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Preparing teachers to teach science and mathematics with technology: Developing a technology pedagogical content knowledge

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Abstract

Preservice teachers' pedagogical content knowledge (PCK) development was investigated with respect to integrating technology. Four components of PCK were adapted to describe technology-enhanced PCK (TPCK). The study examined the TPCK of student teachers in a multi-dimensional science and mathematics teacher preparation program that integrated teaching and learning with technology throughout the program. Five cases described the difficulties and successes of student teachers teaching with technology in molding their TPCK. Student teachers view of the integration of technology and the nature of the discipline was identified as an important aspect of the development of TPCK.

Keywords: Pedagogical content knowledge; Preservice teacher education; Mathematics teacher preparation; Science teacher preparation; Integrating technology

1. Preparing science and mathematics teachers to teach with technology

Emergence into the 21st century features tools that are different, communication that is different, information that is different, and work that is different. Given this shift, education must shift to incorporate computer-based, electronic technologies integrating learning with these technologies within the context of the academic subject areas. However, how teachers learned their subject matter is not necessarily the way their students will need to be taught in the 21st century. Learning subject matter with technology is different from learning to teach that subject matter with technology. Few teachers have been taught to teach their subject matter with technology and as a survey by the National Center for Education Statistics found, only 20% of the current public school teachers feel comfortable using technology in their teaching (Rosenthal, 1999).

Shortages of mathematics and science teachers in concert with massive retirements of teachers

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over the next 10 years raise the concern about the preparation of teachers for a changing curriculum that integrates technology. Mathematics and science standards (National Council of Teachers of Mathematics (NCTM), 2000; National Research Council, 1996) point toward a scientifically and mathematically rich curriculum where technology is an essential component of the learning environment, not only in the curriculum but also in the instruction. Similarly, the International Society for Technology in Education (ISTE, 2000a, b) developed new technology standards for students and teachers that specifically confront teachers with integrating technology throughout education. These standards direct that electronic technologies become "an integral component or tool for learning and communications within the context of academic subject areas" (ISTE, 2000a, p. 17).

Science and mathematics teacher preparation programs expect their preservice teachers to develop both a depth and breadth in the content knowledge in science and mathematics. This initial content knowledge assumes basic skills and broad general knowledge of the subject along with knowledge of inquiry in the specific discipline. Increased research attention to teachers' subject matter knowledge has focused attention to how student teachers organize and inter-relate these subject matter facts, concepts, and principles (Ball, 1991; Even, 1989; Kennedy, 1990; Leinhardt & Smith, 1985; Marks, 1990; Tamir, 1988; Wilson & Wineburg, 1988). However, preservice teachers develop their understanding of science or mathematics through classes aimed at the accumulation of knowledge. Whether these pieces of knowledge are interconnected in a manner that supports them in translating the knowledge and understanding into a 21st century curriculum in a form accessible to learners is unknown as they begin their study of learning to teach their subject.

2. Integrating technology with science/mathematics and teaching and learning

The challenge for teacher preparation programs is to prepare their candidates to teach from an integrated knowledge structure of teaching their specific subject matter—the intersection of knowledge of the subject matter with knowledge of teaching and learning, or pedagogical content knowledge (PCK) characterized by Shulman (1986). But, for technology to become an integral component or tool for learning, science and mathematics preservice teachers must also develop an overarching conception of their subject matter with respect to technology and what it means to teach with technology—a technology PCK (TPCK).

TPCK requires a consideration of multiple domains of knowledge. Preservice teachers need a well-developed knowledge base in their subject. This subject matter knowledge is often developed over many years with a focus on personal learning and construction of how that subject is known. With the newness of the investment of technology in some disciplines, the development of knowledge of the subject area may be integrated with the development of their knowledge of technology. As students begin the teacher preparation program, some of the development of their knowledge of the subject matter maybe integrated with the development of their knowledge of teaching and learning. But, preservice teacher students learn much about technology outside both the development of their knowledge of subject matter and the development of their knowledge of teaching and learning. Similarly, they learn about learning and teaching outside both the subject matter and technology. In fact, preservice teachers often learn about teaching and learning with technology in a more generic manner unconnected with the development of their knowledge of the subject matter.

TPCK, however, is the integration of the development of knowledge of subject matter with the development of technology and of knowledge of teaching and learning. And it is this integration of the different domains that supports teachers in teaching their subject matter with technology. The question remains: How can teacher preparation programs guide preservice teachers' development of a TPCK to prepare teachers for a classroom environment where technology significantly impacts and changes teaching and learning in K-12 science and mathematics classrooms?

Beck and Wynn (1998) have described the integration of technology in teacher preparation programs on a continuum. At one end of the continuum, the integration of technology is a course separate from the teacher preparation program while on the other end of the continuum, the entire program is changed to implement the integration. Traditionally, teacher preparation programs have depended on one course focused on learning *about* technology. More recently, teacher preparation programs have shifted the emphasis in this course to incorporate pedagogical concerns; now, concerns about teaching with technology have been included in the methods courses. A variety of additional approaches for preparing teachers to teach with technology have been proposed to move toward the other end of the continuum by (1) integrating technology in all courses in the teacher preparation program in order to be more supportive of the development of a technology-enhanced PCK and content specific applications and (2) requiring preservice teachers to teach with technology in their student teaching experience (Duhaney, 2001; Wetzel & Zambo, 1996; Young et al., 2000). However, little research has been conducted to identify how this more integrated approach supports the development of a PCK that integrates knowledge of technology with knowledge of the content and knowledge of pedagogy—a TPCK.

3. Conceptual and empirical framework

Investigation of PCK research studies provides some insight into the preparation of preservice teachers to develop a TPCK (Ball, 1988; McDiarmid, 1990; Grossman, 1991; Wilcox, Schram, Lappan, & Lanier, 1990; Civil, 1992; Simon & Brobeck, 1993; Simon & Mazza, 1993). Grossman's (1989, 1990) work proposed four central components of PCK. Amending these components with technology provides a framework for describing the outcomes for TPCK development in a teacher preparation program: (1) an overarching conception of what it means to teach a particular subject integrating technology in the learning; (2) knowledge of instructional strategies and representations for teaching particular topics with technology; (3) knowledge of students' understandings, thinking, and learning with technology in a particular subject; (4) knowledge of curriculum and curriculum materials that integrate technology with learning in the subject area (Borko & Putnam, 1996, p. 690). With this perspective, the preparation of science and mathematics teachers should be directed at guiding the development of their knowledge and thinking in a manner that considers the development of an overarching conception of teaching with technology. Preservice teachers must be challenged to reconsider their subject matter content and the impact of technology on the development of that subject itself as well as on teaching and learning that subject. But this attention must recognize the importance that learning to teach is a "constructive and iterative" process where they must interpret "events on the basis of existing knowledge, beliefs, and dispositions" (Borko & Putnam, 1996, p. 674).

Shreiter and Ammon (1989) have argued that teachers' adaptation of instructional practices is a process of assimilation and accommodation that results in changes in the their thinking. This perspective suggests that teacher preparation program must provide numerous experiences to engage the preservice teacher in investigating, thinking, planning, practicing, and reflecting. Numerous studies have yielded consistent findings on differences in the thoughts and instructional practices of expert and novice teachers (Borko & Livingston, 1989; Leinhardt, 1989; Livingston & Borko, 1990; Westerman, 1992). From a constructivist perspective, as novices, preservice teachers' actions largely stem from an understanding based on having been taught in particular ways; with teacher preparation program experiences and instructional practice, their beliefs, knowledge, and thinking must mature.

4. The study

The teacher preparation program for this study was a 1-year, graduate level program focused on the preparation of science and mathematics

Summer Quarter	**Fall Quarter**		**Winter Quarter**		**Spring Quarter**	
4 weeks	**5 weeks**	**11 weeks**	**5 week**	**6 weeks**	**6 weeks**	**5 weeks**
	Instructional Practice **Practicum I** (3) Fulltime in school site 1 focused on schools, learners, teachers – observing and teaching	Last 5 weeks in teaching unit and working halftime in school site 1 focused on planning, teaching, classroom management and reflection	*Instructional Practice* **Practicum II (2)** 1 week becoming familiar with school site 2	*Instructional Practice;* **Full time** (8) **Student Teaching** Full instructional responsibility 3 classes, multiple preparations	*Technology integration (TPCK)* Teach work sample Teach mini unit with technology	*Instructional Practice* **Practicum III (2)** 5 weeks exploring diverse classrooms, schools, and student populations
		Research-based teaching and learning **Analysis of Classrooms I** (3) Classroom management, observing in classrooms, action research	*Research-based teaching & learning* **Analysis of Classrooms II** (3) Classroom management, teaching in classroom, action research		*Research-based teaching & learning* **Analysis of Classrooms III** (3) Diversity, learning in classrooms	
Research-based teaching & learning: **Methods Foundations** (3)		*Research-based teaching & learning:* **Methods I** (3) Planning, Teaching, Classroom management, Reflection	*Research-based teaching & learning:* **Methods II** (3) Planning, Teaching, Assessment, Reflection			*Research-based teaching & learning:* **Methods III** (3) Planning, teaching, assessment, reflection
Research-based teaching & learning: **Materials & Labs** (3)		*Technology Integration (TPCK) ; Instructional Practice* **Microteaching** (3) Planning, Teaching, Reflection	*PCK Development* **Pedagogy I** (2) Pedagogical content knowledge development			*PCK Development* **Pedagogy II** (2) Pedagogical content knowledge development
Technology Integration (TPCK) **Teaching with Technology Foundations** (3)			*Technology Integration (TPCK)* **Technology & Pedagogy I** (1) Planning for teaching with technology			*Technology Integration (TPCK)* **Technology & Pedagogy II** (1) Reflecting on teaching with technology
Summer Quarter	**Fall Quarter**		**Winter Quarter**		**Spring Quarter**	

Fig. 1. Teacher preparation program displaying program themes (technology theme shaded).

teachers to integrate technology. For the study year, 22 student teachers were enrolled; two were preparing to teach physics, five to teach mathematics, four to teach chemistry, five to teach biology, and six to teach integrated science (middle grades science teaching). These students had previously earned at least a Bachelor's degree including the subject matter requirements for their proposed teacher areas. While the mathematics, chemistry, and physics students completed Bachelor's degrees specific to their subject, the biology and integrated science students completed varied undergraduate degree programs such as biology, zoology, botany, environmental science, and forest science.

The teacher preparation program was originally conceptualized in the early 1990s on the development of an integrated knowledge structure of various domains of knowledge (subject matter, learners, pedagogy, schools, curriculum, and PCK). By 1997, in recognition of the impact of technology in mathematics and science disciplines, the program added a concentration on the development of a TPCK. This multi-dimensional approach described in Fig. 1 spanned four quarters over a single year guided by four themes: (1) research-based teaching and learning; (2) technology integration (TPCK); (3) PCK development; and (4) instructional practice integrated with campus-based coursework.

All the faculty and supervisors had previously taught science or mathematics in middle or high schools, providing the subject-specific context throughout the program. The methods courses were team taught by a mathematics educator and a science educator in order to provide subject-specific feedback; in addition each student's subject-specific supervisor reviewed the prepared lessons and unit plans. The methods courses focused on the design of lessons and units guided by national and state goals and objectives. These courses focused students on science/mathematics instruction that maintained essential dimensions of science literacy and mathematics literacy in four primary areas: science/mathematics (1) as a way of thinking, (2) as a way of investigating, (3) as a body of knowledge, and (4) and its interaction with technology and society (Chiappetta & Koballa, 2002; NCTM, 2000).

Science and mathematics educators taught the pedagogy courses separately in order to focus on teaching and learning in the specific content. These courses examined explanations, models, examples, and analogies to guide student's development of an understanding of science or mathematics. Subject-specific technology educators taught the technology pedagogy courses concentrating on subject-specific technology integration in teaching and learning.

4.1. Integrating technology in the teacher preparation program

The technology integration theme highlighted in the shaded areas in Fig. 1 provided the explicit preparation of the student teachers' development of knowledge needed for the development of TPCK. For the study year, all classes were observed, all assignments were collected and analyzed, all supervisor and cooperating teacher analyses were collected, and all student teachers were interviewed extensively over the various parts of the program.

4.1.1. Technology

During the first quarter of the program, a specific technology course used science/mathematics problem-based activities to guide the preservice teachers in learning about (a) various technologies, (b) pedagogical considerations with these technologies, and (c) teaching/learning with these technologies. This course was their first exposure to the real-time data collection devices (calculator-based ranger (CBR) or calculator/computer-based laboratory (CBL) probes) that they were expected to teach with in their student teaching experience. The students explored a variety of mathematics and science problems that could be considered in the curriculum. While these activities were designed to help the student teachers become familiar with the use of the sensors for gathering real-time data, their attention was also focused on how they might design lessons to focus on specific goals and objectives in their curriculum.

4.1.2. Microteaching

The Microteaching course focused the students on gaining teaching experience with four specific instructional methods: demonstrations, hands on/laboratories, and inductive versus deductive modes. The student teachers were expected to develop a science/mathematics lesson for each model (integrating technology in at least one), teach (videotaping the instruction) their lessons to their peers, and reflect (assessing and considering revisions) on the lessons using the videotapes to recall the teaching and the debriefs of the lessons by their peers and the instructor. All models included one technology lesson supporting the discussion of important planning and implementation issues for integrating technology in the lesson.

4.1.3. Content, technology, and pedagogy

The remaining 6 months of the program focused specifically on providing extended practical experiences that required the student teachers to plan, teach, and reflect on teaching hands-on lessons with technology.

Prior to the fulltime student teaching, Science Pedagogy I included instruction focused on teaching the interaction of science, technology, and society (STS). Similarly, Mathematics Pedagogy I included instruction on NCTM's Technology Principle from the national standards. The Technology and Pedagogy I course guided student teachers in planning for teaching a sequence of lessons that included student hands-on experiences with technology during the fulltime student teaching. Student teachers were expected to connect with their cooperating teacher, identifying reasonable places in the curriculum for an integration of technology. With limited availability of technologies at the public school site, student teachers in the study were provided with classroom sets of the real-time data collection devices for hands-on student exploration.

During fulltime student teaching, student teachers were expected to adjust their plans under the supervision of their university supervisors and cooperating teachers. Either the university supervisor or the cooperating teacher observed the lessons and guided the student teacher in analyzing the effectiveness of the lesson. After each lesson, the student teacher prepared written reflections that considered revising plans for succeeding lessons. At the completion of the sequence, the student teacher prepared an analysis of: (1) each student's understanding of the science/mathematics concepts, (2) the success of the integration of the technology in the lessons (overall as well as recommendations for changes), and (3) their teaching while integrating technology in teaching science/mathematics.

A follow-up course to student teaching (Technology Pedagogy II) focused student teachers on an examination and analysis of the use of technology in teaching science and mathematics. This course challenged them to consider the impact of the instruction on students' understanding and thinking.

5. Preservice teachers' development of TPCK

At the end of the program, all 22 student teachers were recommended for their respective teaching licenses, although they had made varying degrees of progress in the development of TPCK. Assessments by the supervisors, cooperating teachers and the students themselves, declared that 14 of the 22 students as having met the outcome of a TPCK for using technologies to engage students in learning science and mathematics; the remaining eight students all recognized they needed more work toward TPCK. Five case studies describe the differences in their development of TPCK.

Denise was a biology student teacher who demonstrated in-depth knowledge of biology with solid academic biology undergraduate and masters degree programs after more than 10 years in another career unrelated to education. Her Master's work focused on ecology and environmental biology where she did extensive work as a habitat surveyor for the forest service, for 1 year before coming to the preservice program. In her career previous to the college level work, she worked with computer-based technologies designed to maintain communications among different field locations.

Denise' work in the technology class demonstrated a positive attitude toward working with technology and considering various technologies for teaching science. Her work in the general pedagogy courses was acceptable but suggested some difficulty in considering a variety of strategies for teaching science. This difficulty appeared connected with her educational experiences learning science. In describing her beliefs, she indicated that "lectures complemented with classroom experiments and field observations…will promote critical thinking". She had good classroom management skills using this lecture, recitation, and lab approach in her biology classes. Prior to the fulltime student teaching, she explained her feeling about integrating technology into her teaching: "I have lots of ideas for incorporating technology into my own classroom, but as a guest in someone else's classroom, I can only feel comfortable with technology that is familiar to the tenets of the school."

Denise' cooperating teacher was not a strong advocate for using technology in teaching science but he verbally supported the program requirement for student teachers experience teaching with technology. The technology lesson for Denise' high school Biology class was a lab where students analyzed the relationship of water temperature to the respiration rate of goldfish. The temperature sensor of the CBL system was used to continuously monitor the temperature change of the water while the gill beats/minute of the goldfish were collected each time the temperature of the water changed by 2 °C. Upon completion of data collection, the students graphed the data by hand in preparation for the discussion of the affect of either an increase or decrease in the temperature on the fish.

Denise expected the students to connect the change in the temperature with the ability of water to hold the dissolved oxygen that fish needed. Although she hoped for them to make the connection, she had to tell them "the amount of oxygen water can hold is directly related to the temperature of the water". Given this information, they were directed to discuss the effects their increased or decreased temperature data described.

While the supervisor had suggested that she consider the use of the dissolved oxygen probe by one of the groups to compare the data with that of the temperature probe, Denise' rationalized that it would require too much time to instruct them with the technology. "The instruction of the mechanics of the CBL and the TI-83 were not appropriate in this classroom; I…do not explain the use of the different mirrors in a microscope or how microwaves cooks food." In this lab, in order to avoid having to instruct the students with the technology, Denise prepared all the equipment setups so that students simply had to monitor the temperature change and read the data. Denise admitted to being confused about *how* to integrate technology, indicating that if she were to do the lab again, she would "just use thermometers". While she attributed her reluctance to extend the technology to her role as a guest in the classroom, she admitted to believing that "technology is a tool in science but that teaching students to operate the technology" was outside her job as their biology teacher.

Denise' overarching conception of the integration of technology proposed that introducing students to the use of technologies interfered with the content development and her teaching of the technology only served to confirm her belief. She was able to identify ways to use technology in several biology lessons, but when pressed to extend the ideas in instructional plans, she resisted, indicating that the procedures "can be performed without the use" of the technology. The program emphasis on pedagogy did not seem to overcome Denise' prior experiences in learning her subject matter. She continued to question the integration of technology because she did "not know how to change and modify" an instructional approach that, for her, was not "yet fully developed". For Denise the curriculum should emphasize science-society interactions. But, she resisted any discussion of the broader perspective of "science and its interactions with technology and society" discussed in the pedagogy classes (Chiappetta & Koballa, 2002, p. 15).

Marissa was an integrated science student teacher planning to teach science at the middle school level. She had just completed a general science Bachelor's degree prior to entering the graduate teacher preparation program. As an undergraduate, she had volunteered to participate in many experiences as a teacher's aide at both the middle and high school levels along with several after school science programs. She had a broad academic preparation in life, physical and earth sciences that was evident as she worked with students in her student teaching experiences. She had not had previous experiences using many of the newer technologies as she learned science.

Marissa's cooperating teacher had already been using the CBL sensors in the middle school science class. Her early impression of the classroom was that "there are many different probes that plug right into computers in the classroom… But it is not used as much as it could, or as effectively as it could be…it would be wise to have [these probes] available during labs (even if they are only an option)". Marissa described that the technology allowed students to "see processes and concepts that might not be as clear using traditional techniques".

Marissa designed a mini unit (over 2 weeks) where 8th grade earth science students collected and analyzed data, first by hand, and then using the technology. The students collected data on how the angle of insolation affected the rate of temperature changes of a surface using a thermometer. The next day the students collected the same data using the temperature probe connected to the calculator-CBL. Marissa required the students to work in groups setting up each lab; she provided them with detailed instructions for each day. On the second day, she designed a lesson where students practiced setting up the CBL system as a way of gaining experience with the equipment. The students "caught onto the equipment very quickly". According to Marissa, "I felt that the integration of technology in the class was successful. The students generally liked using the technology better because it was faster and seemed more accurate. They could see why scientists use technology…to collect data. It is much more efficient than collecting data by hand." Upon reflection, Marissa felt the next time she did the lab she would schedule another class "just for a class discussion about comparing the two labs. I could also incorporate a great deal of the nature of science". She also felt that by providing students with practice using technology ("which is very important to learn in our technology-based world"), the students were able to "see or better understand concepts that might not be as clear without the use of technology". She did admit to not being as comfortable as she would have liked to when teaching this sequence of lessons. "I was not hesitant about letting the students know that I would be learning along with them. They appreciated this and gave me a few pointers on how to use the equipment." She did think her questioning of the students helped them to relate the information "they already knew what the technology was telling them. In other words, I…helped to reinforce the concept of angle of insolation [through my questioning]".

Marissa's overarching conception of what it means to teach science included the importance of incorporating technology as the students learned science. She saw computer-based technologies as becoming increasingly important to the development of science. As she continued to investigate teaching various science concepts, she began to see how the technology could support students in better understanding the concepts. She recognized that she had had limited experiences with technologies but finished the student teaching experience with the statement that "Technology is always evolving and progressing. Unless teachers do too, they cannot teach the students as effectively." This perspective seemed to energize her to search for instructional strategies and representations that included technology. She focused on her students gaining a clearer understanding with the incorporation of technology but also in their gaining practice using technology. For her "Technology is important in meeting the objectives in a science course." Throughout her student teaching experience and the remainder of the program, she continued to look at the science curriculum from that perspective.

Terry completed a Bachelor's degree in chemistry continuing the following year to the teacher preparation graduate program. He planned to seek an endorsement in both chemistry and physics since he was able to complete the necessary physics coursework. He had had experience using many different technologies (including the probeware sensors) in learning science in his undergraduate science program.

Terry clearly articulated his perspective on the use of technology for teaching science using the area of freezing point depression.

> The students should know both what it is and have some idea of the magnitude of the effect. With standard equipment, the students would take a thermometer and check the freezing point of water with different amounts of salt added. The changes are subtle at low concentrations of salt and so the students may not notice a change until 0.5 m. or larger. This might lead students into a misconception that it is not true for dilute solutions of salt. But if a temperature probe on a CBL…was employed, the students would see the subtle effect immediately and would avoid the misconception. This would not only help to achieve the objective at a higher level, but also keep the teacher from having to address the misconception later and lose valuable instructional time.
> In planning his units, he felt that an important first step for the teacher is to
> brainstorm -list…all the ways technology (and different forms of technology) could be used…both simple and complex…pick the ones that would be most beneficial…to teach the subject matter and if they will use anything like it later in life (relevance and realness). This way the students get the benefit of technology they will need to know…and also the strongest activities pedagogically to help them learn the subject matter.

For several years, Terry's cooperating teacher had used the technologies to support his students' learning in his chemistry and physics classes. Thus, when Terry began his fulltime student teaching, he was able to work with students who were familiar with learning chemistry with technologies. In his student teaching, he designed and taught a sequence of lessons concerning the concept of temperature loss through a medium. His students questioned the use of the CBL thermometers but realized that basic thermometers do not have as great a reaction time to temperature change as the CBL ones had. When students were getting erratic readings, the class was encouraged to analyze the problem and to redesign their setups to avoid "air currents from disturbing" their temperature readings. He worked with the students to identify at least two ways that would work and to explain the science of the ways the technology worked. After the final lesson in the sequence, he reflected that

> the students used the technology well, yet the focus was on the topic. When we started discussing the subject…there were no comments on how the technology worked or why they had errors. The technology was not clouding over the reason for doing the lab in the first place… This discussion went so well that I wasn't sure whose class it was when they left. I am almost positive that every student answered a question or gave an example… The success of the technology came from a good lab design and also from familiarity with the equipment. Making these students familiar throughout the year with this technology has helped them to integrate it flawlessly and without interruption to the learning.

Terry's overarching conception of teaching chemistry and physics included technology as an important component for student learning. He described his conception as "gathering data with the technology and processed by their content and subject matter". Certainly his experiences in learning his content with technology had shaped his ideas. But the focus in the program about considering student misconceptions developed in some of their learning experiences, directed his examination of various instructional strategies and representations. He found, as a result of his teaching, that an integration of technology in the strategies motivated students as well as enhanced their learning. He did admit to being more nervous when he taught with technology, resulting from a fear of whether the students would get good results. This nervousness caused him to "roam around the room almost neurotically looking for good lab procedure and good data". His experiences in student teaching also showed him things that he needed to change about his teaching with technology. He recognized that he did not "always give enough wait time to let students figure things out on their own". He requested that his supervisor and cooperating teachers collect data about his wait time so that he could improve in this area. Terry was fortunate to have a cooperating teacher who had an in-depth knowledge of technology as well as developed pedagogical strategies for incorporating technology to enhance learning. They usually worked as a team in designing the lessons and preparing the equipment. As the term progressed, Terry took more and more of the lead.

Karen was a chemistry student teacher with a Bachelor's degree in Biochemistry. Following graduation, she began a graduate program in Biochemistry working as a research assistant for 2 years. Her experiences working in informal science education programs for youths caused her direction toward preparing to teach science. She indicated that her motive was to guide students in becoming critical thinkers who participated in their own community. She expressed her belief that "all of the content objectives" for chemistry could be "met without computer-based technology". She felt that technology was "frivolous" and that students did not need expensive technology to learn the basic concepts—nor do they need technology to do "inquiry". In fact she said, "I see the most important objectives being met better without the use of technology." For Karen, students need to understand "the complex relationship between economy, science, and technology" and the best way for them to gain this understanding is by "researching technologies" and then debating "the complexities and the issues".

Karen's sequence of technology lessons in the fulltime student teaching reflected her beliefs. She developed two chemistry lessons each requiring that students use the pH probe. The first lesson guided her students in using indicators to determine the pH of seven household solutions. She asked the students to rank the solutions from most acidic to most basic using three different methods. She asked the students to compare the "advantages and disadvantages" of a red-cabbage juice solution versus litmus paper versus the pH probe. Her second lesson required the students to again use the pH probe to simulate the formation of acid rain, "a topic of concern in our society". She expected the students' discussion would focus on society's widespread use of automobiles with petroleum-fueled engines and coal-burning power plants.

Karen described the connection of the two activities by the nature of their consideration of pH. She said that these two activities were "intended to familiarize students with the pH scale, the use of indicators, and the formation of acid solutions from dissolved gases". With no prior instruction with the probes, she found that the students "had a difficult time following the procedures. From the errors they were making, I feel that they did not really understand what they were measuring with the pH probe".

Even though Karen indicated that the concept of pH and the relative amounts of hydrogen and hydroxide ions was "the real focus of the [first lab]", she rejected the idea of extending the first lab to an investigation of how these three "technologies" actually measured pH. This suggestion actually fit within an investigation of pH because of the three devices, the probe was the technology designed to actually measure the hydrogen ion concentration in the solution while the other two technologies responded through chemical changes resulting in the color differences. She did not consider this extension to be within the curriculum even though the methods and pedagogy classes had emphasized incorporating a study of technology and its relationship to science and society. The chapter in the methods text by Chiappetta and Koballa (2002) specifically suggested that teachers should "explain how the technology works and include the scientific principles upon which it is based" (p. 135).

Karen's biggest fears for the lessons were realized as she found that she was not able to use the probes successfully herself. Her thought was that "it was difficult for me to gauge the difficulty in using the technology" because she had not previously used it with a class. She indicated that she had spent at least 10 hours in getting ready to use the equipment and her final comment was that "I feel that these sorts of activities are a waste of time and resources, and [I] would probably not go that route in the future."

Karen's overarching conception for teaching high school chemistry courses was to motivate students for studying the topics with real-life applications and issues in order to become involved in the community. She felt it important to have students question "technology in our lives". She believed that students learned best in this manner. The computer-based technologies she found useful for learning chemistry included the web and word processing to support students in research and presenting the results of their research (this method "makes grading easier because hand writing will not be an issue").

She resisted a consideration of how the pH was measured with the probe even though that technology was directly aligned with the concept of pH—one of the main goals of her lessons. The students' excitement at seeing the results from the cabbage juice indicator was what Karen described as the success of the lesson. "The cabbage juice was definitely the highlight…the colors are very pretty and the range of the indicator is great." When the students indicated their appreciation for the numerical values provided by the pH probe, she commented, "It seems that people like to have numerical values for comparison."

Karen did not value the opportunity to direct her instruction to consider an interaction among STS. Her view of the nature of science focused more on the interaction of science and society. She considered the computer-based technologies for their motivational value in instruction rather than as part of the nature of her discipline. She was willing to have students use technologies to support their learning, but she seemed to structure her lessons in ways that did not encourage the students to learn more about science along with learning about the science of the technology.

Dianne had completed a mathematics degree the year prior to the program with a minor in computer science. She had had several experiences helping teachers in mathematics classrooms in both middle and high school. She had strong beliefs about the importance of the use of technology in learning mathematics because "present day mathematicians" use it all the time. She indicated that technology "allows students to visualize and experience math in previously impossible ways". She planned to continually look back at the way she was taught math in high school and "compare it with the way society, math and technology have changed". With mathematics' emphasis on problem solving using real-world situations, she indicated that "the 'real world' is rich in its use of technology and many real problems occur with technology". Technology's capability for speeding "up the problem solving process by performing rapid, complex computations", highlighted for her the importance for students doing computations by hand, "but since the technology is available, why not teach that at the same time and save some of the precious classroom time?" Her perspective on the use of technology was that "I will not refuse a new technology because it appears too difficult to learn. I will only refuse a new technology if it does not relate to mathematics."

Dianne's lesson sequence focused on connecting slope with linear functions and using the CBR to describe graphs of distance versus time using a walking motion. The CBR lab was a closure to the unit and was meant to help students see an application of slope and practice using their knowledge of slope. She was surprised at the students' comment that the lab was viewed as not doing math even though they were using the concepts from the previous lessons. Her reflection on this realization was that the demonstration focused on the technology rather than the mathematics. She felt that she should have asked the students "why we are doing this and get the students to think of the connections between slope and rates of change". She admitted to "assuming the students would pick upon the connection". Both cooperating teacher and university supervisor supported Dianne in the incorporation of technology guiding her at thinking of "ways to view technology as integrated with the class—it seemed distant from the math".

In planning the sequence of lessons, Dianne realized that she was restricted from adequately grouping the students because it was to be taught early in her student teaching and she did "not know which students would work together and which would not get anything done". Dianne felt that her management of these lessons could have been better because as a result of the groupings she allowed some students to be "passive and only participate a small amount". Not knowing the students' names made the lab difficult to control.

Dianne's overarching conception of teaching mathematics with technology was that technology was integral to mathematics and thus to learning mathematics. She looked for ways to incorporate technology as she planned her instructional strategies. With this desire to incorporate technology, she taught her technology sequence early in the fulltime student teaching. This timing became a problem for her because her knowledge of the students was limited and she had not yet developed a classroom environment that assured all students were actively engaged in the lessons. While she made continued improvement over the student teaching experience, she had to focus on lessening the amount of teacher talk and incorporating more student exploration of the ideas through active hands-on experiences. By the end of the student teaching experience, she had been able to engage her students as active learners of mathematics.

6. Connecting the preparation program with student teachers' TPCK development

Preparing student teachers to teach with technology in science and mathematics content areas offers a unique lens from which to investigate the development of TPCK. The content knowledge of technology is both scientific and mathematical. Teaching with technology using demonstrations and labs/hands-on activities is consistent with major pedagogical strategies employed in teaching mathematics and science. Classroom management issues with technology are consistent with classroom management issues in science and mathematics lab activities. Thus, the addition of preparing teachers to teach with technology is consistent with many of the programmatic experiences designed for the development of PCK.

Amending Grossman's (1989, 1990) central components of PCK provides the framework to view the student teachers' development of TPCK.

6.1. An overarching conception of teaching science/mathematics with technology

As noted by Kinach (2002), teacher educators must challenge their preservice teachers ''habitual ways of thinking about subject matter and subject matter teaching'' (p. 69). These case studies uncovered an important consideration in the development of TPCK—the interaction of the content of science/mathematics and the content of the specific technology. Terry extended his lessons to have his students investigate the effects of the external environment on the temperature reading, redesigning the probeware setup to improve the data collection. Yet, when the integration was a natural inclusion in the unit, Karen resisted using class time to explore the science embedded in the design of the technology. Denise simply rejected the consideration of the science of the technology thinking of the technology as a tool to do science rather than a tool embodying science.

Only some of these student teachers seemed to recognize the interplay of technology and science despite the emphasis throughout the program. Borko and Putnam (1996) described the conception of what it means to teach a particular subject as being ''related more specifically to how the teacher thinks about the subject matter domain for *students*—what it is that students should learn about…the nature of those subjects''(p. 690).

Perhaps some of the reasons for this difficulty lie with issues like Karen's personal discomfort with technology and her belief that technology was frivolous to learning science. Another potential explanation may lie with some of Denise' issues. Denise had learned science through lectures and other experiences to promote critical thinking. For her the focus was on promoting critical thinking and students should just use the technologies, as tools, and there was no need to understand them. The other student teachers all demonstrated a broader perception of students gaining knowledge of the science or mathematics of the particular technologies they used. The reason for this difference is unclear. But, teacher preparation programs need to consider specific directions to guide student teachers in expanding their understandings of the interactions of the knowledge of technology and the knowledge of their subject area.

6.2. Instructional strategies and representations for teaching with technologies

Research has hinted that student teachers have inadequate repertoires for teaching their subject matter (Ball, 1991; Borko et al., 1992; McDiarmid, 1990) resulting in a limited PCK. Given the recent inclusion of technology in education, many preservice teachers have had limited experiences in learning their subject matter with technology. They have not seen or experienced many instructional strategies and representations of their subject within a technology framework. Terry actively looked for instructional strategies that incorporated technology, brainstorming, and picking ones that were most beneficial. His cooperating teacher (with many prior experiences designing instructional strategies and representations with technology) was instrumental in guiding Terry as he implemented the various strategies. Dianne looked for ways to incorporate technology in as many of her mathematics lessons as she could but classroom management issues interfered with her instructional strategies. She collected many resources but was reluctant to incorporate their use because she seemed to be more comfortable with a classroom environment where she did the talking. While Marissa's background with technology in learning her subject was limited, she believed that her students were able to see and understand some concepts better with technology. As a result, she consistently looked forward to incorporating instruction with technology in teaching earth science.

Marissa was comfortable with ''learning with the students'' since she recognized her limitations with technologies. But she recognized the importance of her questioning in helping the students in these cases. The importance of questioning in developing students' understanding has been recognized for many years. The program emphasized this strategy in the various models—demonstrations, hands-on laboratory, and inductive and deductive modes.

The subject-specific nature of the program supported the emphasis on questioning allowing multiple subject-specific models and examples. More importantly with respect to this area of the development of a TPCK, the program provided a consistent focus on instructional strategies and representations of the content with technology. A feature of all courses in the program was a focus on modeling instructional strategies that incorporated technology. In the Microteaching course, e.g., the faculty modeled instruction for each model, using the experiences to discuss the particular models. Moreover, both science and mathematics models were provided with at least one model incorporating technology. The consistent subject-specific modeling provided the student teachers with many more opportunities to consider instructional strategies that incorporated technology. Perhaps this direction of the program prior to their student teaching supported them in the component of TPCK that considers instructional strategies and representations.

6.3. Students' understandings, thinking, and learning in a subject with technology

In their beginning student teaching experience, the student teachers were naturally focused on their own teaching and less likely to think about their students' understandings, thinking, and learning. Dianne proved to be a clear example of this problem. Her experience in teaching with technology was early in the experience and she simply admitted to not even knowing her students' names. Her reflections at that time were focused on her actions and she was surprised by her students' thinking the activity with the technology was not mathematics. Karen also seemed focused on her own actions with the technology and her conception of how students would learn about pH—that they would be motivated by the color changes. She seemed to discount her students' motivation of seeing the numerical values offered by the pH probe. Marissa's instruction with technology was guided by the motivation of her students to use technology to thinking about the science they were learning.

Terry's experience provided the clearest example of a consideration of student's understandings, thinking, and learning with technology. He provided an example of how a lesson on the area of freezing point depression that without the use of the technology might lead to student misconceptions and that with the technology would encourage students to learn at a higher level.

The pedagogy courses emphasized how students' interpretations of the concepts when technology was part of the instruction. A guiding question for consideration by the student teachers as they planned, taught and reflected on their lessons was: "How will the students understand the concepts in the technology-enhanced instructional activity?" The possibility of misconceptions was a focus of the discussions as the various instructional strategies were considered. However, the richest discussions came following the student teaching experience in the Technology and Pedagogy II course. At this time, the student teachers were focused on students' understandings because their concern for their own actions as a teacher had shifted to a concern for what the students were learning as a result of the teaching.

6.4. Curriculum and curricular materials

The integration of technology in the curriculum has been a newer shift in the past 10 years. The majority of their science and mathematics precollege and undergraduate education was a curriculum that did not necessarily embrace learning with and about the technology. In Karen's case, her experience in learning about pH was with litmus paper. In her search for different indicators as a way of looking at pH, she found the cabbage-juice activity. With the exciting color change with cabbage-juice indicators, she was pleased with their inclusion in the activities. But, she was unwilling to think about the pH probe even though the way the probe collected measurements provided a way to talk about pH. Marissa recognized the importance of considering technology in her science class because scientists used technology to collect data. Thus, her concept of the curriculum was one that included an integration of technology. Dianne had a strong background with computer-based technologies and viewed the connection of society, mathematics and technology. She viewed the mathematics curriculum from this perspective with a particular emphasis on problem solving with technology. Her primary consideration for technology in the curriculum was whether it related to mathematics.

A major assignment in the program was to gather over 60 resources for teaching their content. In describing these resources, they were required to align the idea to their content standards and to the technology standards. This assignment over the year had the effect of a consistent focus in considering the curriculum from a standards base. From NRC'S National Science Education Standards "The relationship between science and technology is so close that any presentation of science without developing an understanding of technology would portray an inaccurate picture of science" (NRC, 1996, p. 190). From NCTM's mathematics standards (2000) "Technology is essential in teaching and learning mathematics; it influences the mathematics that is taught and enhances students' learning" (NCTM, 2000, p. 11).

Certainly, the requirement to teach a sequence of lessons with technology focused the student teachers on identifying potential integrations of technology in their respective curricula. The type of technology was limited to CBRs or CBLs because of access to technology at the various school sites. The support of cooperating teachers also limited the student teachers in looking at the curriculum for natural places for technology integration. The mathematics, chemistry, and physics cooperating teachers were more apt to help in the identification of curriculum areas for integration. However, the support of university supervisors and science and mathematics education faculty, the student teachers were challenged to consider the curriculum more broadly and to consider how technology supported the national standards.

These results provide a beginning for understanding TPCK and preparing teachers to teach with technology. What program models support teachers in gaining the skills, knowledge, and beliefs that support teaching different subjects with technology? What are the important skills, knowledge, and beliefs? How does TPCK change for different content areas? What experiences are essential in building a TPCK? What technologies are important? What support do student teachers need as they practice teaching with technologies? Questions such as these will continue to challenge teacher educators and researchers as they search to meet the demands of the preparation of 21st century teaches—teachers with a commitment to prepare today's student to live, learn, and work in tomorrow's "increasingly complex and information-rich society" (ISTE, 2000a).

References

Ball, D. L. (1988). *Knowledge and reasoning in mathematical pedagogy: Examining what prospective teachers bring to teacher education*. Unpublished Doctoral dissertation, Michigan State University, East Lansing.

Ball, D. L. (1991). Research on teaching mathematics: Making subject matter knowledge part of the equation. In: J. Brophy (Ed.), *Advances in research on teaching: Teachers' subject matter knowledge and classroom instruction* (Vol. 2, pp. 1–48). Greenwich, CT: JAI Press.

Beck, J. A., & Wynn, H. C. (1998). *Technology in teacher education: Progress along the continuum*. ERIC Document Reproduction No. ED 424 212.

Borko, H., Eisenhart, M., Brow, C. A., Underhill, R. G., Jones, D., & Agard, P. C. (1992). Learning to teach hard mathematics: Do novice teachers and their instructors give up too easily? *Journal for Research in Mathematics Education*, *23*, 194–222.

Borko, H., & Livingston, C. (1989). Cognition and improvisation: Differences in mathematics instruction by expert and novice teachers. *American Educational Research Journal*, *26*(4), 473–498.

Borko, H., & Putnam, T. (1996). Learning to teach. In D. C. Berliner, & R. C. Calfee (Eds.), *Handbook of educational psychology* (pp. 673–708). New York, NY: Simon & Schuster Macmillan.

Chiappetta, E. L., & Koballa, T. R. (2002). *Science instruction in the middle and secondary schools*. New Jersey: Merrill Prentice Hall.

Civil, M. (1992). *Prospective elementary teachers' thinking about mathematics*. Paper presented at the annual meeting of the American Educational Research Association, San Francisco.

Duhaney, D. C. (2001). Teacher education: Preparing teachers to integrate technology. *International Journal of Instructional Media*, *28*(1), 23–30.

Even, R. (1989). *Prospective secondary mathematics teachers' knowledge and understanding about mathematical functions*. Unpublished Doctoral dissertation, Michigan State University, East Lansing, MI.

Grossman, P. L. (1989). A study in contrast: Sources of pedagogical content knowledge for secondary English. *Journal of Teacher Education*, *40*(5), 24–31.

Grossman, P. L. (1990). *The making of a teacher: Teacher knowledge and teacher education*. New York: Teachers College Press.

Grossman, P. L. (1991). Overcoming the apprenticeship of observation in teacher education coursework. *Teaching and Teacher Education*, *7*, 245–257.

International Society for Technology in Education. (2000a). *National educational technology standards for students: Connecting curriculum and technology*. Eugene, OR: Author.

International Society for Technology in Education. (2000b). *National educational technology standards for teachers*. Eugene, OR: Author.

Kennedy, M. M. (1990). *A survey of recent literature on teachers' subject matter knowledge*. Issue Series 90-3. East Lansing: Michigan State University, National Center for Research on Teacher Education.

Kinach, B. M. (2002). A cognitive strategy for developing pedagogical content knowledge in the secondary mathematics methods course: Toward a model of effective practice. *Teaching and Teacher Education*, *18*, 51–71.

Leinhardt, G. (1989). Math lessons: A contrast of novice and expert competence. *Journal for Research in Mathematics Education*, *20*(1), 52–75.

Leinhardt, G., & Smith, D. A. (1985). Expertise in mathematics instruction: Subject matter knowledge. *Journal of Educational Psychology*, *77*, 247–271.

Livingston, C., & Borko, H. (1990). High school mathematics review lessons: Expert–novice distinction. *Journal for Research in Mathematics Education*, *21*, 372–387.

Marks, R. (1990). Pedagogical content knowledge. From a mathematical case to a modified concept. *Journal of Teacher Education*, *41*(3), 3–11.

McDiarmid, G. W. (1990). Challenging prospective teachers' beliefs during early field experience: A quixotic undertaking? *Journal of Teacher Education*, *41*(3), 12–20.

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

National Research Council. (1996). *National Science Education Standards*. Washington, DC: National Academy Press.

Rosenthal, I. G. (1999). New teachers and technology: Are they prepared? (Technology information). *Technology and Learning*, *19*(8), 1–2.

Shreiter, B., & Ammon, P. (1989), *Teachers' thinking and their use of reading contracts*. Paper presented at the annual meting of the American Educational Research Association, San Francisco.

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher*, *15*, 4–14.

Simon, M. A., & Brobeck, S. (1993). *Changing views of mathematics learning: A case study of a prospective elementary teacher*. Paper presented at the annual meeting of the North American Chapter of the International Group for the Psychology of Mathematics Education (PME-NW), Monterey, CA.

Simon, M. A., & Mazza, W. (1993). *From learning mathematics to teaching mathematics: A case study of a prospective teacher in a reform-oriented program*. Paper presented at the annual meeting of the North American Chapter of the international Group for the Psychology of Mathematics Education (PME-NW), Monterey, CA.

Tamir, P. (1988). Subject matter and related pedagogical knowledge in teacher education. *Teaching and Teacher Education*, *4*, 99–220.

Westerman, D. A. (1992). Expert and novice teacher decision making. *Journal of Teacher Education*, *42*(4), 292–305.

Wetzel, K., & Zambo, R. (1996). Innovations in integrating **technology** into student teaching experiences. *Journal of Research on Computing in Education*, *29*(2), 196–215.

Wilcox, S., Schram, P., Lappan, G., & Lanier, P., et al. (1990). *The role of a learning community in changing preservice teachers' knowledge and beliefs about mathematics education*. Paper presented at the annual meeting of the American Educational Research Association, Boston.

Wilson, S. M., & Wineburg, S. (1988). Peering at history through different lenses: The role of disciplinary perspectives in teaching history. *Teachers College Record*, *89*, 525–539.

Young, S., Cantrel, P., Bryant, C., Archer, L., Roberts, C., & Paradis, E. (2000). The state of technology in university teacher preparation and public schools in Wyoming. *Teaching and Change*, *8*(1), 134–144.