Improving Geometric and Trigonometric Knowledge and Skill for High School Mathematics Teachers: A Professional Development Partnership

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Abstract

In the summer of 2009, a professional development partnership was established between the Peoria Public School District (PPSD), a local education agency (LEA), and Illinois State University (ISU) to improve geometric and trigonometric knowledge and skill for high school mathematics teachers as part of the Illinois Mathematics and Science Partnership (MSP) grant, which was funded by the Federal Department of Education. The MSP is aimed at improving the content knowledge of mathematics teachers regarding the implementation of three-dimensional (3-D) solid modeling in the mathematics classroom; the ultimate goal is to improve students' learning in mathematics. The premise for this professional development grant can be found in the literature that suggests that there is a significant positive relationship between spatial visualization abilities and mathematical performance. Also, the literature implies that spatial ability and visual imagery play vital roles in mathematical thinking. Further, the professional development program maintains that spatial visualization and reasoning are core skills that all students should develop. Eight mathematics teachers from the PPSD and the LEA's Mathematics Coordinator completed over 80 hours of professional development geared toward the improvement of teaching mathematics; they used 3-D solid modeling software (SolidWorks, 2009) during the summer and fall semesters of 2009 and during the spring 2010 semester, these teachers conducted action research projects based on their professional development. Formative and summative evaluation techniques were developed and implemented.

Introduction

In the summer of 2009, a professional development partnership was established between the Peoria Public School District (PPSD) and Illinois State University (ISU) to improve geometric and trigonometric knowledge and skill for mathematics teachers as part of the Illinois Mathematics and Science Partnership (MSP) grant, which was funded by the Federal Department of Education. The purpose of this MSP grant was to improve the content knowledge of mathematics teachers (seven high schools and one middle school) regarding the use and implementation of three-dimensional (3-D) solid modeling in the mathematics classroom. The ultimate goal is to improve student learning in mathematics. The premise of this professional development can be found in the literature that suggests that there is a significant positive relationship between spatial visualization abilities and mathematical performance. Additionally, the literature implies that spatial ability and visual imagery play vital roles in mathematical thinking. Further, the professional development program maintains that spatial visualization and reasoning are core skills that all students should develop. Therefore, the purposes of this research are to (a) share related literature on spatial visualization as it pertains to mathematics, (b) highlight a collaborative professional development program for mathematics teachers that utilized a 3-D solid modeling software approach to better teach geometric and trigonometric concepts, (c) explain the initial findings of this professional development program, and (d) discuss implications for collaborative efforts among science, technology, engineering, and mathematics (STEM) educators.

Eight mathematics teachers from the PPSD and the LEA's Mathematics Coordinator completed more than 80 hours of professional development geared toward the improvement of teaching mathematics using 3-D solid modeling software during the summer and fall semesters of 2009 and the spring 2010 semester. These teachers conducted action research projects based on their professional development. Formative and summative evaluation techniques have been developed and implemented to measure the affect of this professional development experience.

At the conclusion of the spring 2010 semester, eight new mathematics teachers from PPSD were selected to participate in the second part of this professional development program, and they were matched with four of the original eight cohort members. The four original mathematics teachers will serve as mentors and teacher leaders for the new group. The research team has planned to scale up the cohort for a third-year professional development program, in which members of the first and second groups, aligned with select science teachers from PPSD, will complete an integrated 3-D program. This professional development program has been funded for a total of $283,948 for the 2009 and 2010 fiscal years.

Background of Proposal and Requirements

The broad goal of the Federal MSP program is to increase the academic achievement of students in mathematics and science by enhancing the content knowledge and teaching skills of classroom teachers. More specifically, according to the request for proposal (RFP), the goals for the MSP programs follow: (a) to improve teacher's subject matter knowledge, strengthen the quality of mathematics and science instruction, and promote student academic achievement in mathematics and science; (b) to promote strong teaching skills through access to the expertise of mathematicians, scientists, and engineers and their technologies and resources, including integrating reliable scientifically based research teaching methods and technologically based teaching methods into curriculum; and (c) to increase the understanding and application of scientifically based educational research appropriate to mathematics and science teaching and learning. Specifically, the research plan, directed by external evaluators and dovetailed with the Federal MSP guidelines, was to examine (a) teacher change in terms of content and pedagogical content knowledge; (b) quality of professional development activities; (c) teacher perceptions of their current preparedness; (d) teacher attitudes toward teaching; (e) frequency of using designated instructional resources; (f) teacher use of promoted practices, including inquiry-based lessons and implementation of 3-D visualization tools in the classroom; (g) design, implementation, content, and culture of the professional development experience; (h) student change by analyzing state and district test scores, as well as any additional criterion-referenced student assessment; and (i) collaborative efforts between and among the mathematics teachers.

The RFP required a partnership between an institution of higher education and a high-need school district. In the RFP, a high-need district was defined as one in which 50% or more of their students were failing to meet the state's learning standards, as evidenced by performance on state achievement tests. The district also must have a student population of which 15% or more of the students who are from low-income families, and the district must be facing teacher quality issues, including inappropriate certification or teaching assignments. The partnerships were viewed in the RFP as a way to bring the resources of an institution of higher education (equipment, space, libraries, etc.) to a high-need school. The higher education faculty involved in this professional development program were from the College of Applied Science & Technology and the College of Education. Each member of the higher education faculty had an interest in science, technology, engineering, and mathematics (STEM) teaching and learning, but none had a formal degree in science or mathematics.

The RFP specified that there must be a summer workshop-style program for professional development that consisted of 80 hours or more of professional development with at least four follow-up days during the following academic year. The workshop was to be designed to utilize state-of-the-art technologies used by scientists, mathematicians, and engineers and to encourage there use in the classroom. The intended participants were to be mathematics and science teachers with less than 10 years of experience who had leadership potential. After completion of the scheduled professional development, the teacher participants would be expected to complete an action research project to determine the effectiveness of their learning. The intended outcomes of the professional development were clearly an increase in teacher content knowledge, instructional practice, and an improvement of student academic achievement in mathematics.

After careful examination of the goals of the MSP's RFP, the research team contacted the Mathematics Coordinator at PPSD. The rationale for partnering with PPSD includes its geographical relationship to ISU, successful past experiences regarding educational initiatives, and the research team's efficacy toward partnering with a school district that is dynamic, yet poses myriad challenges.

PPSD has a 30.5% White student population (state average 54%), 61.1% Black student population (state average 19.2%), and a 5.5% Hispanic population (state average 19.9%). The low-income rate for PPSD is 70.3% (state average 41.1%). The mobility rate of students (families) in PPSD is 30.1%, which is more than double (14.1%) the state average. The total student enrollment for PPSD is 13,642. The number of economically disadvantaged students taking the mathematics exams totaled 5,182 (13,642 total students in PPSD), whereas the number of disadvantaged students taking the science exam was 2,034 (Illinois District Report Card, 2008). The PPSD did not earn adequate yearly progress in 2008. The graduation rate of PPSD students was 75% (Illinois District Report Card, 2008).

Student achievement is lacking in the LEA. The American College Testing (ACT) assessment score for the graduating class of 2008 in PPSD was a composite 18.7 score. In mathematics, PPSD students earned an 18.8 (state average 20.6), and in science, PPSD students earned an 18.4 (state average 20.3). The percentage of students who met or exceeded the standards on the 2008 state achievement exam in mathematics and science were 37.3 and 31.9; both scores fell well below state averages. This level of failure is systemic throughout the school district. The percentage of students in sixth, seventh, eighth, and eleventh grades who did not meet the minimum level of achievement in mathematics was 32.9%, 29.7%, 29.6%, and 44.7%, respectively. The percentage of seventh and eleventh grade students who did not meet the minimum level of achievement in science was 18.6% and 53.3%, respectively (Illinois District Report Card, 2008).

When the research team conducted a needs assessment with the LEA mathematics teachers and LEA Mathematics Coordinator, the following themes emerged as the areas of most need/interest:

- Increasing teachers' understanding and application of research to improve student learning (research must be teacher and school friendly);

- Promotion of strong teaching skills (e.g., effective instructional strategies);

- Improved subject matter knowledge (both teachers and students);

- Access, use, and implementation of technology in the classroom to promote new and improved teaching skills and student knowledge/skill; and

- Inquiry-based (problem-based) teaching and learning.

Based on the findings of the needs assessment and discussions with the LEA Mathematics Coordinator, the research team devised a cutting-edge professional development program, based on literature findings and grounded in the premise of helping students to learn and improve their mathematical ability. It also provided mathematics teachers with the opportunities to improve their pedagogical approaches in the classroom. Based on the findings of the needs assessment, the research team explored related literature centered on mathematics, 3-D solid modeling, and the connection with teacher content knowledge, pedagogy, and assessment.

Related Literature on Mathematics and 3-D Solid Modeling

The National Council of Teachers of Mathematics in its 1989 *Curriculum and Evaluation Standards for School Mathematics* came forward with an attempt to "create a coherent vision of what it means to be mathematically literate" (p. 67). The NCTM has since revised its standards (NCTM, 2000), seeking to simplify and clarify its vision with the *Principles and Standards for School Mathematics (PSSM)*. The standards made explicit that technology should be used in teaching, stating that, "appropriate calculators should be available to all students at all times" (p. 8), and previously it stated:

> Technology, including calculators, computers, and videos, should be used when appropriate. These devices and formats free students from tedious computations and allow them to concentrate on problem solving and other important content. They also give them new means to explore content. As paper-and-pencil computation becomes less important, the skills and understanding required to make proficient use of calculators and computers become more important. (NCTM, 1989, p. 67)

Recommendations at the high school level also called for the use of technology. The integration of ideas from algebra and geometry is particularly strong, with graphical representation playing an important connecting role. The standards also called for increased use of computer-based explorations of 2-D and 3-D figures and real-world applications and modeling as well as decreased attention to paper-and-pencil graphing of equations by point plotting and paper-and-pencil solutions to trigonometric equations (NCTM, 1989). Instructional technologies for the mathematics classroom were being developed and refined. The most dominant is the graphing calculator.

Although mathematics researchers and educators clearly acknowledge the role of technology in mathematics instruction, research findings in mathematics education also suggest there is a significant positive relationship between spatial visualization abilities and mathematical performance, and that spatial ability and visual imagery play vital roles in mathematical thinking. Seng and Chan (2000), for example, stated "much of the thinking in higher mathematics is spatial in nature" (p. 2). Furthermore, "positive correlations have been found between spatial ability and mathematics performance at all grade levels in solving problems that involve geometry" (Seng & Chan 2000, p. 2). Jones & Fujita (2002) claimed that students cannot solve geometrical problems unless they can create proper geometrical images in the mind. Similarly, the National Council of Teachers of Mathematics (NCTM) contends that 2-D and 3-D spatial visualization and reasoning are core skills that all students should develop (Christou et al., 2007).

Because spatial ability has been shown to correlate to mathematics performance, there are obvious concerns for students who have less-developed spatial skills. In many studies, for example, females have been shown to possess fewer visualization skills than their male counterparts (Medina, Gerson, & Sorby, 1998; Melancon, 2001; Sorby, 1999). In a 2008 study, Moore and Johnson found that males tended to perform better than females on spatial relationships/visualization. Researchers do not know why males surpass females at spatial visualization, but note that the differences can be found in as early as five months of age (Moore & Johnson, 2008); four and one-half years of age in a 1999 study by Levine, Huttenlocher, Taylor, and Langrock. Levine et al. (1999) also noted that spatial visualization gaps between genders widen as both genders mature in age. In a 2007 meta-analysis study on gender differences in spatial abilities, McNulty found that researchers have only been able to indicate that a gender difference exists in mentally manipulating objects. Linn and Peterson (1985) found male subjects favored mental rotations, whereas Alexander (2005) found that females favored visual memory. McNulty synthesized from a study conducted by Ginn and Pickens (2005), that "women who participated in music, art, or athletics had more experience with spatial activities than women who did not participate in these activities" (p. 17). Although instruction in mathematics relies heavily on graphical images to convey conceptual ideas, the current mathematics curriculum offers little formal support to foster the acquisition of spatial skills. This is unfortunate, because neglecting instruction in spatial competence could discriminate against the less spatially minded student.

Dynamic Geometry Software (DGS) has been used in the mathematics classroom since the late 1980s to help teach the principles of geometry (Christou et al., 2007). Even though most of the DGS applications that are available to mathematics teachers are 2-D in nature, a handful of 3-D DGS systems are being developed and tested (e.g., Kaufmann, Steinbügl, Dünser, & Glück, 2008). The mathematics research community is excited about the development of the new 3-D DGS applications because these provide opportunities for students to create and explore geometric shapes that are rendered and easy to visualize. "Computer software for the teaching of 3-D geometry should allow students to see a solid represented in several possible ways on the screen and to transform it, helping them to acquire and develop abilities of visualization in the context of 3-D geometry" (Christou et al., 2007, p. 3). Although 3-D geometry construction is relatively new and still under development in the DGS field, 3-D solid modeling is a mature technology that has been the mainstay of the engineering community for decades.

The engineering community has been using computer-aided design (CAD) software since the 1960s. Early 2-dimensional CAD systems were used to create product designs using curves, such as lines, arcs, and splines. As time progressed, 3-D CAD systems were developed that allowed the definition of 3-D objects. Early 3-D CAD systems common in the 1970s and 1980s used surface modeling technology to describe the outer envelope of products. Though surface modeling was a significant improvement over 2-D modeling, the lack of interior product details limited the use of this CAD data. Today, almost every 3-D CAD system used in mechanical design utilizes solid modeling technology. Solid modelers unambiguously define the entire 3-D object, which allows the CAD data to be used in new ways. For example, specific materials, such as metals or plastics, can be applied to a solid model making it possible to evaluate many physical properties of the design, such as weight, center of gravity, and strength.

One of the most significant trends in engineering graphics in recent years has been the maturation and widespread adoption of constraint-based solid modeling technology. A significant advantage of constraint-based modelers is the ability to define 3-D solid models using a series of modifiable features. In a constraint-based modeler, the modeling process usually starts by creating a 2-dimensional sketch, which is then "swept" to create a 3-D solid. The 2-D sketches are comprised of coplanar curves, such as lines and arcs, which have been geometrically and dimensionally constrained. Geometric sketch constraints are geometric rules that describe how the sketch should behave when edited. For example, two lines can be constrained to always be perpendicular, two circles can be constrained to always share the same center point (concentric), and a circle can be constrained to be tangent to a line. In addition to geometric constraints, specific dimensions are added to sketch geometry to further constrain the sketch. A line, for example, may be constrained using an explicit numeric dimensional value, such as 2 inches, or a mathematical expression, such as "line length = 2/3 circle diameter." The use of constraints is critically important because they allow the sketches to behave predictably during editing. The ability of constraint-based solid modelers to create modifiable "dynamic" models rather than static solid models offers great advantages to industry (Bertoline & Wiebe, 2007).

Because many of the principles of geometry are used when creating models using 3-D constraint-based solid modelers, and 3-D solid models are displayed in a rendered form that is easy to visualize, it is reasonable to assume that using a 3-D solid modeler during mathematics instruction could benefit some learners. Even though there is agreement that 3-D solid modelers share many aspects of the new 3-D DGS applications, some researchers contend that 3-D CAD systems are not well suited for geometry education. Kaufmann et al. (2008), for example, argued that commercial CAD software is too complex and the learning curve too steep for use in the mathematics classroom. There are, however, several published studies in which constraint-based solid modelers have been used in the K-12 classroom to teach in a variety of STEM-related disciplines, including mathematics, physics, and engineering technology.

Devine (2008) conducted a study to measure the extent to which using a constraint-based solid modeler during high school mathematics instruction affects student learning. Devine's study used two intact groups, a control group and an experimental group, to measure the extent to which using a parametric solid modeler during instruction affects student learning relating to the mathematical principles of areas and volumes of solids. The control group was taught using traditional instructional methods, and the experimental group was taught using a combination of traditional methods and experimental methods utilizing a constraint-based solid modeler. At various times during each class period, the researcher worked through problems for the students using a solid modeler. The computer images were projected on a screen for all students to see. The solid modeling techniques used typically involved creating and constraining a two-dimensional sketch, which was then extruded or revolved to create a solid. Named expressions were used to dimensionally constrain the sketches, with the expression names chosen to match the mathematics terminology presented in geometry texts. Boolean operations provided opportunities to illustrate the concept of volumetric addition and subtraction. The solids were shaded, rotated, and sometimes sectioned to help the students visualize the shape. When specific information was required for a calculation (e.g., height and diameter of a cylinder), the dimensions were obtained both algebraically and graphically using various measuring functions in the software.

In Devine's (2008) study, the students who received instruction using the solid modeler scored 3% higher on their unit exam. The cooperating mathematics instructors were also quick to point out that they observed many nonquantifiable benefits to using the software during geometry instruction. The instructors commented that the rendering capabilities of the system allowed students to visualize the geometry like they had never before experienced in their classes. One female student, for example, excitedly told her instructor that for the first time all year she had been able to visualize the geometry concepts being taught in the class. The mathematics instructors also commented that the solid modeling software allowed them to test their students' understanding of geometry principles by asking probing questions they would not normally be able to answer using graphical means (Devine, 2008).

Planchard (2007) described a project in which educators in a variety of STEM fields used a commercially available constraint-based solid modeling application called SolidWorks. The overarching objective of the project was to improve the understanding of STEM principles through the use of 3-D CAD software. Additionally, the project was designed to enhance instructors' skills in instructional design by utilizing 3-D CAD to illustrate theory. Planchard's (2007) project also provided a venue to share resources for STEM-related courses. The project provided SolidWorks software to teachers, from middle school to college level, who represented a wide range of STEM disciplines. The instructors developed lesson plans that required students to use SolidWorks in some manner. Secondary instructors developed lessons for Algebra, Art, Biology, Calculus, Chemistry, Geometry, Robotics, Technology, and Trigonometry. All lesson plans were posted on a web blog sponsored by SolidWorks for other instructors to see and use. Even though many of the instructors involved in Planchard's project did not have any prior experience of working with 3-D CAD software, they were able to learn SolidWorks with little difficulty. Planchard stated, "for both instructors and students, 3-D CAD software provides a powerful complement that makes science, technology, engineering, and math more understandable" (2007, p. 4).

Traditionally, instruction in many STEM disciplines has been deductive in design, beginning with abstract theories and progressing to applications of those theories. Alternatively, inductive instructional methods start with specific observations, case studies, or problems, and theories are taught or students discover them only after the need to know them has been established. Inductive methods are constructivist in nature and require students to take more responsibility for their learning. Inductive methods have been shown to be at least as effective, and in most cases more effective, than deductive methods (Prince & Feldner, 2006). A review of the SolidWorks education blog (http://blogs.solidworks.com/teacher) revealed that many instructors used SolidWorks as a vehicle to employ inductive methods in many disciplines. One instructor, for example, created a lesson to allow students to examine trigonometric ratios on circles of varying radii, thereby discovering that the ratios remain constant regardless of the radius of the circle. Another lesson helped students to discover the formula to figure the sum of the interior angles of an *n*-gon.

The use of commercially available 3-D CAD software to teach STEM principles has many potential benefits. The ability of constraint-based solid modelers to provide feedback to learners that is both immediate and readily observable is an ideal tool to promote inductive learning in many STEM disciplines. Furthermore, because a 3-D solid modeler is the tool of choice for engineers and technologists in the workplace today, exposure to this modern technology may demonstrate how mathematics principles are used in the real world. This is important because educational researchers have long realized the importance of context in the learning environment, and the lack of an authentic context for learning experiences has long been a concern in mathematics education (Hiebert & Lefevre, 1986; Silver, 1986). Exposure to real- world applications of mathematics and science also may help students to see value in pursuing STEM-related education (Kesidou & Koppal, 2004; Raju, Sankar, & Cook, 2004; Swift & Watkins, 2004).

Discussion of SolidWorks as a Tool for Mathematics

SolidWorks was selected for use in this project because it is one of the most popular constraint-based solid modelers available today, and it has technical capabilities that rank among the leaders in the industry. Another benefit to this project was that SolidWorks is widely used in K-12 schools and supporting materials, including numerous text-books and a SolidWorks teachers' blog, are readily available. Finally, SolidWorks is currently being used in other grants, such as the NSF-funded "Biomechanics and Robotics Explorations for IT Literacy and Skills in Rural Schools," which is underway at East Carolina University. Because granting agencies encourage grant recipients to disseminate grant materials and lessons learned, the use of SolidWorks also had nontechnical benefits.

The general approach taken in this project was to work with the participants (middle and high school teachers) initially to help them learn the basic functionality and real-world applications of the SolidWorks application. However, prior to the discussion of how SolidWorks was used as a tool in mathematics classrooms it is worth listing what each teacher participant received for being a part of this professional development program. As mentioned previously, the PPSD is extremely poor, and therefore many items that other school districts may take for granted are not an option for purchase. Each teacher participant from PPSD and the PPSD Mathematics Coordinator were given a laptop computer, an LCD projector, a security lock, a backpack, a 3-D mouse, a stipend to attend professional conferences, advanced SolidWorks training outside of the normal professional development program, 3-D manipulative cubes for the classroom, an individual and district-wide site license for SolidWorks, a financial stipend for being part of the professional development, over $850 worth of educational textbook and reference materials, screen capture software, a laptop camera and microphone, and six hours of graduate credit. In addition, the LEA received a financial allocation for administrative costs.

The use of SolidWorks as an educational tool in mathematics began through teacher professional development sessions. The professional development sessions started with a focus on the basic functionality of SolidWorks. During each weekly meeting, the participants observed software demonstrations and completed hands-on activities using their laptop computers loaded with SolidWorks software. Early sessions were somewhat prescriptive in nature, with participants completing exercises that were assigned by one of the principle investigators. Participants completed "homework" assignments, including software tutorials, between sessions.

Specific attention was paid initially to the basic concepts of creating planar (2-D) sketches comprised of lines and arcs, which are then swept using either the extrude or revolve operations to create 3-D geometry. While working in the 2-D sketcher environment, specific mathematical relationships (constraints) were applied to the curve geometry. These rules included basic mathematical concepts, such as parallelism, perpendicularity, concentricity, and more. The participants used SolidWorks to create curves, apply the designed geometric rules, and "drag" the geometry on the screen to see the resulting behavior of the geometry. While working with the 2-D geometry, geometric properties, such as perimeter and surface area, were also explored.

Because the strength of any solid modeler lies in the 3-D capabilities of the software, and the fact that there are other 2-D software tools available for use in the mathematics classroom, the next logical step was the transition from 2-D to 3-D geometry. Basic sweeping operations such as extrude and revolve were explored at length. Using the extrude function, previously created 2-D sketches were swept linearly a specified distance along a vector, thus creating 3-D solid geometry. The geometry could then easily be rendered and rotated to help the user visualize the 3-D shape. The 2-D sketches were also revolved to form 3-D solids. When using the revolve function, the 2-D sketch is rotated about a linear axis to create a 3-D solid.

As the professional development sessions progressed, the sessions became less prescriptive and more varied based on input from the participants. The participants were frequently asked to comment on how the software functions that they were learning might be helpful in the mathematics classroom. The teachers were also asked to identify specific "problem" areas where they thought the use of SolidWorks might be helpful. As a group, the participants and principle investigators brainstormed to identify other software tools and possible demonstrations and/or activities that would help improve mathematics instruction. Of interest to the teachers was the ability to visualize the results of revolving the same set of 2-D curves about different axes. The concepts of Boolean operations (unite, subtract, and intersect) and 3-D geometric properties such as volume and center of gravity could now also be explored.

After the participants had explored and grown comfortable with the basic functionality of SolidWorks, some advanced functions were targeted that had specific mathematical applications of interest to the teachers. For example, the ability to create 2-D curves using mathematical functions and the ability to link various model dimensions using mathematical equations and an Excel spreadsheet were explored. Finally the ability to convert a 3-D solid into a 2-D "net" using the sheet metal design function of SolidWorks was explored.

Over time, the professional development sessions shifted away from weekly demonstrations and modeling "assignments" toward explicitly exploring ways that SolidWorks could be used during mathematics instruction to improve student learning. Each participant was asked to develop a detailed lesson plan in which they would use SolidWorks in some way to help teach mathematics. This transition dovetailed well with the increased professional development emphasis placed on teaching pedagogy and action research.

In addition to the SolidWorks and mathematics education professional development listed above, teacher-based and school-based issues were discussed, knowing that mathematics is only one area associated within the larger circle of the school. For example, during the last 15 hours of the fall 2009 professional development program, educational materials, such as *How Students Learn: Mathematics in the Classroom* (National Research Council, 2006), *Qualities of Effective Teaching* (Stronge, 2007), *The Art and Science of Teaching* (Marzano, 2007), and *Classroom Strategies for Helping At-Risk Students* (Snow, 2005), were discussed in order to bridge the use of SolidWorks with best practices in teaching and learning. The concluding piece of professional development is a focus on action research in which the focus of inquiry is to determine the affect that their new knowledge of SolidWorks had on their students and instruction.

Mid-Program Findings

Described in this section is an abbreviated synthesis of the evaluation results from the mid-year professional development evaluation conducted by the external evaluators. The external evaluators found that the teacher participants rated the *quality* of the professional development experience as a 4.4/5.0. Teacher participants commented that this professional development experience had provided them with the opportunity to reflect on their practice with fellow teachers and share ideas for improvement. Teacher participants rated the *value* of the professional development experience as a 4.5/5.0, despite feeling that their students would not likely have the ability to understand 3-D visualizations. When asked whether the teacher participants would recommend this professional development experience to other teachers, all teacher participants said "yes," yielding a 5.0/5.0. The "impact of the professional development program on teachers' understanding of how to use technology in their classrooms" was rated as a 4.1/5.0, despite very positive written comments provided by the teacher participants. When asked about the "impact of the professional development program on teachers' understanding of integrated STEM", the teacher participants yielded a mean score of 4.0/5.0. Teacher participants noted that being able to integrate STEM activities in their classrooms seems to be segregated due to the nature of the school/district setting. "The extent to which teachers' instructional practice has improved as a result of the professional development program" yielded a 4.2/5.0 mean score.

Barriers and Lessons Learned

During the time this professional development initiative had taken place and as the research team moves forward into the next phase, the LEA school board voted to close one of its four high schools, all teachers without tenure were given a "pink slip," the current year's teaching contract went to a "vote to strike" before being ratified, and the superintendent decided to retire mid-year. Any one of these events would be enough to cause severe chaos for the teachers in this LEA, but despite these events, the teacher participants continued their professional endeavors, even knowing that they will likely be without a teaching position the next school year. Needless to say, the research team has learned a great deal about professional development with an LEA that is facing adversity at many different levels. Although the barriers listed below were areas that the research team faced, they should be seen as opportunities for future STEM-based faculty who want to conduct professional development.

Barrier #1. Before the professional development experience started, the external evaluators for the project conducted an interview protocol as a pre-measure of data collection with the eight mathematics teachers and the PPSD Mathematics Coordinator. One of the quotes from the teachers was, "I don't really have any hopes for what I'm going to get out of it [professional development]." Additionally, the mathematics teachers expressed concern over the lack of time to fit the material into their curricula and their lack of background knowledge. Classroom teachers are overworked and have extracurricular activities to lead; it is difficult for them to give time to professional development opportunities, even if they have asked to be involved in professional development. The solution to this barrier was that the research team understood the time involved for classroom; the majority of the research team were former middle and high school teachers. Therefore, the research team did not dismiss the rationales given by the teacher participants, but rather worked with them to find mutual, beneficial experiences. Although one might dismiss when professional development is held, the research team found that one of the early findings of their professional development experience was to hold weekly meetings early in the week (e.g., Tuesday). Approximately half way through the professional development experience, the same teacher who did not have any hope for a successful experience was quoted as saying, "So far, this is the best thing I've done as far as PD goes. It's taught by guys who teach the program but still understand how we can apply it every day; they always gear it towards those teachers."

Barrier #2. The language of "technology" was different for the research team and the mathematics teachers. The research team and mathematics teachers often used different terminology to describe similar concepts, which took time to decipher. For example, during one of the SolidWorks sessions, the participants worked on pattern developments (a technical drawing term) and the mathematics teachers called these same items "nets." Further, in a technical drawing scenario, one would be concerned with hems and folds, whereas the mathematics teachers were concerned with mathematical applications – they did not care how the object came together.

Barrier #3. Some of the teacher participants engaged in this professional development seemed to be more serious than others, although this was based only on the perceptions and observations of the research team. Some of the teacher participants immediately tried to implement classroom-based strategies and adjust their curricula, while others seemed to have a lesser degree of urgency. Based on the post-evaluation instruments used by the external evaluators, however, the professional development participants rated the quality of the professional development *experience* a 4.4 out of 5, and they rated the *value* of the professional development a 4.5 out of 5. Further, 100% the professional development participants said that they would recommend this professional development experience to others.

Barrier #4. Without common planning periods or time throughout the school day in addition to other curricular demands, teacher participants were less successful in applying their professional development experiences in the classroom. This was despite the research team's efforts to have multiple teachers from the same school on the professional development program and help from a district level coordinator to coordinate time. Insufficient planning time continues to be a barrier not only for this professional development experience, but also for the majority of schools in the country. One lesson learned by the research team is to consider allocating enough money into future budgets for "purchasing" teachers' time, but the research team also knows that this plan will not be sustainable based on the budgets of the LEA after the professional development experience concludes.

Barrier #5. Most teacher participants possessed a fear of moving out of their comfort zone of teaching traditional mathematics and lacked the confidence to use technology in the classroom. Nearly all of the teachers also expressed concern about how they would provide opportunities for their students to "get their hands on it" (referring to the SolidWorks software). The research team understood that access to SolidWorks and other professional development materials would be difficult for the LEA. In the case of SolidWorks, however, the research team purchased software copies for the entire LEA, so all students and teachers would have access. One of the professional development participants was quoted in the post-interview conducted by the external evaluators as saying,

> A lot of people are reluctant to go out there and do something different, but I found that is why I enjoy it. It kind of stretches my thinking and makes me rethink some of the things that I am doing that I thought were working, but I realize if I use some of the things that I see or hear in this program, it would help.

Conclusion

From the formative and limited summative assessments that the research team and external evaluators have conducted to this point in the program, there is value in professional development that challenges the traditional ways teachers teach and what they teach. "I've changed a lot of things and it's better than before. The more hands-on and visualization tools I use, the better the students understand it" (post-interview quote from teacher participant). Another teacher participant was quoted in the post-interview stating, "It has definitely given me different ideas and different ways that I can approach it – different ways that I can talk to students about what they are doing and how it can work." A different teacher was quoted as saying, "When the students can see it and visualize it, they can understand the relevance . . . and the relevance promotes rigor."

As the professional development program expands into its second year and forecasted third year, the research team is focused on implementing what they have learned from the teachers and continuing the efforts of using SolidWorks as a tool to teach teachers how to use technology to better teach geometric and trigonometric concepts. The research team feels confident that what has been documented thus far adds to the literature base on professional development, and that after the second and third year of professional development has concluded, additional literature and quantitative and qualitative results will be of benefit for not only technology educators, but also for mathematics educators. It is clear that professional development, even funded professional development, is not easy, but with sustained efforts, meaningful and productive professional development can occur.

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References

Alexander, G .M. (2005). Memory for face locations: Emotional processing alters spatial abilities. *Evolution and Human Behavior, 26*(4), 352-362.

Bertoline, G. R., & Wiebe, E. N. (2007). *Fundamentals of graphics communication* (5th ed.). Boston: McGraw Hill.

Christou, C., Jones, K., Pitta-Pantazi, D., Pittalis, M., Mousoulides, N., Matos, J. F., Sendova, E., Zachariades, T., & Boytchev, P. (2007). Developing student spatial ability with 3D software applications. Paper presented at the *5th Congress of the European Society for Research in Mathematics Education (CERME)*, Larnaca, Cyprus.

Devine, K. L. (2008). Using a parametric solid modeler as an instructional tool to teach high school geometry. *Engineering Design Graphics Journal, 72*(2), 11-18.

Ginn, S. R., & Pickens, S. J. (2005). Relationships between spatial activities and scores on the mental rotation test as a function of sex. *Perceptual and Motor Skills, 100*(3), 877-881.

Hiebert, J., & Lefevre, P. (1986). Conceptual and procedural knowledge in mathematics: An introductory analysis. In J. Hiebert (Ed.), *Conceptual and procedural knowledge: The case of mathematics* (pp. 1-26). Hillsdale, NJ: Erlbaum.

Illinois District Report Card (2008). *Peoria School District 150.* Retrieved from http://www.peoria.psd150.org/docs/ReportCard2008.pdf.

Jones, K., & Fujita, T. (2002). The design of geometry teaching: Learning from the geometry textbooks of Godfrey and Siddons. *Proceedings of the British Society for Research into Learning Mathematics, 22*(2), 13-18.

Kaufmann, H, Steinbügl, K., Dünser, A., & Glück, J. (2008). *General training of spatial abilities by geometry education in augmented reality*. Retrieved from http://www.ims.tuwien.ac.at/media / documents/ publications/CT05_GeomEdu_SpatialAbilities.pdf accessed on 5-21-09.

Kesidou, S., & Koppal, M. (2004). Supporting goals-based learning with STEM outreach. J*ournal of Science, Technology, Engineering and Mathematics Education, 5*(3&4), 5-16.

Levine, S. C., Huttenlocher, J., Taylor, A., & Langrock, A. (1999). Early sex differences in spatial skill. *Developmental Psychology, 35*(4), 940-949.

Linn, M .C., & Petersen, A. C. (1985). Emergence and characterization of sex differences

in spatial ability: A meta-analysis. *Child Development, 56*(6), 1479-1498.

Marzano, R. J. (2007). *The art and science of teaching: A comprehensive framework for effective instruction.* Alexandria, VA: Association for Supervision and Curriculum Development.

McNulty, K. P. (2007). *Gender differences in spatial abilities: A meta-analysis*. Unpublished manuscript, Georgia Institute of Technology. Retrieved from http://smartech.gatech.edu/ handle/1853/19945

Medina, A. C., Gerson, H. B. P., & Sorby, S. A. (1998). *Identifying gender differences in the 3-D visualization skills of engineering students in Brazil and in the United States.* Columbus, OH: ERIC Clearinghouse on Adult, Career, and Vocational Education. (ERIC Document Reproduction Service No. ED443729).

Melancon, J. (2001). Developing visualization and spatial skills. Retrieved from: http://www.nade.net/documents/SCP94/SCP94.12.pdf.

Moore, D. S., & Johnson, S. P. (2008). Mental rotation in human infants: A sex difference. *Psychological Science, 19*(11), 1063-1066.

National Council of Teachers of Mathematics [NCTM]. (1989). *Curriculum and evaluation standards for school mathematics.* Reston, VA: Author.

National Council of Teachers of Mathematics [NCTM]. (2000). *Principles and standards for school mathematics.* Reston, VA: Author.

National Research Council. (2006). M. S. Donovan & J. D. Bransford (Eds.). *How students learn mathematics in the classroom.* Washington, DC: The National Academies Press.

Planchard, M. (2007). 3D CAD: A plus for STEM education. *Engineering Design Graphics Journal, 71*(2), 1-4.

Prince, M., & Feldner, R. (2006). Inductive teaching and learning methods: Definitions, comparisons, and research bases. *Journal of Engineering Education, 95*(2), 123-138.

Raju, P. K., Sankar, C. S., & Cook, J. A. (2004). An innovative method to teach physics to 4-H students. *Journal of Science, Technology, Engineering and Mathematics Education, 5*(3&4), 53-66.

Seng, S., & Chan, B. (2000). *Spatial ability and mathematical performance: Gender differences in an elementary school.* Columbus, OH: ERIC Clearinghouse on Adult, Career, and Vocational Education. (ERIC Document Reproduction Service No. ED438973).

Silver, E. A. (1986). Using conceptual and procedural knowledge: A focus on relationships. In J. Hiebert (Ed.), *Conceptual and procedural knowledge: The case of mathematics* (pp. 181-198). Hillsdale, NJ: Erlbaum.

Snow, D. (2005). *Classroom strategies for helping at-risk students.* Alexandria, VA: Association for Supervision and Curriculum Development.

SolidWorks Teacher blog. Retrieved from http://blogs.solidworks.com/teacher.

Sorby, S. A. (1999). Developing 3-D spatial visualization skills. *Engineering Design Graphics Journal, 63*(2), 21-32.

Stronge, J. H. (2007). *Qualities of effective teachers* (2nd ed.). Alexandria, VA: Association for Supervision and Curriculum Development.

Swift, T. M., & Watkins, S. E. (2004). An engineering primer for outreach to K-4 education. *Journal of Science, Technology, Engineering and Mathematics Education, 5*(3&4), 67-76.