support was measured using partnership surveys. The participant use of new knowledge and skills was measured by assessment rubrics for the integrated curriculum projects. Finally, the student learning outcomes were measured by the Wisconsin Knowledge and Concepts Exam, GIZMO computer simulation assessments, performance tasks, and benchmark assessments.

The principle investigator and external evaluator selected an overall pre-experimental design for teacher participant evaluation. A one-group pre-post-test method that involved three steps: (1) administration of pre-test measuring the dependent variable; (2) application of the experimental treatment; (3) administration of post-test measuring the dependent variable again was used. Use of this design (no control group) was justified because researchers were confident that extraneous factors could be estimated with a high degree of certainty or could be safely assumed to be non-existent. The dependent variable analyzed was teacher content knowledge in BOTH mathematics and science. The experimental treatment consisted of 100 hours of STEM professional development.

Sample size included sixty K-12 teachers who were administered two standardized instruments in a pre-post-test format: Diagnostic Teacher Assessment in Mathematics (DTAM): University of Louisville; Assessing the Impact of Math-Science Partnerships (AIM): K-8 Science Test (Horizon Research, Inc). Data were analyzed by both the test developers and the external evaluator. A one-tailed t-test was used to determine if the difference between the pre-post test scores and/or means were statistically significant. Additionally, effect sizes were calculated using Cohen's d to indicate the relative magnitude of the experimental treatment or the strength of the relationship among variables. Data were disaggregated and analyzed to determine the effect of additional independent variables such as content, type of knowledge, and grade level. Additionally, a contextual learning survey was used to measure teachers' pedagogical change and growth.

There were four major successes identified in this project, based on the data collected. First, sixty-two percent (37 out of 60 participants) demonstrated statistically significant gains in science content knowledge related to populations, ecosystems, and interdependence as evidenced by pre-post test scores on the AIM exam. Effect sizes were .81 at the elementary level and 1.0 at the secondary level; both indicated large effects. Second, eighty-three percent (50 out of 60 participants) demonstrated statistically significant gains in mathematics content knowledge in probability and statistics as evidenced by pre-post test scores on the DTAM exam. The combined effect size was 1.06 (suggesting large effects) and disaggregated results indicated significant differences in three of the four knowledge types that were being addressed. Third, participants showed statistically significant gains in their understanding of contextual teaching and learning strategies on the Teaching Contextually

Survey. Fourth, on the summative assessment of the effectiveness of the two-week STEM Summer Academy, participants rated the overall quality of the professional development at 8.4 on a 10-point Likert scale. Some of our participants submitted quotes to describe the two-week academy, including: "smokin hot"; "fun with application"; "science GIZMOS rock"; "awesome two weeks"; "STEM = Stimulating to Educators' Minds."

INTEGRATED CURRICULUM PROJECTS

During the 2010 Summer Academy, the 60 teachers were divided into ten multidisciplinary grade band teams to develop an integrated STEM curriculum project. The grade band teams included two K-2 teams, two 3-5 teams, three 6-8 teams, and three 9-12 teams. Each of the projects addressed the mathematical topics of mean, median, mode, and range and the science topics of organisms, populations, and ecosystems. The curriculum developed included an overview, scenario, learning objectives, alignment to standards, lesson plans, test blueprint, and assessments for each project.

The integrated curriculum project “Loopy for Ladybugs” was developed by a K-2 grade band team. In this curriculum, the students developed a terrarium for ladybugs to facilitate student understanding of living things and their environment. The other K-2 integrated curriculum project was entitled “Amazing Animals.” In this curriculum, the students were introduced to the characteristics and structures of living things and investigated how living things interact with one another and their environment. The integrated curriculum project called “PONDering Ideas” focused on teaching the same concepts to students in grades 3-5. However, this project focused on the organisms that live in and around a pond. Another integrated project designed for grades 3-5 was “Project Karner Blue.” This curriculum introduced students to the Karner Blue Butterfly and its preferred habitat. The curriculum fostered curiosity and stewardship by establishing a butterfly garden, which allowed students to study, monitor, and investigate ecosystems, life cycles, photosynthesis, and the interdependence of organisms.

There were three integrated curriculum projects designed for the middle school level or grades 6-8. First, “Aromatic Adventures” provided students with an opportunity to study and experience the benefits of producing and processing an indoor herb garden. Like the “Project Karner Blue,” this experience allowed students to study many important life science concepts in an authentic and meaningful context. In “The Amazing Forest Race,” students were given the challenge of navigating a forest. Along the way, students learned about the ecological and economical benefits of the forest as well as how to sustain and evaluate the value of a forest. “What’s the Dirt on Organics?” was the third and final curriculum project designed for grades 6-8. In this curriculum, students were engaged in inquiry-based learning activities to compare and contrast conventional and organic farming. In the process, students learned about soils, plant growth, and food product choices available to consumers.

There were also three integrated curriculum projects designed for the high school level or grades 9-12. “Creating a Frisbee Golf Course” presented students with the fun and interesting challenge of designing a Frisbee golf course. Students were asked to identify and evaluate the ecological consequences of designing, building, and implementing a local Frisbee golf course during this project. “Pew – Dumpster Diving for the Environment” engaged students in a service-oriented recycling project in their own school. In this curriculum, students developed an awareness and knowledge of the benefits of recycling and its environmental impact on the local school and community. Finally, “Something for Nothing? Repurposing Food Grade Oil into Biodiesel” used the topic of biodiesel fuel to engage students in learning about science, math, engineering, and technology (STEM). Students were provided with an opportunity to investigate the economic feasibility and ecological impact of converting recycled food grade oil for practical uses within the community.

CONCLUSION

The STEM integrated approach has proven to be an effective professional development model that results in growth in teacher content and pedagogical knowledge—in both mathematics and science. Data analysis revealed that of the 60 teacher participants, 83% demonstrated significant gains in mathematics content knowledge and 62% demonstrated significant gains in science content knowledge. Aspects of the model that contributed to this effectiveness included higher education faculty with subject-matter expertise; field-based learning activities; career pathway focus; two-week summer academy; multi-district collaboration; grade-band teams; contextual-, problem-, and project-based learning. Teachers embraced this integrated approach to professional development as evidenced by the wide range of STEM Integrated Projects they developed and taught in their own classrooms. The implications of this project are far-reaching and can be applied to future professional development initiatives. It is clear that a STEM integrated approach is an effective professional development model for improving teacher content and pedagogical knowledge in mathematics and science.

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AUTHORS INFORMATION

Kevin Mason

Kevin Mason is an Assistant Professor of Science Education in the School of Education at the University of Wisconsin-Stout. Dr. Mason has served as the Program Director of Science Education at the University of Wisconsin-Stout since 2006. He previously held positions as a chemistry and physics teacher at Chippewa Falls High School and Middleton High School. Dr. Mason can be reached by email at masonk@uwstout.edu.

Charles Bomar

Charles Bomar is a Professor of Biology in the College of Science Technology Engineering and Mathematics at the University of Wisconsin-Stout. Dr. Bomar has served as the program Director of Applied Science since 2005. He has worked with over 100 school districts across Wisconsin through RESTORE and the UW-Madison Arboretum, teaching place based education and the utilization of outdoor classrooms. Dr. Bomar can be reached by e0mail at bomarc@uwstout.edu.

Petre Ghenciu

Petre Ghenciu is an Associate Professor of Mathematics in the College of Science, Technology, Engineering, and Mathematics at the University of Wisconsin-Stout. Dr. Ghenciu has received awards for his teaching and published numerous articles in the field of mathematics. He has worked on multiple grants to improve the pre-service teacher education and professional development of K-12 teachers in mathematics. Dr. Ghenciu can be reached at ghenciup@uwstout.edu.

Mike LeDocq

Mike LeDocq is a Physics Instructor in the General Studies Division at Western Technical College. Dr. LeDocq has served as the Physical Science Department Head since 2005. He previously held positions as a mathematics and physics lecturer at the University of Wisconsin-La Crosse and has helped present inquiry-based physical science workshops for

preK-12 classrooms since 2000. Dr. LeDocq can be reached by e-mail at ledocqm@westerntc.edu.

Carolyn Chapel

Carolyn Chapel is a Mathematics Instructor in the General Studies Division at Western Technical College. She has been there since 2005. She previously held a position as a Mathematics Instructor for ten years at Luther College. She can be can be reached by e-mail at chapelc@wesaterntc.edu

Jerrilyn Brewer

Jerrilyn Brewer is a grant developer for the Sparta and Norwalk-Ontario-Wilton school districts and is serving as Principle Investigator for the STEM grant. She retired from the position of Associate Vice President for Strategic Effectiveness at Western Technical College in La Crosse, WI in 2006. Dr. Brewer is an Associate Lecturer in the School of Education at the University of Wisconsin—Stout and can be reached at brewerj@uwstout.edu.

Jerry Redman

Jerry Redman is CEO of Redman & Associates, LLC. and served as External Evaluator on the project. Dr. Redman has been a science teacher, assistant professor, curriculum, instruction, and assessment coordinator, instructional services director, and assistant administrator. He has worked at various levels of education ranging from middle/secondary to technical college and university to CESA. Dr. Redman can be reached at jerry.redman@teaching2learning.com