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From TPACK Concept to TPACK Practice: An Analysis of the Suitability and Usefulness of the Concept as a Guide in the Real World of Teacher Development

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This paper describes the TPACK model and how it was used to guide the design and development of a school district's teacher development program that was funded by a grant from the New York State Department of Education. The usefulness of the TPACK model as a framework for teacher development projects was evaluated using interviews of teachers who participated in a project. The results indicate that TPACK is a very powerful and appropriate model when used as a framework for such projects. Even critiques and recommendations made by teachers were often expressions of TPACK basic principles or assumptions that highlighted where the project could have better met TPACK ideals. However, TPACK does not appear to be a model that can be used as a single source of conceptual guidelines. The interview data highlighted important, even crucial, aspects of a project that are not directly addressed by the TPACK model. Chief among these were logistical issues, the need to consider principles of adult learning and diffusion models when designing development projects, and the crucial importance of building and supporting social/professional networks.

Keywords: TPACK, teacher development, technology integration, cognitive flexibility theory, pedagogical knowledge, qualitative research

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INTRODUCTION

One of the most important and influential 21st Century conceptual developments in the area of technology and teacher education is the development of the TPACK model (Koehler & Mishra, 2008; Mishra & Koehler, 2006) for thinking about the knowledge, skills, and dispositions a teacher needs in order to successfully integrate educational technologies into the classroom. Technology coordinators and directors are often in those jobs because they have an abiding and intense interest in the use of information and educational technologies in schools. This is to be expected but that intense devotion to one aspect of the complex and many faceted processes of teaching and learning, even an aspect as important as instructional technology, brings with it the danger that teacher development programs designed and implemented by the "techies" may be too focused on hardware and software while giving short shrift to related topics such as the use of innovative teaching methods that become possible when modern technologies are available in the classroom (Papert, 1987).

Such a concern is the latest in a robust history of worries about how technology integration is initiated and supported. There have been many others. For example, the Office of Technology Assessment (1995) report on the then current state of technology and teacher education noted that only about 15% of the money available to support technology integration in schools was spent on teacher training and development. Many districts seemed to assume that just buying and installing the hardware and software was enough – that teaching and learning would be enhanced by the sheer presence in the schools of more computers and related learning technologies. In the 16 years since the OTA report a general consensus has been reached in the field that both staff development and ongoing support are necessary for successful integration of technology, and that 15% of the technology budget is not generally enough to accomplish this crucial component of a district technology plan (NCREL, 2000).

Another question about technology and teacher education that was not clearly answered in 1995 does seem answered today. It is whether what are now called "one shot" workshops are an effective way of providing teacher education and development on the integration of technology into the classroom. The answer is no, it is not. It is not an effective approach when it comes to educational technology and it is not when it comes to most, if not all, other complex professional topics that are the focus of teacher development today. "Traditional one-shot workshops rarely if ever result in changes in classroom practice" (Meltzer, 2010).

These are but a few of the issues that must be addressed when it comes to how teachers are to be prepared to infuse technology into the learning experiences of their students. Valanides & Angle (2005) concluded, for example, that there is a general "failure of teacher development programmes to adequately prepare teachers to integrate ICT in teaching and learning" (p. 81). One of their explanations for that failure was the "lack of a systematic framework to systematically guide teachers' integration of ICT in teaching and learning." They nominated Shulman's (1986) framework, PCK or Pedagogical Content Knowledge, as a way to address what they consider to be one of the major root causes of the failure of teacher development efforts to support the infusion of technology into the classroom. At the heart of Shulman's PCK is the idea that teaching requires knowledge of content, knowledge of teaching methods (pedagogy), *and* knowledge of how these two domains of knowledge interact and influence each other. This relationship is illustrated in Figure 1.

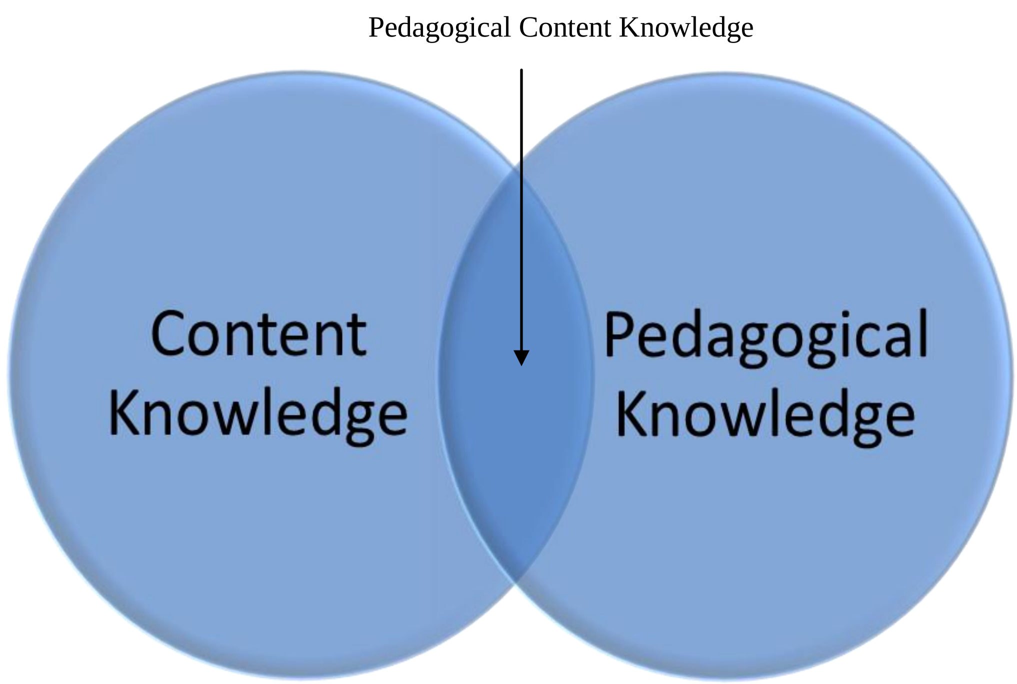

Figure 1. Graphical Representation of Shulman's PCK Model.

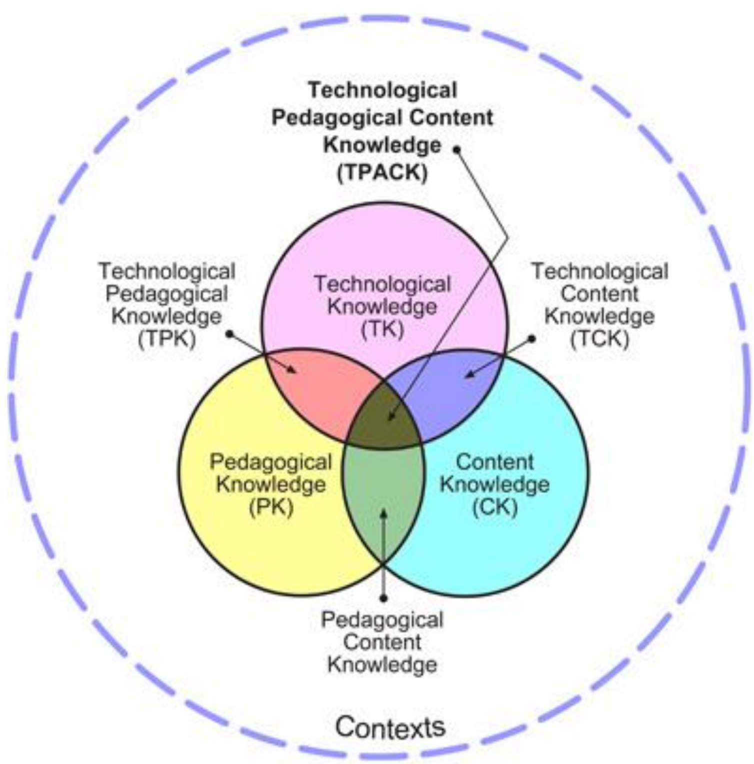

Figure 2. The TPACK Model. (Adapted from the Wikipedia entry "TPCK – Technological Pedagogical Content Knowledge." The original abbreviation for this model was TPCK but was recently changed to TPACK.)

PCK has helped the field of teacher education think about what teachers "need to know" in a more sophisticated way. That essential knowledge is not two separate bodies of knowledge – content and pedagogy. It is, instead, those two bodies of knowledge plus a body of knowledge that is created through the interaction of content and pedagogy knowledge. There are thus three bodies of knowledge and they are not separate from each other. They interact and influence each other in ways that require a teacher to think about them together, not separately.

Shulman's PCK model has been examined, expanded, and elaborated by many scholars and practitioners since 1986. And, while all those contributions are important, we will focus here on one of them. It is the work of Mishra & Koehler (2006) on expanding PCK to include another domain – the use of technology to support teaching and learning. The resulting model – Technological Pedagogical Content Knowledge or TPACK – adds further complexity to the way we think about teaching, learning, and technology. It does that by adding another knowledge domain (technological knowledge or TK) to the basic model and also adding additional interactive relationships between the different core domains. Figure 2 is currently the most popular way of representing the TPACK model.

As you can see the model has three basic or core content areas: content knowledge (CK), pedagogical knowledge (PK), and technological knowledge (TK). However, a major contribution to our understanding of the knowledge and skills needed to integrate technology into teaching and learning is the four areas of interaction. TK and PK interact to produce "Technological Pedagogical Knowledge." An example of this type of knowledge would be the different teaching methods teachers have developed for geometry when they use software such as Geometers Sketchpad or Cinderella. Knowing

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> TPACK is an emergent form of knowledge that goes beyond all three "core" components (content, pedagogy, and technology). Technological pedagogical content knowledge is an understanding that emerges from interactions among content, pedagogy, and technology knowledge. Underlying truly meaningful and deeply skilled teaching with technology, TPACK is different from knowledge of all three concepts individually. Instead, TPACK is the basis of effective teaching with technology, requiring 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 to develop new epistemologies or strengthen old ones. (Koeher & Mishra, 2009)

Since it was developed the TPACK model has been used to guide the design and delivery of teacher development programs and the current literature contains a number of descriptions of successful teacher development programs based on the TPACK model (e.g., Neiss, et al., 2009). Much of the model is represented in Figure 2 but there are also some very important assumptions of the model that are not represented in the figure. TPACK's organization of knowledge domains teachers need to know into three core areas, three two-way knowledge domains, and the multiply interactive domain of TPACK, is a very important contribution to our understanding of technology and teacher education. However, the underlying assumptions made by the developers of the model are also very important. There are three major assumptions and each of them has significant implications for the way we think about preparing teachers to use technology in their classroom.

ASSUMPTION 1: TEACHING IS AN ILL-STRUCTURED ACTIVITY.

Koehler & Mishra (2009) used Rand Spiro's Cognitive Flexibility Theory (Spiro & Jehng, 1990) as a foundation for TPACK. Spiro's theory essentially asserts that some knowledge domains are "ill-structured" as well as complex and that teaching that type of knowledge calls for different pedagogies than those that are ideal for teaching "well-structured" and simple knowledge. Though his theory does not adequately deal with the question of how to authoritatively decide what is well structured and what is ill structured, Spiro's Cognitive Flexibility Theory does offer a conceptual framework for making decisions about when to use traditional direct instruction (e.g.., behavioral) pedagogies, which he believes are most appropriate for well structured, simple knowledge, and when to use more flexible and constructivist pedagogies which he sees as needed when learning ill-structured, complex knowledge is the goal. Koehler and Mishra (2009) make it clear that TPACK is based on the assumption that teaching is ill-structured:

> As educators know, teaching is a complicated practice that requires an interweaving of many kinds of specialized knowledge. In this way, teaching is an example of an ill-structured discipline, requiring teachers to apply complex knowledge structures across different cases and contexts … . Teachers practice their craft in highly complex, dynamic classroom contexts . . . that require them constantly to shift and evolve their understanding. Thus, effective teaching depends on flexible access to rich, well-organized and integrated knowledge from different domains including knowledge of student thinking and learning, knowledge of subject matter, and increasingly, knowledge of technology.

This is a vitally important assumption because it points teacher educators away from conceptualizing teaching as a, for example, "technical-rational" process that involves the application of validated methods to each new group of learners. Instead, teaching is viewed as a "craft" which implies that artistry is involved in the practice of teaching and not simply the application of pre-determined rules or recipes. As Koehler and Mishra (2009) put it, "By simultaneously integrating knowledge of technology, pedagogy and content, expert teachers bring TPACK into play any time they teach. Each situation presented to teachers is a unique combination of these three factors, and accordingly, there is no single technological solution that applies for every teacher, every course, or every view of teaching."

ASSUMPTION 2: DIGITAL TECHNOLOGIES HAVE UNIQUE CHARACTERISTICS.

The assumption that teaching is an ill-structured activity acknowledges the work of constructivists as well as cognitive science and learning sciences scholars. This second assumption adds a perspective from communications theory and related fields. It is the idea that digital technologies are knowledge or information tools that are qualitatively different from the revolutionary tools of earlier eras, such as the printing press, that significantly changed the course of human history. Several authors have even argued that the use of digital technologies radically changes not only the means of knowledge dissemination and communication, but also changes the learner and the content of learning (e.g., Prensky, 2001).

> Today's students have not just changed *incrementally* from those of the past, nor simply changed their slang, clothes, body adornments, or styles, as has happened between generations previously. A really big *discontinuity* has taken place. One might even call it a "singularity" – an event which changes things so fundamentally that there is absolutely no going back. This so-called "singularity" is the arrival and rapid dissemination of digital technology in the last decades of the 20th century. (Prensky, 2001)

The way this general view of digital technologies was incorporated into the TPACK model (Koehler & Mishra, 2009) is through the assumption the digital technologies that are increasingly important elements of education are not like earlier technologies such as pencils, chalkboards, or a Bunsen burner in a chemistry lab. Virtually all the traditional technologies share three characteristics: specificity, stability, and transparency (see Figure 3).

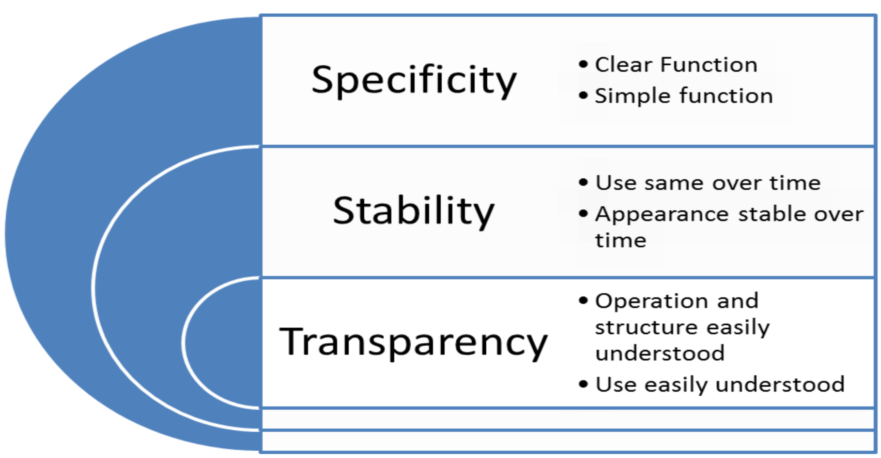

Figure 3. Koehler & Mishra's characteristics of traditional educational technologies such as chalkboards.

Common traditional classroom technologies like the chalkboard all share the characteristic of *specificity* – they were designed to accomplish one particular type of work and that function is fairly easy to understand. Even when there is a change in the technology – such as from chalkboards that use traditional chalk and felt erasers to whiteboards that use pens and cloth erasers – the old and new versions of a "chalkboard" essentially do one particular job. Those traditional technologies are thus stable – the way they are used and even their appearance or structure tends to be stable over decades if not centuries. The chalkboard was invented in 1801 and, while there were many technical improvements over the last 200+ years, such as "dustless chalk," the chalkboard has been a familiar classroom technology since it was popularized in the early 19th century. Chalkboards are still in use in hundreds of thousands of classrooms today but new schools will typically install whiteboards that require special pens rather than chalk, however, the form and function of whiteboards is essentially the same as chalkboards.

Koehler & Mishra's (2009) third and final characteristic of traditional classroom technologies was that of *transparency*. It is relatively easy for children, and teachers, to understand the way most traditional classroom technologies work as well as how to use them.

The authors went to some efforts to point out that traditional classroom technologies have specific uses, are relatively stable over time, and are transparent or easy to understand. They did that in order to make the point that digital technologies – the technologies that are most often the focus of teacher development work – have none of those characteristics. In fact, they tend to have the opposite characteristics as shown in Figure 4.

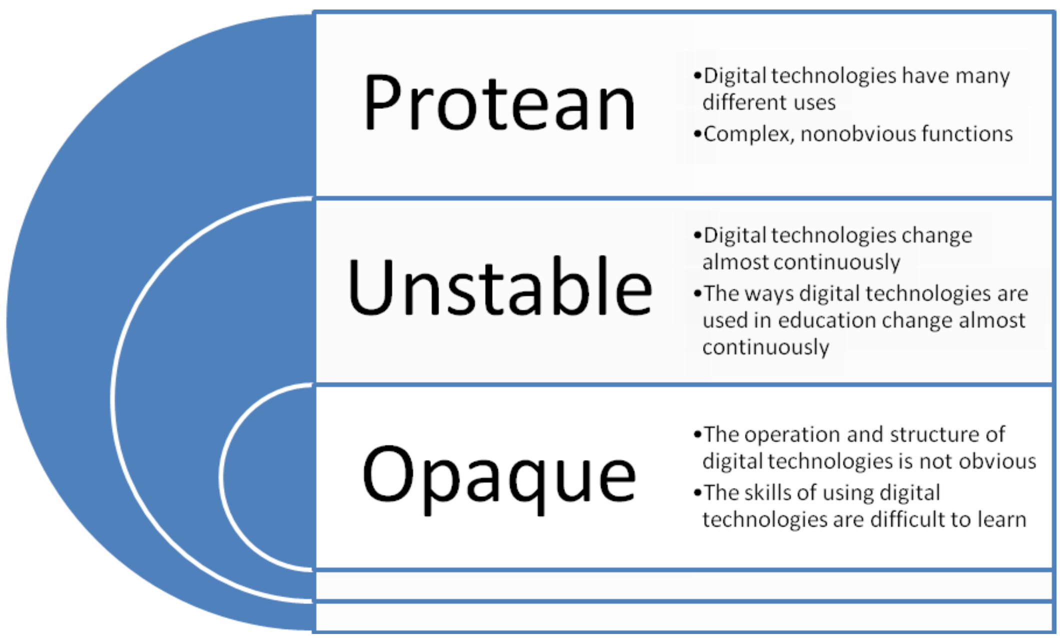

Figure 4. Mishra and Koehler's characteristics of digital technologies.

The truth of Koehler & Mishra's (2009) statement that "digital technologies—such as computers, handheld devices, and software applications—by contrast, are protean (usable in many different ways . . .); unstable (rapidly changing); and opaque (the inner workings are hidden from users)" is demonstrated daily in preservice and inservice teacher development programs where teachers struggle to understand how to use a range of digital technologies and why they should. The characteristics of digital technologies used in the classroom have important implications for the way teacher development programs are designed. (Note: while Koehler and Mishra did not include it in their list of digital technology's characteristics we think the *unreliability* of the current generation of digital classroom technologies is a fourth characteristic that must be taken into consideration. Few digital technologies work 24/7 which means support, backup, and alternative plans are an inherent component of many if not most successful technology integration projects.)

ASSUMPTION 3: TECHNOLOGIES ARE NOT NEUTRAL.

The assumption that teaching is an ill-structured activity acknowledges the work of constructivists as well as cognitive science and learning sciences scholars. The assumption that digital learning technologies have unique characteristics recognizes important theoretical contributions from communications research and related fields. This third assumption adds the ideas of critical theorists about learning technologies into the foundation of TPACK:

> Also complicating teaching with technology is an understanding that technologies are neither neutral nor unbiased. Rather, particular technologies have their own propensities, potentials, affordances, and constraints that make them more suitable for certain tasks than others . . . Using email to communicate, for example, affords (makes possible and supports) asynchronous communication and easy storage of exchanges. Email does not afford synchronous communication in the way that a phone call, a face-to-face conversation, or instant messaging does. Nor does email afford the conveyance of subtleties of tone, intent, or mood possible with face-to-face communication. Understanding how these affordances and constraints of specific technologies influence what teachers do in their classrooms is not straightforward and may require rethinking teacher education and teacher professional development. (Koehler & Mishra, 2009)

APPLYING THE TPACK MODEL

Although TPACK is a relatively recent development, it has already had a significant influence on the field. Numerous papers, for example, have been published describing the use of the TPACK model to design, develop, and deliver preservice teacher education (Chai, Koh, & Tsai 2010; Shin, Koehler, Mishra, Schmidt, Baran, & Thompson, 2009; Burns, 2007;) as well as inservice teacher development (Harris & Hofer, 2011; Wilson, 2011; Allan, Erickson, Brookhouse, & Johnson, 2010). Virtually all of the available publications on the application of TPACK report positive outcomes, and the inherent logic of the model is difficult to fault because it highlights the importance of content, pedagogical, and technological knowledge – and the *interactions* between those core knowledge domains – in any effort of teachers to improve teaching and learning that includes the use of technology. This paper is a report of yet another application of TPACK to the process of helping practicing teachers enhance student learning. However, our focus is not on either describing this inservice project in detail or reporting an evaluation of it. It is on the use of our experiences in the project to analyze the usefulness, relevance, meaningfulness, and possible limits of the TPACK model in practice.

There is a typical adoption cycle for conceptual frameworks and models like TPACK. Such models break new ground and offer researchers and practitioners innovative and powerful ways of thinking and acting. The first phase of adoption is often one of almost unbounded enthusiasm about the new model, accompanied by efforts to further develop it so that it fits many different contexts. The activities of this phase may continue until the model is replaced by another revolutionary model, but additional types of studies eventually begin to be disseminated. One type is an analysis of the model that is, in essence, a test of whether it is truly a good "fit" with the contexts to which it is applied. The basic question asked in such studies is, "Does Model X actually reflect what really happens in the real world and will using it help us do our job better?" One recent dissertation (Wilson, 2011) on TPACK asked such questions and reported results that ask us to seriously consider some of the basic ideas/assumptions of TPACK.

Michele Wilson (2011) made this comment in her dissertation:

> Typically, the TPACK model is represented by three equal circles that blend technology, pedagogy and content. In practice as observed in the study, emphasis on the three areas is not equal. For example, teachers are clear about selecting technologies to support their teaching. Moreover, teachers also describe quickly the content they wish to teach. The fact that content and technology are readily accessible to teachers is consistent with the first theme of the study which described the pattern of the sessions. These two circles, representing content and technology, seem to be equally balanced for the teachers participating in the study. (p. 46)

Wilson's point is that in practice teachers may not learn and use knowledge about pedagogy (what she called HYPS or "high yield pedagogical strategies") at the same level and rate as knowledge about content and technology even if technology, pedagogy and content receive balanced treatment in a teacher development program. A related point was made by Chai, Koh, & Tsai (2010) in their statistical analysis of the knowledge domains of TPACK, TPK, PCK, and TCK. They correctly noted that these four aspects of the model are *constructs* – as opposed to demonstrated elements of the real world – and they questioned whether these four domains can always be differentiated. "Preservice teachers may see using ICT for classroom teaching as an act of integrating TK, PK and CK to form TPACK for a particular lesson [thus cognitively bypassing the interactive domains of TPK, PCK, and TCK]. Inservice teachers with more pedagogical experience may better benefit from professional development making fine grained differences between constructs such as TPACK, TCK, and TPK, which could possibly hone their technology integration expertise. This is an area that needs to be further studied through longitudinal studies of how preservice teachers' technology integration expertise develops as they become full-fledged teachers." The authors proposed that "a better understanding of the relationships between TPACK constructs can inform the design of ICT programs for both preservice and in-service teachers."

Chai, Koh, and Tsi based their analysis of TPACK constructs on empirical evidence but questions have also been raised from an epistemological perspective. Angeli and Valanides (2008) questioned whether TPACK is an adequate "analytical theoretical framework for guiding and explaining teachers' thinking about technology integration in teaching and learning" (p. 157). Though they concluded that TPACK is a promising conceptual framework, they also advocated its use through a particular set of instructional design procedures drawn primarily from the learning sciences literature.

In this paper we will explore what might be called the “validity” of the TPACK model through an analysis of data collected on an inservice teacher development program.

DESCRIPTION OF THE INSERVICE PROJECT

The project was funded by an American Recovery and Reinvestment Act (ARRA) Enhancing Education Through Technology (EETT) grant from the New York State Department of Education to a medium size school district in Westchester County that serves a high percentage of low income students and has a below average high school graduation rate. The focus of the project was enhancing student learning in two high school courses that are required for graduation - Integrated Algebra and Living Environment (biology).

The district adopted a three-pronged approach to enhancing instruction in these two core courses:

1. Providing teachers and their students with a range of instructional technologies (IT), and delivering both initial training and ongoing support for teachers as they integrated these technologies into their professional life and classroom practice.
2. The second major component of the project was an extended set of staff development activities that included both online activities and weekly face-to-face meetings (Mondays after school). Teachers were paid for their participation in these activities and their involvement was voluntary. There was also an additional incentive in that teachers received a new, well equipped laptop computer if they participated, and a “laptop cart” for use in their classrooms was available only to those who participated in the project. Additional technologies including a SmartBoard and clicker technology were also installed in their classrooms.
3. The third component of the project was a set of online resources and tools designed for ease of use and applicability to teaching and learning. The online tools included resources such as links to useful web sites, on site resources, discussion forums, and areas where teachers could “easily” create personal and course web sites.

The district adopted the TPACK model as a foundation for design, development, and deployment of the three components of the project.

TEACHER PARTICIPATION

Fifteen algebra and biology teachers from three different high schools in the district participated in the project. Each year these teachers impact approximately 1500 students.

DATA COLLECTED ON THE PROJECT

This paper focused on the results of a set of teacher interviews conducted by the third author of this paper who served as an outside evaluator for the project. Seven teachers were interviewed and they were selected totally by availability at a time when the evaluator could be at the school for the interview. All teachers who were available were scheduled for an interview.

The interviews were semi-structured and open ended. The evaluator asked questions such as why the teacher had decided to apply to participate in the program, what aspects of the project had worked well (or poorly), the types of benefits the teacher had obtained from participation, and what changes or revisions should be made to improve the quality or relevance of the teacher development program. The evaluator also asked about how much focus there was in the project relative to (1) technology, (2) pedagogy, and (3) math or biology content.

RESULTS

A total of seven of the fifteen participating teachers were interviewed in June near the end of the school year. Interviews were conducted at the teachers' schools, usually in the teacher's room during planning periods when no one else was in the room. In all cases, the interviews were private – no other person was in the room. All teachers were asked for permission to record the interview and given assurances that the recordings would be safeguarded and no one other than the evaluator would have access to them. They were also assured that any presentation of the data obtained from the interviews would not include information that would allow individual teachers to be identified. Five of the teachers gave permission for the interview to be recorded. Two did not and in those interviews the evaluator took extensive notes during the interview and at regular intervals restated his understanding of what the teacher had said, then asked for confirmation or clarification if the restatement was not completely accurate.

THE ANALYSIS PROCESS

TPACK provides an organizing structure to the entire process of providing teacher development – from planning the learning experience to selecting the content to evaluating the outcome. TPACK seems particularly powerful as a constant reminder to keep a broad focus at every stage. Harris & Hofer (2011), for example, noted that "technology-related professional development has overemphasized hardware and software affordances, awareness, and skills giving short shrift to usable, customizable strategies for curriculum-based uses for educational technologies" (p. 227-228). Harris and Hofer borrowed the term "technocentric" from Seymour Papert to describe this type of teacher development. Because it supports a conceptualization of teacher development that includes content and pedagogy well as technology, and emphasizes the importance of those knowledge domains that are in the interactions between these three core domains, TPACK seems to be an ideal guide to structuring development work. Our analysis of the interview data in this study was organized around the search for data that helps us demonstrate the value, and the limitations, of using TPACK as an organizing framework. The subsections below are organized around the seven different domains of knowledge in the TPACK model plus the three major assumptions that serve as the foundation for the TPACK model. The results section also includes a subsection on Other Issues that do not seem to fit into the TPACK model but are, nevertheless, very relevant to any discussion of teacher development. The results section ends with a presentation of interview data relevant to the highest level of integrated knowledge – TPACK.

TK – TECHNOLOGICAL KNOWLEDGE

Despite the warnings in the literature that often teacher development about technology is too "technocentric" and thus omits knowledge about pedagogy and content, the interview data made it clear that TK was the focus of the teacher development in this project. Most of the Monday meetings were devoted to training sessions on the new technologies being added to the classrooms such as SmartBoards, clickers, laptops, and Internet connectivity. This appears to be a direct violation of both the consensus advice in the literature and the basic idea of TPACK. However, the interviews also indicated that this focus on technology was what teachers wanted and expected. Their complaints and concerns about the technology training were not about there being too much. Instead, they wanted more, but different, TK training. For example, three of the teachers described the training as too fast with too little opportunity for the teachers to practice and learn to use the new technologies. They typically described the training as sitting and watching someone who was an expert demonstrate the technology. However, without opportunities for guided practice and support, teachers often found that when they tried to use features of the new hardware and software they had watched the "expert" use with ease, they could not. This was frustrating and irritating, and more than one teacher noted that the instructors working for the companies that supplied the hardware and software would not survive long at their high school if they employed the inadequate teaching methods that were commonplace in the teacher development program. As one teacher put it after describing the frustration she felt during the expert presentations, "When we actually sat down and did hands on, that is when I learned." She concluded that the teacher development sessions would have been better if the expert presentations had been eliminated entirely and the time spent doing hands-on exploration of the hardware and software. She, and several other teachers, also saw the technocentric focus of much of the training sessions as undesirable. They wanted more focus on the way the technology could be used in the classroom – more models, more examples, and more chances to work on creating lessons that take advantage of the new technologies and new pedagogies. The teacher's views, therefore, were an expression of the TPACK model that calls for more integration and less attention to separate knowledge such as TK.

PK - PEDAGOGICAL KNOWLEDGE

The views of teachers about PK, particularly as it was addressed in the training sessions of the project, were complex. Early in the project three Monday sessions were invested in presentations of basic ideas about how students learn, principles of constructivist and student centered learning, and other topics in that same vein. No teacher made positive comments about these sessions and several had very negative views of them. In their view these were "theory" sessions and they not only found them unhelpful, they felt they took up time that should have been spent learning the new technologies that were being installed in their classrooms and learning new or innovative pedagogies through exploring lesson plans and discussing ideas about ways of teaching their subject matter.

On the other hand, teachers had virtually the opposite view of other PK-focused activities. For example, they worked individually and together to create lesson plans they would implement in their classes. Most teachers were very positive about this activity and many considered it to be one of the major strengths of the project. They often described it as learning to incorporate the SmartBoard, or clicker technology, or student laptops into lessons. One teacher even named learning to "do website development" as a highlight of the project for her. However, the teachers' descriptions of their technology work indicated they also changed their teaching methods as well. For example, the teacher who rated highly learning to create websites had plans to use a class website in ways that involved a significant change in her pedagogy. Interest in pedagogy was also a reason why teachers were very positive about the sections of the project website where they could find sample lessons or links to web resources with lesson plans and teaching advice. Their view of PK and its importance to their professional practice was, therefore, mixed. Theoretical knowledge was not valued, but practical pedagogical knowledge was, even if it was hidden behind a focus on technology. Many of the recommendations for how to improve the project involved providing more opportunities to learn about new ways of teaching – not at the theoretical level but at the practical level such as looking at lesson plans created by other teachers or working in groups to study ways of developing lesson plans that took advantage of the student laptops provided by the project.

Another indication of both a respect for, and interest in, PK was frequent mention by teachers of what they planned to do next year. Their plans often included the use of new pedagogies but they were often wrapped in a cover of technology. For example, one teacher felt that a very valuable addition to the resources for students would be a web site where they could pose questions and get answers about the subject matter. She felt this would give students more opportunity to get involved with the subject and also make more decisions about what they learned. She described this as a technological change (TK) but it was probably more of a pedagogical change (PK) and an interactive change (TPK).

CK - CONTENT KNOWLEDGE

Data from the teacher interviews indicated very little content knowledge was covered in the training sessions and that most teachers did not feel content knowledge was where the emphasis should be placed. When asked about learning new content one teacher noted that she had a degree in the subject she taught, that she had been teaching the subject for many years, and that she saw no need for additional training on content. However, two other teachers felt the combination of science and mathematics teachers put them at a disadvantage because any content knowledge covered in the development sessions was bound to be irrelevant to half the teachers. These teachers wanted more math or science content but they also wanted the program to be organized so that they did not have to sit through examples and lessons about the "other" content – either science or math.

Two other teachers agreed there was not much need for "a lot of focus on content" but they felt they needed more exposure to how to use the new digital technologies to teach their content. This was an expression for the need to emphasize TCK and other interactive domains of knowledge (TPK and PCK). The interview data relevant to that are presented in the next section.

TPK - TECHNOLOGICAL PEDAGOGICAL KNOWLEDGE, TCK - TECHNOLOGICAL CONTENT KNOWLEDGE, AND PCK – PEDAGOGICAL CONTENT KNOWLEDGE

Because the interview data on the interactive knowledge domains – TPK, TCK, and PCK – lead to similar conclusions we have grouped the data about these three domains together.

In the interviews teachers regularly gave examples of innovative uses of technology in their classrooms. However, in almost every instance their descriptions focused on the use of a particular technology rather than the new or revised pedagogy they adopted, new content added, or new ways of teaching the content. For example, one math teacher, Alberto, described how students were skeptical about the usefulness of the clicker technology that was available when the SmartBoards were added to the classroom. Alberto also expressed some clicker skepticism himself. However, when he used the clickers to present tasks students should be able to do if they had understood the new concepts in a lesson, the procedure was so useful that both the teacher and the students were enthusiastic and wanted more. Eventually clickers became a routine element of lessons that dealt with new procedures and topics. Students liked the ability to get fast feedback that helped them pinpoint problems in the way they tried to solve a new type of problem. For the teacher, the performance of students on the application problems not only provided information about how successful the lesson was for the group, it helped identify individual students who needed help. The teacher saw this as the application of "clicker technology" but it was actually much more than that. It involved a change in lesson planning and teaching methodology as well. Problems had to be created and included in the database of problems available through the clicker software. This was not a trivial task because the problems needed to be dependent primarily on whatever the focus of the lesson was and to be solvable within a reasonable amount of time. Further, the information from the instant feedback changed the teacher's work in two ways. Alberto spent more time working with students who did not master the new procedure or concept on first exposure, and knowledge about student difficulties led him to make changes in those initial or introductory lessons. However, Alberto did not focus on the pedagogical changes, though there were many. Instead his emphasis was on the technology. This was a common approach among the teachers interviewed. They saw the new technology as the major force in changing what they and their students were doing in the classroom, but in fact there were significant changes in the pedagogy as well. Another teacher's comments about clickers also exemplified this approach. Ellen talked about using the clicker technology to create a "little drama" in her classes. She posed problems, had students try to solve them and then revealed the answers and students' answers in a style similar to the drama that accompanies the selection of the daily lottery numbers on television. This was a change in pedagogy as well as the use of new technologies. However, even though teachers had been introduced to the full TPACK model, TPK seemed to be collapsed into the TK domain which effectively hid the contribution that PK made to changes in their classrooms.

Although this type of knowledge (TPK, TCK, PCK) was not mentioned often in the interviews, it was discussed by several teachers. For example, one teacher noted that when you are teaching geometric concepts the ability to pull off the Internet and display an animated visual representation of what students are studying is not only helpful to learning, it actually changes students understanding of the content. They "know more" about it because the technology has added another dimension to their knowledge.

Had the interview data been coded for instances where TPK, TCK, and PCK domains were directly discussed, the conclusion would have been that they were rare. The focus would have been on TK. However, when the teacher's discussions were looked at more deeply, there were many instances where they discussed changes in their classrooms that reflected new TPK, TCK, and PCK as well as PK and CK domains. Thus, classroom practices demonstrated the use of a range of interactive knowledge but teacher vocabulary did not. Again, children's use of language correctly versus their ability to explain that use in the language of a grammarian comes to mind.

Ironically, one pertinent comment was directed at the quality of the presenters who introduced teachers to the new technologies being installed in their classrooms. Much of the training on the new technologies was conducted by employees of the manufacturer or distributor. This is a common practice and is often included in the bid submitted to the school district. One teacher politely suggested that the people who trained them to use the hardware and software should be knowledgeable of their content area and the specialized teaching methods used in that content area. Several teachers echoed that perspective – that quality instruction on the use of hardware and software is more likely to be provided by someone who knows both content and the pedagogy.

The interactive domains of knowledge were also discussed indirectly through comments about the value of resources. Several teachers, for example, talked about the project web site and the resources available there. As one teacher put it, "I found a lot of lessons. I would pick and choose the parts I liked and create my own lessons." She went on to say that now that she had learned about what is available on the web, "I search all the time." Her goal for the summer was to use the Internet resources she had located to prepare all new lessons for the classes she would be teaching next year. This is one example of how a teacher focused on technology (e. g., web sites where lesson plans were located) but the interest expressed was actually one that related to TPK, TCK, and CKP. The lessons were specific to a particular content, pedagogy, and supporting educational technology. The teacher could take, for example, the TPK, TCK, or CKP (or TPACK) knowledge expressed in a lesson plan and then adapt it to fit her particular teaching context. The result was often a good example of TPACK.

ASSUMPTION 1:
TEACHING IS AN ILL-STRUCTURED, COMPLEX KNOWLEDGE DOMAIN.

In addition to the knowledge domains TPACK emphasizes, the model is based on three major assumptions that have a major impact on how TPACK is used in practice. The first assumption is about the nature of teaching. Teachers in this study seemed to come to the project understanding that teaching is indeed an ill-structured and complex activity that requires flexibility and ongoing adjustments and decision-making. They rarely talked about finding a lesson and using it with their students exactly as they found it. Adaptations of both teaching methods and content were frequently mentioned and teachers treated that as a normal, and obvious, aspect of their professional work. None of the teachers seemed to be looking for "recipes" they could apply to their classes with the expectation they would "work" without any change or adaptation.

ASSUMPTION 2:
DIGITAL TECHNOLOGIES ARE PROTEAN, UNSTABLE, AND OPAQUE.

This TPACK assumption is relatively abstract and was not discussed by any of the teachers in their interviews. However, they did discuss what may be considered the consequences of these characteristics. For example, many talked about the technical problems they had with equipment that did not work at critical times. Support was available through a process that involved filling out a "work order" and waiting for someone to come and fix the problem. This often took weeks and in the meantime the technology could not be used. In their current state digital technologies call for support procedures that provide repair and other forms of help in a timeframe that spans minutes and hours, not days, weeks, and months. Many school districts do not have such a support structure and this will inevitably deter teachers from using pedagogies that depend on the routine use of digital technologies.

ASSUMPTION 3:
DIGITAL TECHNOLOGIES ARE NOT VALUE NEUTRAL.

This assumption, which is derived from the work of critical theorists, was not mentioned in the interviews. Teachers did not seem to view pedagogy, content, or technology through an ideological lens that highlighted the inherent value decisions that influenced the design of various educational technologies. They saw what the technology could do and then decided if they wanted to use it as intended, adapt it, or ignore it. A good example in this project was clicker technology. This technology allows teachers to prepare tests, typically multiple choice, and project them on a screen. Students use their clickers to choose the answer they consider correct, and the teacher sees the results by individual and group on a video monitor. Clicker technology clearly derives from a behavioral, teacher-centered, or "instructionist" view of what teaching is, and it is difficult to see how this technology can support constructivist to "student centered" methods such as problem-based learning or interactive simulations. That virtually no comment was made about the fact digital technologies are not value neutral does not mean, however, that teachers were not aware of that point. That awareness was perhaps more indicated by the level and type of use teachers made of clicker technology. Those who often used teacher centered or instructionist methods tended to use the clicker technology more often, and those who were more student centered in their approach used the clickers in ways that fit with their approach to teaching. Thus, while clickers are based on behavioral and teacher-centered ideologies of teaching, their use may not indicate either ignorance of or lack of awareness of their foundations. They can be adaptively used within other teaching and learning frameworks. Teachers were often able to adapt technologies based on one paradigm of pedagogy to fit their own model of pedagogy.

OTHER ISSUES

The interview data highlighted a number of important aspects of the teacher development project that are important even though they are not a focus of the TPACK model.

Creating a collaborative network of teachers. All the participant teachers had busy lives, including busy professional days. Without formally scheduled meetings like the Monday afternoon teacher development sessions, they might progress through week after week getting the required tasks done but missing opportunities to share ideas and experiences with other teachers. Many of the teachers discussed how important the support from their fellow teachers was. This happened during the Monday meetings but it also happened during the school day. For example, when a teacher could not get the SmartBoard software to work in her classroom, another teacher who had already mastered it came in and helped set it up and get the teacher started. The teacher development program helped create a supportive network of colleagues who not only provided technical help, they critiqued lesson plans, shared their own tentative experiences with new approaches as well as ideas and insights. The literature on adult learning, which is what teacher development is, is filled with discussions about cohort groups, learning communities, participatory action research groups, strategies for the diffusion of innovation, and many other ways of helping adults work collaboratively to develop their expertise. This body of knowledge, while not specifically addressed in the TPACK model, makes a significant contribution to our understanding of how to help teachers develop TPACK.

Using appropriate teaching and support pedagogies when dealing with protean, unstable, opaque content. Teachers are adults and do not learn in the same way, or for the same reasons, as children. There is a substantial body of knowledge about adult learning that was not always used in this project. There is also a body of professional practice knowledge about how to effectively help teachers prepare to use new digital technologies that, as the TPACK model assumes, have characteristics that make them difficult to learn and apply. One teacher described some of the training sessions on

SmartBoards as being too fast, covering too many concepts in each session, and providing too little time for practice. He noted that teachers often understood that it was possible to do some interesting things with the SmartBoards but that they never actually learned to do those interesting things. From comments by several teachers it appears that the sessions designed to teach "how to" knowledge did not always accomplish that goal. Instead, teachers learned "what is possible" by watching experts use the technology. Expanding a teacher's understanding of "what is possible" is certainly a desirable goal but without additional experiences that give teachers a chance to master the technical aspects of the new digital technologies a primary result is likely to be frustration.

Another teacher described an example of the mismatch between pedagogy and desirable outcomes. The instructor who taught teachers to use the clicker technology put teachers in a situation that involved simulating the use of clickers in the classroom. However, the instructor put teachers in the role of students who took tests the instructor had prepared beforehand. Teachers quickly learned to use the clickers to take tests. This was helpful to see how students could use clickers but the more important expertise for the teachers was how to use the clicker software to set up the tests and to use them in various ways in the classroom. This they mainly had to learn on their own. This aspect of professional practice – the creation of lessons that incorporate technology and innovative teaching methods – was mentioned several times in the interviews as something teachers would have liked more time devoted to in the project. In TPACK terms this was a plea to move beyond TK, PK, or CK, and to spend more time on integrative domains like TPK, TCK, CPK, and TPACK. Another example of a desire for more opportunities to focus on the highest level of integrative knowledge (TPACK) was a teacher's statement that it would be "great to sit with someone who can help find resources for what I will be teaching this week, or next week. It would be good to do this individually or in a group – especially in groups." She felt access to persons with expertise at the TPACK level would enable teachers to develop interesting and innovative lessons.

Finally, one teacher noted another mismatch between what she felt teachers needed and what they received in the initial phase of the teacher development sessions. She described the first few weeks of Monday meetings as "listening to lectures on why technology is important in education" and said they were a waste of time "because we already know that." She thought the sessions should have begun immediately with hands on work with the technology and that there should be two groups – one for novices like herself and one for more experienced teachers. As an alternative she suggested novices like her could be paired with a teacher who knew more about technology and could help her learn the basics of the technology – something she struggled with.

Using appropriate teaching and support strategies for different teachers. Another aspect of decisions about appropriate teaching and support pedagogies relates to the range of expertise, motivation, and interests of the participating teachers. This program was designed primarily for teachers who were relative novices in the use of educational technologies, and to some extent the use of innovative teaching methods. However, not all teachers in the project fit that profile. Most, in fact, differed in one way or another from the profile presented above. For example, one of the teachers, Ellen, described how she had been disappointed when she came to the high school and learned that she would not have access to the SmartBoard technology she had avidly used in her previous school. Ellen described the situation as a move backward to "chalk and talk" and she saw the project as an opportunity to get the technology she had already integrated into her teaching. She needed little if any of the technical training provided but she sat through it and found some aspects useful. However, her primary motivation for applying to participate appeared to be the opportunity to get the hardware and software. Perhaps because of her prior experience, she did not find the technology training too fast paced. And, as she discussed the new lessons she was creating and using in her classroom, it was also clear that she was using new pedagogies and also expanding the content her students were learning. For example, she had never used YouTube videos before but once she discovered the many tutorials, experiments, and lessons on YouTube she started using them almost daily. She described how much students enjoyed them, and how they began to "talk about math" with her as well as comment on the diversity of people they saw on the YouTube (and TeacherTube) videos. She used material from Africa, Ireland, India, and many other regions of the world, and students would often ask about the teachers' or students' accents and languages. She described it as "bringing the world into the classroom." This teacher was highly motivated, began the program with advanced expertise, and had developed the professional skills to change her approach to teaching and learning at a relatively fast pace. She used the web resources for the project as a beginning point to find useful web sites and mentioned several she now regularly used in class, including the RegentsPrep.Org where materials about the New York Regents exams were available.

Ellen planned to spend the summer creating new lessons for her math classes that would make math more meaningful by linking it to the work of people like engineers and architects. She was also working on an email homework system she hoped would help reduce a major problem several teachers noted – that many students did nothing school-related outside class time, especially homework. And, she enthusiastically described how she was going to the annual ISTE educational computing conference where she would pick up every sample piece of educational software available that she could use in her classes. Her goal was to get students more invested and interested in math and to make her classroom a place where students did more things. She planned on making mathematics more practical, more applied, and more of a "hands on" activity. She even talked about several ways of getting students involved in making presentations, including having a "math poetry day."

Ellen was atypical and had the program been designed specifically to meet her needs, it probably would have been a failure with other teachers who needed more basic support and a slower pace. However, she exemplified both the core ideas of TPACK and could play roles other than that of learner. For example, she could probably have done a better job of introducing the SmartBoard technology to other teachers than the instructors from the distributor, and she would have had the expertise in technology, pedagogy, and content that some teachers felt was needed, but missing, in some of the technology instructors. In addition, Ellen exemplified many of the characteristics of what has been called a *teacher leader* in the literature, and formal recognition as well as support for her, and perhaps other teachers who participated in this program, might be a next step in diffusing TPACK knowledge to other teachers.

In spite of, or perhaps because of, her advanced knowledge and high motivation, Ellen said the teacher development provided by the program was "fabulous, top of the line." She said she had been in other technology training program and "this one was better." However, thinking of this teacher as a resource and teacher leader as well as a student learning new professional skills would probably enhance both her learning and her contributions to the process of diffusing TPACK throughout the school.

The Problem of Logistics. The Wikipedia definition of logistics is "the management of the flow of goods and services between the point of origin and the point of consumption in order to meet the requirements of customers." It is not a glamorous or high profile activity but the military has long recognized that logistics is what may determine the outcome of a battle or even a war. Corporations also recognize the importance of logistics and those that do well at it often thrive while the relics of those that do not often become articles in memorabilia collections. Schools and other non-profit organizations have not yet grasped the fact that good logistics can be as important as the goods and services being delivered. The teacher interviews highlighted numerous problems in delivery, successful installation, and support of the new technologies in the teachers' classrooms. For example, laptops for use by students were delivered late in the academic year, SmartBoards were installed in classrooms but in some cases did not work for weeks or months because of delays in getting the installers back to the classrooms. These are just two of several logistical problems the program suffered and while this is common in projects like this, that does not reduce the negative impact they have on a project. The knowledge domain on logistics is well established in the field of business, and education may need to recognize and use the practices and procedures that have been developed in business to reduce the negative impact poor logistics has on diffusion of innovation programs like the one described here. Both the need for better logistics and possible ways of addressing that need were voiced by several teachers in their interviews. One for example, after noting that three days was much too long to wait for help, suggested that the Teacher Center at the school be staffed with someone who could provide help and support as needed. On site help, such as having a knowledgeable teacher, or someone in the school's Teacher Center, would, she felt, help solve a major logistical problem.

TPACK - TECHNOLOGICAL PEDAGOGICAL CONTENT KNOWLEDGE

In spite of insightful criticisms and recommendations for improving the teacher development project, virtually all the teachers were very positive about the overall benefit of the program. One described it as "money well spent." Another said it "was the first time the district taught me to integrate technology." Still another earnestly said that every effort should be made to get more teachers involved in this type of training and support project. That was one of only two recommendations he made for improving the program. Another teacher described the project as "the best professional development this district has ever given." Another used the term "fabulous" to summarize her view. Another said the project was "Well worth it! I put a lot of time into it because I was a novice. I spent a lot of time mastering the basics but it was totally worthwhile. I don't think we can possibly stop and we don't want to stop."

Teachers also had recommendations for improving the experience that apply to this broadest level of the TPACK model. Several noted that there had been some opportunities for teachers who taught mathematics and teachers who taught science to meet in separate groups and focus on the knowledge about technology and pedagogy that is specific to the particular content they teach. One said she would have "loved to have all the math teachers sit together and work on lesson plans with an expert who understands the technology and one who knows the curriculum for algebra and geometry." This is in many ways a validation of the TPACK model that assumes there is something unique about both the way technology is successfully deployed, and the most useful pedagogies that can be used, to teach a particular type of content such as introductory high school algebra or high school biology. Teachers recognized the specialized nature of that knowledge domain and saw that their TPACK was not necessarily the same as the TPACK of a teacher from another content area. This could be expanded to additional aspects of teaching (e.g., level, type of student), but an implicit assumption of TPACK that knowledge is not universal and, instead, is contextual, was affirmed by this group of teachers.

In saying that one of the major benefits of the program was "understanding how much is out there" a teacher also illustrated thinking at the highest level of the TPACK model. This teacher talked about resources related to content, pedagogy, and technology – and her examples were generally not sites that covered those knowledge domains separately. They were, instead, sites that provided integrated knowledge, often at the TPACK level.

DISCUSSION AND IMPLICATIONS

Overall, data from the interviews supports the value and appropriateness of the TPACK model as a guiding framework for the teacher development program. This was especially true when it came to analyzing what worked and what needed improvement. Though teachers rarely referred to the TPACK model, the criticisms and recommendations they made were usually expressions of TPACK principles or ideas. In addition, the highly praised elements of the project also tended to be applications of TPACK concepts.

The general value of TPACK seems clear from the data presented in the previous section but there was also data that suggests TPACK must be thoughtfully implemented. For example, even though teachers were aware of and used both new pedagogical and content knowledge they often did not distinguish between TK and PK or CK. Further, they did not always recognize that many of their innovations in the classroom involved interactive use of domains such as TPK, TCK, and PCK as well as TPACK. In many ways the teachers, who were learning in the context of their daily work, were much like children learning their native language. At some point in their language development children may not be able to explain what a present perfect or past continuous verb is, but they can use them correctly. The teachers in this project did not learn to routinely communicate in the terms and language of TPACK, but they did learn to practice according to the principles those terms refer to. This has implications for teacher development programs. Do you spend time teaching a new TPACK vocabulary and language to teachers using blunt force instruction or do you encourage application and professional practice of the TPACK vision – with the assumption that if it is important the understanding of TPACK language and structure will evolve through that practice?

One of the consistent themes found in the interview data was that of conflation. Teachers tended to conflate TPK into TK, for example. The authors of a study cited earlier in this paper (Chai, Koh, & Tsai, 2010) proposed one explanation for this pattern. They suggested that novice or preservice teachers might have less sophisticated and therefore less differentiated knowledge about TPACK and thus tend to organize their knowledge into broad, coarse categories. This may be true, but we do not believe it was the case in this study. Instead, it appears that these teachers, who all had at least several years of teaching experience, had reached a phase in their career when pedagogical decisions were more automatic and required less deliberation. When they learned a new technology and felt they knew how to use it, they "automatically" thought of ways it could enhance teaching and learning. Thus, to them, the new technology was the focus because it was the root cause of change in their classroom. That the technology was part of a larger change, one including changes in the content taught and the pedagogies used, was certainly a part of their tacit knowledge but not necessarily what they emphasized or even acknowledged when asked to explain what they were doing and why they did it. This pattern is similar to explanations of their work given by experts in many fields. Experts tend to build up a significant body of tacit knowledge they use routinely and almost automatically without full awareness they are using it (Gorazon, Ennels, & Hammeron, 2006). In his paper on the development of an instrument to assess TPACK knowledge Sahin (2011) noted that the integration of technology into a classroom may facilitate a student's activation of tacit knowledge relevant to the course content. The use of unacknowledged but nevertheless very important tacit knowledge may apply not only to students, it may apply to teachers as they develop TPACK expertise. The roles and implications of tacit knowledge have not, however, been adequately explored relative to TPACK.

Another implication of these results is the concern on the part of teachers that training on technology be conducted by instructors who are more than experts in the use of the particular hardware and software. In fact, several teachers felt the high level of technical expertise some of their instructors had was a problem rather than a positive characteristic. As teachers were interviewed an image gradually emerged of a young expert standing at the front of the room talking quickly and demonstrating one feature after another of the new equipment in a desperate attempt to get through the full list of features and options for the new Gizmo Model 127. The three interactive knowledge domains (TPK, TCK, and PCK) are emphasized in the TPACK model as necessary types of knowledge a teacher must have. Failure to adequately consider this when selecting and planning training and teacher development sessions was a reason teachers felt the technology training was not as effective as it should have been. In essence, they were saying that when it comes to instructors for teacher development, TK is not enough – even instructors who are responsible primarily for TK should also be competent in CK, and PK, as well as TPK, TCK, PCK, and TPACK.

A third implication of the results is the issue of time. Those of us who work in the area of preservice and inservice support for technology integration seem innately prepared to overestimate what can be accomplished in a given amount of time. One of the almost universal comments from teachers in this study was that they needed more time for all the learning they wanted to accomplish. However, this weakness - devoting too little time to training and support - is not a problem that belongs solely on the shoulders of those who plan and deliver training and support. Grant agencies demand that the unreasonable be accomplished in unbelievably short periods of time; school districts are unwilling to support, or even allow, teachers to invest extended periods of professional time in development activities; and virtually every stakeholder group demands that changes in metrics such as state, group administered, achievement test scores happen after very short periods of development. Real and meaningful change, and real and substantial learning, require realistic and extended investments of time and resources. TPACK does not address this issue directly but until it is recognized and acknowledged as a serious limit to what can be accomplished, it will continue to be one of the hidden barriers to the very goals that everyone desires and hopes for.

Finally, while the TPACK model is a significant step in the right direction – emphasizing the importance of both a range of knowledge domains and the domains that are created at the points of interaction between those domains - it is not a comprehensive model that helps us attend to all the critical issues that influence the outcome of teacher development projects. Examples of important knowledge domains outside the TPACK model that were identified in this study include logistics, collaboration and diffusion of innovation, and adult learning as well what might be broadly described as differentiated instruction. However, that these additional domains also need to be used in planning and delivering teacher development does not detract from the enormous and fundamental contribution TPACK has made to the field. TPACK is so influential today that there may be a tendency to take for granted the core ideas of the model, to assume that we have always know that. But we need only look at our recent past to see that TPACK core values were not always there.

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