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Teaching Science with Technology: Case Studies of Science Teachers' Development of Technology, Pedagogy, and Content Knowledge

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Abstract

This study examines the development of technology, pedagogy, and content knowledge (TPACK) in four in-service secondary science teachers as they participated in a professional development program focusing on technology integration into K-12 classrooms to support science as inquiry teaching. In the program, probeware, mind-mapping tools (CMaps), and Internet applications – computer simulations, digital images, and movies – were introduced to the science teachers. A descriptive multicase study design was employed to track teachers' development over the yearlong program. Data included interviews, surveys, classroom observations, teachers' technology integration plans, and action research study reports. The program was found to have positive impacts to varying degrees on teachers' development of TPACK. Contextual factors and teachers' pedagogical reasoning affected teachers' ability to enact in their classrooms what they learned in the program. Suggestions for designing effective professional development programs to improve science teachers' TPACK are discussed.

Science teaching is such a complex, dynamic profession that it is difficult for a teacher to stay up-to-date. For a teacher to grow professionally and become better as a teacher of science, a special, continuous effort is required (Showalter, 1984, p. 21).

To better prepare students for the science and technology of the 21st century, the current science education reforms ask science teachers to integrate technology and inquiry-based teaching into their instruction (American Association for the Advancement of Science, 1993; National Research Council [NRC], 1996, 2000). The *National Science Education Standards* (NSES) define inquiry as “the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work” (NRC, 1996, p. 23). The NSES encourage teachers to apply “a variety of technologies, such as hand tools, measuring instruments, and calculators [as] an integral component of scientific investigations” to support student inquiry (p.175). Utilizing technology tools in inquiry-based science classrooms allows students to work as scientists (Novak & Krajcik, 2006, p. 76).

Teaching science as emphasized in the reform documents, however, is not easy. Science teachers experience various constraints, such as lack of time, equipment, pedagogical content knowledge, and pedagogical skills in implementing reform-based teaching strategies (Crawford, 1999, 2000; Roehrig & Luft, 2004, 2006). One way to overcome the barriers and to reform teaching is to participate in professional development programs that provide opportunities for social, personal, and professional development (Bell & Gilbert, 2004). Professional development programs in which teachers collaborate with other teachers, reflect on their classroom practices, and receive support and feedback have been shown to foster teachers’ professional development (Grossman, Wineburg, & Woolworth, 2001; Huffman, 2006; Loucks-Horsley, Love, Stiles, Mundry, & Hewson, 2003).

In this light, the professional development program, Technology Enhanced Communities (TEC), which is presented in this paper, was designed to create a learning community where science teachers can learn to integrate technology into their teaching to support student inquiry. TEC has drawn heavily on situated learning theory, which defines learning as situated, social, and distributed (Brown, Collins, & Duguid, 1989; Lave & Wenger, 1991; Putnam & Borko, 2000). Since a situated learning environment supports collaboration among participants (Brown et al., 1989; Lave & Wenger, 1991; Putnam & Borko, 2000), and the collaboration among teachers enhances teacher learning (Cochran-Smith & Lytle, 1999; Krajcik, Blumenfeld, Marx, & Soloway, 1994; Little, 1990), TEC was designed to provide teachers with opportunities to build a community that enables learning and is distributed among teachers. The situated learning theory was used as a design framework for TEC, but technology, pedagogy, and content knowledge (TPACK) was employed as a theoretical framework for the present study.

Since the concept of TPACK has emerged recently, there has been no consensus on the nature and development of TPACK among researchers and teacher educators. As suggested by many authors in the *Handbook of Technological Pedagogical Content Knowledge* (AACTE Committee on Innovation and Technology, 2008), more research needs to examine the role of teacher preparation programs teachers’ beliefs (Niess, 2008), and specific student and school contexts (McCrorry, 2008) regarding the nature and development of TPACK. Thus, this study was conducted to investigate the effects of an in-service teacher education program (TEC) on science teachers’ development of

TPACK. The research question guiding this study was: How does the professional development program, TEC, enhance science teachers' TPACK?

Review of the Relevant Literature

Technology Integration Into Science Classrooms

Educational technology tools such as computers, probeware, data collection and analysis software, digital microscopes, hypermedia/multimedia, student response systems, and interactive white boards can help students actively engage in the acquisition of scientific knowledge and development of the nature of science and inquiry. When educational technology tools are used appropriately and effectively in science classrooms, students actively engage in their knowledge construction and improve their thinking and problem solving skills (Trowbridge, Bybee, & Powell, 2008).

Many new educational technology tools are now available for science teachers. However, integrating technology into instruction is still challenging for most teachers (Norris, Sullivan, Poirot, & Soloway, 2003; Office of Technology Assessment [OTA], 1995). The existing studies demonstrate that technology integration is a long-term process requiring commitment (Doering, Hughes, & Huffman, 2003; Hughes, Kerr, & Ooms, 2005; Sandholtz, Ringstaff, & Dwyer, 1997). Teachers need ongoing support while they make efforts to develop and sustain effective technology integration. Professional learning communities, where teachers collaborate with other teachers to improve and support their learning and teaching, are effective for incorporating technology into teaching (Krajcik et al., 1994; Little, 1990). As a part of a community, teachers share their knowledge, practices, and experiences; discuss issues related to student learning; and critique and support each others' knowledge and pedagogical growth while they are learning about new technologies (Hughes et al., 2005).

Technology integration is most commonly associated with professional development opportunities. The need for participant-driven professional development programs in which teachers engage in inquiry and reflect on their practices to improve their learning about technology has been emphasized by many researchers (Loucks-Horsley et al., 2003; Zeichner, 2003). Zeichner, for example, argued that teacher action research is an important aspect of effective professional development. According to Zeichner, to improve their learning and practices, teachers should become teacher researchers, conduct self-study research, and engage in teacher research groups. These collaborative groups provide teachers with support and opportunities to deeply analyze their learning and practices.

Pedagogical Content Knowledge

Shulman (1987) defined seven knowledge bases for teachers: content knowledge, general pedagogical knowledge, curriculum knowledge, pedagogical content knowledge (PCK), knowledge of learners and their characteristics, knowledge of educational context, and knowledge of educational ends, goals, and values. According to Shulman, among these knowledge bases, PCK plays the most important role in effective teaching. He argued that teachers should develop PCK, which is "the particular form of content knowledge that embodies the aspects of content most germane to its teachability" (Shulman, 1986, p. 9). PCK is not only a special form of content knowledge but also a "blending of content and pedagogy into an understanding of how particular topics, problems, or issues are

organized, presented, and adapted to the diverse interests and abilities of learners, and presented for instruction” (Shulman, 1987, p. 8).

Shulman argued that teachers not only need to know their content but also need to know how to present it effectively. Good teaching “begins with an act of reason, continues with a process of reasoning, culminates in performances of imparting, eliciting, involving, or enticing, and is then thought about some more until the process begins again” (Shulman, 1987, p. 13). Thus, to make effective pedagogical decisions about what to teach and how to teach it, teachers should develop both their PCK and pedagogical reasoning skills.

Since Shulman’s initial conceptualization of PCK, researchers have developed new forms and components of PCK (e.g., Cochran, DeRuiter, & King, 1993; Grossman, 1990; Marks, 1990; Magnusson, Borko, & Krajcik, 1994; Tamir, 1988). Some researchers while following Shulman’s original classification have added new components (Grossman, 1990; Marks 1990; Fernandez-Balboa & Stiehl, 1995), while others have developed different conceptions of PCK and argued about the blurry borders between PCK and content knowledge (Cochran et al., 1993). Building on Shulman’s groundbreaking work, these researchers have generated a myriad of versions of PCK. In a recent review of the PCK literature, Lee, Brown, Luft, and Roehrig (2007) identified a consensus among researchers on the following two components of PCK: (a) teachers’ knowledge of student learning to translate and transform content to facilitate students’ understanding and (b) teachers’ knowledge of particular teaching strategies and representations (e.g., examples, explanations, analogies, and illustrations).

The first component, knowledge of student learning and conceptions, includes the following elements: students’ prior knowledge, variations in students’ approaches to learning, and students’ misconceptions. This component of PCK refers to teachers’ knowledge and understanding about students’ learning and their ideas about a particular area or topic. This type of knowledge also refers to teachers’ understanding of variations in students’ different approaches to learning. The second component refers to teachers’ knowledge of specific instructional strategies and representations that can be helpful for students to understand new concepts.

TPACK

In recent years, many researchers in the field of educational technology have been focused on the role of teacher knowledge on technology integration (Hughes, 2005; Koehler & Mishra, 2005, 2008; Mishra & Koehler, 2006; Niess, 2005). The term TPACK (also known as TPCK; Koehler & Mishra, 2005) has emerged as a knowledge base needed by teachers to incorporate technology into their teaching. Koehler and Mishra (2005) discussed TPACK as a framework for teacher knowledge for technology integration. Their TPACK framework is based upon Shulman’s conception of PCK. In Koehler and Mishra’s model of TPACK, there are three main components of teacher knowledge: content, technology, and pedagogy. They described TPACK as a combination of these three knowledge bases. According to the authors, TPACK is the

...basis of effective teaching with technology and requires an understanding of the representation of concepts using technologies; pedagogical techniques that use technologies in constructive ways to teach content; knowledge of what makes concepts difficult or easy to learn and how technology can help redress some of problems that students face; knowledge of students’ prior knowledge and theories of epistemology; and knowledge of how technologies can be used to build on existing knowledge and to develop new epistemologies or strengthen old ones. (Koehler & Mishra, 2008, p. 17-18)

Koehler and Mishra (2008) argued that for effective technology integration all three knowledge elements (content, pedagogy, and technology) should exist in a dynamic equilibrium. Niess (2005) described TPACK as the “integration of the development of knowledge of subject matter with the development of technology and of knowledge of teaching and learning.” However, Niess (2008) argued that TPACK is a way of thinking rather than a knowledge base. According to Niess (2008) TPACK is

....a way of thinking *strategically* while involved in planning, organizing, critiquing, and abstracting, for specific content, specific student needs, and specific classroom situations while concurrently considering the multitude of twenty-first century technologies with the potential for supporting student learning. (p. 224)

McCrorry (2008) investigated science teachers, TPACK, pointing out that four knowledge bases are vital to science teachers’ development of TPACK: content, students, technology, and pedagogy. According to McCrorry, science teachers need to possess adequate knowledge of science to help students develop understandings of various science concepts. In order to address students’ particular needs, teachers should have deep knowledge and understanding about student learning. Teachers’ knowledge about students facilitates the development of strategies to address students’ prior knowledge of particular science concepts and misconceptions in science (McCrorry, 2008). Having adequate pedagogical knowledge allows teachers to teach effectively a particular science concept to a particular group of students. A teacher with strong pedagogical knowledge employs effective teaching strategies, creates well-designed lessons plans, applies successful classroom management techniques, and develops an understanding about student learning (Koehler & Mishra, 2008).

Furthermore, well-developed knowledge of technology allows teachers to incorporate technologies into their classroom instruction. Importantly, technology knowledge is much more than just knowing about technology; a deep understanding of technology is needed to use technology for effective classroom instruction, communication, problem solving, and decision making (Koehler & Mishra, 2008). As emphasized by McCrorry (2008), these four knowledge bases—knowledge of, science, students, pedagogy, and technology—work collaboratively “in knowing *where* [in the curriculum] to use technology, *what* technology to use, and *how* to teach with it” (McCrorry, 2008, p. 195). In this study, we followed McCrorry’s (2008) conceptualization of TPACK for science teachers to investigate the affects of TEC on science teachers’ development of TPACK.

The Study

Context

TEC was designed to help secondary science teachers develop necessary knowledge and skills for integrating technology for science-as-inquiry teaching. TEC was a yearlong, intensive program, which included a 2-week-long summer introductory course about inquiry teaching and technology tools and follow-up group meetings throughout the school year associated with an online course about teacher action research. A LeMill community Web site was created at the beginning of the program. LeMill is a “Web community for finding, authoring, and sharing learning resources” (<http://lemill.net>). Participant teachers created accounts and joined the TEC community Web site. Through this Web site, teachers interacted with the university researchers and their colleagues and were able to share and discuss lesson resources.

Several instructional technologies were presented in the summer course: concept mapping tools (CMap tools; Novak & Gowin, 1984), VeeMaps (Roehrig, Luft, & Edwards, 2001), probeware (e.g., pH, temperature, concentration of solutions, blood pressure, and respiration rate), computer simulations, digital images, and movies. Teachers engaged in inquiry-based activities while they were learning these technology tools. For example, teachers implemented a cookbook lab experiment about the greenhouse effect following the procedure given by the university educators. Teachers then modified this activity to be inquiry based. Through implementation, discussions, and reflections, teachers developed their understanding of inquiry and effectiveness of technology tools in student learning and inquiry. Throughout the entire program teachers were encouraged to reflect on their classroom practices. Teachers each wrote about their experiences with technology tools and inquiry in their blogs on the LeMill community Web site.

After learning about technology tools, teachers created lesson plans that included technology tools and loaded these lesson plans onto the LeMill Web site. Furthermore, each teacher developed a technology integration plan to follow in the subsequent school year. During the school year, the teachers and the university educators met several times to discuss the constraints teachers had experienced in the integration of technology to practice reform-based science instruction. In addition, during the school year teachers used the LeMill site to ask questions, share lesson plans and curricula, and reflect on their teaching. In the online discussions and face-to-face meetings, the members of the learning community, the teachers and the university educators, engaged in numerous conversations about how to overcome these barriers (e.g., lack of access to technology).

In spring 2008, the teachers were formally engaged in teacher action research. They designed and conducted action research studies to reflect upon their practices and learning about technology. During this phase, university educators and teachers worked collaboratively. Teachers each prepared a Google document with their action research report and shared it with university educators and other teachers. The researchers provided necessary theoretical knowledge for teachers to design their studies. Conducting action research allowed teachers to see the effectiveness of using technology tools in student learning. During this phase, the collaboration among teachers and the university educators fostered the growth of the learning community.

Participants

The teachers in this study were the participants in the TEC professional development program that focused on technology integration in science classrooms. Eleven secondary science teachers enrolled in the program. These teachers had varying levels of teaching experience, ranging from 1 to 17 years. Five of them were experienced and 6 of them were beginning secondary science teachers. Only beginning teachers were invited to participate in the present study since they had more commonalities with each other than with experienced teachers. For example, the beginning teachers all graduated from the same teacher education program and were all teaching their academic specialty. The teachers had recently completed preservice coursework focused on inquiry-based teaching and implementing science instruction with technology tools. Of the six beginning teacher participants in TEC, four – Jason, Brenna, Matt, and Cassie – participated in this study. The other two beginning teachers did not participate in the study, as they did not have enough time to devote to the research study. More information about teachers can be found in Table 1. Pseudonyms are used for all teacher participants.

Table 1
Demographic Information About the Participating Teachers

Teacher	Subject	School	Years of Teaching Experience[a]	Previous Knowledge and Skills About Technology
Jason	9th and 10th grade Biology	Public school in a suburban area	1	Developing
Brenna	8th grade Earth Science	Public school in a suburban area	2	Developing
Matt	8th grade Physical Science and Life Science	Private school in an urban area	3	Sophisticated
Cassie	9th,10th,11th, and 12th grade Life Science and Physical Science	Charter school in an urban area	2	Limited

[a] Years of experience includes the current year of teaching.

Data Collection

Various data collection instruments were used to investigate how TEC impacted teachers' development of TPACK. These data collection instruments included surveys, interviews, teachers' technology integration plans created at the end of the summer course, field notes from the classroom observations of the teachers, and teachers' action research reports. In this study, triangulation was achieved through the various techniques of data collection (as in Patton, 1987).

Electronic surveys were sent to teachers four times during the program. The first survey requested information about teachers' knowledge and skills about using technology tools in their classrooms. The second survey was sent at the end of the summer course requesting information about the effectiveness of the summer course on teachers' learning about technology tools. To find what, when, and how teachers used technology tools and inquiry-based teaching during the fall semester, we sent a survey at the end of the semester. Finally, after completing the online course, teachers received another survey that included questions about their overall experience in the program, what they learned, and how they applied their knowledge in their instruction.

Interviews were conducted at the beginning and end of the summer program. Questions included were (a) How do your students learn science best? (b) How do you decide what to teach and what not to teach? (c) What does it mean to you to teach science with technology tools? (d) How often do you implement inquiry in your classroom? (e) Can you give an example of your inquiry instruction? and (f) What did you consider while planning this inquiry lesson?

Teachers were required to write a technology integration plan at the end of the summer course. In their plans, teachers explained in what ways, when, and how they could use technology tools in their classrooms during the upcoming school year. In addition, in their plans teachers talked about the constraints they might face while integrating technology into their teaching and how they could overcome these obstacles.

Teachers were observed in their classrooms at least two times during the 2007-2008 school year. Observations were deliberately scheduled during a time when the teacher was using technology. Detailed field notes about teachers' practices, technology tools being used, and student engagement were taken during the observations. Teacher artifacts such as lesson plans and student handouts were also collected.

During spring 2008, each teacher designed and conducted action research studies. Teachers reflected on their practices by identifying their own questions, documenting their own practices, analyzing their findings, and sharing their findings with university educators and other teachers. A range of topics were addressed by the teachers. Many teachers, for example, focused on impact of a particular technology tool (e.g., concept mapping, simulations, and online discussions) on student learning.

Data Analysis

Each participant teacher's set of documents (interview transcript, observation notes, surveys, technology integration plan, classroom artifacts, and action research reports) were analyzed separately. The process of constant comparative analysis (Strauss & Corbin, 1990) was used to analyze the data. First, each incident in a teacher's document was coded for a category. As the incidents were coded, we compared them with the previous incidents that coded in the same category to find common patterns, as well as differences in the data (as in Glaser, 1965).

As discussed in Merriam (1998), categories emerging from the data were exhaustive, mutually exclusive, sensitizing, and conceptually congruent and reflected the purpose of the study. For example, the following categories were created for participant Cassie: misunderstanding of inquiry, lack of technological resources, unwillingness to change, mixed beliefs about technology, feeling of isolation, undeveloped conception of science, and weak teacher-student relationships.

After coding the categories, we compared categories for each participating teacher and recorded "memos" (Glaser & Strauss, 1967). At this time, we wrote case studies for each teacher based on the most salient categories that provided memos. The emergent salient categories were previous experiences with technology; beliefs about teaching, learning, and technology; the use of technology in classroom instruction; and the implementation of inquiry-based teaching. Case studies were written as recommended in Yin (1994). We then integrated diverse memos with other memos of analysis to discern the impact of TEC on teachers' development of TPACK. In the last phase of the analysis, we defined major themes derived from the data.

Results

At the end of the program, the participant teachers of this study, Jason, Brenna, Matt, and Cassie met all the requirements for completing the program. However, teachers were each found to integrate technology into their teaching to various degrees. The cases of these teachers describe the differences in their development of TPACK.

Jason's Profile

Jason was a first-year teacher at a suburban high school. He taught 9th- and 10th-grade biology. Before participating in the program, Jason had some experience with technology tools. He felt comfortable using concept mapping tools (CMap and Inspiration), temperature and pH probeware, and digital microscopes. Jason believed that the purpose of using technology tools in science classrooms is to “motivate students to answer their own questions and get more into the process of inquiry.”

At the end of the summer course, Jason designed a technology integration plan, in which he specifically explained which technology tools he was planning to use during the school year. Jason was excited to use VeeMaps and CMap tools in his classroom. He said that these tools were a “very high priority to implement in [his] classroom. They are much better at helping students clarify their previous knowledge, experimental procedure and implications of their work.” Ultimately, however, Jason did not employ VeeMaps in his classroom due to a “lack of familiarity” with them. As a beginning teacher Jason could not make effective decisions about how and when to use VeeMaps.

TEC had been his first experience with the concept of VeeMaps, and he did not feel comfortable using them in his classroom. On the other hand, Jason used CMaps once a month in his instruction. Furthermore, he also conducted an action research study on the effectiveness of concept mapping on his students' retention and understanding of content knowledge. Results of this study encouraged Jason to use this tool more frequently in the next teaching year. In addition to these tools, Jason created a Web site on his school server. He posted all his notes online for students to access. His students submitted their homework electronically. Jason said that this helped him “to get more organized.”

Since Jason had limited access to the probeware in his school, he did not incorporate it into his teaching. Jason believed that the limited number of probes would cause “disengagement and or improper use...in small groups.” Jason was also reluctant to use simulations. He expressed that “many of the simulations [he] has found online are informative but have a great potential for students to become disengaged or ‘click happy.’” Even though he used two simulations when he taught about DNA during the fall semester, he did not believe that these tools were effective in enhancing student learning.

Jason was an advocate of inquiry-based teaching. He said that “since the beginning of the teacher education program, inquiry-based instruction has been a significant priority in [his] classroom lessons. Whether small guided activities or full inquiry labs, inquiry-based instruction is important to implement in place of typical cookbook labs.” Prior to the program, his biggest barrier to implementing inquiry lessons was modifying step-by-step labs into inquiry activities. During the program, Jason learned how to turn the cookbook labs into inquiry activities.

Jason had a rigid conception of inquiry. For him, all inquiry lessons, technology integrated or not, should allow students to

ask their own questions about a topic and taking the necessary steps to research and set up an experiment to test their ideas. Student experiments should reduce their investigation into a single variable. Students' methods and experimental setup should go through several reviews not only by a teacher but also be clear in their instructions and testing the correct variable.

Jason's understanding of inquiry was mirrored in his classroom practices. In the observed inquiry lesson on bacteria, students investigated antibacterial products on strains of bacterial colonies. Students posed their own research questions; they set up experiments and then tested variables such as detergent, soap, and toothpaste on bacterial growth. Interviews with Jason revealed that he defined inquiry activities exclusively as full or "open-ended," in which students pose their own questions and design their own experiment to test variables. The "bacteria inquiry" lesson was the only observed inquiry activity (as defined by Jason) that he implemented during the school year. This inquiry activity did not involve any technology tools.

Brenna's Profile

Brenna was a second-year teacher at a suburban middle school. She taught eighth-grade Earth science. Prior to participating in the program, Brenna did not have much previous experience with many of the basic technology tools. She was not comfortable with using computers for sharing and collaboration. However, she knew about probeware, Google Earth, and CMap tools. Brenna's biggest concern was implementing basic troubleshooting techniques for technology tools. She had not used many of the tools previously since she did not know how to solve technology-related problems.

Before participating in the program, Brenna used only Powerpoint presentations and some Google Earth demos in her teaching. After learning various tools in the program, Brenna decided to create a 3-year technology integration plan. The main goal of her teaching in the first year of this plan was to be able to "check out computers as often as [she] would like and use concept maps, VeeMaps, and clickers (classroom response systems)." Her second and third year commitments included creating more laboratory activities that utilize probeware and designing a personal Web page and maintain updates on this Web page.

During the school year, Brenna frequently used CMap tools, VeeMaps, and clickers. For example, in an observed lesson, Brenna asked her students to design their density lab in which they compare the density of different materials of their choice. Brenna provided many materials, such as vinegar, vegetable oil, and irregular shapes of solids like pennies and rocks. The question students focused on was "How can we compare the density of different things?" Brenna asked students to create VeeMaps instead of writing traditional lab reports. In their VeeMaps students wrote hypotheses, a list of new words, procedures, results, and conclusions of their experiments.

Brenna was also observed while she used clickers in her teaching. Clickers, also known as student response systems or classroom response systems, help teachers create interactive classroom environments. In her classroom, Brenna used clickers to get information about student learning. At the end of each unit, Brenna asked multiple choice questions to her students; students each submitted their answers using the clicker, and Brenna's computer gathered students' answers. This approach allowed Brenna to see student feedback in real time and address the areas where students had difficulty understanding.

Brenna designed an action research study to investigate the effectiveness of clickers on her students' understanding of new concepts. Brenna believed that "clickers are very effective in assessing the students' prior knowledge and current understanding." However, Brenna mostly used clickers as a "summative assessment at the end of units." She assigned each student to a particular clicker and tracked students' understanding of various topics. For Brenna, clickers are effective tools since they "provide immediate feedback for both students and [her]."

Even though Brenna integrated many of the technology tools that she learned in the program, she felt that she still needed more training with technology. She was not comfortable with using many of the tools. For example, during one of the observed classes, Brenna used a PowerPoint presentation when suddenly the computer screen turned black. Brenna could not figure out how to solve the problem. Ten minutes later, she sent a student to the administration office to find the technology teacher and asked him for help. While waiting for the technology teacher to come and fix the problem, a student offered Brenna help to figure out the problem. The student found that the computer turned off since Brenna forgot to plug in the power cord. After the 15-minute long chaos, Brenna fixed the problem and then continued her lesson. Another concern that Brenna had was that she needed more time creating technology-enhanced curriculum units. Brenna thought that collaboration among her colleagues might help her to create technology-rich lesson plans because it was time consuming otherwise.

Brenna implemented a few inquiry activities in her classroom. According to her, she took the ordinary labs that she implemented before and changed parts of them to be more inquiry based. To modify the labs to more inquiry, Brenna “offered more choices of materials that the students could choose from.” The observed “density inquiry” lesson was an example of this strategy.

Brenna believed that in an inquiry activity “students should come up with their own questions and procedure.” However, the classroom observations show that Brenna often provided the research questions and she provided little opportunity for students to design their own procedure. In addition, during the inquiry activities rather than facilitating students Brenna was mostly directing them on what to do and what not to do.

Matt’s Profile

Matt was a third-year science teacher in a private middle school. He taught eighth-grade physical science and life science. Prior to participating in the program, Matt had previous knowledge and experience with many technology tools. He frequently used simulations and Google Earth and Celestia “to facilitate concept demonstration.” However, Matt did not use any kind of probeware in his instruction. Matt believed that technology tools have a “very strong potential to greatly assist the students in their knowledge creation.”

At the end of the summer course, Matt expressed in an interview that he had “decided that concept mapping fits very well with his beliefs about the way that ideas and concepts are best described.” Thus, Matt made “plans on using concept mapping in his class regularly to assess his students’ understanding as well as to help learn them the connections between terms and concepts as they move through instruction.” The classroom observations demonstrated that Matt incorporated concept mapping into his teaching. As Matt put it,

I taught in a method that used shared CMaps to elicit student understandings about concepts I was teaching about. After engaging students in activities that challenged their understandings we had a class discussion that built a class consensus around the results of the activity. The activities included: examining the variables that affect elastic interaction, how a constant force affects a low friction car, and what affect added mass has to acceleration.

Matt uploaded many of these maps to his class Web site. In the spring semester, Matt’s students posted online discussion to the class Web site. In his action research study, Matt

investigated how online discussions influence his students' learning. Matt valued online discussions since he believed that they encourage students to participate in and more deeply analyze the course materials. Matt provided topics such as water quality or guiding questions, such as "What forms the boundary of a watershed?" and "How should we take our knowledge (that we have already and will continue to acquire) to help our society and our environment?" and asked students to write individual postings and respond to at least two of their classmates' postings.

In addition to concept mapping and online student discussion boards, Matt also implemented probeware several times in his teaching after he participated in the program. He used motion detector probes in his physical science classroom when he taught about Newton's laws, and pH and temperature probeware in his life science classroom. Students were involved in a multiday environmental study at a local creek, and they made quick measurements of temperature and pH using probeware. In their investigations students focused on the research question, "What is the water quality of our creek?" Based on their measurements and observations, students wrote research reports about the water quality in the creek.

Another tool that Matt gave priority to in his teaching was simulation. Matt expressed that he used "technology to help [his] presentation of concepts to the students." According to him, "animations and simulations give the students a wide array of pathways towards understanding." Simulations that he used while he taught mitosis and meiosis and velocity and acceleration helped his students build a conceptual understanding of these abstract concepts.

Even though Matt was "excited about the potential demonstrated by the VeeMaps and would like to move towards them as [his] means of assessment and presentation of lab reports," he did not use them during the school year. Matt felt "somewhat uncertain," and he thought he "needed to spend more time thinking about them before he is ready to turn to them as an organizing feature of [his] teaching."

Matt was a proponent of inquiry-based teaching. He believed that students learn science best while they are doing it. Thus, he frequently used inquiry activities in his classroom. Although some of these activities were long term science projects such as testing water quality in the creek, others were one-class-period-long inquiry activities. At the beginning of the spring semester, Matt taught students about organisms, and students conducted various directed inquiry activities about cabbage white butterflies, Wisconsin fast plants, and wow bugs. Matt provided the research question on all these activities, and students made observations to answer his questions. For example, students did a long-term project to investigate how cabbage white butterflies hatch.

Cassie's Profile

Cassie was a second-year teacher in an urban charter school that served only immigrant students. She taught 9th-, 10th-, 11th-, and 12th- grade Earth science, physical science, and life science. Before she participated in the program she had basic computer skills (e.g., using word processing, Excel, and PowerPoint applications). In her teaching, Cassie did not use many of the tools such as probeware and simulations that she learned in the teacher education program, since she did not feel comfortable using them in her classroom. For Cassie, "using technology has always been difficult. "She would rather do things the old fashioned way." However, she believed that she should integrate technology into her classroom instruction since "the world is becoming more technology savvy."

Cassie was the only teacher who expressed that the summer course was less helpful for her than she expected. Cassie stressed that she “learned a lot about technology and how to integrate it into the classroom, but we did not really do it a lot [during] the summer.” She wanted more “structure and specific expectations.” Cassie struggled with learning how to use many of the technology tools since the university educators in TEC used an inquiry-based approach rather than giving teachers step-by-step procedures that Cassie wanted to follow to learn about the technology tools. During a classroom observation in fall 2008, Cassie expressed that she had already forgotten how to use CMap tools that she learned two months prior in the summer course.

After participating in the summer program, Cassie expressed that her commitment for the following year was “to introduce VeeMaps as an alternative to traditional lab reports, and to incorporate one aspect of inquiry into each of [her] biology units.” She continued, “Introducing VeeMaps makes me a little nervous, and I am not sure how I will approach it.” During the school year, Cassie’s concerns prevented her from using VeeMaps in her instruction. She did not feel comfortable using them with her minority students who had limited English skills.

Cassie did not incorporate any of the technology tools that she learned in the program into her teaching. In an interview, she expressed that she had limited access to these tools, and she taught in a school environment that did not give her many choices but lecturing. Most of her students came to the U.S. just before the school started. In addition to limited language skills, her students had a conception of science different than Western science. For example, in an observed class, Cassie taught students about cell organelles in an animal cell. Since she did not even have an overhead projector in her classroom, Cassie gave her students photocopied papers that showed the organelles of an animal cell. After explaining the role of each organelle Cassie asked her students to make cells using plastic plates, candies, and jelly. Cassie was surprised when her students did not show any interest in making cells. Students could not understand this cell analogy activity.

Cassie stated “Science is not fact and science is not just memorizing. Inquiry is the true scientific method and it is important to teach students how to think critically because inquiry can be applied anywhere in their lives.” For Cassie, inquiry is “a student-centered activity where students explore something first and then they maybe get an introduction to it and then they apply it.” In an inquiry activity, Cassie wanted her students to “drive the most part of the work. The students are, hopefully, in theory investigating something that they are interested in first and then learn something and apply it. For me this is ideally and I never do it...open inquiry” [laughs]. According to Cassie it is difficult to implement the inquiry emphasized in the NSES and literature. Cassie said that to be able to do reform based teaching, a science teacher needs to have “enough science supplies and science space [own classroom].” In the following quote, Cassie talked about her constraints in implementing inquiry-based teaching.

I try to create a student centered environment but it exhausted me. I have to focus on how to teach people who do not speak English very well about science without any books. I do not have any books that really work and I do not have my own classroom.

Cassie attempted “to increase the amount of inquiry within each biology unit.” At the beginning of the school year, Cassie had many concerns. She did not know “how inquiry will work within the school structure.” Also, she did not have many science supplies with which to work. Thus, she hoped to start small and train the students to think more in-depth about science, but more importantly about their world. However, having so many barriers prevented Cassie from implementing any inquiry lessons during the school year.

Discussion

The Influence of TEC on Science Teachers' Development of TPACK

As emphasized earlier, in this study McCrory's (2008) conceptualization of TPACK was employed as a theoretical framework. In the present study, the four components of TPACK—knowledge of science, of students, of pedagogy, and of technology – were investigated to find science teachers' development of TPACK. TEC was found to have a varying impact on each participant teacher's development of TPACK. In the following section, each component of TPACK and how TEC impacted these components are discussed. In addition, the school context and teachers' reasoning skills are discussed as critical influences on teachers' development of TPACK.

Knowledge of Science. To teach science effectively, science teachers need to have an adequate level of knowledge of science. Thus, science teachers should refresh their knowledge of science to maximize their students' learning. Teachers in TEC were provided with opportunities to review and update their knowledge about science. The summer course readings helped teachers broaden their knowledge construction. For example, when teachers practiced with pH and temperature probes in performing experiments on greenhouse gases, they also improved their knowledge on this topic. The university educators assigned teachers to read articles about greenhouse gases before participating in the activities. Prior to conducting experiments about greenhouse gases, the university educators and the teachers discussed the topic. Through these readings and classroom discussions teachers improved their understanding of greenhouse gases. According to Brenna, this strategy really helped her to increase her understanding of the topic and to figure out various ways to design an inquiry lab activity on greenhouse gases for her Earth science class.

TEC did not specifically target improving teachers' content knowledge. As participants taught in different science subject areas, it was difficult to target growth in content knowledge. Thus, TEC specifically focused on helping teachers to rethink science and their representation of science in their teaching. In TEC, teachers frequently engaged in classroom discussions on what science is and what inquiry is, and these discussions helped teachers understand how scientific knowledge is generated and justified. All the teachers found these discussions "intensive."

Knowledge of Pedagogy. Most beginning science teachers struggle with developing effective lesson plans. In order to create lesson plans that meet all students' needs, teachers need to have a deep understanding about student learning and strategies that help students construct knowledge and improve skills and abilities. In TEC, teachers learned how to create technology-supported, inquiry-based lesson plans. In the summer course, teachers wrote lesson plans and shared them with other teachers in the community Web site. The university educators provided suggestions to improve lesson plans if needed. The community Web site now has several lesson plans that teachers can use in their classrooms.

Creating classroom management and organization is one of the biggest challenges for beginning science teachers (Roehrig & Luft, 2004). These challenges become more complicated when integrating technology into teaching. Given the preponderance of beginning teachers in TEC, the university educators provided extensive guidance for teachers in helping them overcome the classroom management issues they faced during their instruction. In classroom discussions, face-to-face meetings, and online discussion boards teachers shared their experiences and constraints, while university educators and colleagues provided possible solutions. However, all the teachers were found to struggle

with management issues during the school year. Brenna, for example, had a hard time managing her classroom when she faced problems with her computer. Since she was not able to troubleshoot the computer-related problem, she panicked and could not establish classroom order.

Matt also struggled with introducing technology tools to his students. In his instruction, Matt used various tools and showed great enthusiasm for these technology tools. He wanted all his students engaged in technology tools. However, students did not show high interest in the technology tools every time Matt used them in his instruction. Although students engaged in using CMap tools, they showed low engagement when they used the digital microscope. Matt still needed to find effective strategies to keep each student involved in technology-rich lessons.

Knowledge of Technology. The main goal of TEC was to help teachers integrate technology tools into their classrooms. As discussed previously, Jason, Matt, and Brenna integrated technology in their teaching in various degrees. On the other hand, Cassie could not incorporate technology tools into her classroom. One possible explanation was the difference in teachers' previous experiences with technology tools. When Jason and Matt started the program, they were more comfortable using many of the technology tools in their teaching than Cassie and Brenna were. In her first and second teaching year, Brenna attempted to use some of the tools that she learned during the teacher preparation program. However, in her first teaching year, Cassie did not use any of the tools that she learned in the teacher preparation program. Thus, Cassie was the only teacher who had limited knowledge and skills required to teach science with technology.

Jason and Matt were "technology enthusiasts" and they focused on learning and also integrating as many technology tools as possible. They actively searched for opportunities to improve their technology knowledge. Both these teachers used other tools such as digital microscopes and interactive white boards that were not presented in the summer course. Moreover, these teachers took leadership roles in their schools. Jason taught his colleagues how to use CMaps. Matt attempted to help his colleagues to use online student discussions as a new strategy to assess student learning.

Knowledge of Students. Jason, Matt, Brenna, and Cassie all believed that students learn science best when they are "engaged in science." As such, all these teachers were advocates of inquiry-based teaching. During the program, teachers learned how to turn cookbook labs into inquiry activities. In science classrooms, teachers commonly use cookbook lab activities in which students follow a given procedure. However, according to Brenna students do not "retain too much" through cookbook lab activities. Allowing students to "write their own procedure" helps students learn better. Before participating in the program, Brenna's concern was how much help she should provide students in an inquiry activity. In the summer program, teachers performed the inquiry activities as students. Teachers were facilitated but not directed by the university educators. Participating in these activities helped Brenna understand a teacher's role in an inquiry activity.

The classroom discussions on effective science teaching also allowed teachers to have a better understanding of what good science teaching and learning look like. In addition, university educators shared their previous experiences with teachers in classroom discussions and online discussions. They shared their knowledge about common student misconceptions and difficulties in learning science.

The Critical Factors Influencing Teachers' Development of TPACK

The school context and teachers' pedagogical reasoning were found to have notable impact on teachers' development of TPACK. We found that contextual constraints such as availability of technology tools and characteristics of student population had large impacts on the teachers' development of TPACK, as previously suggested by Koehler and Mishra (2005, 2008) and McCrory (2008). Furthermore, detailed analysis revealed that teachers' development of TPACK was closely related to their pedagogical reasoning (Shulman, 1987). It was found that teachers' pedagogical reasoning skills influence teachers' use of knowledge bases that are necessary to develop TPACK. Thus, it is possible that a relationship exists between teachers' development of TPACK and their pedagogical reasoning skills.

School Context. Jason, Matt, and Brenna all had access to technology tools in their schools, and their school community encouraged them to teach with technology. This continuous support from the school community allowed these teachers to reform their practices. As emphasized earlier, in TEC, university educators and participating teachers build a learning community to support teachers to integrate technology into their teaching. However, as previous research suggested, communities are not quickly formed (Grossman et al., 2001). Not all teachers are equally interested in entering the community, as in the case of Cassie.

At the end of the program, Cassie was not comfortable with using many of the technology tools in her science classroom. Even though she learned about these tools in her teacher education program and TEC, Cassie still wanted to have more time and training to learn to use technology tools. Perhaps issues related with Cassie's school environment also impacted her decision to keep teaching without using any technology tools. Her ESL students had almost no background with science or technology. Cassie mostly focused on finding ways to help these students learn about science, but she did not put effort into implementing inquiry activities and finding technology tools to incorporate that may have fostered her students' learning of science. However, many research studies have shown the effectiveness of using inquiry as well as technology tools with ESL students (Mistler-Jackson & Songer, 2000).

Teachers' Pedagogical Reasoning. Similar to previous studies (Shulman, 1987), it was found that teachers' pedagogical reasoning mirrored their pedagogical actions. Teachers' reasons for their decisions about classroom instruction closely related to their conceptions of science, effective science teaching and instructional strategies, purposes of science teaching, and student understanding. For example, Matt said that technology scaffolds students' learning of science, and students can learn science best when they are actively engaged in science. Matt was found to transform his ideas into his teaching. He decided to use instructional strategies such as inquiry-based teaching, representations such as concept mapping tools, and simulations after participating TEC. Based on his students' characteristics, he adapted many of the strategies he learned in the program. During his instruction, he clearly expressed his expectations to his students. He wanted all his students to be active learners. In some of the lessons, however, students did not show the interest Matt expected. Thus, he decided to use different classroom management strategies in the next teaching year. This process of reflection was a part of his pedagogical reasoning and guided his classroom practices.

In TEC, teachers were encouraged to be reflective about their teaching. The classroom and online discussions helped teachers restructure their ideas about effective science teaching. Teachers found opportunities to analyze their pedagogical reasons behind their actions. Jason, Matt, and Brenna thought about how they teach and how they wanted to

teach in the future. They reflected on their practices and then reformed their practices. Thus, it seems that the development of TPACK closely related to teachers' pedagogical reasoning and TEC encouraged teachers critically to analyze their pedagogical reasoning and pedagogical actions.

Implications

The findings of this study provide suggestions for designers of professional development programs that aim to improve science teachers' development of TPACK. Well-developed programs that provide opportunities for participating teachers to build and sustain "learning communities" seem to have positive impacts on science teachers' technology integration. Continuous support is necessary to help teachers overcome the constraints in incorporating technology. With models such as Loucks-Horsley et al., (2003) and Bell and Gilbert's (2004), which focus on collaboration among teachers, effective professional development programs can be designed for science teachers to reform their practices. It is important to note that in the summer course we were limited in our ability to address certain aspects of TPACK (content knowledge) and broader, related issues such as school context. The follow-up activities and action research were critical in addressing and developing individual teachers' classroom practices. In particular, it was found to be necessary to provide teachers follow-up assistance during the time when they were designing and implementing their technology-enriched lessons and action research projects.

The findings of this study also suggest that teachers should reflect on their classroom practices in order to incorporate technology and inquiry into their teaching more effectively. Conducting action research projects and keeping reflective blogs (or journals) in which teachers analyze their experiences and reflect on their practices allowed them to see the effectiveness of technology on students' learning and to reflect on and modify their practices. As emphasized by other researchers, reflective practice can help teachers improve their knowledge of pedagogy and knowledge of students (Cochran-Smith & Lytle, 1993). Thus, professional development programs focusing on technology integration should provide teachers opportunities to reflect on their teaching and share their experiences both with professional development leaders and their peers.

Further Research

Based on the results of this study it is evident that further research needs to be conducted in some areas. Regarding science teachers' development of TPACK, it is clear that more data needs to be collected from experienced science teachers who have already incorporated technology into their teaching. Experienced science teachers with well-developed TPACK may help us to gain a better understanding of the nature and development of TPACK. In addition, the comparison studies between beginning and experienced science teachers' TPACK may allow us to create better teacher education and professional development programs that focus on improving teachers' TPACK.

In this study, participating teachers were followed for one year. Technology integration takes time and requires commitment. Thus, there is a need to conduct long-term research studies to track teachers' development for a long period of time. In addition, at the end of the program, the university researchers and the participating teachers decided to sustain the learning community that they built during the program. Further research is needed to find the effects of participating in a learning community during and after the professional development program in teachers' development of TPACK.

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