Preparing Teachers to Teach Mathematics With Technology

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Abstract: The challenge for mathematics teacher educators is to identify teacher preparation and professional development programs that lead toward the development of technology pedagogical content knowledge (TPCK). TPCK is an important body of knowledge for teaching mathematics that must be developed in the coursework in teaching and learning as well as within the coursework direct at developing mathematical knowledge. Preparing teachers to teach mathematics is highlighted by its complexities. What technologies are adequate tools for learning mathematics? What about teacher attitudes and beliefs about teaching mathematics with technology? What are the barriers? These questions and more frame the challenge for the development of a research agenda for mathematics education that is directed toward assuring that all teachers and teacher candidates have opportunities to acquire the knowledge and experiences needed to incorporate technology in the context of teaching and learning mathematics.

Introduction

Imagine for a moment that today is September 1, 2056 and you have been charged to investigate the status of mathematics instruction in elementary, middle and high schools. What will you find? What mathematics will be taught? How will teachers teach? How will students learn? Will the mathematical knowledge and skills that are taught be directed toward students becoming mathematically proficient? Will you see that the National Council of Teachers of Mathematics' (NCTM) vision for school mathematics has been realized?

> *Imagine a classroom, a school, or a school district where all students have access to high-quality, engaging mathematics instruction. There are ambitious expectations for all, with accommodation for those who need it. Knowledgeable teachers have adequate resources to support their work and are continually growing as professionals. The curriculum is mathematically rich, offering students opportunities to learn important mathematical concepts and procedures with understanding. Technology is an essential component of the environment*. (NCTM, 2000, p.3)

Will the vision of the National Research Council (NRC, 2001) be implemented such that all students can become mathematically proficient, a proficiency that is an integration and balanced development of five key strands: conceptual understanding, procedural fluency, strategic competence, adaptive reasoning, and productive disposition? Will technology play a part in the development of mathematical proficiency? Will technology play a role in the development of this mathematical proficiency?

Will the technology be an integral component or tool for learning and communication within the context of mathematics as called for by the National Education Technology Standards for Students (International Society for Technology in Education, ISTE, 2000)? Will students be learning about various technologies as they learn mathematics with the technologies? Will students be actively engaged in mathematics using technologies as productivity, communication, research and problem-solving and decision-making tools?

Time will tell!

The challenge is what must happen to move toward these visions by 2056. Perhaps one of the most critical respondents for actualizing this vision is the mathematics teacher. What will these teachers need to know and be able to do? Here in 2006, most teachers have not learned mathematics using technology tools. So the question now is to identify what and how to prepare mathematics teachers to teach in the 21st century. What do teachers need to know and be able to do and how do they need to develop this knowledge for teaching mathematics?

Technology Pedagogical Content Knowledge

In 1986, Shulman proposed a more in-depth look at what teachers must know in order to teach, highlighting that future teachers need to be prepared to be able to transform that subject matter content through teaching strategies to make that knowledge accessible to learners. To teach, teachers need to have developed an integrated knowledge structure that incorporates knowledge about subject matter, learners, pedagogy, curriculum, and schools; they need to have developed a pedagogical content knowledge or PCK for teaching their subjects. But for technology to become an integral component or tool for learning the subject, teachers must also develop "an overarching conception of their subject matter with respect to technology and what it means to teach with technology – technology pedagogical content knowledge (TPCK)" (Niess, 2005, p. 510).

To be prepared to teach mathematics then, teachers need an in-depth understanding of mathematics (the content), teaching and learning (the pedagogy), and technology. More importantly, however, they need an integrated knowledge of these different knowledge domains, the overlap and integration of these domains. TPCK for teaching with technology means that as they think about particular mathematics concepts, they are concurrently considering how they might teach the important ideas embodied in the mathematical concepts in such a way that the technology places the concept in a form understandable by their students.

The challenge is to identify teacher preparation programs that lead toward the development of TPCK for teaching mathematics. Grossman (1989, 1991) developed four central components as a means of thinking about PCK; Niess (2005) extended these components as a means of clarifying TPCK development for teacher preparation programs:

(a) an overarching conception of what it means to teach a particular subject such as mathematics **integrating technology** in the learning;
(b) knowledge of instructional strategies and representations for teaching particular mathematical topics **with technology**;
(c) knowledge of students' understandings, thinking, and learning **with technology** in a subject such as mathematics;
(d) knowledge of curriculum and curriculum materials that **integrates technology with learning mathematics**.

Teacher Preparation and Professional Development

How will current teachers have the opportunity to develop a TPCK for teaching mathematics? How should the teacher preparation programs guide their students in developing this TPCK? These questions are plaguing teacher preparation and professional development programs alike. The students and teachers have at best a limited knowledge of potential technologies for use in mathematics. And, more importantly, they have not learned mathematics with these technologies. Beck and Wynn (1998) described the integration of technology in teacher preparation programs through a continuum that on one end is a course separate from the teacher preparation program and on the other end where technology is integrated throughout the program. Niess (2005) examined the development of TPCK in a program that integrated teaching and learning with technology throughout a science and mathematics program. This program modeled integration of technology with teaching of mathematical concepts, guided student teachers in designing lessons, and practiced teaching the lessons with their peers, and taught the lessons in their student teaching. Margerum-Leys and Marx (2002) studied the impact of field practices on broadening the development of TPCK through attention to the importance of the student teaching placement. They argued that from a constructivist perspective, "opportunities for authentic experiences are a necessary condition" for this learning to occur (Margerum-Leys & Marx, 2002, p. 434). Other researchers including Pierson (2001), Mishra and Koehler (in press), and Zhao (2003) have provided additional support and direction for the importance of the development of TPCK as an important body of knowledge for teaching specific subject matter, for the importance of integrating its development within the coursework in teaching and learning as well as within coursework directed at developing subject matter knowledge. A vision for implementing lesson processes that improve instruction is possible through reflective practice. For the preservice programs, though, much more research needs to clarify essential conditions for the development of TPCK, and develop guidelines for integrating technology and the development of TPCK through content courses, methods courses, assessment courses, and pedagogy courses as well as in student teaching. As summarized in a draft technology position statement prepared by the Technology Committee for the Association of Mathematics Teacher Educators (2005), teacher preparation programs need to focus on strengthening the preservice teachers' knowledge of how to incorporate technology to facilitate student learning of mathematics through experiences that:

- allow teacher candidates to explore and learn mathematics using technology in ways that build confidence and understanding of the technology and mathematics;
- model appropriate uses of a variety of established and new applications of technology as tools to develop a deep understanding of mathematics in varied contexts;
- help teacher candidates make informed decisions about appropriate and effective uses of technology in the teaching and learning of mathematics; and
- provide opportunities for teacher candidates to develop and practice teaching lessons that take advantage of the ability of technology to enrich and enhance the learning of mathematics.

TPCK is an important body of knowledge for teaching mathematics, for the importance of integrating its development within the coursework in teaching and learning as well as within the coursework directed at developing knowledge of mathematics. For the preservice programs, much more research needs to clarify the essential conditions for the development of TPCK, and develop guidelines for integrating technology with teaching and learning of mathematics in content courses, methods courses, assessment courses, and pedagogy courses as well as in student teaching.

For inservice teachers, this coursework must be focused in professional development programs dedicated to helping the teachers become knowledgeable about the technology while being challenged to integrate technologies in their teaching. These programs need to recognize and emanate from the teachers' experiences and provide them with extended experiences in teaching mathematics with technology. More research is needed to provide the frameworks for professional development programs toward developing TPCK for inservice teachers. This research must build on critical aspects for high quality professional development. Sparks and Hirsh (2000) highlight the importance of sustained, rigorous, and cumulative programs that are directly linked to what teachers do in their classrooms. In concert with the idea of providing authentic experiences, these professional development programs need to provide inservice teachers with opportunities to collaborate in planning lessons, to practice and share new teaching methods, and to practice solving problems with peer teachers. Recognition of the success of peer-coaching and peer observations in their classrooms is essential.

Unraveling the Complexities: Challenging Research Areas and Questions

Preparing teachers to teach mathematics with technology is far more complex than identifying TPCK as an important knowledge base for teachers. Several areas highlight the complexities and the challenges for mathematics education researchers.

What Technologies are Tools for Learning Mathematics?

Technology has become an essential tool for doing mathematics in today's world. It can be used in a variety of ways to improve and enhance the learning of mathematics. As NCTM (2000) highlights in its standards, technology can facilitate mathematical problem solving, communication, reasoning and proof; moreover technology can provide students with opportunities to explore different representations of mathematical ideas and support them in making connections both within and outside of mathematics (NRC, 2000). Which technologies make useful tools for learning and communicating mathematics?

Since their emergence, calculators have stimulated an on-going debate among educators. They appear to be tools for adults to use as they wish but not for children to use in learning mathematics. The challenge continues for mathematics educators to investigate how calculators may be used as tools to think with rather than as tools to replace thinking. What will the use of calculators at all grade levels mean for teaching mathematics? How do calculators and similar technologies influence students' developing knowledge of mathematical processes? Are students mindlessly using these technologies? Or are they thinking about mathematics differently? What is the minimum mathematical knowledge needed before a student can use calculators to meaningfully explore mathematical understandings of specific concepts?

Spreadsheets are often described as a mathematical tool. They offer access to advanced functions for exploration of problems. But, should students understand the mathematics behind the functions before making use of the functions? How can students' development of mathematics be supported by an integration of the development of their knowledge of designing spreadsheets? Designing solutions to problems with spreadsheet seems to mirror the issues that surround the development of programming in computer science. If teachers do not guide students in the design of spreadsheets, students are more apt to create spreadsheets that are not reliable when changes are made in some of the cell values. Thus, the result is a spreadsheet that only solves one problem reliably. Can spreadsheets be designed to dependably and reliably solve more than one problem? What mathematics can students learn as they learn to design spreadsheets to generalize problems?

Geometer's Sketchpad and some applets provide students with wide-ranging opportunities for mathematical exploration and sense-making. With these tools students are encouraged to make mathematical conjectures and use the dynamic capabilities to visualize an idea under a wide variety of situations. Do students develop the idea that they are proving their conjecture? Is their conception of mathematical proof influenced by these explorations? What mathematics are students learning as they use these tools for exploration and problem solving?

What about Teacher Attitudes and Beliefs about Teaching Mathematics With Technology?
These technologies are only examples. What other technologies are available or are emerging that might support learning mathematics? Teachers need to be prepared for exploring the current and emerging possibilities. They need to develop a professional attitude of evaluation and reflection about tools for teaching mathematics – a thoughtful visioning that investigates and considers the impact of the tools for teaching mathematics. Niess, Lee and Kajder (in press) identified six important areas of questions that teachers must be prepared for:

1. **Curricular needs in mathematics in the 21st century.** Can the technology be used as a productivity, communication, research and or problem-solving and decision-making tool for learning in the subject area? Does the technology offer the capabilities to facilitate technology-enhanced experiences that address subject matter content standards and student technology standards? Does the technology offer capabilities that challenge the accepted standards, opening the possibility for a shift in what students need to know to be productive citizens in the 21st century?
2. **Instructional needs in mathematics in the 21st century.** Can the technology support learner-center strategies for learning the subject? Can use of the technology as a learning tool help students develop a more robust understanding of the content? Can the technology address the diverse needs of students in learning the subject? How must the instruction be scaffolded to guide student learning with and about the technology?
3. **Student learning in the 21st century.** Can the technology engage students in important experiences that support their learning? Can the technology provide multiple perspectives for the students to view of mathematics? Can the technology be applied to developing students' higher order thinking and reasoning skills? Can the technology maximize student learning?
4. **Unique capabilities of the new tool.** What are the capabilities of the tool? How are these capabilities useful in accomplishing 21st century skills? Do the capabilities challenge accepted ways of knowing and doing? What must be learned before incorporation of the tool as a learning tool?
5. **Student knowledge, access and management concerns.** Will inclusion of the new tool create student access issues? What preparation must be provided for students working with the technology as a tool for learning? What management issues need consideration if the tool is incorporated in the classroom situation?
6. **Assessment and evaluation with the new tool.** How will assessment of students' learning of mathematics be affected by the incorporation of the new tool? Will performance assessments be important to demonstrate students' knowledge of the content with use of the new tool?

What are the Barriers?
While billions of dollars have been spent on technologies for schools, access continues to be labeled a major barrier. Many studies have documented this barrier, but, on the other hand, in some situations where technology is readily available, some teachers do not know how to take advantage of it, and still others are against it. Is lack of knowledge of integration the barrier or is it the teachers' beliefs about how mathematics is to be learned the issue? Norton, McRobbie and Cooper (2000) investigated this question by studying a mathematics staff in a technology-rich secondary school where the technology was rarely used in teaching mathematics. Their results suggested that these teachers' resistance was related to their beliefs about mathematics teaching and learning and their existing pedagogies. In essence then, knowledge and beliefs may be the actual barriers. Perhaps these teachers are either uncomfortable with technology, are unsure how to incorporate technology into their curricula, or have not seen examples of effective use.

The result challenges teacher educators as they identify requirements to support the development of TPCK through the student teachers' program. While some programs simply make the requirement and provide access through classroom sets to be used during student teaching, others are more carefully investigating the classroom barriers. Garofalo and Bell (2005) at the University of Virginia plan to provide their secondary mathematics and science student teachers with a laptop, projector and Smartboard for use during field practice with actual students. Their plan is to study the role of student teachers' beliefs and TPCK on classroom use of technology, when access is less of an issue.

Continued research needs to be undertaken to expose real barriers so that teacher preparation and professional development programs are to be able to deal with the issues. What are some areas to search in teaching and learning mathematics? Mathematics anxiety is certainly an issue in mathematics education. Does mathematics anxiety extend to technology anxiety?

What about the discontinuity in the mathematics curriculum from pre-college to college level? Students at the pre-college level have relatively few opportunities to use technology in learning mathematics. But, when they enter college, they are confronted with a ubiquitous incorporation of technology in learning mathematics. Calculators are expected. Students need to be able to readily use MATLAB as a tool for developing mathematical models for solving problems. How will students' mathematics technological toolkit develop if teachers in the pre-college level are resistant to teaching mathematics with technology?

Another barrier is the knowledge base about how students learn and how to design the curriculum that supports students in learning mathematics with technology. Will students learn about the technologies on their own or will teachers have to carefully scaffold learning about technologies within the mathematics instruction? Does Vygotzky's Zone of Proximal Development have importance in this area? What are other issues for student learning?

What about the knowledge, skills, and beliefs of mathematics teacher educators? And of course the same needs to be asked of the mathematicians who are teaching the college level mathematics courses.

A Research Agenda

The National Educational Technology Standards for Teachers (NETS•T, 2002) provide a framework for a research agenda around technology integration in teaching and learning mathematics. The question(s) are only provided to initiate discussions about theory, research, and projects in each standard:

1. Technology operations and concepts. What are the general operations and concepts for all technologies and how do they apply to mathematics-specific technologies? What mathematics-specific concepts are important in technologies?
2. Planning and designing learning environments and experiences. What strategies are essential when guiding students in learning particular mathematics concepts with specific technologies?
3. Teaching, learning and the curriculum. How should student learning about the technologies be scaffolding with learning mathematics? Should students learn mathematics concepts before using the technology tools?
4. Assessment and evaluation. How is assessment different in a technology-rich educational experience?
5. Productivity and professional practice. How do teachers' develop the professional attitude toward continuing to develop their TPCK?
6. Social, ethical, legal and human issues. How do mathematics teachers deal with a diversity of access to technologies?

The research agenda needs to consider each of these areas not in isolation along with learning and teaching mathematics if teachers are to develop a TPCK for teaching mathematics. Ultimately, mathematics teacher preparation programs must ensure that all mathematics teachers and teacher candidates have opportunities to acquire the knowledge and experiences needed to incorporate technology within the context of teaching and learning mathematics.

This section of SITE 2006 is designed to encourage the sharing of theory, research, and applications of results from innovative projects that result in the distribution of uses of information technology in mathematics teacher education along with instruction in preservice, inservice, graduate teacher education and faulty and staff development. The immediate concern is on teachers and teacher candidates who have primarily learned mathematics without the use of technologies as tools for exploring mathematics. However, as Everett Rogers (1995) explains, teachers need to progress through a five-step process in the process of facing the ultimate decision as to whether to accept or reject a particular innovation for teaching mathematics with technology:

1. **Knowledge** where teachers become aware of integrating technology with learning mathematics and has some idea of how it functions;
2. **Persuasion** where teachers form a favorable or unfavorable attitude toward teaching and learning mathematics with technology;
3. **Decision** where teachers engage in activities that lead to a choice to adopt or reject teaching and learning mathematics with technology;
4. **Implementation** where teachers actively integrate teaching and learning with technology
5. **Confirmation** where teachers evaluate the results of the decision to integrate teaching and learning with technology.

Thus, as more and more teachers teach mathematics with technology as a tool, the shift must be towards the evolving issues more directly focused on student learning of mathematics – evaluating the results of the decision and its impact on the mathematics curriculum and instructional strategies needed so that all students are able to learn mathematics. Ultimately if technology is used to improve the learning of mathematics at all levels, students will be better prepared to use technology appropriately, fluently, and efficiently to do mathematics in techno-rich environments in which they will study and work in the future. Will this result be in effect in the mathematics classroom in 2056? Time will tell!

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