Technological Pedagogical Content Knowledge: A Framework for Teacher Knowledge

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Research in the area of educational technology has often been critiqued for a lack of theoretical grounding. In this article we propose a conceptual framework for educational technology by building on Shulman's formulation of "pedagogical content knowledge" and extend it to the phenomenon of teachers integrating technology into their pedagogy. This framework is the result of 5 years of work on a program of research focused on teacher professional development and faculty development in higher education. It attempts to capture some of the essential qualities of teacher knowledge required for technology integration in teaching, while addressing the complex, multifaceted, and situated nature of this knowledge. We argue, briefly, that thoughtful pedagogical uses of technology require the development of a complex, situated form of knowledge that we call Technological Pedagogical Content Knowledge (TPCK). In doing so, we posit the complex roles of, and interplay among, three main components of learning environments: content, pedagogy, and technology. We argue that this model has much to offer to discussions of technology integration at multiple levels: theoretical, pedagogical, and methodological. In this article, we describe the theory behind our framework, provide examples of our teaching approach based upon the framework, and illustrate the methodological contributions that have resulted from this work.

> The important thing in science is not so much to obtain new facts as to discover new ways of thinking about them.
>
> —Sir William Henry Bragg

The advent of digital technology has dramatically changed routines and practices in most arenas of human work. Advocates of technology in education often envisage similar dramatic changes in the process of teaching

Teachers College Record Volume 108, Number 6, June 2006, pp. 1017–1054

0161-4681

and learning. It has become clear, however, that in education the reality has lagged far behind the vision. Why?

Part of the problem, we argue, has been a tendency to only look at the technology and not how it is used. Merely introducing technology to the educational process is not enough. The question of *what* teachers need to know in order to appropriately incorporate technology into their teaching has received a great deal of attention recently (International Society for Technology in Education, 2000; National Council for Accreditation of Teacher Education, 1997; U.S. Congress Office of Technology Assessment, 1995; U.S. Department of Education, 2000; Zhao, 2003). It has become clear, however, that our primary focus should be on studying *how* the technology is used (Carr, Jonassen, Litzinger, & Marra, 1998; Mishra & Koehler, 2003).

Some of this oversight can be attributed to the lack of theoretical grounding for developing or understanding this process of integration (American Association for the Advancement of Science, 1999, 2001; Issroff & Scanlon, 2002; Selfe, 1990). Most educational technology research consists of case studies, examples of best practices, or implementations of new pedagogical tools. Of course, good case studies, detailed examples of best practices, and the design of new tools for learning are important for building understanding. But they are just the first steps toward the development of unified theoretical and conceptual frameworks that would allow us to develop and identify themes and constructs that would apply across diverse cases and examples of practice. As Selfe argued,

> [An] atheoretical perspective . . . not only constrains our current educational uses of computers, but also seriously limits our vision of what might be accomplished with computer technology in a broader social, cultural, or educational context. Until we examine the impact of computer technology . . . from a theoretical perspective, we will continue, myopically and unsystematically, to define the isolated pieces of the puzzle in our separate classrooms and discrete research studies. Until we share some theoretical vision of this topic, we will never glimpse the larger picture that could give our everyday classroom efforts direction and meaning. (p. 119)

Developing theory for educational technology is difficult because it requires a detailed understanding of complex relationships that are contextually bound. Moreover, it is difficult to study cause and effect when teachers, classrooms, politics, and curriculum goals vary from case to case. One approach, called *design experiments*, honors this complexity and has recently gained prominence in educational research (Brown, 1992; Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003; Design-Based Research

Collective, 2003). Design experiments, as a research methodology, emphasize the detailed implementation and study of interventions with evolving pedagogical goals in rich authentic settings. It acknowledges the complexities of classroom teaching and enlightens both practitioners and researchers by leading to the development of theoretical ideas grounded in contexts of practice; design experiments narrow the gap between research and practice, between theory and application.

Over the past 5 years, we have been involved in conducting a design experiment aimed at helping us understand teachers' development toward rich uses of technology while simultaneously helping teachers—both K–12 teachers and university faculty—develop their teaching with technology. This work has informed theory and practice and has been represented through a range of publications. Our work has been aimed at theoreticians and researchers, as well as practitioners and educators. We have published this work in the name of theory (Ferdig, Mishra, & Zhao, 2004; Mishra, Koehler, & Zhao, in press; Mishra, Zhao, & Tan, 1999), empirical research (Koehler & Mishra, 2005; Koehler, Mishra, Hershey, & Peruski, 2004; Koehler, Mishra, & Yahya, in press; Koehler, Mishra, Yahya, & Yadav, 2004; Vyas & Mishra, 2002) and practical applications (Koehler & Mishra, 2002; Mishra, 2005; Mishra, Hershey, & Cavanaugh, in press; Wong, Mishra, Koehler, & Siebenthal, in press).

In this article we step back from the individually published pieces to offer a bird's-eye view of the conceptual framework that has emerged from this body of work. This is precisely one of the main goals of conducting design experiments: to not only use theory to provide a rationale for the intervention or to interpret findings but also to help "develop a class of theories about both the process of learning and the means that are designed to support learning" (Cobb et al., 2003). Having a framework goes beyond merely identifying problems with current approaches; it offers new ways of looking at and perceiving phenomena and offers information on which to base sound, pragmatic decision making.

In this particular context, the implications of developing a framework go beyond a coherent way of thinking about technology integration. We argue that a conceptually based theoretical framework about the relationship between technology and teaching can transform the conceptualization and the practice of teacher education, teacher training, and teachers' professional development. It can also have a significant impact on the kinds of research questions that we explore.

In the sections that follow, we will address these related issues in the following order: (1) We introduce the technological pedagogical content knowledge (TPCK) framework for thinking about teacher knowledge and how it informs the debate on what teachers need to know (and how they might develop it); (2) we show how our pedagogical approach to teachers' professional development, *learning technology by design*, leads to the development of TPCK; and (3) we discuss, and provide examples of, how this framework has guided our research and analysis of the effectiveness of our pedagogical approach. An additional goal of this article is to offer an example of a research program that brings together the pragmatic and the theoretical, the practical and the abstract. We hope to show that the power of this multifaceted program lies in the combining of these different approaches and in its ability to speak to researchers and practitioners alike.[2]

A FRAMEWORK FOR TEACHER KNOWLEDGE FOR TECHNOLOGY INTEGRATION

The basis of our framework is the understanding that teaching is a highly complex activity that draws on many kinds of knowledge. Teaching is a complex cognitive skill occurring in an ill-structured, dynamic environment (Leinhardt & Greeno, 1986; Spiro, Coulson, Feltovich, & Anderson, 1988; Spiro, Feltovich, Jacobson, & Coulson, 1991). Like expertise in other complex domains, including medical diagnosis (Lesgold, Feltovich, Glaser, & Wang, 1981; Pople, 1982), chess (Chase & Simon, 1973; Wilkins, 1980), and writing (Hayes & Flower, 1980; Hillocks, 1986), expertise in teaching is dependent on flexible access to highly organized systems of knowledge (Glaser, 1984; Putnam & Borko, 2000; Shulman, 1986, 1987). There are clearly many knowledge systems that are fundamental to teaching, including knowledge of student thinking and learning, and knowledge of subject matter.

Historically, knowledge bases of teacher education have focused on the content knowledge of the teacher (Shulman, 1986; Veal & MaKinster, 1999). More recently, teacher education has shifted its focus primarily to pedagogy, emphasizing general pedagogical classroom practices independent of subject matter and often at the expense of content knowledge (Ball & McDiarmid, 1990). We can represent this bifurcated way of looking at teacher knowledge as two circles independent of each other (Figure 1). For

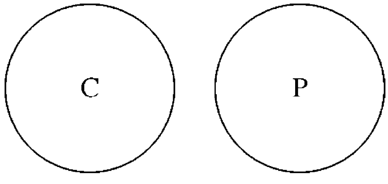

Figure 1. The Two Circles Representing Pedagogical and Content Knowledge.

instance, different approaches toward teacher education have emphasized one or the other domain of knowledge, focusing on knowledge of content (C) or knowledge of pedagogy (P). Shulman (1986) advanced thinking about teacher knowledge by introducing the idea of pedagogical content knowledge (PCK). He claimed that the emphases on teachers' subject knowledge and pedagogy were being treated as mutually exclusive domains in research concerned with these domains (Shulman, 1987). The practical consequence of such exclusion was production of teacher education programs in which a focus on either subject matter or pedagogy dominated. To address this dichotomy, he proposed considering the necessary relationship between the two by introducing the notion of PCK.

PCK exists at the intersection of content and pedagogy. Thus, it goes beyond a simple consideration of content and pedagogy in isolation from one another. PCK represents the blending of content and pedagogy into an understanding of how particular aspects of subject matter are organized, adapted, and represented for instruction. Shulman (1986) argued that having knowledge of subject matter and general pedagogical strategies, though necessary, was not sufficient for capturing the knowledge of good teachers. To characterize the complex ways in which teachers think about how particular content should be taught, he argued for "pedagogical content knowledge" as the content knowledge that deals with the teaching process, including "the ways of representing and formulating the subject that make it comprehensible to others" (p. 9). For teachers to be successful, they would have to confront both issues (content and pedagogy) simultaneously by embodying "the aspects of content most germane to its teachability" (p. 9). At the heart of PCK is the manner in which subject matter is transformed for teaching. This occurs when the teacher interprets the subject matter and finds different ways to represent it and make it accessible to learners.

The notion of PCK has been extended and critiqued by scholars after Shulman (for instance, see Cochran, King, & DeRuiter, 1993; van Driel, Verloop, & De Vos, 1998). In fact, Shulman's (1986) initial description of teacher knowledge included many more categories, such as curriculum knowledge and knowledge of educational contexts. Matters are further complicated by the fact that Shulman has himself proposed multiple lists, in different publications, that lack, in his own words, "great cross-article consistency" (p. 8). Our emphasis on PCK is based on Shulman's acknowledgement that

> pedagogical content knowledge is of special interest because it identifies the distinctive bodies of knowledge for teaching. It represents the blending of content and pedagogy into an understanding of how particular topics, problems, or issues are organized, represented, and

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

Our emphasis on PCK is consistent with the work of many other scholars and recent educational reform documents. Since its introduction in 1987, PCK has become a widely useful and used notion. For instance, in the area of science education, scholars such as Anderson and Mitchner (1994); Hewson and Hewson (1988); Cochran, King, and DeRuiter (1993); and professional organizations such as the National Science Teachers Association (NSTA, 1999) and National Council for the Accreditation of Teacher Education (NCATE, 1997) have all emphasized the value of PCK for teacher preparation and teacher professional development. An analysis of *Teacher Educator's Handbook* (Murray, 1996) shows Shulman as the fourth most cited author of the close to 1,500 authors in the book's author index, with an overwhelming majority of those references made to this concept of PCK (Segall, 2004). The notion of PCK since its introduction in 1987 has permeated the scholarship that deals with teacher education and the subject matter of education (see, for example, Ball, 1996; Cochran, King, & DeRuiter, 1993; Grossman, 1990; Ma, 1999; Shulman, 1987; Wilson, Shulman, & Richert, 1987). It is valued as an epistemological concept that usefully blends the traditionally separated knowledge bases of content and pedagogy.

We can represent Shulman's contribution to the scholarship of teacher knowledge diagrammatically by connecting the two circles of Figure 1 so that their intersection represents PCK as the interplay between pedagogy and content (see Figure 2). In Shulman's (1986) words, this intersection contains within it "the most regularly taught topics in one's subject area, the most useful forms of representation of those ideas, the most powerful analogies, illustrations, examples, explanations, and demonstrations—in a

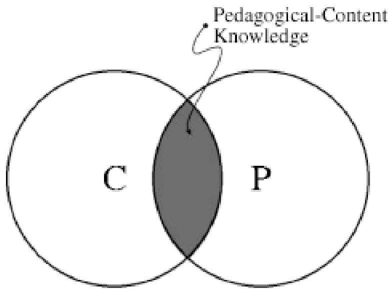

Figure 2. The Two Circles of Pedagogical Knowledge and Content Knowledge Are Now Joined by Pedagogical Content Knowledge.

word, the ways of representing and formulating the subject that make it comprehensible to others" (p. 9).

Although Shulman did not discuss technology and its relationship to pedagogy and content, we do not believe that these issues were considered unimportant. When Shulman first made his argument, issues surrounding technologies weren't foregrounded to the extent that they are today. Traditional classrooms use a variety of technologies, from textbooks to overhead projectors, from typewriters in English language classrooms to charts of the periodic table on the walls of laboratories. However, until recently, most technologies used in classrooms had been rendered "transparent" (Bruce & Hogan, 1998), or in other words, they had become commonplace and were not even regarded as technologies. In contrast, the more common usage of *technology* refers to digital computers and computer software, artifacts and mechanisms that are new and not yet a part of the mainstream. Thus, though Shulman's approach still holds true, what has changed since the 1980s is that technologies have come to the forefront of educational discourse primarily because of the availability of a range of new, primarily digital, technologies and requirements for learning how to apply them to teaching. These new technologies incorporate hardware and software such as computers, educational games, and the Internet and the myriad applications supported by it.

These new technologies have changed the nature of the classroom or have the potential to do so. Consider the aspects or examples that Shulman provided as being important to PCK, such as "the most powerful analogies, illustrations, examples, explanations and demonstrations," or, in other words, "the ways of representing and formulating subject" to make it more accessible and comprehensible. Clearly, technologies play a critical role in each of these aspects. Ranging from drawings on a blackboard or interactive multimedia simulations to etchings on a clay tablet or Web-based hypertexts to the pump metaphor of the heart or the computer metaphor of the brain, technologies have constrained and afforded a range of representations, analogies, examples, explanations, and demonstrations that can help make subject matter more accessible to the learner.

Though not all teachers have embraced these new technologies for a range of reasons—including a fear of change and lack of time and support—the fact that these technologies are here to stay cannot be doubted. Moreover, the rapid rate of evolution of these new digital technologies prevents them from becoming "transparent" any time soon. Teachers will have to do more than simply learn to use currently available tools; they also will have to learn new techniques and skills as current technologies become obsolete. This is a very different context from earlier conceptualizations of teacher knowledge, in which technologies were standardized and relatively stable. The use of technology for pedagogy of specific subject matter could be expected to remain relatively static over time. Thus, teachers could focus on the variables related to content and pedagogy and be assured that technological contexts would not change too dramatically over their career as a teacher. This new context has foregrounded technology in ways that could not have been imagined a few years ago. Thus, knowledge of technology becomes an important aspect of overall teacher knowledge.

What is interesting is that current discussions of the role of technology knowledge seem to share many of the same problems that Shulman identified back in the 1980s. For instance, prior to Shulman's seminal work on PCK, knowledge of content and knowledge of pedagogy were considered separate and independent from each other. Similarly, today, knowledge of technology is often considered to be separate from knowledge of pedagogy and content. This approach can be represented as three circles, two of which (content and pedagogy) overlap as described by Shulman, and one circle (technology) stands isolated from these two.

Figure 3 represents the knowledge structures that underlie much of the current discourse on educational technology. That is, technology is viewed as constituting a separate set of knowledge and skills that has to be learned, and the relationship between these skills and the tried and true basis of teaching (content and pedagogy) is nonexistent or considered to be

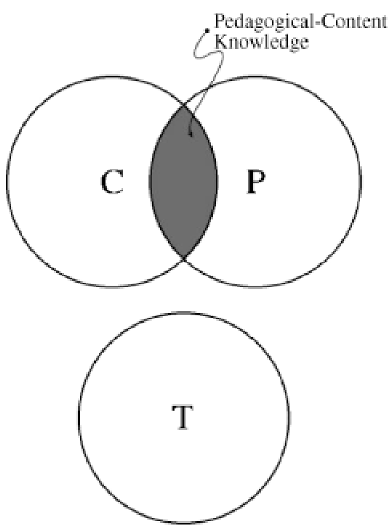

Figure 3. The Three Circles Represent Pedagogy, Content, and Technology Knowledge. Content and Pedagogy Overlap to Form Pedagogical Content Knowledge While Technology Is Seen as Being a Separate and Independent Knowledge Domain.

relatively trivial to acquire and implement. The design and implementation of workshops or teacher training programs that promote the learning of specific hardware and software skills as being sufficient to round out teachers' knowledge bases for teaching with technology are direct consequences of this perspective.

However, the relationships between content (the actual subject matter that is to be learned and taught), pedagogy (the process and practice or methods of teaching and learning), and technology (both commonplace, like chalkboards, and advanced, such as digital computers) are complex and nuanced. Technologies often come with their own imperatives that constrain the content that has to be covered and the nature of possible representations. These decisions have a ripple effect by defining, or in other ways, constraining, instructional moves and other pedagogical decisions. So it may be inappropriate to see knowledge of technology as being isolated from knowledge of pedagogy and content.

In contrast to the simple view of technology (Figure 3), our framework (Figure 4) emphasizes the connections, interactions, affordances, and constraints between and among content, pedagogy, and technology. In this model, knowledge about content (C), pedagogy (P), and technology (T) is central for developing good teaching. However, rather than treating these as separate bodies of knowledge, this model additionally emphasizes the complex interplay of these three bodies of knowledge.

We do not argue that this TPCK approach is completely new. Other scholars have argued that knowledge about technology cannot be treated as

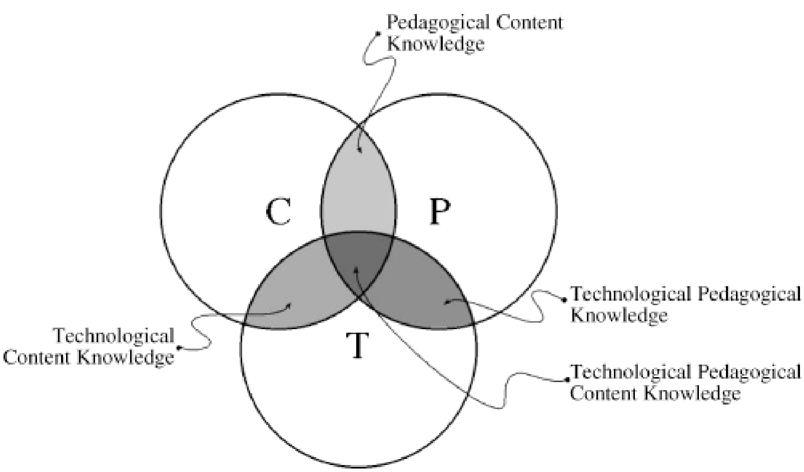

Figure 4. Pedagogical Technological Content Knowledge. The Three Circles, Content, Pedagogy, and Technology, Overlap to Lead to Four More Kinds of Interrelated Knowledge.

context-free and that good teaching requires an understanding of how technology relates to the pedagogy and content (Hughes, 2005; Keating & Evans, 2001; Lundeberg, Bergland, Klyczek, & Hoffman, 2003; Margerum-Leys & Marx, 2002; Neiss, 2005; Zhao, 2003).

What sets our approach apart is the specificity of our articulation of these relationships between content, pedagogy, and technology. In practical terms, this means that apart from looking at each of these components in isolation, we also need to look at them in pairs: pedagogical content knowledge (PCK), technological content knowledge (TCK), technological pedagogical knowledge (TPK), and all three taken together as technological pedagogical content knowledge (TPCK). This is similar to the move made by Shulman, in which he considered the relationship between content and pedagogy and labeled it pedagogical content knowledge. In our case, a similar consideration leads us to three pairs of knowledge intersection and one triad. One of the pairs, pedagogical content knowledge, was introduced and articulated by Shulman, but we introduce two new pairs and one new triad.

Thus, the following elements and relationship are important in the framework we propose.

CONTENT KNOWLEDGE

Content knowledge (CK) is knowledge about the actual subject matter that is to be learned or taught. The content to be covered in high school social studies or algebra is very different from the content to be covered in a graduate course on computer science or art history. Clearly, teachers must know and understand the subjects that they teach, including knowledge of central facts, concepts, theories, and procedures within a given field; knowledge of explanatory frameworks that organize and connect ideas; and knowledge of the rules of evidence and proof (Shulman, 1986). Teachers must also understand the nature of knowledge and inquiry in different fields. For example, how is a proof in mathematics different from a historical explanation or a literary interpretation? Teachers who do not have these understandings can misrepresent those subjects to their students (Ball & McDiarmid, 1990).

PEDAGOGICAL KNOWLEDGE

Pedagogical knowledge (PK) is deep knowledge about the processes and practices or methods of teaching and learning and how it encompasses, among other things, overall educational purposes, values, and aims. This is a generic form of knowledge that is involved in all issues of student learning, classroom management, lesson plan development and implementation, and student evaluation. It includes knowledge about techniques or methods to be used in the classroom; the nature of the target audience; and strategies for evaluating student understanding. A teacher with deep pedagogical knowledge understands how students construct knowledge, acquire skills, and develop habits of mind and positive dispositions toward learning. As such, pedagogical knowledge requires an understanding of cognitive, social, and developmental theories of learning and how they apply to students in their classroom.

PEDAGOGICAL CONTENT KNOWLEDGE

The idea of pedagogical content knowledge is consistent with, and similar to, Shulman's idea of knowledge of pedagogy that is applicable to the teaching of specific content. This knowledge includes knowing what teaching approaches fit the content, and likewise, knowing how elements of the content can be arranged for better teaching. This knowledge is different from the knowledge of a disciplinary expert and also from the general pedagogical knowledge shared by teachers across disciplines. PCK is concerned with the representation and formulation of concepts, pedagogical techniques, knowledge of what makes concepts difficult or easy to learn, knowledge of students' prior knowledge, and theories of epistemology. It also involves knowledge of teaching strategies that incorporate appropriate conceptual representations in order to address learner difficulties and misconceptions and foster meaningful understanding. It also includes knowledge of what the students bring to the learning situation, knowledge that might be either facilitative or dysfunctional for the particular learning task at hand. This knowledge of students includes their strategies, prior conceptions (both "naïve" and instructionally produced), misconceptions that they are likely to have about a particular domain, and potential misapplications of prior knowledge.

TECHNOLOGY KNOWLEDGE

Technology knowledge (TK) is knowledge about standard technologies, such as books, chalk and blackboard, and more advanced technologies, such as the Internet and digital video. This involves the skills required to operate particular technologies. In the case of digital technologies, this includes knowledge of operating systems and computer hardware, and the ability to use standard sets of software tools such as word processors, spreadsheets, browsers, and e-mail. TK includes knowledge of how to install and remove peripheral devices, install and remove software programs, and create and archive documents. Most standard technology workshops and tutorials tend to focus on the acquisition of such skills. Since technology is continually changing, the nature of TK needs to shift with time as well. For instance, many of the examples given above (operating systems, word processors, browsers, etc.) will surely change, and maybe even disappear, in the years to come. The ability to learn and adapt to new technologies (irrespective of what the specific technologies are) will still be important.

TECHNOLOGICAL CONTENT KNOWLEDGE

Technological content knowledge (TCK) is knowledge about the manner in which technology and content are reciprocally related. Although technology constrains the kinds of representations possible, newer technologies often afford newer and more varied representations and greater flexibility in navigating across these representations. Teachers need to know not just the subject matter they teach but also the manner in which the subject matter can be changed by the application of technology. For example, consider Geometer's Sketchpad as a tool for teaching geometry. It allows students to play with shapes and form, making it easier to construct standard geometry proofs. In this regard, the software program merely emulates what was done earlier when learning geometry. However, the computer program does more than that. By allowing students to "play" with geometrical constructions, it also changes the nature of learning geometry itself; proofs by construction are a form of representation in mathematics that was not available prior to this technology. Similar arguments can be made for a range of other software products.

TECHNOLOGICAL PEDAGOGICAL KNOWLEDGE

Technological pedagogical knowledge (TPK) is knowledge of the existence, components, and capabilities of various technologies as they are used in teaching and learning settings, and conversely, knowing how teaching might change as the result of using particular technologies. This might include an understanding that a range of tools exists for a particular task, the ability to choose a tool based on its fitness, strategies for using the tool's affordances, and knowledge of pedagogical strategies and the ability to apply those strategies for use of technologies. This includes knowledge of tools for maintaining class records, attendance, and grading, and knowledge of generic technology-based ideas such as WebQuests, discussion boards, and chat rooms.

TECHNOLOGICAL PEDAGOGICAL CONTENT KNOWLEDGE

Technological pedagogical content knowledge (TPCK) is an emergent form of knowledge that goes beyond all three components (content, pedagogy, and technology). This knowledge is different from knowledge of a disciplinary or technology expert and also from the general pedagogical knowledge shared by teachers across disciplines. TPCK is the basis of good 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 the 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.

Describing PCK, Marks (1990) said that it "represents a class of knowledge that is central to teachers' work and that would not typically be held by non-teaching subject matter experts or by teachers who know little of that subject" (1990, p. 9). In the case of TPCK, we can paraphrase his quote to read, "TPCK represents a class of knowledge that is central to teachers' work with technology. This knowledge would not typically be held by technologically proficient subject matter experts, or by technologists who know little of the subject or of pedagogy, or by teachers who know little of that subject or about technology."

Thus, our model of technology integration in teaching and learning argues that developing good content requires a thoughtful interweaving of all three key sources of knowledge: technology, pedagogy, and content. The core of our argument is that there is no single technological solution that applies for every teacher, every course, or every view of teaching. Quality teaching requires developing a nuanced understanding of the complex relationships between technology, content, and pedagogy, and using this understanding to develop appropriate, context-specific strategies and representations. Productive technology integration in teaching needs to consider all three issues not in isolation, but rather within the complex relationships in the system defined by the three key elements.

Clearly, separating the three components (content, pedagogy, and technology) in our model is an analytic act and one that is difficult to tease out in practice. In actuality, these components exist in a state of dynamic equilibrium or, as the philosopher Kuhn (1977) said in a different context, in a state of "essential tension." The traditional view of the relationship between the three aspects argues that content drives most decisions; the pedagogical goals and technologies to be used follow from a choice of what to teach. However, things are rarely that clear cut, particularly when newer technologies are considered. The introduction of the Internet can be seen as an example of a technology whose arrival forced educators to think about core pedagogical issues (Peruski & Mishra, 2004; Wallace, 2004). So, in this context, it is the technology that drives the kinds of decisions that we make about content and pedagogy.

Viewing any of these components in isolation from the others represents a real disservice to good teaching. Teaching and learning with technology exist in a dynamic transactional relationship (Bruce, 1997; Dewey & Bentley, 1949; Rosenblatt, 1978) between the three components in our framework; a change in any one of the factors has to be "compensated" by changes in the other two. For example, teaching chemistry (the content) would drive the kinds of representations to be used (symbolic representations such as equations, or visual representations such as molecular diagrams—that is, the pedagogy) and the technologies used to display and manipulate them. In this example, suitable technologies include special plug-ins, such as CHIME, that allow students to dynamically view and manipulate molecular representations. If, on the other hand, the technology currently available would not support the writing of equations or representations, it would force an online instructor to develop other ways to represent content and thus impact pedagogy. Similarly, if the course content is about learning simple facts about the properties of each of the periodic chemical elements, then some pedagogical representations (e.g., essays) are not as attractive. Likewise, a course about film might require certain technological tools, like digital video. These interactions go both ways; deciding on a particular technological tool will offer constraints on the representations that can be developed and the course content that can be covered and delivered, which in turn affects the pedagogical process as well.

The incorporation of a new technology or new medium for teaching suddenly forces us to confront basic educational issues because this new technology or medium reconstructs the dynamic equilibrium among all three elements. For instance, consider faculty members developing online courses for the first time. The relative newness of the online technologies forces these faculty members to deal with all three factors, and the relationships between them, often leading them to ask questions of their pedagogy, something that they may not have done in a long time (Peruski & Mishra, 2004). The addition of a new technology is not the same as adding another module to a course. It often raises fundamental questions about content and pedagogy that can overwhelm even experienced instructors.

Thus, TPCK is a form of knowledge that expert teachers bring to play anytime they teach. Sometimes this may not be obvious, particularly in cases in which standard (transparent) technologies are being used. But newer technologies often disrupt the status quo, requiring teachers to reconfigure not just their understanding of technology but of all three components.

In the remainder of this article, we address some potential consequences of the TPCK framework for practicing teachers, teacher educators, and educational researchers. In particular, we focus our attention on how TPCK may be developed and how this development may be studied. We argue that a serious consideration of this framework suggests a possible restructuring of professional development experiences for teachers so that they might develop the kind of nuanced understandings called for in our TPCK framework. Our approach to professional development in light of this framework, learning technology by design, is the emphasis of the following section.

APPLYING THE TPCK FRAMEWORK TO PEDAGOGY

How are teachers to acquire an understanding of the complex relationships among content, pedagogy, and technology? The standard approach suggests that teachers simply need to be trained to use technology. Underlying this approach is a view of technology that sees it as being a universally applicable skill; unlocking the power and potential of technology can be achieved by acquiring basic competency with hardware and software packages. This approach is best exemplified by the plethora of state and national technology standards that have been implemented recently and that emphasize enhancing teachers' knowledge of current versions of hardware and software (CEO Forum on Education and Technology, 2000; Handler & Strudler, 1997; Hirumi & Grau, 1996; National Council for Accreditation of Teacher Education, 1997; U.S. Congress Office of Technology Assessment, 1995; U.S. Department of Education, 2003; Wiebe & Taylor, 1997; Zhao & Conway, 2001). The leap of faith, however, is that by demonstrating their proficiency with current software and hardware, teachers will be able to successfully incorporate technology into their classrooms. Lankshear (1997) described this emphasis as a form of applied technocratic rationality—a view that technology is self-contained and has an independent integrity, and that to unlock its potential and power requires merely learning certain basic skills.

As a consequence of these initiatives by policy makers, teacher educators, and technology enthusiasts, we see a wide range of workshops and teacher education courses about general software tools that have application across content and pedagogical contexts. This content-neutral emphasis on generic software tools assumes that knowing a technology automatically leads to good teaching with technology. Standard techniques of teacher professional development or faculty development, such as workshops or standalone technology courses, are based on the view that technology is self-contained and emphasize this divide between how and where skills are learned (e.g., workshops) and where they are to be applied (e.g., classrooms). This is somewhat akin to the kind of knowledge representation portrayed in Figure 3.

Most scholars working in this area agree that traditional methods of technology training for teachers—mainly workshops and courses—are ill suited to produce the "deep understanding" that can assist teachers in becoming intelligent users of technology for pedagogy (Brand, 1997; Milken Exchange on Education Technology, 1999; U.S. Department of Education, 1999). As we have argued (Koehler & Mishra, 2005; Mishra & Koehler, 2003; Mishra, Koehler, & Zhao, in press; Zhao, 2003), this emphasis on competencies and checklists of things that teachers need to know is inherently problematic for a range of reasons.

The rapid rate of technology change. Training teachers to use specific software packages not only makes their knowledge too specific to be applied broadly, but it also becomes quickly outdated. Technology is changing so fast that any method that attempts to keep teachers up to date on the latest software, hardware, and terminology is doomed to create knowledge that is out of date every couple of years.

Inappropriate design of software. Most software tools available today are designed for the world of business and work, not education. As Zhao (2003) argued, most software tools are rarely created as solutions to pedagogical problems. More often than not, they are created as potential solutions to problems in the world of business as anticipated by programmers and other developers. Converting these general tools for classroom teaching is neither trivial nor obvious. It requires the teacher to engage with the affordances and constraints of particular technologies in order to creatively repurpose these technologies to meet specific pedagogical goals of specific content areas. An emphasis on merely learning the technology may lead to an emphasis on students learning technology (technology as the subject and content of learning) rather than the subject matter that they are supposed to learn.

The situated nature of learning. Context-neutral approaches to technology integration encourage generic solutions to the problem of teaching. However, technology use in the classroom is context bound and is, or at least needs to be, dependent on subject matter, grade level, student background, and the kinds of computers and software programs available. Our argument is not that such generic uses are never useful. However, despite valuable generic uses of technology (such as grade books), such approaches do not avail the full potential of technology for teaching specific subject matter. Finally, such generic solutions do not value the individual teacher—their experience, teaching style, and philosophy—by assuming that all teachers teach the same way and hence would use technology the same way.

An emphasis on what, not how. Standard checklists of technology skills are very efficient means of listing what teachers need to know, but offer little suggestion on how teachers are to achieve these skills. This often leads to the development of technology learning situations that adhere to the letter of the standards but go against the spirit of true technology integration. For example, workshops to teach specific hardware or software packages, we argue, lead to the accumulation of inert facts (Whitehead, 1953), as opposed to knowledge integration or application. Teachers have often been asked to learn to apply these skills in their own classrooms by themselves (Kent & McNergney, 1999), usually through trial and error. Though part of the problem is shortage of resources (time and money), we believe that there are deeper and more intractable issues related to values, goals, and methods that need to be addressed if we are to develop appropriate and useful ways for teachers to integrate technology in their classrooms.

In terms of the TPCK framework that we have proposed, context-neutral approaches are likely to fail because they overemphasize technology skills (the "T" in the model) without developing pedagogical technology knowledge, technological content knowledge, or technological pedagogical content knowledge. In other words, merely knowing how to use technology is not the same as knowing how to teach with it. A survey by the Milken Family Foundation and the International Society for Technology (ISTE) found that teacher training programs in general do not provide future teachers with the kinds of experiences necessary to prepare them to use technology effectively in their classrooms (Milken Exchange on Education Technology, 1999). Specifically, they found that formal standalone IT coursework does not correlate well with technology skills and the ability to integrate technology into teaching. They recommended that teacher preparation programs increase the level of technology integration in their own academic programs.

More recent standards, such as those of the International Society for Technology (ISTE) and the National Council for Accreditation of Teacher Education (NCATE, 1997, revised in 2001), have moved away from an emphasis on just basic skills and have enumerated a series of higher order goals that are essential for effective pedagogy with technology (Glenn, 2002a, 2002b; Handler & Strudler, 1997; Wise, 2001).

The rich, complex, and situated perspective that we and others have been arguing for clearly requires the development of very different strategies for developing teachers. A review of the recent teacher education research regarding technology will show numerous examples of teacher education programs that have implemented instructional technology in ways that encourage integration (for examples see, Fulton, Glenn, & Valdez, 2003; Fulton, Glenn, Valdez, & Blomeyer, 2002; Hacker & Niederhauser, 2000; Loucks-Horsley, Hewson, Love, & Stiles, 1997; Niederhauser, Salem, & Fields, 1999; Niederhauser & Stoddart, 2001; Strudler & Wetzel, 1999). Most of these approaches have involved providing teachers and teacher candidates with experiences with real educational problems to be solved by technology. Our work on learning technology by design also capitalizes on the idea of involving teachers in authentic problem solving with technology.

LEARNING TECHNOLOGY BY DESIGN

> In theory, there is no difference between theory and practice. But, in practice, there is.
>
> —Jan L.A. van de Snepscheut

Brown and Campione (1996) have argued that successful curricula are not collections of isolated pedagogical elements, but rather should function as coherent systems. Most failed curricula try to pull together disparate sets of items, often because of a lack of a foundational framework that lays out the underlying principles of learning and knowledge construction. It is important to have a framework to guide the design of curriculum. We argue that the TPCK framework has allowed us to guide curriculum design and help us create conceptually and epistemologically coherent learning environments. We call our approach *learning technology by design*.

Our experience in developing the TPCK framework has coevolved with our effort to teach courses that develop teachers' understanding of technology. Initially, our attempts to develop master's level courses in educational technology were grounded in situated cognition theory (Brown, Collins, & Duguid, 1989), a theoretical perspective that acknowledges that knowing is an activity that is codetermined by individual–environment interactions (Gibson, 1986; Roschelle & Clancey, 1992; Young, 1993). From this perspective, "knowledge is situated, being in part a product of the activity, content, and culture in which it is developed and used" (Brown et al., p. 32). Central to situated cognition is the notion that learning is best supported when the content is part of a context that the students can perceive as meaningful, assign value to the subject matter, and develop an understanding of the relation of it with their lives (Lave, 1997).

As we developed our teaching approach, we pursued the idea that the design of educational technology represented an authentic context for teachers to learn about educational technology. Because design-based activities provide a rich context for learning and lend themselves to sustained inquiry and revision, we thought that they were well suited to help teachers develop the deep understanding needed to apply knowledge in the complex domains of real-world practice. This emphasis on design has been informed by longstanding research on the use of design for learning complex and interrelated ideas (Brown, 1992; Blumenfeld et al., 1991; Harel & Papert, 1990, 1991;

Kafai, 1996; Kolodner, 2002; Perkins, 1986). Design-based activities also make a nice bridge to many of the models of project-based learning (Blumenfeld, Marx, Soloway, & Krajcik, 1996; Blumenfeld et al., 1991; Dewey, 1934; Papert, 1991; Roth, 1995; Roup, Gal, Drayton, & Pfister, 1993).

In the learning-technology-by-design approach, emphasis is placed on learning by doing, and less so on overt lecturing and traditional teaching. Design is learned by becoming a practitioner, albeit for the duration of the course, not merely by learning about practice. Learning through design embodies a process that is present in the construction of artifacts (such as online courses, digital videos, and so on), which is often located in the interplay between theory and practice, between constraints and tradeoffs, between designer and materials, and between designer and audience. Learning technology by design affords students the opportunity to transcend the passive learner role and to take control of their learning. The move to design-based activities has implication for instructors as well. Design cannot be taught in conventional ways; design is experienced in activity, depends on recognition of design quality, entails a creative process, is understood in dialogue and action, and involves reflection in action (Mishra & Koehler, 2003; Mishra, Zhao, & Tan, 1999; Schon, 1983, 1987, 1996).

Our approach has been described in greater detail elsewhere (Koehler & Mishra, 2005; Mishra & Koehler, 2003; Mishra, Koehler, & Zhao, in press). Here we briefly summarize what we believe its strengths to be. Consistent with other research in this area (Barab & Duffy, 2000), we offer learners authentic and engaging ill-structured problems that reflect the complexity of the real world (Marx, Blumenfeld, Krajcik, & Soloway, 1997; Pea, 1993)—the design of online courses, for example. Learners have to actively engage in practices of inquiry, research, and design in collaborative groups—groups that have included higher education faculty members and graduate students with an interest in educational technology—to design tangible, meaningful artifacts as end products of the learning process (Blumenfeld et al., 1991). The actual process of design is the anchor around which the rest of the class (and learning) unfolds. This evolving artifact is also the test of the viability of individual and collective understandings, conceptions, and ideas of the project. And finally, the main role of the instructor in such an environment is that of a facilitator and problem-solving expert rather than an expert in the content. Learning in this context involves becoming a practitioner, not just learning about practice (Brown & Duguid, 1991).

EXAMPLES OF THE LEARNING-TECHNOLOGY-BY-DESIGN APPROACH

We offer three examples drawn from three different master's-level courses in an educational technology master's program that used the learning-technology-by-design approach. These three examples were drawn over three different courses spanning 2 years. Although each class had different course goals, there were a number of similarities across the examples. Most of the participants in these courses were working teachers, often with years of experience in the classroom. In each class, we divided participants into working groups that were responsible for defining, designing, and refining a solution to a problem throughout the course of the semester. In each of the courses, students were required to complete assigned readings, participate in class discussion, and complete their writing assignments, typical of master's-level coursework. All the course requirements were aimed at supporting the main activity of the class: the design and evaluation of the artifacts created by the design teams.

In these courses, there was little direct instruction about particular software programs or technology. More common were spontaneous and short tutorial sessions—both student to student and instructor to student—driven by the immediate requirements of the groups. The instructors rarely suggested or required the use of any specific technology; the emphasis on design required teachers to propose software and hardware solutions to their specific contexts and problems.

The three examples we offer below build on these sets of principles and ideas, though they do differ from each other in some respects, allowing us to see how the same ideas play out across multiple contexts. Finally, we use one of the examples as a site for explaining the development of TPCK over time.

Example 1: Making Movies

As the capstone sequence toward a master's in educational technology, the second author and a colleague taught a 9-credit educational technology sequence to 28 teachers. Their goals were to give teachers additional insight into the fields of educational psychology and educational technology, and how the two fields interact in expert practice. An additional course goal was to have teachers learn some concrete advanced technology skills. A design-based approach was used to accomplish these goals. Teachers worked in groups to make two iVideos (idea-based videos) to communicate an important educational idea (Wong et al., in press). Self-chosen topics for the videos included the role of technology in the library sciences, affective communication online, and appropriate uses of technology. Instead of learning the decontextualized skill of creating and editing digital video, the teachers had to learn the technology within the context of communicating their understanding of larger ideas that form the basis of their own practice.

Students spent most of their time in groups discussing or debating their idea, storyboarding, filming, digitizing, editing, revising, and soliciting feedback. The instructors scheduled regular times for the whole class to preview the participants' work in progress and receive feedback. Versions of their iVideos were posted to a Web site so that feedback from other master's-level courses could also serve as an impetus to change and redesign. Once the movies were complete, they were shown to an audience of approximately 80 other people involved in the summer session and were posted to the Web site so that people outside the summer school could also participate in the viewing and feedback.

The design approach often results in classrooms that look and feel quite different than traditional university offerings. This was especially true in this case. The teachers were never all in one place and spread to other rooms of the school, the hallway, outside, and any other place that they could find room to talk, film, edit, storyboard, discuss, screen, and preview video. These activities went well beyond class time, and teachers worked late into the night and through the weekends in the lab and in their dorms.

Given that there was no list of skills that teachers needed to learn, nor was their grade based on learning specific skills, the list of technologies that were learned was impressive. These included skills such as learning to operate digital cameras (still and video); using video and image editing software (iMovie, Adobe Premiere, and Adobe Photoshop); conducting Internet searches and uploading and downloading files via FTP or other means; and designing Web pages using software such as Dreamweaver or FrontPage. Apart from these specific skills, students also learned key concepts in information technology, such as Internet protocols, file formats and structure, and video compression technologies (codecs).

More important than acquiring the individual technology skills was learning about the subtleties and relationships between and among tools, actors, and contexts. Technology was learned in the context of expressing educational ideas and metaphors. Teachers learned a lot about how to focus a message in just two minutes of video, let images and symbolism convey ideas in an effective manner, inspire audiences, work together in groups, give and receive feedback, and communicate with audiences.

Example 2: Redesigning Educational Web Sites

This master's-level course offered by the first author dealt with technical, pedagogical, and social issues around design and educational uses of Web-based technologies. Most participants in this graduate class were practicing K–12 teachers who brought their rich professional knowledge of teaching and learning to this course. Participants in this class were expected not only to learn interactive Web-based technology but also to generate abstract knowledge about designing educational technology through working in groups on four different design projects. In the learning process, each member of the group was engaged in activities that compelled him or her to seriously study technology, education, the interface between the two, and the social dynamics of working with others.

Participants in this course were involved in the redesign of existing Web sites or Web resources. This emphasis on redesign was to ensure that the participants would not spend a lot of time researching the topic but instead would focus on key issues related to content, pedagogy, and technology. Sixteen teachers were divided into four groups, and each group took on a different redesign task. These included the redesign of a Web publishing course for middle school students and the redesign of a database on educational psychology theory and practice. Teachers in this class also participated in whole-class discussion, project presentations and critiques, asynchronous online discussion, journals, and final written group reflection on design process.

That the teachers were engaged in authentic design activities around educational technology compelled them to seriously study the complex relationships between technology and education. The redesign projects forced the participants to think deeply about evaluating the needs of the audience and to configure their design to meet these needs.

Participants learned about technologies as and when they needed to complete their projects. For example, individual groups learned about QuickTime VR, JavaScript, Web-based databases, and a variety of site building and image manipulation tools. They did this by studying manuals, talking to each other, talking to the instructor, and seeking out other locally available experts.

Example 3: Faculty Development and Online Course Design

Six tenured faculty members became "students" in a regular master's-level educational technology course co-taught by the authors. Project teams consisted of one faculty member and three or four master's students who worked together to design an online course to be taught by the faculty member the following year. A typical class period had a whole-group component that was used to discuss readings about the theory and practice of online teaching and issues that applied to all groups, and a small-group component in which the design teams worked on their projects (Koehler, Mishra, Hershey, & Peruski, 2004; Koehler & Mishra, 2005; Mishra & Koehler, 2003; Mishra & Koehler, in press).

In our learning-technology-by-design approach, learning about technology was made implicit; participants learned about technologies as they needed to in order to fulfill some desired feature of the course that they were designing. One design team, for instance, focused a great deal on understanding how a faculty member could provide audio feedback to his students. Another group investigated the use of PowerPoint presentations via the Web to offer overviews of the lessons to be covered. Groups also explored a range of pedagogical issues, such as developing techniques for creating a learning community online, and strategies for problem-based learning. There were also topics common to all teams, including ideas about effective Web page design and issues of copyright, intellectual property, and privacy.

The task of designing an online course was a unique opportunity for most teachers. Seeing and participating in the process of developing a graduate-level course from scratch provided the participants with a opportunity to apply their knowledge of educational theory to a real-world context and thus further their own development as future lecturers, instructors, and professors. In addition, the chance to work with tenured faculty provided novel experiences for most of the students. By working with expert educators, they were able to interact with ideas in ways that they are seldom allowed. They worked over a whole semester with these ideas and were able to influence the experts' ideas and apply them to a real problem. Most student-participants reported that this course was one of the best they had ever had in their graduate program. Working on an authentic design problem within a group led by a faculty member made the experience a unique one—one very different from most courses that the students had taken before. As one student-participant said, "This class has been one that I will never forget. From how much work building, maintaining, and revising an online course is to learning how to work in a group again, this experience has been one that has reshaped many things that I have held to or thought about teaching."

TPCK AS A FRAMEWORK FOR RESEARCH

Philosophers of science have argued that one of the most important functions played by theoretical frameworks is that they guide observation. As Chalmers (1976) said, "Precise, clearly formulated theories are a prerequisite for precise observation statements" (p. 27). In other words, observation statements cannot be made without using the language of some theory, and in turn, these theories determine what is investigated. Thus, frameworks play an important role by guiding the kinds of questions that we can ask, the nature of evidence that is to be collected, the methodologies that are appropriate for collecting this evidence, the strategies available for analyzing the data, and finally, interpretations that we make from this analysis.

How does the learning-technology-by-design approach lead to the development of TPCK? Clearly, the participants learned technology and were immersed in content and pedagogy. But it was more than that. The design team participants were also forced to appreciate that design is about finding optimal solutions, not perfect solutions, through the process of "satisficing" (Simon, 1969). Applying this knowledge is a complex task, often riddled with contradictions and tensions. Participants in the design teams have to resolve these contradictions and tensions by looking at all the components that play into their design. They have to weigh alternatives and take decisions factoring the differential effects of their choices.

For example, consider the group redesigning the astronomy Web site for fifth graders. Teaching astronomy to fifth graders requires understanding not just astronomy but also what fifth graders know, the various misconceptions they have and how these misconceptions can be fruitfully addressed and rectified, and how to involve and motivate learners at this age. These issues are a crucial aspect of PCK. Similarly, participants in the design seminars had to contend with the fact that technologies afford newer and more complex representations of content, the idea at the heart of TCK. The development of this understanding—that is, the interconnection between technology and its representational affordances and constraints—can be seen in the manner in which the online course design teams would incorporate different technologies such as PowerPoint, Flash, images, video, and HTML pages into their course Web sites. The task of design reveals that not every topic can be shoehorned into any technology and, correspondingly, any given technology is not necessarily appropriate for every topic. The design teams also needed to deal with the relationship between technology and pedagogy (TPK). For instance, the process of developing an online community of learners varies complexly with both the technology selected (synchronous versus asynchronous discussion systems) and the norms and guidelines established for online discussion.

Most important, participating in the design tasks necessitates seeing all three of these components as being interdependent parts of a larger, more complex knowledge structure (TPCK). Thus, situations that call for reasoning about interactions (e.g., between technology, pedagogy and content) are an inherent feature of the learning-technology-by-design approach.

Dewey (1938/1997) argued that every experience should prepare a person for later experiences of a deeper, more expansive quality. However, not all experiences are equally moving or transformative. The learning technology by design seminars, by integrating pedagogy, content, and technology, allow teachers to extract "the full meaning" of the experience in order to be "prepared for doing the same thing in the future" (p. 49). This is not to say that we believe that some simple learning-technology-by-design experiences fully prepare teachers. Rather, we see learning by design as the foundation for building a beginning repertoire (Feiman-Nemser, 2001) in which *repertoire* is defined as "a variety of techniques, skills, and approaches in all dimensions of education that teachers have at their fingertips" (Wasley, Hampel, & Clark, 1997, p. 45).

That participants in our design teams develop TPCK is not something that needs to be accepted at face value. Whether students develop TPCK is an empirical question and one that we have addressed in our research (Koehler & Mishra, 2005; Koehler, Mishra, Hershey, & Peruski, 2004; Koehler, Mishra, & Yahya, 2004; Koehler, Mishra, & Yahya, in press). Added to these research studies are first-person accounts by the participants of their lived experience in these seminars (see Mishra, Koehler, & Zhao, in press).

Accordingly, we have found the TPCK framework not only helpful for articulating a clear approach to teaching (learning technology by design) but also as an analytic lens for studying the development of teacher knowledge about educational technology. We present three research studies that in different ways offer insight into the manner in which TPCK develops in a learning technology by design seminar.

CASE STUDIES OF DESIGN TEAMS

In Koehler, Mishra, Hershey, and Peruski (2004), we studied design teams as they worked on developing an online course. Participants in the design team included a senior faculty member at the college and three master's students. We collected a wide range of chronological data, including progress reports, group postings, e-mail interviews with the students, in-depth interviews with the faculty members, the students' reflection papers, and versions of their evolving course Web site. These data were used to develop case studies of the design groups. Initially, all the data were reviewed to identify emerging themes and develop a narrative of the development of the online course. The process of analyzing the development of the course was iterative; the data and instantiations of the analysis were continually revisited based on feedback from other members in the group.

Analysis revealed that the scenarios enacted by each design group have common elements that play out in unique ways depending upon the course, the faculty member, and the students in the team. Common to each group were various episodes of grappling with issues of representation of content, pedagogy, and technology. Three stages characterized the progress of the design teams. In the first stage, the emphasis was on determining proper goals and roles for the participants and constructing the first draft of the course Web site. The second stage was characterized by role consolidation and a broader concern with issues of representation of course content and pedagogical strategies as possible through this new technological medium: the Web. In the final stage, toward the end of the semester, groups tended to focus on integrating different parts of their course to fit together smoothly, or work on a problem of particular interest to the group.

Although each group spent a differing amount of time in each stage, they all progressed through each stage during the course.

We tracked one faculty member, Dr. Shaker, focusing on the evolution of her thinking and the thinking of her design team. Our analysis revealed important changes in Dr. Shaker's technological literacy and her thinking about her personal relationship with technology. In accounting for these changes, we argued that the learning-by-design approach afforded rich opportunities for Dr. Shaker and her other team members to deeply consider the relationships among content, pedagogy, and technology.

When we began this study, we had a nascent conceptualization of the TPCK framework. This study led to the first clear articulation of the TPCK framework. This study is an example of how the TPCK framework guided the research even while allowing us to develop the framework further by empirically grounding it.

USING TPCK AS AN ANALYTICAL FRAMEWORK

In later work (Koehler, Mishra, & Yahya, in press; Koehler, Mishra, Yahya, & Yadav, 2004), we looked more closely at the manner in which TPCK developed through participation in a design-based activity. Data for the study were collected by a trained researcher who observed the group interactions and maintained detailed field notes on the discussions of two groups in our design seminar.

We used the TPCK framework for analyzing the observation notes. To study changes in the way that the group interacted, we analyzed three weeks of recorded notes—an early week, a middle week, and a late week. The recorded notes were segmented into discourse episodes according to turns in the conversation and then independently analyzed and categorized into three categories: content (C), pedagogy (P), and technology (T). The coding categories were not mutually exclusive, so, for example, a segment might be about technology and pedagogy (TP), or about technology, pedagogy, and content (TPC), and so on.

These data were then analyzed both quantitatively and qualitatively to demonstrate the manner in which TPCK develops through engagement with authentic design tasks. Quantitative analysis showed that both design teams moved from considering technology, pedagogy, and content as being independent constructs and toward a more transactional and codependent construction that indicated a sensitivity to the nuances of technology integration. At a qualitative level, we used the classification scheme to develop a diagrammatic model to represent design talk. Our analysis shows both similarities and differences between the two groups at multiple levels. The groups evolved with time, both in terms of the roles played by the participants and the nature of meaning making within the groups. This suggests that developing TPCK is a multigenerational process that involves the development of deeper understandings of the complex web of relationships between content, pedagogy, and technology, and the contexts within which they function.

DEVELOPING A SURVEY INSTRUMENT TO TRACK THE EVOLUTION OF TPCK

Our most recent research work (Koehler & Mishra, 2005) has focused on measuring the development of TPCK through surveys administered at different times during the semester. In particular, we are concerned that although qualitative (or mixed-method) studies, such as the ones described above, offer rich and detailed information about the phenomena (teacher knowledge around technology), they are time consuming and difficult to replicate. In this study, we developed and administered a survey instrument to assess the development of TPCK by student and faculty participants in the learning technology by design seminar.

The survey instrument consisted of 35 items—33 Likert scale items and 2 short-answer questions—attempting to determine the level of TPCK knowledge both at the individual and group levels. For example, we asked participants the following questions: (1) Our group has been thinking and talking about course pedagogy [to address pedagogical knowledge—PK]; (2) Our group has been thinking and talking about technology [to address technological knowledge—TK]; and (3) Our group has been considering how pedagogy and technology influence one another [to address technological pedagogical knowledge—TPK]. Similar items were created for each component of the framework, including TPCK.

Four faculty members and 13 students completed surveys twice, once toward the beginning of the semester and once at the end. Our data clearly show that participants in our design teams moved from considering technology, pedagogy, and content as independent constructs toward a more transactional and codependent construction that indicated a sensitivity to the nuances of technology integration. In other words, they showed a significant shift toward developing TPCK, involving the development of deeper understandings of the complex web of relationships between content, pedagogy, and technology and the contexts within which they function.

DISCUSSION: WHAT DOES THE TPCK FRAMEWORK BUY US?

What is the value of a theoretical framework? Theories, frameworks, or models can be seen as conceptual lenses through which to view the world. They help us in identifying objects worthy of attention in the phenomena that we are studying, highlighting relevant issues and ignoring irrelevant ones. They can work as classification schemes by providing insights into the nature and relationships of the objects under scrutiny. In the following sections, we outline the value of the TPCK framework for thinking about complex systems, such as educational technology. Additionally, we briefly summarize the different contributions that this work makes to the scholarship of educational technology.

DESCRIPTIVE

Theories and frameworks help to make sense of the world. They provide us with concepts and terminologies with which to describe phenomena accurately. In this regard, the TPCK framework allows us to make sense of the complex web of relationships that exist when teachers attempt to apply technology to the teaching of subject matter. Though separating the three concepts and their relationships may be difficult in practice, the TPCK approach helps us identify important components of teacher knowledge that are relevant to the thoughtful integration of technology in education.

The TPCK framework allows us to conceptualize and discuss a complex web of relationships in a methodological, grounded manner. It respects the richness of the field of study even while offering analytic tools that allow us to study it. This not only helps us identify phenomena in the world, but it also gives us a language to talk about it. For instance, one of the most frequent criticisms of educational technology is that it is driven more by the imperatives of the technology than by sound pedagogical reasons. Our framework argues that, though this can often be problematic, it is not necessarily a bad thing. Newer tools and technologies often offer possibilities that could not have been envisaged earlier. Teachers and educational technology scholars who understand that there is a relationship between technology and content (TCK in our framework) understand that, for example, there is no simple relationship between content and technology. Technology and content exist in a continually evolving relationship, sometimes driven by newer content-related ideas that emerge and at other times by newer technologies that allow for different kinds of representations and access. The TPCK framework, we argue, has given us a language to talk about the connections that are present (or absent) in conceptualizations of educational technology. In addition, our framework places this component, the relationship between content and technology, within a broader context of using technology for pedagogy.

INFERENTIAL

Theories and frameworks allow us to make inferences about the world. These inferences may be about phenomena that we have not yet understood sufficiently to know what to look for and where to look. Inferences can also be used to predict the consequences of making changes in the situation. The TPCK framework allows us not just to understand what effective teaching with technology is about, but it also allows us to make predictions and inferences about contexts under which such good teaching will occur. Clearly, workshops for professional development that focus on developing skill sets specific to particular technologies or the programs that merely focus on generic pedagogical techniques removed from content are not sufficient; they only address the TK (technology) in our framework and ignore the connections with CK (content) and PK (pedagogy). In addition, the TPCK framework allows us to look more closely at successful programs of technology integration and suggest inferences about the causal mechanisms underlying their success. Furthermore, the framework also allows us to make predictions about the contexts within which teachers will apply technology in smart, interesting, and useful ways.

APPLICATION

Theories, particularly those in the arena of education, need to tell us how we can apply the ideas to the real world. This is a pragmatic concern and helps us design better learning contexts and systems. In addition, a good theory or framework offers us the right level of analysis to bridge the gap between description and design. There are two aspects to the application of the TPCK framework. First, the TPCK framework allows us to critique simplistic approaches toward developing teacher knowledge. Further, it assists us in developing better learning environments. In particular, it argues against teaching technology skills in isolation and supports integrated and design-based approaches as being appropriate techniques for teaching teachers to use technology. It argues that learning environments that allow students and teachers to explore technologies in relationship to subject matter in authentic contexts are often most useful. Additionally, the TPCK framework can also help us in conducting scholarship and research into the nature and development of teacher knowledge. It provides an analytic framework and categorization schemes for the analysis of teacher knowledge and its evolution.

CONCLUSION

The complexity of teacher knowledge makes it extremely difficult to represent it within one overarching framework or theory (Fenstermacher, 1994). In particular, any representation of teacher knowledge needs to reflect its socially constructed and dynamic nature. In this article, we have argued that underlying the complexities of teacher knowledge are certain key components and the transactional relationships among these components. The TPCK framework allows us to tease apart some of the key issues that are necessary for scholarly dialogue about educational technology. Our model considers how content, pedagogy, and technology dynamically co-constrain each other. Additionally, we show how the TPCK framework can be used to design pedagogical strategies and an analytic lens to study changes in educators' knowledge about successful teaching with technology. Our research shows that, given opportunities to thoughtfully engage in the design of educational technology, teachers showed tremendous growth in their sensitivity to the complex interactions among content, pedagogy, and technology, thus developing their TPCK. Often, analysis of group discussions focuses on the nature of control and evolution of group dynamics. However, by using a lens suggested by our model, focus was directed instead to what is truly important: a coherent and nuanced understanding of technological pedagogical content knowledge.

We believe that developing TPCK ought to be a critical goal of teacher education. As Shulman (1987) argued,

> The goal of teacher education is not to indoctrinate or train teachers to behave in prescribed ways, but to educate teachers to reason soundly about their teaching as well as to perform skillfully. Sound reasoning requires both a process of thinking about what they are doing and an adequate base of facts, principles and experiences from which to reason. Teachers must learn to use their knowledge base to provide the grounds for choices and action. . . . Good teaching is not only effective behaviorally, but must also reset on a foundation of adequately grounded premises. (p. 13)

We believe that the TPCK framework can guide further research and curriculum development work in the area of teacher education and teacher professional development around technology. The framework allows us to view the entire process of technology integration as being amenable to analysis and development work. Most important, the TPCK framework allows us to identify what is important and what is not in any discussions of teacher knowledge surrounding using technology for teaching subject matter.

To sum up, we see our work as contributing, at multiple levels, to theory, pedagogy, methodology, and practice. In the realm of theory, we have extended previous discussions of TPCK (Hughes, 2005; Keating & Evans, 2001; Lundeberg et al., 2003; Margerum-Leys & Marx, 2002; Zhao, 2003) and put them on firmer ground. In the area of pedagogy, we provide additional support to the use of authentic design-based activities for teaching technology by allowing students to learn in contexts that honor the rich connections between technology, the subject matter (content), and the means of teaching it (the pedagogy). Methodologically, we have presented a representation scheme that permits tracking the socially constructed and dynamic nature of TPCK as it develops through discussion and engagement with pedagogical, technological, and content-related issues. Finally, we believe that the approach that we have developed in this article and in other publications can be the basis for a more integrated perspective on research and pedagogy. We also believe that such approaches can help bridge the gap between educational research and practice (Brown, 1992; Cobb et al., 2003; Design-Based Research Collective, 2003).

We are sensitive to the fact that in a complex, multifaceted, and ill-structured domain such as integration of technology in education, no single framework tells the "complete story"; no single framework can provide all the answers. The TPCK framework is no exception. However, we do believe that any framework, however impoverished, is better than no framework at all. As Charles Darwin said,

> About thirty years ago there was much talk that geologists ought only to observe and not theorize; and I well remember someone saying that at this rate a man might as well go into a gravel pit and count the pebbles and describe the colors. How odd it is that anyone should not see that all observation must be for or against some view if it is to be of any service! (Darwin & Seward, 1903, p. 195)

In proposing the TPCK framework, we have sought to provide one such view.

The authors would like to thank all the participants in our courses, faculty and students, without whose efforts none of this work would have been possible. We would also like to thank the following individuals for their help over the years (in alphabetical order): Carole Ames, Rick Banghart, Kathryn Dirkin, Irfan Muzaffar, Lisa Peruski, Aparna Ramchandran, Aman Yadav, Kurnia Yahya, and Yong Zhao. Finally, we would like to thank three anonymous reviewers for their feedback. This research has been partially supported by a Preparing Tomorrow's Teachers to Use Technology grant from the United States Department of Education.

Notes

1 Contributions of the first two authors to this article were equal. We rotate the order of authorship in our writing.

2 In a famous article titled, "Is the Scientific Paper a Fraud?" (1963), Sir Peter Medawar argued that written presentations of the research process (a.k.a. journal articles) often give a "misleading narrative of the processes of thought" that go into the actual doing of the research. This article is somewhat guilty of the same, attempting as it does to compress years of work into

a single comprehensible narrative. The development of the TPCK framework did not happen ex nihilo. A precursor to the TPCK idea was a brief mention of the triad of content, theory, and technology in Mishra (1998), though within the context of educational software design. In the context of the research presented in this article, the first indications of TPCK came from the learning-technology-by-design seminars. We taught these seminars based on our constructivist leanings and a sense of the futility of teaching particular software programs or skills (for reasons given in the article). However, as we taught and observed these courses, we realized that there were positive things happening that went beyond merely learning technology. This led to our initially unfunded research program. We began with a qualitative research study of one design team member, a higher education faculty member whom we called Dr. Shaker (Koehler, Mishra, Hershey, & Peruski, 2004). It was in preparing this case study that we received the first suggestion about the TPCK idea. This idea was made concrete in discussions that fed into the design and analysis of the next study (Koehler & Mishra, 2005; Koehler, Mishra, & Yahya, 2004). In this study, we made TPCK the focus, using that to analyze design discourse to chart the development of TPCK over time. In Koehler and Mishra (2005), we attempted to capture TPCK through the design of a survey instrument. Of course, in the meantime, we were still teaching the Learning Technology by Design seminars—initially face to face and now online as well—in addition to writing about our experiences.

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