Solid Modeling in High School Mathematics Instruction: A Professional Development Partnership

Kevin L. Devine, Illinois State University
Chris Merrill, Illinois State University
Josh Brown, Illinois State University
Ryan Brown, Illinois State University

Abstract

In the summer of 2009, a professional development partnership was established between Peoria Public School District and Illinois State University to improve geometric 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 on the use and implementation of three dimensional (3-D) solid modeling in the mathematics classroom, with the ultimate goal of improving student learning in mathematics. The premise of this professional development program resides on the literature base that suggests that 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. Further, the professional development program maintains that spatial visualization and reasoning are core skills that all students should develop.

Eight mathematics teachers from the Peoria Public School District and the school district's Mathematics Coordinator completed more than eighty hours of professional development geared toward the improvement of teaching mathematics using 3-D solid modeling software (SolidWorks) during the summer and fall of 2009. During the spring 2010 semester, these same teachers conducted action research projects based on the professional development. Formative and summative evaluation techniques were implemented as part of the professional development program. The MSP grant has been renewed for the 2010-2011 school year and is currently underway with a second cohort of teachers. The 2010-2011 grant activities will include several substantive changes based on lessons learned and feedback from participants in the first cohort. This paper includes a discussion of the requirements of the MSP grant, activities conducted during the first and second years, barriers, and lessons learned..

Introduction

In the summer of 2009, a professional development partnership was established between Peoria Public School District (PPSD), and Illinois State University to improve geometric 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 MSP is aimed at improving the content knowledge of mathematics teachers (seven high school and one middle school) on the use and implementation of three dimensional (3-D) solid modeling in the mathematics classroom, with the ultimate goal of improving student learning in mathematics. The premise of this professional development grant resides on the literature base that suggests that 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 & Chan, 2000). Further, the professional development program maintains that spatial visualization and reasoning are core skills that all students should develop. Therefore, the purposes of this manuscript 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 utilizes a 3-D solid modeling software approach to better teach geometric concepts; (c) explain the initial findings of this professional development program; and (d) discuss year two grant activities to improve collaborative efforts with science, technology, engineering, and mathematics (STEM) educators.

The first group of teachers, Cohort 1, included eight mathematics teachers from the PPSD and the school district's Mathematics Coordinator who completed more than eighty hours of professional development geared toward the improvement of teaching mathematics using 3-D solid modeling software (SolidWorks) during the summer and fall of 2009. During the spring 2010 semester, these same teachers conducted action research projects based on the professional development. Formative and summative evaluation techniques were implemented as part of the professional development program. The MSP grant has been renewed for the 2010-2011 school year and is currently underway with a second cohort of teachers (Cohort 2). The 2010-2011 grant activities include several substantive changes based on lessons learned and feedback from participants in the Cohort 1. 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 are to: (a) Improve teacher's subject matter knowledge, strengthen the quality of mathematics and science instruction and promote student academic achievement in mathematics and science; (b) 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) Increase the understanding and application of scientifically-based educational research appropriate to mathematics and science teaching and learning.

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 percent or more of students were failing to meet the state's learning standards, as evidenced by performance on state achievement tests. The district must also have a student population of which 15% or more of the students 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 was 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 at least 80 hours of workshop-style 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 their use in the classroom. The intended participants were to be mathematics and science teachers with less than ten years of experience and identified by district personnel as having 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 request for proposal, the research team contacted the Mathematics Coordinator at PPSD. The rationale for partnering with the PPSD includes its geographical relationship between Illinois State University, successful past experiences in regard to educational initiatives, and the research team's efficacy toward partnering with a school district that is dynamic, yet poses a myriad of significant challenges.

The 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, while the number of disadvantaged students taking the science exam was 2,034 (2008, Peoria Public School District Report Card). PPSD did not earn adequate yearly progress in 2008. The graduation rate of PPSD students is 75% (2008, Peoria Public School District Report Card).

Student achievement is lacking in the PPSD. The American College Testing (ACT) assessment score for the graduating class of 2008 in the 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 that 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 not meeting 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 not meeting the minimum level of achievement in science was 18.6% and 53.3%, respectively (2008, Peoria Public School District Report Card).

The research team conducted a needs assessment with the PPSD mathematics teachers and 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 needs to 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 PPSD Mathematics Coordinator, the research team developed a professional development program that was cutting-edge, based on literature findings, and was grounded in the premise of helping students learn and improve their mathematical ability, and to provide 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 and 3-D solid modeling and the connection with teacher content knowledge, pedagogy, and assessment.

Related Literature

The National Council of Teachers of Mathematics in the 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". NCTM has since revised the standards (NCTM, 2000), seeking to simplify and clarify their vision with the *Principles and Standards for School Mathematics* (*PSSM*). The revised standards call for an 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."

While 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) contend 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, Jones, Pitta-Pantazi, Pittalis, Mousoulides, Matos, Sendova, Zachariades, & Boytchev, 2007). Although instruction in mathematics relies heavily on graphical images to convey conceptual ideas, the current mathematics curriculum offers little formal support to foster spatial skill acquisition. 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 1980's to help teach the principles of geometry (Christou, et. al, 2007). While most of the DGS applications available to mathematics teachers are 2-D in nature, a handful of 3-D DGS systems are being developed and tested (see for example Kaufmann, Steinbügl, Dünser & Glück, 2008). The mathematics research community is excited about the development of the new 3-D DGS applications because they 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). While 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 1960's. 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. 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 that are constrained using a variety of geometric constraints such as tangent, perpendicular, and parallel. Specific dimensions are also added to sketch geometry to further constrain the curves. 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 of critical importance 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. While there is agreement that 3-D solid modelers share many aspects of the new 3-D DGS applications, there are some researchers who contend that 3-D CAD systems are not well suited for geometry education. Kaufmann, Steinbügl, Dünser & Glück (2008), for example, contend 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 (Devine, 2008), science (Planchard, 2007), and engineering (Howard, Williams & Yao, 2009).

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 by making 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) reveals that many instructors use 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 helps 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 may also help students see value in pursuing STEM related education (Kesidou & Koppal, 2004; Raju, Sankar, & Cook, 2004; Swift & Watkins, 2004).

Description of Cohort 1 Professional Development

SolidWorks was selected for use with Cohort 1 in this project because it is a common constraint-based solid modeler and has technical capabilities that rank among the leaders in the industry. Another benefit to this project was the fact that SolidWorks is widely used in K-12 schools, readily available support material exist, and a SolidWorks teachers' blog is accessible for teachers.

The initial approach taken in this professional development project was to work with the participants (middle and high school teachers) 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. As detailed earlier, the PPSD is financially challenged and items that other school districts may take for granted are not an option to purchase for this school district. Each teacher participant and the PPSD Mathematics Coordinator were provided with a laptop computer, LCD projector, security lock, backpack, 3-D mouse, stipend to attend professional conferences, advanced SolidWorks training outside of the normal professional development program, 3-D manipulative cubes for the classroom, individual and classroom network licenses for SolidWorks, financial stipend for being part of the professional development, over $850 worth of educational textbook and reference materials, screen capture software, laptop camera and microphone, and six hours of graduate credit. In addition, the PPSD 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 solid modeling and 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 “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 the like. 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 upon 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 together to identify other specific 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 functionality 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 in their mathematics classroom. This transition dovetailed well with the increased professional development emphasis placed on teaching pedagogy and action research.

Findings from Cohort 1

Described in this section is an abbreviated synthesis of the evaluation results from the Cohort 1 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 from Cohort 1

During the fall 2009 semester, the PPSD 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 school district, but despite these events, the teacher participants continued their professional endeavors, even knowing that they would likely be without a teaching position the following school year. Needless to say, the research team has learned a great deal about professional development with a school district that is facing adversity at many different levels. Although the issues described above, and barriers listed below were areas that the research team faced, they should be seen as opportunities for future STEM-based faculties who want to conduct professional development.

Barrier One – 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 their 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 lack of time to fit the material into their curricula and their lack of background knowledge. Classroom teachers are overworked and have extra-curricular activities that they are involved in leading; it is difficult for them to give time to professional development opportunities, even if they are the ones who have asked to be involved in professional development. The solution to this barrier was the fact the research team understood the time involved for classroom teachers because the majority of the research team are 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 Two – Some of the teacher participants engaged in this professional development seemed to be more serious than others, although this was only based 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 utilized by the external evaluators, however, the professional development participants rated the quality of the professional development *experience* a 4.4 out of 5 and 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 Three – Without common planning periods or time throughout the school day on top of other curricular demands, teacher participants were less successful in applying their professional development experiences in the classroom. Insufficient planning time continues to be a barrier for not only this professional development experience, but for the majority of schools in the country. One of the lessons learned by the research team is to consider allocating enough money into future budgets for 'buying out' teachers' time, but the research team also knows that this plan will not be sustainable based on the budgetary requirements of the school district after the professional development concludes.

Barrier Four – 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 could 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 school district. In the case of SolidWorks, however, the research team purchased software copies for the school district, so students and teachers would have access. Unfortunately, although many requests were made to have the purchased seats of SolidWorks installed in the classrooms, the school district's IT staff never installed the software and consequently students never had the opportunity to work with the software.

Cohort 2

As the professional development program expands into its second year, work with a second group of teachers (Cohort 2) is underway. Based on lessons learned with Cohort 1, three significant changes have been made with the second cohort. First, the participants in this cohort were not limited to mathematics teachers; rather, this cohort is divided into support teams comprised of science, technology, engineering-related, and mathematics (STEM) teachers. The teachers in these teams are working together to share ideas, solve problems, and develop and implement teaching strategies that utilize solid modeling across the STEM disciplines. Second, Autodesk Inventor is being used by Cohort 2 rather than SolidWorks. The change to Inventor was made because the participating technology and engineering-related teachers are already teaching using Inventor in their classes. The technology and engineering related teachers can provide local assistance in the schools for teachers struggling with the modeling software. From a software perspective, this provides immediate leadership in the school. Third, because the use of Inventor eliminated the need to purchase software, resources were available to expand Cohort 2 to include 15 participants.

During the summer of 2010, Cohort 2 participants received 40 hours of solid modeling training. The training followed the same general procedures and topics that were covered with Cohort 1, this time using Inventor rather than SolidWorks. During training, the participating instructors worked with their support teams to come up with ideas for lessons that can be developed and implemented during the first month of the school year. The intention was to get the teachers using Inventor in the classroom as quickly as possible to help build experience and confidence. Additional Inventor training will be provided in October and November after the teachers have had an opportunity to work with the software for a few months. The professional development plans for Cohort 2 will include action research during the Spring 2011 semester.

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 cohort 1 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.” Another teacher was quoted as saying, “When the students can see it and visualize it, they can understand the relevance…and the relevance promotes rigor.”

The research team feels very 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 the engineering graphics community, but for entire STEM community. It is clear that professional development, even funded professional development, is not easy, but with sustained efforts, meaningful and productive professional development can occur.

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, MA: 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, 22-26 Feb 2007.

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: Lawrence Erlbaum Associates.

Howard, W., Williams, R., & Yao, J. (2009). Simulations of Carnival Rides and Rube Goldberg Machines for the Visualization of Concepts or Statics and Dynamics. Presented at the 64th Annual American Society for Engineering Educators/Engineering Design Graphics Division Mid-Year Conference, Erie, PA.

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, Steinbügl, Dünser & Glück (2008) General training of spatial abilities by geometry education in augmented reality. 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. *Journal 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. 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. ED 443 729).

Melancon, J (2001). Developing Visualization and Spatial Skills. Retrieved 05/12, 2010, from the World Wide Web: 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. (2000). *Principles and standards for school mathematics*. Reston, VA: Author.

National Council of Teachers of Mathematics. (1989). *Curriculum and evaluation 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*. (ED438973). Columbus, OH: ERIC Clearinghouse on Adult, Career, and Vocational Education.

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: Lawrence Erlbaum Associates.

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

SolidWorks Teacher blog. http://blogs.solidworks.com/teacher. Accessed 5-21-09.

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 edition)*. 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.