Introducing Technological Pedagogical Content Knowledge

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In this paper we offer an argument for Technological Pedagogical Content Knowledge (TPCK) as a framework for teacher knowledge for technology integration. The idea of TPCK builds on Shulman's construct of Pedagogical Content Knowledge (PCK) and in this paper our goal is to further flesh out the idea of TPCK, as enumerated in previous publications by numerous authors (for instance see Ferdig, 2006; Hughes, 2005; Keating & Evans, 2001; Lundeberg, Bergland, Klyczek, & Hoffman, 2003; Margerum-Leys, & Marx, 2002; Neiss, 2005; Zhao, 2003; also see other chapters in this book).

The structure of this paper is as follows. We begin with a brief introduction to the complex, ill-structured nature of teaching, and the additional difficulties introduced by technology integration. We propose to view teaching with technology as "wicked problem" (Rittel & Webber, 1973), in turn requiring a view of teaching as developing complex, nuanced solutions that derive from (and further develop) flexible and integrated bases of knowledge. We argue that underlying the complexity and ill-structuredness of effective teaching with technology, there are better-defined descriptions of teacher knowledge (and their interactions) that give rise to deep understanding. We offer our TPCK framework for teacher knowledge in detail, as a complex interaction between three bodies of knowledge: Technology, Pedagogy, and Technology. In emphasizing a dialogic relationship between abstract knowledge and practice, we argue that TPCK should be viewed a flexible knowledge framework that teachers need to develop in order to successfully integrate technology in their teaching. Finally we argue that the complexity of developing and applying TPCK suggests that a greater prominence be placed on the idea of teachers as "curriculum designers."

Teaching as an ill-structured, complex domain

Teaching is a highly complex activity that occurs in ill-structured, dynamic environments (Leinhardt & Greeno, 1986; Spiro, Coulson, Feltovich, & Anderson, 1988; Spiro, Feltovich, Jacobson & Coulson, 1991). Like expertise in other complex domains, including medical diagnosis (Lesgold, Glaser, Feltovich, & Wang, 1981; Pople, 1982), and writing (Hayes & Flower, 1980; Hillocks, 1986), expertise in teaching is dependent on flexible access to and application of highly organized systems of knowledge (Glaser, 1984; Putnam & Borko, 2000; Shulman, 1986, 1987) that have to continually shift and evolve based on the context within which they are applied.

There are clearly many knowledge systems that are fundamental to teaching, including knowledge of student thinking and learning, and knowledge of subject matter, and increasingly knowledge of technology. Moreover these knowledge domains relate to each in ways that are contextually bound, varying on a case-by-case basis, making the application of knowledge to actual practice (and studying cause-effect relationships) difficult. As Spiro and colleagues have argued ill-structured domains have two main characteristics: (a) complexity of concepts and cases; and (b) irregularity of cases with variability of relevant features across different cases (Spiro, Coulson, Feltovich, & Anderson, 1988; Spiro, Feltovich, Jacobson, & Coulson, 1992; Spiro & Jehng, 1990).

In this regard teaching is akin to other real-world problems in that they are ill-defined, lacking required information, and not having a known correct nor best solution (Frederiksen, 1986; Glass, Holyoak, & Santa, 1979; Nickerson, 1994; Reitman, 1964; Roberts, 1995). Other examples of ill-structured domains are biomedicine (Feltovich, Coulson, Spiro, & Dawson-Saunders, 1992); literary analysis (Jones & Spiro, 1992, 1996; Spiro & Jehng, 1990); and law (Feltovich, Spiro, Coulson, & Myers-Kelson, 1995; Lawrence, 1988; Williams, 1992). Domains that appear to be well-structured can also be Ill-structured either at advanced levels of study or when applied to unconstrained, naturally occurring situations (Spiro, Feltovich, Jacobson & Coulson, 1992; Spiro, Vispoel, Schmitz, Samarapungavan, & Boerger, 1987). For example, mathematics is typically treated as a very structured field with no open questions or debates. Professional mathematicians, however, who work at the cutting-edge encounter a very different view of their field (Davis & Hersh, 1981). Ill-structuredness also appears when students face difficulties transferring abstract mathematical principles to real-world situations (Resnick, 1988). Similarly, physics is an orderly and regular discipline—when considered in the abstract. When applied to the real world, as in the case of engineering, matters become far more complex. Building a bridge, for example, applies principles of physics, but the unique features of each case (including cost, materials, and location) prevents the indiscriminate generalization from one case to another (Guzdial, Turns, Rappin & Carlson, 1995; Petroski, 1985, 1994).

Technology further complicates matters

The inherent complexity of teaching is further exacerbated by the inclusion of technology. Technologies provide more options and possibilities to teachers to structure their lesson plans, to teach old curricula in new ways, and to develop new curricula that utilize the affordances of digital technologies to help students engage deeply with important ideas in the subject. This also means that the inclusion of new technology places an even greater burden on teachers as they attempt to integrate it in their teaching. There are a variety of ways in which technologies complicate pedagogy. We describe some of these below.

Technologies have always played an important role in pedagogy (consider the pencil or the blackboard, the microscope or the simple pendulum). Most traditional pedagogical technologies can be characterized by *specificity* (a pencil is for writing, while a microscope is for viewing small objects); *stability* (pencils and pendulums, microscopes and blackboards have not changed a great deal over time); and *transparency of function* (the inner-workings of the pencil or the pendulum are quite simple and directly related to their function). Most importantly, over time these technologies have become commonplace, and in most cases are not even regarded as being technologies (what has been called *transparency of perception).*

Digital technologies, (such as computers, and hand-held devices, and the software programs that run on them), in contrast, are *protean*, *unstable* and *opaque*. The protean nature of the computer emphasizes the fact that that it can dynamically simulate the details of any other medium including those that cannot exist physically. It is a meta-medium with degrees of freedom for representation and expression never before encountered and as yet barely investigated (Kay, 1984). The digital computer is unique in its ability to store, deliver, and help manipulate a variety of symbol systems: visual, acoustic, textual and numerical. As a tool, the computer (or the computer application or system) provides humans with new ability or greater power, allowing people to do things they could not do before, or to do familiar things more easily.

This protean nature also means that digital technologies are many different things to different people. So in some sense though we often use the word "technology" in the singular form, it is not a monolithic entity and we are very often discussing very different manifestations of technology. The digital computer can be a tool for communication (through email or instant messaging), a tool for design and construction (through software for scientific model building or software for designing websites, themselves very different activities), a tool for inquiry (such as through digital libraries and digital probes) and as a tool for artistic expression (through art and graphic design software programs). This protean nature gives digital technologies their greatest strength. These strengths, however, come at a cost—that of significantly increasing the complexity of having to use these different symbol systems. It is no wonder that computers are complicated to learn and use.

Digital technologies are also functionally opaque. That is, the inner workings of most contemporary technologies are hidden from those who use them. The computer becomes a *virtual* domain with cause and effect relationships divorced from everyday rules. This makes our interactions with computers symbolic and often quite arbitrary, though with real-world consequences. This separation often makes working and learning to work with computers difficult—akin to learning a new language or culture. Adding to the opacity is the fact that most software tools available today are designed for the world of business and work, not education (Zhao, 2003). Converting general-purpose tools created for the world of business (e.g., spreadsheet programs) in the classroom requires working through this opacity and reconfiguring and repurposing these existing technologies for pedagogical purposes (a complex, nontrivial task).

Another factor that increases the complexity of technology integration is that *digital technologies are unstable*. This instability manifests itself in two different ways though the cause is usually the rapid rate of change of technology. First, the knowledge required to learn to use digital technologies is never fixed. Technology changes fast, causing hardware and software applications to become outdated every couple of years. One has to continually keep up with the changing demands of new technologies, be they hypercard or Logo, webpages or HTML, blogs or wikis, podcasts or social bookmarking. Thus, learning technology is not a one-shot deal and teachers need to become life-long learners, willing to contend with ambiguity, frustration and change. A second consequence of this rapid rate of change in technology is that the technologies we are often given are not fully tested and robust. Most software programs are riddled with bugs, and error-prone, something all technology users have to contend with.

Apart from these reasons that have to do with the very nature of modern technologies, the integration of technology complicates matters in other ways as well. One of the most important reasons has to do with *inadequate (or inappropriate) teacher training*. Teachers often lack experience in teaching / learning with technology. Many teachers earned their degrees without using a lot of technology, or at a time when educational technology was at a very different state than it is today. Many teachers, accordingly, do not see the value of using technology for teaching, nor consider it relevant to good teaching, and do not see themselves as prepared use technology in their classrooms.

Having to pick up a new knowledge base and skill set can be quite challenging particularly when it is a time-intensive activity that needs to be fit into an already busy schedule.

Technology integration is made even more complex by the kinds of *social and institutional contexts* within which teachers work. These contexts often do not support their successful working with technology. An important part of the problem of technology integration has been, what we have called the "Somebody Else's Problem" (SEP) syndrome (Koehler, Mishra, Hershey & Peruski, 2004). Technology and pedagogy are often seen as being domains ruled by different groups of people — teachers and instructors, who are in charge of pedagogy; and technologists, who are in charge of the technology. Similar to C. P. Snow's (1959) idea of two cultures, teachers and techies live in different worlds and often hold curiously distorted images of each other. On one hand, the technologists view the non-technologists as luddites, conservative, resistant to change, and oblivious to the transformative power of technology. On the other hand, the non-technologists tend to view technologists as being shallowly enthusiastic, ignorant of education and learning theories, and unaware of the reality of classrooms and schools. This tension between educators and technologists can complicate the teacher's role greatly.

Finally, we must remember that technologies are neither neutral nor unbiased, rather, particular technologies have their own propensities, biases, and inherent attributes, that make them more suitable for certain tasks than others (Bromley, 1998; Bruce, 1993). Technologies (particularly digital technologies such as computers and the Internet) are knowledge systems (Hickman, 1990) with specific affordances and constraints. Knowledge of technology cannot be treated as being unrelated and separate from knowledge about teaching tasks and contexts.

Viewing teaching with technology as a "wicked problem"

One fruitful way of thinking of the problem of technology integration in teaching is to view it as a classic example of a "wicked problem" (Rittel & Webber, 1973). Rittel and Webber argued that wicked problems, in contrast to "tame" problems (such as those in mathematics, chess etc.), have incomplete, contradictory and changing requirements. Solutions to wicked problems are often difficult to realize (and maybe even recognize) because of complex interdependencies between a large number of contextually bound variables. Wicked problems, they argued, cannot be solved in a traditional linear fashion, because the problem definition itself evolves as new solutions are considered and/or implemented. Rittel and Webber stated that while attempting to solve a wicked problem, the solution of one of its aspects may reveal or create another, even more complex problem. Moreover, wicked problems have no stopping rule—and solutions to wicked problems are not right or wrong, simply "better," "worse," "good enough," or "not good enough." Most importantly, every wicked problem is essentially unique and novel. There are so many factors and conditions, all embedded in a dynamic context, that no two wicked problems are alike. Accordingly, solutions to them will always be custom designed. For this reason, there is no definitive solution to a technology integration problem. It is an ill-structured problem constituted by an evolving set of interlocking issues and constraints.

Rittel and Webber show that the biggest mistake that one can make when tackling wicked problems is to think of it as a "normal" or "tame problem" that can be tackled in conventional ways. Wicked problems always occur in a social context, that of classrooms, and teachers, and students, and technology coordinators and often the wickedness of the problem reflects the diversity among the stakeholders in the problem. Indeed it is the social, psychological complexity of these problems, rarely their technical complexity, that overwhelms standard problem solving approaches. Because of this complexity, there is no such thing as a "perfect solution" to a "wicked problem," instead solutions are often a "one-shot operation" because every solution leads to newer knowledge, and unintended consequences, which are likely to lead to further wicked problems. The problem solving process typically ends when you run out of resources (time, money, support etc.).

Finding structure in the complexity

Classifying a domain as being complex and ill-structured does not mean that it lacks any structure at all. What it means is that understanding a typical case in the domain in question requires understanding a variety of complex concepts (and their contextual interactions) and that the pattern of interaction of these concepts is not consistent across cases. As an analogy consider the interdisciplinary field of complexity science. Scholars in this field study a range of complex systems ranging from physics, biology, to economics. One interesting characteristic of these systems the behavior of the overall system is complex and unpredictable even though the system itself is comprises a smaller number of better-understood components (Science, 1999; Solomon & Shir, 2003). The system itself is more than the sum of its parts, change in one of the system components does not easily predict system change, and complexity emerges from the *complex interactions from components in the system*. An ant-colony, for example, exhibits many of the properties of a complex system. Individual ants have very low intelligence, are autonomous (the queen does not give orders), and only react to very local stimuli. Yet the colony is able to exhibit complex behaviors and solve intricate problems, including the building of ant-hills and build up food stores. Complexity science has been helpful for understanding complex human behavior as well. For example, within the financial markets many local decisions of buying and selling stock seem to be rather well-structured, but lead to complex and unpredictable large scale changes in the overall market.

Our goal is not to suggest that we necessarily take a complex systems approach to understanding educational technology but, rather, that to make the larger point that complexity and ill-structuredness do not imply the total lack of structure, and instead that complexity can emerge from a smaller set of more tractable and understandable phenomena that interact with one another. In our case of educational technology, it requires understanding a variety of complex concepts (and their contextual interactions) and an appreciation that the pattern of interaction of these concepts is not likely to be consistent across cases. As we deal with our "wicked problems", we must simultaneously navigate multiple, wide-application conceptual structures.

As researchers and scholars, we are challenged with finding the structures and level of description that satisfy multiple goals. The level of description has to be detailed and nuanced enough that it captures local and contextually-bound qualities that make sense to practitioners. It also has to be high level enough that it helps identify conceptually significant, broad and cross-cutting qualities that are important to researchers. What is exciting about the framework that is presented in this book (monograph?) and the various scholars' work represented here is that it navigates this scylla of detail with the charybdis of generalization through the appropriate level of discussion pertaining to what it is that teachers need to know in order to successfully integrate technology into their teaching. We believe that this description, as it has evolved over time, incorporates relatively simple components of knowledge (Content, Pedagogy, and Technology) and their complex interactions that could lead to the widely varied situations and contexts that could account for the wide variations seen in the educational technology today (as well as in the future). This variety of application is represented quite clearly in this volume {CONNECTIONS TO OTHER CHAPTERS}

We offer an overview of the model below, though more detailed descriptions of if can be found in other published reports (Mishra & Koehler, 2006 being one). It is important to note that this perspective is consistent with other approaches that have attempted to extend Shulman's idea of Pedagogical Content Knowledge (PCK) to the domain of technology (see citations above).

The TPCK Model

The TPCK framework builds on Shulman's (1987, 1986) descriptions of Pedagogical Content Knowledge to describe how teachers understanding of Technology, Pedagogy, and Content interact with one another to produce effective teaching with technology. (see REFS for an evolution of these ideas). In this model (see Figure 1), there are three main components of knowledge: Content, Pedagogy, and Technology. Equally important to the model are the interactions of these bodies of knowledge, Pedagogical Content Knowledge (PCK), Technological Content Knowledge (TCK), Technological Pedagogical Knowledge (TPK), and Technological Pedagogical Content Knowledge (TPCK).

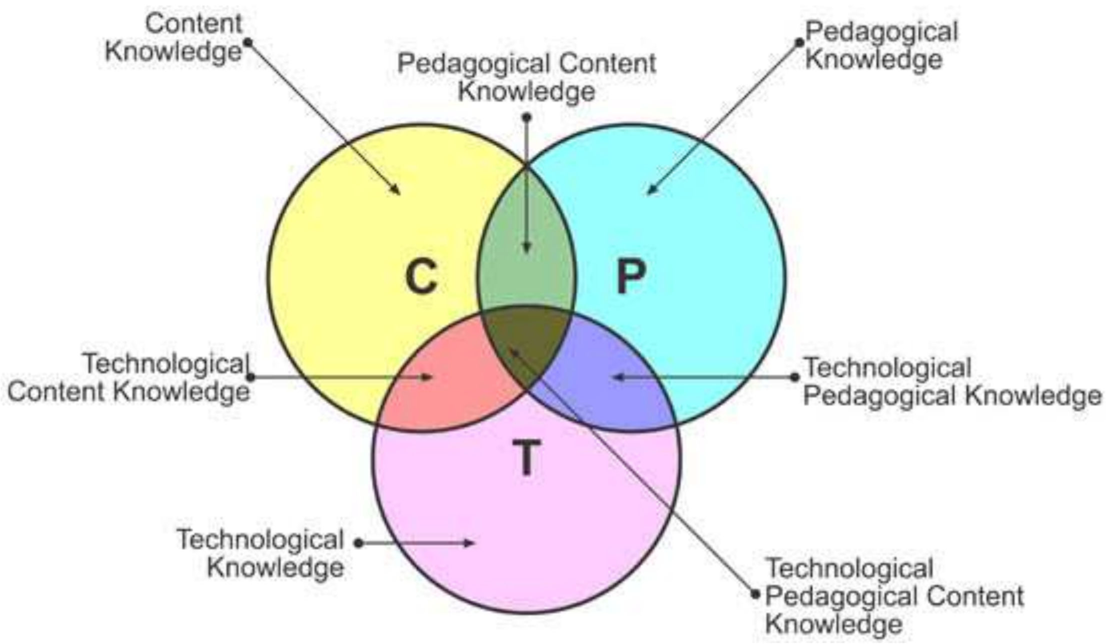

Figure 1. The TPCK framework and its knowledge components

The goal of describing each of these bodies of knowledge is not to engage in philosophical discussions about the nature of knowledge. Even though many philosophers have typically defined knowledge as "justified true belief" and have spent decades in attempting to understand each of these words, the conception of knowledge promoted here is more pragmatic and influenced by scholars including Dewey, Schon and Perkins (Dewey, 1934; Dewey & Bentley; 1949; Perkins, 1986; Schon, 1983, 1987; 1996). Perkins in particular poses a provocative metaphor, that of "knowledge as design" (Perkins, 1986). In fact he goes on to argue that knowledge can be considered as a tool that is designed and adapted to a purpose. As he says:

> To think of knowledge as design is to think of it as an implement one constructs and wields rather than a given one discovers and beholds. The kinesthetic imagery

implicit in knowledge as design fosters an active view of understanding worthy of emphasis in teaching and learning. (p. 132)

In this view of knowledge, the truth-value of the knowledge is less important than what you can do with that knowledge, what has also been called usable knowledge (Dede, ????). We briefly describe each in turn.

Content Knowledge (CK)

Content Knowledge is knowledge about the actual subject matter that is to be learned or taught. The content to be covered in middle school science or history is different from the content to be covered in an undergraduate course on art appreciation or a graduate seminar on astrophysics. Knowledge of content is of critical importance for teachers. This would include as Shulman (1986) noted: knowledge of concepts, theories, ideas, organizational frameworks, knowledge of evidence and proof, as well as established practices and approaches towards developing such knowledge. Knowledge and the nature of inquire differ greatly between fields and it is important that teachers understand the deeper fundamentals of their disciplines. In the case of science this would include knowledge of scientific facts and theories, knowledge of the scientific method, and evidence based reasoning. In the case of art appreciation such knowledge would include knowledge of art history, famous paintings, sculptures, artists and their historical contexts, as well as knowledge of aesthetic and psychological theories for evaluating art, among other things. The cost of not having a good base in content knowledge can be quite prohibitive, leading to students receiving incorrect information as well as developing misconceptions about the topic at hand (REF). As is clear, content knowledge, in and of itself, is an ill-structured domain, and as the culture wars (REFS) and the great books controversies (REFS) as well as court battles over the teaching of evolution (REFS) demonstrate, issues of content can be areas of significant contention and disagreement.

Pedagogical Knowledge (PK)

Pedagogical Knowledge 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 and acquire skills; develop habits of mind and positive dispositions towards 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 (PCK)

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*. PCK covers the core business of teaching, learning, curriculum, assessment and reporting, such as the conditions that promote learning and clearly articulate the links between curriculum, assessment and pedagogy. An awareness of common misconceptions and ways of looking at them, the importance of forging links and connections between different content ideas, students' prior knowledge, alternative teaching strategies and the flexibility that comes from seeing alternative ways of looking at the same idea or problem are all essential for effective teaching.

Technology Knowledge (TK)

Technology knowledge is always in a state of flux—more so than the other two "core" knowledge domains in the TPCK framework (P and C). This makes pinning it down notoriously difficult. Earlier in this paper we described the manner in which technology keeps changing and how keeping up-to-date with it can become a full-time job, in and of itself. This also means that any definition of technology knowledge is in the danger of becoming outdated by the time this text has been written, edited, proofread and published. With that important caveat, we argue, that at this time, knowledge of technology would include a basic understanding of the full range of digital technologies (video, internet, computers, peripheral devices etc.) and commonplace educational technologies such as print media and overhead projectors. It also includes the ability to use important and relevant software tools (including word processing, email, and spreadsheets). Increasingly knowledge of technology has come to include newer technologies made popular through the advancement of the Internet and gaming technologies. For instance knowledge of blogs, and wikis, podcasting and tagging/social bookmarking, video games and simulations are increasingly become a part of the technologies that teachers need to be familiar with.

Technological Content Knowledge (TCK)

Technology and content have a long historical relationship with each other. Progress in fields as far apart as medicine and history, archeology and physics has depended on the advancement or introduction of new technologies that allow for the subject matter in question to be represented and manipulated in new and fruitful ways. Consider Roentgen's discovery of X-Rays or the technique of Carbon-40 dating and the influence of these technologies on the fields of medicine and archeology respectively. Consider how the advent of the digital computer had changed the nature of physics and mathematics, moving them both towards understanding phenomena through simulation. (Though physics and mathematics approach simulation from somewhat opposite directions, physics from the side of grounded experimentation and mathematics from more abstract axiomatic method, they both "meet" in the realm of the virtual.) Technologies sometimes also offer new metaphors for understanding the world. For instance, metaphors such as viewing the heart as a pump, or the brain as an information-processing machine, are just some of the ways in which technologies have provided new perspectives for looking at and understanding phenomena in the world.

These representational and metaphorical connections are of great value to educators as well. Understanding these connections becomes critical if we are to develop appropriate technological tools for educational purposes. The choice of technologies affords and constrains the types of content ideas that can be taught. Likewise, certain content decisions limit the types of technologies that can or should be used. Technology both constrains the kinds of representations possible but also affords the construction of newer and more varied representations and a greater degree of flexibility in navigating across these representations. {EXAMPLES FROM THE OTHER CHAPTERS NEED TO COME HERE. FOR INSTANCE, GRANDGENETT'S DISCUSSION OF FRACTALS IN MATH ED ETC. ETC.}

Given this, we can define TCK as an understanding of the manner in which technology and content influence and constrain one another. Teachers need to know not just the subject matter they teach but also the manner in which the subject matter (or the kinds of representations that can be constructed) can be changed by the application of technology. Teachers need to understand what are the specific technologies suited for addressing subject-matter learning in their domains and if there are examples in which the content dictates or perhaps even changes the technology (or vice versa)?

In some way TCK is the most neglected aspect of the various intersections in the TPCK framework. As Thompson (2006) says, this framework "suggests that teachers' experiences with technology need to be specific to different content areas (Thompson, 2006). This book (monograph series?) attempts to redress this neglect through asking scholars in different disciplinary contexts to describe just how technology and content are reciprocally related in their particular domain.

Technological Pedagogical Knowledge (TPK)

Technological pedagogical knowledge is an understanding of how teaching and learning changes when particular technologies are used. This includes knowing the pedagogical affordances of for a range of technological tools as well as an understanding of the pedagogical strategies and applications for various technologies. This includes knowledge of tools for facilitating communication, for managing records of assessments, and for engaging students.

TPK becomes particularly important because most popular existing software programs are not designed for educational purposes. Software programs such as the Microsoft Office Suite (that include Microsoft Word, Powerpoint and Excel), or services such as Blogs or Podcasts are usually designed either for businesses or for purposes of entertainment/communication. Teachers need to develop the kind of knowledge that can look beyond the immediate technology and "reconfigure it" for their own pedagogical purposes. Thus TPK requires a forward-looking, creative and open-minded seeking of technology, not for its own sake, but for the sake of advancing student learning and understanding.

Technological Pedagogical Content Knowledge (TPCK)

TPCK is an emergent form of knowledge that goes beyond all three components (content, pedagogy, and technology). Technological pedagogical content knowledge is an understanding that emerges from an interaction of content, pedagogy, and technology knowledge. Underlying true meaningful and deeply skilled teaching with technology, TPCK is different than knowledge of all three concepts individually. We argue that 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.

TPCK is a form of knowledge that expert teachers bring to play anytime they teach by simultaneously integrates knowledge of technology, pedagogy, and content. Each "wicked problem" or situation presented to teachers is a unique combination or weaving together of these three factors, and accordingly, and *there is no single technological* *solution that applies for every teacher, every course, or every view of teaching*. Rather, solutions lie in the ability of a teacher to flexibly navigate the space defined by the three elements of content, pedagogy, and technology and the complex interactions between them. This is the hallmark of deep and nuanced understanding when it comes to teaching with technology that we seek.

There are clearly significant epistemological implications of living and working in such domains that are characterized by complexity and ill-structuredness. Dealing with “wicked problems” of technology integration requires the development of flexible knowledge structures and value the interconnections and relationships between the three key aspects of technology integration in teaching: Technology, Content, and Pedagogy. Ignoring the complexity each of these as well as the complexity of the relationships between them, can lead to oversimplified solutions and even failure. Thus teachers need to develop fluency and cognitive flexibility not just in each of these key domains (T, P, and C) but also in the manner in which these inter-relate with each other in order to attempt solutions that are sensitive to the contexts within which they occur. Thus TPCK knowledge needs to be both flexible and pragmatic (i.e. connected to real contexts of practice).

The act of seeing technology, pedagogy and content as three knowledge bases is not straightforward. As we have said before:

> … separating the three components (content, pedagogy, and technology) … 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”… 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. (Mishra & Koehler, 2006, p. 1029).

This compensation is most evident whenever incorporating a new teaching technology suddenly forces teachers to confront basic educational issues and *reconstruct the dynamic equilibrium between all three elements.* This view inverts the more conventional perspective that it is the content to be covered that drives most decisions i.e. 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, particularly the rise of online learning, can be seen as an example of a technology whose arrival forced educators to think about core pedagogical issues (Peruski & Mishra, 2004). Consider also the example of cognitive flexibility hypertexts as espoused by Spiro and his colleagues (Spiro, Feltovich, Jacobson, & Coulson, 1991; Spiro & Jehng, 1990). Over the years many CFT hypertexts have often been developed by academics, often for use in their research. By their very nature these hypertext environments restrained to unique, specialty software projects focused on specific subject matter areas and with limited availability to other users. Thus, most of the work in this area has been restricted to publications, research papers and journal articles. The advent of user-created tagging (also known as social-bookmarking) and their use in popular websites such as Furl, Delicious, and Flickr has suddenly moved core CFT ideas from the research lab into the real world. Educators are now realizing the constructivist power of folksonomies, and other user-created tagging/categorization schemes, to reconfigure how we understand texts and their relationships between them. In this context, it is the technology that drives the kinds of decisions we make about content and pedagogy.

Pedagogy and content, however, are not always driven by the capabilities of technology (as in the examples above). A good example of how pedagogical constraints of schools can restrict how technology is designed and used has to do with the design of educational computer games. In a study comparing commercial games to educational games Heeter et al. (2003) found that commercial games often were more demanding than educational games in terms of cognitive effort as well as in time required for mastery. Educational games were easier to install, easier to learn, less complex, shorter, less challenging to play, and required less social interaction than commercial games (mainly to fit the standard school curricular 45-50 minute time-slots). What was clear from the study was that the constraints of working within a school setting led to design solutions that limited playability particularly related to length and complexity of game play. The authors argue that the constraint of educational games needing to be playable in a classroom situation may be a bigger constraint to creating a fun educational game than the focus on learning subject matter. This emphasis on pedagogy through play leads Heeter et. al. to argue that "educational games are schizoid" in that they continually try to serve two masters (learning versus fun).

As must be obvious, the application of the TPCK framework to the problem of teacher knowledge does not imply a rigid or algorithmic adherence to one single approach to tech integration. In making his argument for knowledge as design Perkins suggests that practitioners have to "learn to see through" (p. 36) these design colored glasses and, "be inventive" (p. 36) in how we approach the problems in our field. For example, a teacher interested in integrating technology in history education may consider the use of primary sources available on the Internet while another may choose to have students develop hypertexts that focus on the inter-linked cause-effect relationships between historical events. A mathematics teacher, may focus on the representational capabilities of technology (graphs, symbols etc.), or different methods of proof. Thus considering knowledge as design requires flexibility and fluency not just with the content but also with pedagogy and technology—keeping in mind that each influences the other in profound ways.

Teacher knowledge in practice, or teachers as curriculum designers

Joseph Schwab (1983) offered a wonderful description of the complexity of the teacher's role in a classroom and the kind of flexibility teachers need to possess in order to succeed in such an environment. This description is also an important reminder that the teacher is an important conduit for any changes that can occur in the classroom. As Schwab says:

> Teachers will not and cannot be merely told what to do… Teachers are not assembly line operators, and will not so behave… There are thousands of ingenious ways in which commands on what and how to teach can, will, and must be modified or circumvented in the actual moments of teaching. Teachers practice an art. Moments of choice of what to do, how to do it, with whom and at what pace, arise hundreds of times a school day, and arise differently every day and with every group of students. No command or instruction can be so formulated as to control that kind of artistic judgment and behavior, with its

> demand for frequent, instant choices of ways to meet an ever varying situation (p. 245).

What this quote makes clear is that curricula do not exist independent of teachers. Teachers are “an integral part of the curriculum constructed and enacted in classrooms” (Clandinin & Connelly, 1992 p. 363). This is consistent with Dewey’s idea that of viewing the teacher “not so much as a maker of the curriculum but as a part of it.” Our description of the unique and case-specific nature of wicked problem solving, and the kinds of knowledge required to function in such contexts, strongly supports the idea that *there is no general solution to a teaching problem that fits every context, every subject matter, every technology, every classroom for every teacher.* Knowing this means that we need to welcome a far greater level of autonomy and power to be handed to the teacher (or better still, we need to accept the fact of our relative powerlessness, and well as the fact that that the power of implementation lies in the hands of particular teachers in particular classrooms). The teacher is an active participant in any implementation or instructional reform we seek to achieve and this is an important fact to keep in mind as we discuss various forms of teacher knowledge. Clearly this has implications for teacher education and teacher professional development—in particular to the idea of teachers as curriculum designers.

Approaches that just teach skills (technology or otherwise) do not go far enough. Learning about technology (how to use email, wordprocessing or the latest version of windows) is different than learning what to do with it. Or in other words, teaching technology skills alone (the T in our model), does little to help teachers develop knowledge about how to use it to teach more effectively (TP), its relationship to content representations (CT), or how to help students learn a particular topic using technology (TPC). Likewise, isolating content learning (C), or general pedagogical skills (P), would not lead to teachers to develop an understanding of how to put it use.

Practice (curriculum design and teaching) is an important route to learning. It is not always the case conceptual learning precedes the ability to apply that knowledge to practice. Learning in complex and ill-structured domains often happens best through working through problems or cases (Shulman, 1986; Williams, 1992), or in our case working with the “wicked problems” posed by integrating technology into effective practice. When (designers) tackle these problems, their solutions are generative, in that each solution leads to newer knowledge, and unintended consequences, which are likely to lead to further wicked problems. That is, learning of new concepts and their relationships comes from practice, and not the rote application of general principles. Teacher educators must find ways to provide preservice teachers a way to work through these problems of practice before they get to their first classrooms.

Context is important to learning and situating teacher knowledge. Because teaching is complex and ill-structured problem, there are few (or perhaps not any) general principles that apply in every situation. In short, context matters. Solutions to “wicked problems” require and nuanced understanding beyond the general principles of content, technology, and pedagogy. Interactions between these bodies of knowledge, and how they are bound in particular context (including knowledge of their particular students, their school social network, understanding of parental concerns, etc.), is the kind of flexibility teachers need to possess in order to succeed in such an environment. In viewing teachers as curriculum designers, teachers are able to adapt to their own contexts and changing conditions, rather than trying to apply general approaches.

{LESSONS FROM THE OTHER CHAPTERS CAN COME HERE, REFERENCE THEM. EMPHASIZE THAT CONTEXT AND CONTENT MATTERS)

Conclusion

In his book *Life in the Classrooms* (1968), Philip Jackson reported the results of one of the first studies that attempted to describe and understand the mental constructs and processes that underlie teacher behavior. The value of Jackson's research was immediately recognized, not for its prescriptive value, but rather for its conceptual value. In representing the full complexity of the teacher's task, Jackson made conceptual distinctions that fit the teacher's frame of reference (for instance the preactive and the interactive stages of teaching) and drew attention to the importance of describing the thinking and planning of teachers (the so called "hidden side of teaching") in an attempt to develop a more complete understanding of classroom processes. Jackson's pioneering work led to a flurry of research studies that focused attention on the "thinking, planning and decision making of teachers" (Clark and Peterson, 1986), a line of research that hopes to "understand and explain how and why the observable activities of teacher's professional lives take on the forms and functions they do" (Clark & Peterson, 1986, p. 255). A major goal of this research has been to understand the relationship between two key domains, (a) teacher thought processes; and (b) teachers' actions and their observable effects. As a field we need to develop better techniques for getting at how knowledge in the head gets implemented and instantiated in practice, and, as importantly, how the act of doing influences the knowledge in the head. The "knowledge as design" framework has at its heart this interactive, bi-directional relationship between thought and action, embedded within ill-structured, complex contexts.

Reitman (1965) described ill-defined problems, or ill-structured problems as those "whose definition included one or more parameters, the values of which are left unspecified." The classic example he gave was the problem of composing a fugue, which in its simplest form, has just one requirement, that of having the quality of fugueness. Of course, this requirement also contains within itself a range of cultural, technical, historical, psychological values and constraints—the context as it were. We particularly like this example as an analogy to teaching, because teaching is (similar to creating music) one of the highest forms of human achievement, requiring the creative dovetailing and coming together of both technical and aesthetic skills. The TPCK framework we hope offers insight into how the myriad complexities and tensions of teaching can be brought together fruitfully.

References

Ball, D.L. & Cohen, D. K. (1999). Developing practice, developing practitioners: toward a practice-based theory of professional development. In L. Darling-Hammond & G. Skyes (Eds.), *Teaching as the learning professional: Handbook of policy and practice*. (pp. 3-32). San Francisco: Jossey-Bass.

Bruce, B. C. (1997). Literacy technologies: What stance should we take? *Journal of Literacy Research, 29*(2), 289-309.

Carr, A., Jonassen, D., Litzinger, M.E., & Marra (1998). Good ideas to foment educational revolution: The role of systematic change in advancing situated learning, constructivism, and feminist pedagogy. *Educational Technology, January-February*, 5-14.

Clandinin, D. J., & Connelly, F. M. (1992). Teacher as curriculum maker. In P. Jackson (Ed.), *Handbook of research on curriculum* (pp. 363-401). New York: Macmillan.

Clark, C. M., and Peterson, P. (1986). Teachers' thought processes. In M. C. Wittrock (Ed.), *Handbook of research on teaching (3rd ed.)* (pp. 255-296). New York: Macmillan.

Cohen, D. (1988). *Teaching practice: plus a change*. (Issue paper No. 88-3). East Lansing, MI: Michigan State University, The National Center for Research on Teacher Education.

Davis, P. J. and Hersh, R. (1981). *The mathematical experience.* Boston: Mariner.

Dewey, J. (1934). *Art as experience.* New York: Perigree.

Dewey, J. *Logic: The Theory of Inquiry*. In John Dewey: The Latter Works, 1925-1953, vol. 12. J. A. Boydston (ed.) Southern Illinois University Press, Carbondale (1991).

Dewey, J., & Bentley, A.F. (1949). *Knowing and the known*. Boston: Beacon.

Feltovich, P., Spiro, R., Coulson, R., & Myers-Kelson, A. (1995). The reductive bias and the crisis of text in the law. *Journal of Contemporary Legal Issues, 6* (1), 187-212.

Glaser. R. (1984). Education and Thinking: The role of knowledge. *American Psychology, 39*(2), 93-104.

Guzdial, M., Turns, J., Rappin, N., & Carlson, D. (1995). "Collaborative Support For Learning In Complex Domains." In J. L. Schnase & E. L. Cunnius Eds.), *Computer Support for Collaborative Learning (CSCL '95)* (pp. 157-160). Bloomington, IN: Lawrence Erlbaum Associates.

Hayes, J.R., & Flower, L.S. (1980). Identifying the organization of writing processes. In L. Gregg & E.R. Steinberg (Eds.), *Cognitive processes in writing* (pp. 3-30). Hillsdale, N.J.: Lawrence Erlbaum Associates.

Heeter, C., Chu, C., Maniar, A., Winn, B., Mishra. P., Egidio, R., Portwood-Stacer, L. (2003). Comparing 14 plus 2 forms of fun (and learning and gender issues) in commercial versus educational space exploration digital games. Proceedings of the International Digital Games Research Conference. University of Utrecht: Netherlands.

Hillocks, G. (1986). The writer's knowledge: Theory, research, and implications for practice. In A. Petrosky and D. Bartholomae (Eds), *The teaching of writing. Eighty-fifth yearbook of the national society for the study of education, part II* (pp. 71-94)..Chicago: University of Chicago Press.

Jackson, P. W. (1968). Li*fe in the classroom.* New York: Holt, Rinehart and Winston.

Leinhardt, G, & Greeno, J.G. (1986). The cognitive skill of teaching. *Journal of Educational Psychology, 78*(2), 75-95.

Lesgold, A.M., Feltovich, P.J., Glaser, R., & Wang, Y. (1981). *The acquisition of perceptual diagnostic skill in radiology*. Technical report no. PDS-1. University of Pittsburgh, Learning Research and Development Center, University of Pittsburgh.

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

Petroski, H. (1985). *To engineer is human: the role of failure in successful design (1st ed.).* New York, N.Y.: St. Martin's Press.

Petroski, H. (1994). *Design paradigms: case histories of error and judgment in engineering*. New York, N.Y.: Cambridge University Press.

Perkins, D.N. (1986). *Knowledge as design*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Peruski, L., & Mishra, P. (in press). Webs of activity in online course design and teaching. *ALT-J: Research in Learning Technology.*

Pople, H.E. (1982). Heuristic methods for imposing structure on ill-structured problems: The structuring of medical diagnostics. In P. Szolovits (Ed.), *Artificial intelligence in medicine* (pp. 119-189). Boulder, CO: Westview Press.

Putnam, R.T. & Borko, H. (2000). What do new views of knowledge and thinking have to say about research on teacher learning? *Educational Researcher, 29*(1), 4-15.

Reitman W R, (1965). Cognition and thought. New York: Wiley.

Resnick, L. B. (1988). Treating mathematics as an ill-structured discipline. In R. I. Charles & E. A. Silver (Eds.), *The teaching and assessing of mathematical problem solving* (pp. 32-60). Hillsdale, NJ: Lawrence Erlbaum Associates.

Rittel. H., & Webber, M., (1973). Dilemmas in a general theory of planning, *Policy Sciences, 4*(2), 155-169.

Rosenblatt, L.M. (1978). *The reader, the text, the poem: The transactional theory of literary work.* Carbondale, IL: Southern Illinois University Press.

Science (1999). Special issue: Complex Systems. *Science, 284*(5412), 1-212.

Solomon, S., & Shir, E. (2003). Europhysics News, 34(2). http://www.europhysicsnews.com/full/20/article4/article4.html, Retreived May 22, 2006.

Schwab, J. J. (1983). The Practical 4: Something for curriculum professors to do. *Curriculum Inquiry, 13*(3), 239-265.

Shulman, L. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher, 15*(2), 4-14.

Shulman, L. S. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review, 57*(1). pp. 1-22.

Snow, C.P. (1959). The two cultures and the scientific revolution. New York: Cambridge University Press.

Spiro, R.J., Coulson, R.L., Feltovich, P.J.,& Anderson, D. K. (1988). Cognitive flexibility theory: Advanced knowledge acquisition in ill-structured domains. In V. Patel (Ed.), *Tenth Annual Conference of the Cognitive Science Society* (pp. 375–383). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Spiro, R.J., Feltovich, P.J., Jacobson, M.J., & Coulson, R.L. (1991). Cognitive Flexibility, Constructivism, and Hypertext: Random Access Instruction for Advanced Knowledge Acquisition in Ill-Structured Domains. *Educational Technology, May*, 24-33.

Spiro, R.J., Jehng, J.-Ch. (1990), Cognitive Flexibility and Hypertext: Theory and Technology for the Nonlinear and Mutlidimensional Traversal of Complex

Subject Matter, in D. Nix, R. Spiro (Eds.), *Cognition, Education, and Multimedia: Exploring Ideas in High Technology* (pp. 163-204). Hillsdale, NJ:Lawrence Erlbaum Associates.

Spiro, R. J., Vispoel, W. L., Schmitz, J. G., Samarapungavan, A., & Boerger, A. E. (1987). Knowledge acquisition for application: Cognitive flexibility and transfer in complex content domains. In B. K. Britton & S. M. Glynn (Eds.), *Executive control processes in reading* (pp. 177-199). Hillsdale, NJ: Lawrence Erlbaum.

Williams, S. M., (1992). Putting case-based instruction into context: Examples from legal and medical education. *The Journal of The Learning Sciences,* 2(4), 367-427.

Zeichner, K., Melnick, S. & Gomez, M. L. (Eds.). (1996). Currents of reform in preservice teacher education. New York: Teachers College Press.

Zhao, Y. (2003). *What teachers should know about technology: Perspectives and practices.* Greenwich, CT: Information Age Publishing.

[i] Contributions of the two authors to this article were equal. We rotate the order of authorship in our writing.