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WHAT HAPPENS WHEN TEACHERS DESIGN EDUCATIONAL TECHNOLOGY? THE DEVELOPMENT OF TECHNOLOGICAL PEDAGOGICAL CONTENT KNOWLEDGE

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ABSTRACT

We introduce *Technological Pedagogical Content Knowledge* (TPCK) as a way of representing what teachers need to know about technology, and argue for the role of authentic design-based activities in the development of this knowledge. We report data from a faculty development design seminar in which faculty members worked together with masters students to develop online courses. We developed and administered a survey that assessed the evolution of student- and faculty-participants' learning and perceptions about the learning environment, theoretical and practical knowledge of technology, course content (the design of online courses), group dynamics, and the growth of TPCK. Analyses focused on observed changes between the beginning and end of the semester. Results indicate that participants perceived that working in design teams to solve authentic problems of practice to be useful, challenging and fun. More importantly, the participants, both as individuals and as a group, appeared to have developed significantly in their knowledge of technology application, as well as in their TPCK. In brief, learning by design appears to be an effective instructional technique to develop deeper understandings of the complex web of relationships between content, pedagogy and technology and the contexts in which they function.

What do teachers need to know about technology and how can they acquire this knowledge? These questions have been at the center of intense debate in the recent past (e.g., Handler & Strudler, 1997; Wise, 2000; Zhao, 2003; Zhao & Conway, 2001). There is, however, little clarity about what form this technological knowledge should take, and how it should be acquired. We offer one perspective that considers the development of *Technological Pedagogical Content Knowledge* (TPCK) within a *Learning Technology by Design* seminar. Our approach toward technology integration values rich knowledge about how technology, pedagogy, and content interact with one another, as well as an understanding of the unique affordances of the *Learning by Design* approach to foster the development of these integrated knowledge structures. These ideas have been covered in greater depth elsewhere (Koehler & Mishra, 2005; Koehler, Mishra, Hershey, & Peruski, 2004; Koehler, Mishra, & Yahya, 2004; Koehler, Mishra, Yahya, & Yadav, 2004; Mishra & Koehler, 2003, in press a, in press b, in press c). However, because our rationale for conducting this study requires an understanding of these multiple (and interrelated) ideas, we use the following sections to broadly introduce these foundational strands before presenting a more in-depth and detailed explanation of the design experiment and our findings.

INTRODUCING TECHNOLOGICAL PEDAGOGICAL CONTENT KNOWLEDGE (TPCK)

It is becoming increasingly clear that merely introducing technology to the educational process is not enough to ensure technology integration since technology alone does not lead to change. Rather, it is the way in which teachers use technology that has the potential to change education (Carr, Jonassen, Litzinger, & Marra, 1998). For teachers to become fluent with educational technology means going beyond mere competence with the latest tools (Zhao, 2003), to developing an understanding of the complex web of relationships between users, technologies, practices, and tools. Thus we view technology as a knowledge system (Hickman, 1990) that comes with its own biases, and affordances (Bromley, 1998; Bruce, 1993) that make some technologies more applicable in some situations than others. In summary, we view teacher knowledge about technology as important, but not separate and unrelated from contexts of teaching i.e., it is not only about what technology can do, but also, and perhaps more importantly, what technology can do for them as teachers.

Consistent with this situated view of technology, we have proposed a framework describing teachers' understanding of the complex interplay between technology, content, and pedagogy (Koehler, Mishra, Hershey, & Peruski, 2004; Mishra & Koehler, in press a, in press b, in press c). In our framework, we have built upon Shulman's (1986, 1987) work describing Pedagogical Content Knowledge, to highlight the importance of *Technological Pedagogical Content Knowledge* (TPCK) for understanding effective teaching with technology (see Mishra & Koehler, in press c, for a more complete discussion of these issues). Our perspective is consistent with other approaches that have attempted to extend Shulman's idea of Pedagogical Content Knowledge (PCK) to the domain of technology (for instance see Hughes, 2005; Keating & Evans, 2001; Lundeberg, Bergland, Klyczek, & Hoffman, 2003; Margerum-Leys, & Marx, 2002).

At the core of our framework (see Figure 1), there are three areas of knowledge: Content, Pedagogy and Technology.

Content (C) is the subject matter that is to be learned/taught. High school mathematics, undergraduate poetry, 1st grade literacy, and 5th grade history are all examples of content that are different from one another.

Technology (T) encompasses modern technologies such as computers, the Internet, digital video, and more commonplace technologies including overhead projectors, blackboards, and books.

Pedagogy (P) describes the collected practices, processes, strategies, procedures, and methods of teaching and learning. It also includes knowledge about the aims of instruction, assessment, and student learning.

However, our approach goes beyond seeing C, P, and T as being useful constructs in and of themselves. Our approach emphasizes the connections and interactions *between* these three elements. For instance, considering P and C together we get *Pedagogical Content Knowledge*. This is similar to Shulman's (1987) idea of knowledge of pedagogy that is applicable to the teaching of

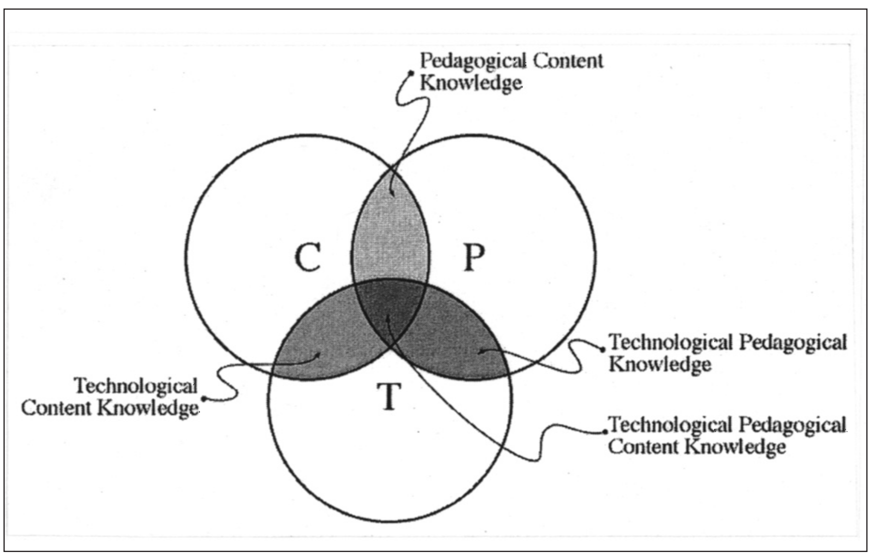

Figure 1. The components of Technological Pedagogical Content Knowledge.

specific content. This would include representation and formulation of concepts, pedagogical techniques, knowledge of what makes concepts difficult or easy to learn, knowledge of students' prior knowledge and theories of epistemology. Similarly, T and C taken together yield the construct *Technological Content Knowledge*, useful for describing teachers knowledge of how a subject matter is transformed by the application of technology (e.g., the use of simulations in physics). T and P together describe *Technological Pedagogical Knowledge*, or knowledge of how technology can support pedagogical goals (e.g., fostering collaboration).

Finally, if we jointly consider all three elements (T, P, and C), e get *Technological Pedagogical Content Knowledge* (TPCK). True technology integration, we argue, is understanding and negotiating the relationships between these three components of knowledge (Bruce & Levin, 1997; Dewey & Bentley, 1949; Rosenblatt, 1978). Good teaching is not simply adding technology to the existing teaching and content domain. Rather, the introduction of technology causes the representation of new concepts and requires developing a sensitivity to the dynamic, transactional relationship between all three components suggested by the TPCK framework.

IMPLICATIONS FOR TEACHERS LEARNING TECHNOLOGY: THE LEARNING TECHNOLOGY BY DESIGN APPROACH

Our conceptualization of teacher knowledge as being a complex web of relationships between content, pedagogy and technology has significant implications for teacher learning and teacher professional development. Clearly instruction that focuses on only one of these items at a time would be relatively ineffectual in helping teachers develop an understanding of how these knowledge bases relate to each other. For instance, technology workshops that focus on the development of software and hardware skills do not help teachers understand how technologies interact with particular pedagogies or specific subject matters. We have argued that developing TPCK requires the design of a coherent curricular system (Brown & Campione, 1996), *not* a collection of isolated modules that focus on just one of the three knowledge bases at a given moment. Developing TPCK requires a curricular system that would honor the complex, multi-dimensional relationships by treating all three components in an epistemologically and conceptually integrated manner. In response to these needs we have been experimenting with an approach we call *Learning technology by design*.

The learning technology by design approach is a constructivist approach that sees knowing as being situated in action and co-determined by individual-environment interactions (Brown, Collins, & Duguid, 1989; Gibson, 1986;

Roschelle, & Clancey, 1992; Young, 1993).[1] Our approach builds on these ideas by emphasizing the value of authentic and engaging ill-structured problems that reflect the complexity of the real world (Marx, Blumenfeld, Krajcik, & Soloway, 1997; Pea, 1993). These problems serve as the context for learning about educational technology. For instance, recent design-based seminars we have conducted have focused on the design of online courses. The participants in the design teams have to actively engage in inquiry, research and design, in collaborative groups (that include higher education faculty members and graduate students) to design tangible, meaningful artifacts (such as the website, syllabus and assignments for an online course) as end products of the learning process. The open-ended nature of design problems prevent us (the instructors) from too narrowly specifying what technologies will be needed. This means that the participating teachers have to learn specific hardware and software skills as and when needed by their evolving project. Design is the anchor around which the class (and learning) happens. The evolving artifact is also the test of the viability of individual and collective understandings as participants test theirs, and others', conceptions and ideas of the project. And finally, the main role of the instructor in such an environment is that of a facilitator and problem solving expert rather than an expert in the content. Learning in this context involves becoming a *practitioner*, not just learning about *practice* (Brown & Duguid, 1991).

Most significantly, by participating in design, teachers build something that is sensitive to the subject matter (instead of learning the technology in general) and the specific instructional goals (instead of general ones). Authentic tasks do not respect disciplinary boundaries. Therefore, every act of design is always a process of weaving together components of technology, content, and pedagogy. Moreover, the ill-structured nature of most authentic pedagogical problems ensures that there are multiple ways of interpreting and solving them. Thereby, teachers are more likely to encounter the complex and multiple ways in which technology, content, and pedagogy influence one another instead of thinking about rigid rules that imply simple cause-effect relationships between these components (Mishra, Spiro, & Feltovich, 1996).

[1] In this, the learning by design approach is philosophically and pragmatically aligned to other project-based approaches such as learning-by-doing, problem-based learning, collaborative learning frameworks, and design-based-learning (Blumenfeld, Marx, Soloway, & Krajcik, 1996; Blumenfeld, Soloway, Marx, Krajcik, Guzdial, & Palincsar, 1991; Dewey, 1934; Papert, 1991; Roth, 1995; Roup, Gal, Drayton, & Pfister, 1993). Similarities can also be found between our approach and those adopted by other advocates of design-based-learning (Perkins, 1986; Blumenfeld, Soloway, Marx, Krajcik, Guzdial, & Palincsar, 1991; Brown, 1992; Harel & Papert; 1990, 1991; Kafai, 1996). Learning by design has been shown to lead to rich, meaningful learning in a variety of contexts, including the development of presentations, instructional software, simulations, publications, journals, and games (Carver, Lehrer, Connell, & Erickson, 1992; Kafai, 1996; Kafai & Resnick, 1996; Lehrer, 1993).

STUDYING THE DEVELOPMENT OF TPCK

So far, we have offered an argument for design-based approaches as a means of helping teachers develop situated and nuanced understandings of the relationship between pedagogy, content and technology. However, this is not a statement that has to be accepted at face value. Whether or not students develop TPCK is an empirical question and it is a question that we have addressed in our research. The development of the TPCK framework has been part of a multi-year design experiment (Brown, 1992; Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003; Designed Based Research Collective, 2003), aimed at helping us understand teachers' development toward rich uses of technology (i.e., develop theory) while *simultaneously* helping teachers (both K-12 teachers and university faculty) develop their teaching with technology (i.e., inform practice).

In a previous publication (Koehler, Mishra, Hershey, & Peruski, 2004), we presented a case study of a college faculty member (Dr. Shaker) as she worked with her design team to create an online course. Our analysis revealed important changes in Dr. Shaker's technological literacy and her thinking about her personal relationship with technology. In accounting for these changes, we hypothesized that the learning by design approach afforded rich opportunities for Dr. Shaker (and her other team members) to deeply consider the relationships between content, pedagogy, and technology.

In later work (Koehler, Mishra, Yahya, & Yadav, 2004), we looked more closely at the manner in which TPCK develops through participation in a design-based activity. Qualitative and quantitative analyses of 15 weeks of field notes for two of the design teams showed that participants moved from considering technology, pedagogy and content as being independent constructs toward a richer conception that emphasized connections among the three knowledge bases. Our analyses suggested that developing TPCK is a multigenerational process, involving the development of deeper understandings of the complex web of relationships between content, pedagogy and technology and the contexts in which they function.

Though these efforts have offered rich and detailed information about the phenomena (teacher knowledge around technology) such qualitative approaches are time consuming and difficult to replicate. For this purpose we have attempted to develop a survey instrument that would allow us to capture the essential elements of the learning by design process. This is the focus on this article and is described in greater detail below.

The Design of the Survey

We designed a survey that attempted to measure participants' learning in one of our learning by design courses. As part of the course, the design teams focused on building an online course to be taught as part of the masters program in the college of education (more about the design course later).

The survey instrument we designed attempts to address three broad questions:

- Students' perceptions of the learning environment (i.e., the learning technology by design approach). In particular, this section focuses on (a) participants' perceptions of the time and effort spent by them in this course; (b) participants' subjective judgments about the learning experience and the amount and value of theoretical and practical knowledge; and (c) the manner in which design teams function, with particular emphasis on the contributions of various team members and their roles.
- The evolution in participant thinking regarding different aspects of online education. Because participants were charged with designing an online course, one measure of success of the learning technology by design approach is a change in participants thinking about the subject of their design challenge—in this case, online teaching and learning. We would expect learners to start with somewhat simplistic ideas about moving from face-to-face to online teaching. However, we would also expect this to change with their participation in the learning by design course.
- The evolution over the course of a semester of the knowledge components (and their relations) suggested by the TPCK framework. Our previous research shows that participants' thinking about technology integration gets increasingly complex with time. However these previous studies studied group learning (as opposed to individual learning). Our survey distinguishes between learning about TPCK at both the individual and the group level.

The Design Course Context

We conducted this research within the context of a faculty development course taught by the first author during the spring semester of 2003. In this class, faculty members and graduate students worked collaboratively to develop online courses to be taught the following year. The task of developing an online class was an authentic one—the College of Education at our university began offering an online Masters degree program, and courses had to be developed as part of the online offerings. As we have described elsewhere, the format of this course was created to integrate faculty development into our learning by design program already in place in the educational technology masters program (Koehler, Mishra, Hershey, & Peruski, 2004).

This particular instantiation of the "learning by design course" included four faculty members and fourteen students. The faculty and students met once a week for three hours in a computer lab. Students were assigned to groups led by individual faculty members. A typical class period included a whole-group component used to discuss readings and issues that applied to all groups, and a small-group component in which the design teams worked on their semester-long projects. In many ways, this design course was a typical graduate class experience for the participants—they read articles, discussed ideas, and were responsible for meeting course deadlines. However, there were some important differences. All the participants (faculty members and teachers alike) worked collaboratively on designing an online course. They were exposed to several technologies, assessed their usefulness, and included some of them in the design of their online class. The technologies used by the groups varied, depending on the content they were covering and the pedagogical decisions they made. One group, for instance, focused a great deal on researching potential ways for a faculty member to provide audio feedback to online students. Another group investigated the use of Web-based PowerPoint presentations to offer overviews of online lessons to be covered. Groups also explored a range of pedagogical issues relevant to the course they were designing, including techniques for developing online learning communities and strategies for incorporating problem-based learning in online settings. All of the groups learned about the principles of effective Web design as well as issues related to copyright and privacy. This knowledge was shared with the larger class through whole groups discussions as well as through online critiques of work done by other groups. There were a few intermediary deadlines imposed by the instructor, but for the most part, the groups worked at their own pace to complete the design of the course by the end of the semester.

Clearly, the most important part of the class was the small group design work aimed at developing a prototype of an online course. The design task went beyond creating a Website for the course and required the faculty members and students to work together to develop the syllabus, the course structure, the readings, student assignments, and assessment rubrics. They had to determine the nature of student interaction, how the course content would be offered and delivered, how technology would be used to accomplish course goals, and how the course Website would be designed to make it both user-friendly and fit with course content and pedagogy.

METHOD

Participants

Data for the present study comes from surveys completed by four faculty members (2 male and 2 female) and 13 students (9 male and 4 female). One student in the class chose not to participate in the research. Participants agreed to allow artifacts created during the course to be used as research data following the completion of the course. They were not reimbursed for their time.

Procedure

As part of the course, participants completed an online survey four times during the course of the semester (week 1, week 4, week 8, and week 13 of the course). Part of students' grades were dependent on completing the surveys (but not on the content or quality of the answers). Surveys were submitted with participant names to the teaching assistant for the purpose of grading (to see which students completed the assignment or not). After the course was completed, the teaching assistant permanently removed the names from the survey data (by deleting the appropriate column in the database), and forwarded the data onto the instructor. Thus the surveys were anonymous relative to the instructor and were not shared until after the course was over. Students (and faculty) were aware of this procedure and were encouraged to submit honest answers to better inform course designers as to the processes underlying the course.

Measures

Each survey consisted of 35 questions, and took less than 15 minutes to complete. Two questions were short answer (e.g., "Please write a short paragraph summarizing what is your role in the group" and "Please write a short paragraph summarizing how your group has been functioning"), and 33 questions used a 7-point Likert scale to rate the extent to which participants agreed or disagreed with statements about the course (e.g., "Our group has had to find different ways of teaching this content online"). The content of each survey question is detailed in the results and discussion sections that follow.

Data Analysis

In this article, we report on the analysis of the data collected by the second and fourth administration of the survey. The results of the third survey were lost due to a server crash as a result of a virus/worm that spread throughout the campus. We chose to include weeks 4 and 13 (and not choose week 1) because these two weeks were more representative of the design process. It took a few weeks for the groups to be formed and the participants to engage in the design tasks. Since many of the questions in the survey were related to the design process, we decided not to include the data from week 1, since at that time the participants would not have had any experience with their design teams and design acts.

Results were analyzed as matched-pair means (*t*-tests) for each of the 33 survey questions. For each pre-post difference, we also report *P*-values and Cohen's ∂ measure of practical significance for descriptive purposes. However, in order to control for overall experimental type-I error (because we conducted 33 comparisons), we also indicate which findings are significant if we set the experimental error rate at alpha = .05, using a sequential Holm procedure, so that the largest effect was tested at .05/33 (directional, 1-tailed test), the next effect was tested at .05/32, and so on. Once one test fails to reach significance, testing stops and the remaining contrasts are non-significant.

RESULTS AND DISCUSSION

We report our findings for the survey by considering the questions organized by the following themes: participants' perceptions of the learning environment; participant's perceptions about online education; and the evolution of the knowledge components suggested by the TPCK framework both from an individual- and group-level perspective. Where appropriate, we annotate our findings with quotations from the two short-answer questions to help interpret the findings supported by the quantitative data.

Students' Perceptions of the Learning Environment

It has been our experience that the initial stages of the learning by design approach are confusing, chaotic, and somewhat frustrating to participants. As groups work to collaboratively define goals, set priorities, and achieve a vision for their project, many students feel like very little is actually getting done. We suspect that this has much to do with how students have become accustomed to completing coursework—they expect to work on their own, to meet well-defined goals that are clearly laid out in the syllabus, and turn coursework in to be traded regularly.

The first couple of weeks of the course result in very few concrete accomplishments and, instead, is characterized more by group conversations. Several survey questions asked participants to characterize the kinds (and amount) of work they were doing (Table 1, Questions T1-T5). In general, at this early stage of the course, participants do not feel like they are working hard, probably as a result of their frustration with the chaotic design process (note, 1.0 indicates strong agreement with the statement and 7.0 indicates strong disagreement with the statement). This carries over to their effort into other phases of the course, including their work with the course readings, and involvement in the online discussion boards about the readings that were required each week. Participants rate their activity as being individual or group related similarly. One participant summed up this phase of the course in her response to a question about her role in the group: "Undefined—I feel like we are not doing much."

A similar effect can be found on participants' ratings for the four questions focused on participants' perception of the amount, type, and enjoyment of their learning in the course (questions L1-L4). Initially, the course is not enjoyable, participants feel as though they are learning some theoretical knowledge, not learning practical skills, and do not feel as though they are learning as much as they expected. Again, this is not totally unexpected given the relatively ill-defined nature of the early goal-setting period of the collaborative design process. Our experiences with teaching this course have led us to believe that how a group forms, develops, and learns to work together is very important in not only developing a final design, but also in the learning that results from the process. We are not surprised, based upon our prior experiences, that the results from

Table 1. Descriptive Statistics for Questions about Students' Perceptions of the Learning Environment

	Week 4 (Ave & Std. Dev.)	Week 13 (Ave & Std. Dev.)	Matched-Pair *t* (*df* = 14)	*p*-Value	Cohen's ∂
Time and Effort Questions					
T1 – Overall, I have been working very hard in this course	5.80 (1.27)	2.07 (1.16)	7.30	< .001*	3.16
T2 – I have spent a lot of my time and effort doing the readings in this course	5.53 (1.06)	2.47 (1.06)	6.63	< .001*	1.86
T3 – I have spent a lot of time and effort in the online discussions for the course	5.33 (1.23)	2.80 (1.15)	4.60	< .001*	1.94
T4 – I have spent most of my time and effort working alone and independently	5.00 (1.07)	3.80 (1.86)	2.00	= .067	0.37
T5 – I have spent most of my time and effort working in groups	4.53 (1.25)	2.87 (1.19)	3.25	< .01*	1.25
Learning and Enjoyment Questions					
L1 – I am enjoying my experience in this course	5.80 (1.08)	1.87 (0.99)	9.64	< .001*	3.92
L2 – I am learning a lot of theoretical knowledge in this course	4.53 (1.69)	3.07 (1.58)	1.84	= .087	0.93
L3 – I am learning a lot of practical knowledge in this course	5.40 (1.18)	2.00 (1.00)	8.50	< .001*	3.21
L4 – I am learning more than I expected	5.00 (1.51)	2.53 (1.56)	4.97	< .001*	1.67
Group Functioning Questions					
G1 – As a whole, my group values my input, thoughts, efforts, and work	5.87 (1.06)	1.87 (0.99)	9.17	< .001*	4.04
G2 – Overall, our group is functioning very well	5.53 (1.13)	2.27 (0.88)	7.23	< .001*	3.34
G3 – Everyone in our group is making a significant contribution	5.40 (0.97)	2.93 (1.53)	4.34	<.01*	1.98
G4 – Our group is getting a lot of work done	5.20 (1.32)	2.07 (1.10)	6.19	< .001*	2.27
G5 – Our group is not accomplishing as much as we hoped	3.53 (1.96)	4.60 (1.84)	1.35	> .05	0.58
G6 – Our group is having a lot of fun	5.20 (1.61)	2.73 (1.10)	3.69	< .01*	1.85

*The change between Week 4 and Week 13 is statistically significant, using an overall experimental error-rate of alpha = .05, using a sequential Holm procedure.

Week 4 for the six questions about group functioning (G1-G6) show that participants generally characterize their groups as: Not valuing members' efforts, not functioning well, not getting a lot of work done, not accomplishing according to expectations, and not enjoying themselves. One participant wrote about this portion of the course: "We have really had problems getting our work started. We have worked with our instructor, but there isn't much content developed for the course yet, so our work seems very slow." Another noted, "Vision . . . Vision . . . Vision . . . lacking in this area a little." Much of the work of the course instructor at this point is structuring activities to keep groups on task, that help build team skills, and lead to better things down the road.

Near the end of the course, it seems much has changed (Table 1 and Figure 2). By week 13, participants rate themselves as working harder on projects, readings, and discussions, and doing more collaboration, this change is statistically significant as well as practically significant. Here Cohen's ∂ is used as a measure of practical significance, where $\partial = .2$ represents small effects, $\partial = .5$ represents medium effects, and $\partial = .8$ indicates a large effect. On this measure of practical significance, we see "very large" effects (∂ ranging 0.93 and 4.04) for the statistically significant changes (Cohen, 1977).

These effects confirm our own experiences teaching in the learning by design approach—the initial discomfort with the approach gradually is replaced with a feeling of deep accomplishment, and a recognition that working collaboratively on ill-defined problems is a legitimate (and rewarding) way to engage learning about (and with) technology. It is interesting to note that the growing familiarity and experience with the design approach leads to a more favorable engagement with course readings and discussions. It is also worth noting, that participants' perception of the work they do independently does not significantly change with experience in the approach. The same student who noted the "undefined" work the group was doing earlier by week 13 noted: "I started out doing everything for the group and it got very taxing on me. . . . What I learned was that I didn't need to do that, and that I could actually focus on the pedagogical issues that I wanted to and get a really fulfilling experience."

It has been our experience by week 8 or 9, the groups begin to "click" and assignments come from within more than from without. This is reflected in the change by week 13 of the course (Table 1 and Figure 2). On every measure, the participants report better group functioning, more enjoyment, better participation, and better fit within the group. The same student who reported the lack of "Vision" at this point noted "Our group is functioning well. . . . Everyone has found a niche or place to fit in . . . [and] is making contributions toward the progress and completion of our web course."

Although we knew group functioning to be an important part of the learning by design approach, we were surprised by the magnitude of its importance on every aspect of student learning. Most of the comments written in the two short answer questions were about group functioning (or not functioning). Furthermore,

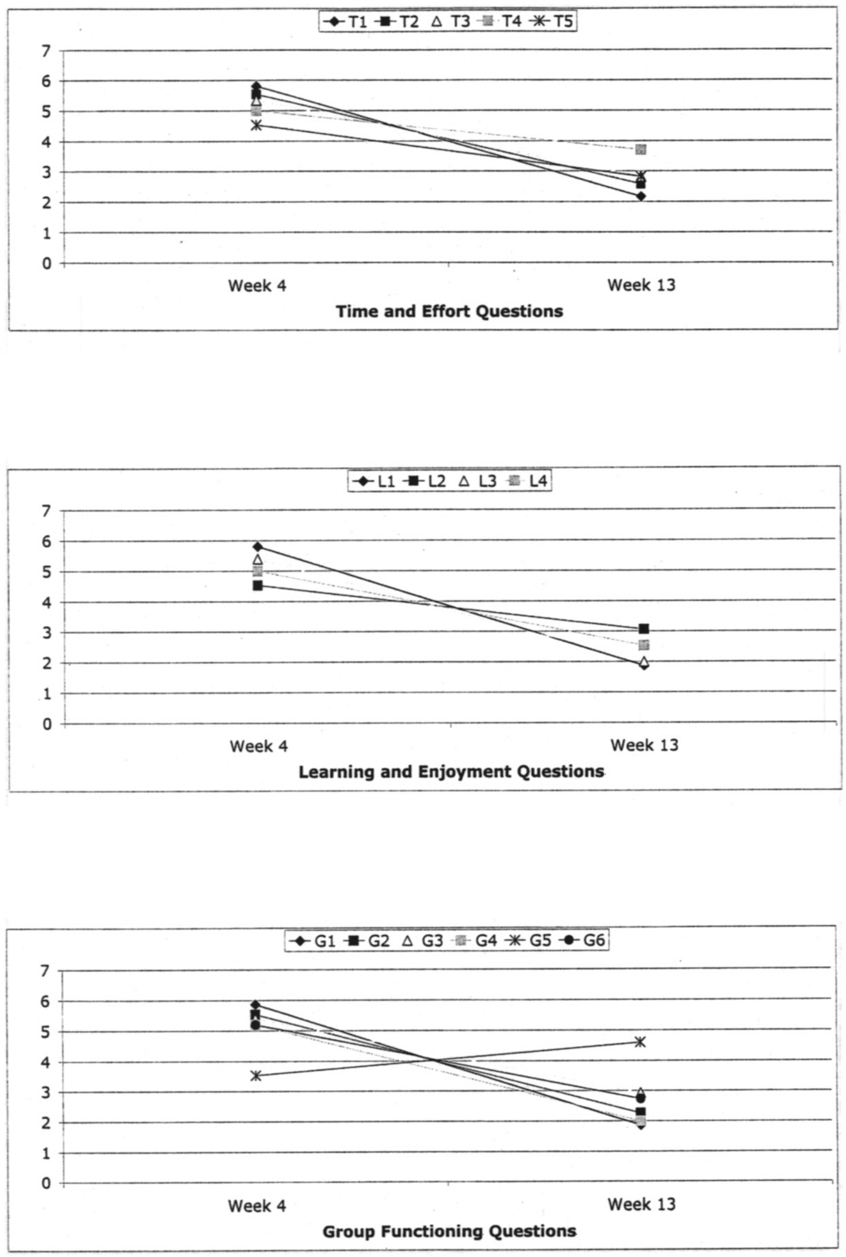

Figure 2. Average rating by week for survey questions about students' perceptions of the learning environment.

a post-hoc analysis showed that participants rating of "Overall, our group is functioning well" statistically predicted every other rating in the survey except for the item about "working individually" (performed as correlation among survey items). That indicates that group functioning can be seen as the gateway by which learning happened. Groups that got along and had more fun accomplished more, learned more, and got more out of the class. With this in mind, it is important to note that not all groups functioned equally well. It is our experience that some groups "gel" early, others not until the middle of the course, others never seem to fully connect even once the course is over (Koehler, Mishra, Hershey, & Peruski, 2004).

Thinking about Technology: The Difference between Online and Face-to-Face Courses

One way to assess whether or not the learning by design approach leads to deep learning about technology is to examine the extent to which participants' thinking about how technology (T) related to teaching and learning (Pedagogy—P) for a subject matter area. As argued earlier, designing an online course introduces new technology into instruction and has the potential to introduce "disequilibrium" in our TPCK model (Peruski & Mishra, 2004). That is, it was our hope that designing an online course would allow students (and faculty) to explore relationships between technology and pedagogy and technology. We hoped that participants would understand that the relationships are not one way—technology is not merely applied to the pedagogy of the past, but rather the introduction of technology has implications for how we teach and what we teach.

Questions O1-O4 of the survey (Table 2) assessed this type of understanding by asking participants about the differences between face-to-face and online courses. Initially, participants see little or no difference between an online course and a face-to-face course—both take about the same amount of time, there is little need to change content or pedagogy, and the process of designing the two types of courses is similar. In other words, the early survey results confirm our suspicion that before designing an online course, participants have relatively simple beliefs about the role of technology in education—technology is just a new medium to be learned, and designing with technology is simply translating previous content and pedagogy into that new medium.

Nine weeks later, participants have come to the opposite conclusion: They agree that online courses require more time; Teaching online requires a changing of content and pedagogy. And, that designing an online course is different than designing a face-to-face course (see Table 2 and Figure 3).

As designers of this learning experience, we couldn't be more pleased. Without ever explicitly talking about developing a more nuanced understanding of the role of technology in the way courses are taught, participants developed these

Table 2. Descriptive Statistics for Questions about Participant Thinking about Aspects of Online Education

Questions about Online Education	Week 4 (Ave & Std. Dev.)	Week 13 (Ave & Std. Dev.)	Matched-Pair *t* (*df* = 14)	*p*-Value	Cohen's ∂
O10 – Designing an online course is a lot like designing a face-to-face course	2.53 (1.36)	5.87 (1.30)	5.72	< .001*	2.60
O11 – Designing an online course is translating existing course content to an online format	2.47 (1.19)	5.40 (1.50)	5.12	< .001*	2.24
O12 – Designing an online course requires changes in how we teach and what we teach	6.27 (0.88)	1.93 (1.03)	9.77	< .001*	4.67
O13 – Teaching online requires more time than face-to-face	5.40 (1.64)	1.80 (1.01)	2.73	< .001*	1.67

*The change between Week 4 and Week 13 is statistically significant, using an overall experimental error-rate of alpha = .05, using a sequential Holm procedure.

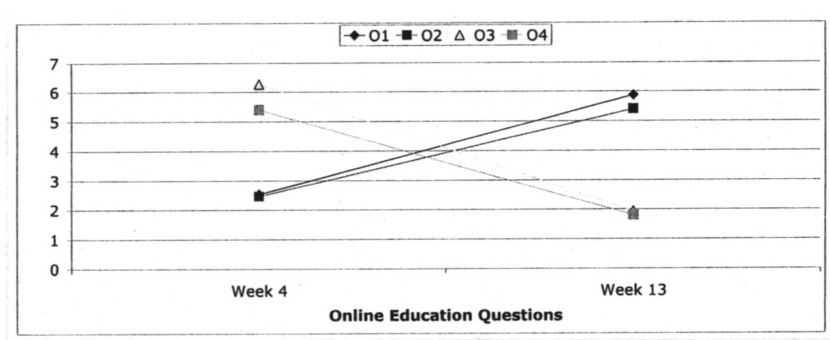

Figure 3. Average rating by week for survey questions about participant thinking about aspects of online education.

deeper connections on their own, as evidenced by their changed beliefs about face-to-face and online teaching.

The Evolution of the Knowledge Components Suggested by the TPCK Framework

In pursuing the extent to which participants were learning about the categories of knowledge suggested by our TPCK framework, we designed several survey questions that asked participants to directly rate their engagement around these ideas. We distinguish, however, between how individuals were functioning (and reasoning), and how the design groups were interacting.

At the beginning, the class participants did not agree that they were thinking differently about technology, nor did they feel as if they were gaining any technology skills (Table 3, questions I-T1 and I-T2). They had difficulty designating themselves as working on technology, content, or pedagogy of the course they were designing (questions I-C, I-P, and I-T3). Here the trend among individuals probably doesn't characterize its members very well: when asked to report their roles in the course, some clearly state their role as "tech guru" or "developing content." Likewise, the standard deviations of the ratings are among the largest observed in this study. We take this to mean that there is great variety as to what individuals are thinking about in any given group. However, overall (as in average rating), there does not seem to be an initial high degree of engagement in any of the three main categories (technology, content, or pedagogy).

We also examined how participants' perceived the issues and ideas their design group were wrestling with, as measured by the TPCK framework (Figure 4). For each of the knowledge components suggested in the framework, we designed at least one question (Table 3: G-C, G-P, G-T, G-TC1, G-TC2, G-PC1, G-PC2, G-TP, and G-TPC). Initially, participants' did not see their group as grappling with issues in any of these categories. We are somewhat surprised by the low ratings on technology—it has been our impression that early discussions are dominated by technology, since it is the new ingredient that is being considered in the design of their course. Perhaps they don't see these discussions as deep, or worth reporting. Regardless, it would seem that at the early stages, the move to online teaching is not forcing the design groups to think about how technology and pedagogy, for example, are related.

By the end of the semester, however, participants are much more likely to indicate changes in their own thinking about content (C), pedagogy (P), and technology (P). They are also more able to identify the development of concrete technology skills within themselves. These changes are also reflected in the group level measures—there are large statistical, and "very large" practical changes on every category of knowledge in the TPCK framework. Because our framework emphasizes beyond seeing C, P, and T as being useful constructs in and of themselves and stresses the importance of the connections and interactions *between* these three elements of knowledge, the changes observed within the complex relational forms are particularly relevant (i.e., G-TC1, G-TC2, G-PC1, G-PC2, G-TP, and G-TPC).

Taken as a whole, our results indicate that the design approach in general, or the task of developing an online course in particular, is well suited to developing knowledge across the spectrum of reasoning suggested by the TPCK framework.

Table 3. Summary Statistics for Questions about Individual and Group Thinking about TPCK

	Week 4 (Ave & Std. Dev.)	Week 13 (Ave & Std. Dev.)	Matched-Pair *t* (*df* = 14)	*p*-Value	Cohen's ∂
Individuals TPCK Questions					
I-T1 – I am learning a lot of practical technology skills that I can use	5.20 (1.27)	2.93 (1.39)	4.35	< .01*	1.77
I-T2 – I am thinking more critically about technology than before	5.13 (1.73)	2.33 (1.29)	4.29	< .01*	1.90
I-C – I have been thinking and working a lot of the course content	4.93 (1.62)	2.87 (1.69)	2.66	= .019	1.29
I-P – I have been thinking and working a lot on the pedagogy of the course we are designing	5.47 (1.51)	2.73 (1.49)	3.76	< .01*	1.89
I-T – I have been thinking and working a lot on the technology of the course we are designing	5.07 (1.39)	2.87 (1.69)	3.01	< .01	1.48
Group TPCK Questions					
G-C – Our group has been thinking and talking about the course content	5.73 (1.16)	2.13 (1.25)	6.44	< .001*	3.09
G-P – Our group has been thinking and talking course pedagogy	5.80 (1.01)	2.20 (1.08)	6.87	< .001*	3.55
G-T – Our group has been thinking and talking about technology	6.00 (0.93)	2.27 (1.22)	7.44	< .001*	3.58
G-PC1 – Our group has been considering how course content and pedagogy influence one another	5.53 (0.99)	2.33 (1.35)	6.29	< .001*	2.80
G-TP – Our group has been considering how course pedagogy and technology influence one another	5.60 (0.91)	2.13 (0.99)	8.65	< .001*	3.77
G-TC1 – Our group has been considering how technology and course content influence one another	5.47 (1.06)	2.07 (1.03)	8.04	< .001*	3.36
G-TC2 – Our group has had to modify course content in order to adapt it to our online course	5.33 (0.90)	2.47 (1.13)	7.15	<.001*	2.91
G-PC2 – Our group has had to find different ways of teaching content online	5.47 (1.06)	2.20 (1.46)	6.77	< .001*	1.93
G-TPC – Our group has chosen technologies to fit our course content and the faculty member's teaching philosophy	6.00 (1.00)	1.93 (1.03)	8.43	< .001*	4.10

*The change between Week 4 and Week 13 is statistically significant, using an overall experimental error-rate of alpha = .05, using a sequential Holm procedure.

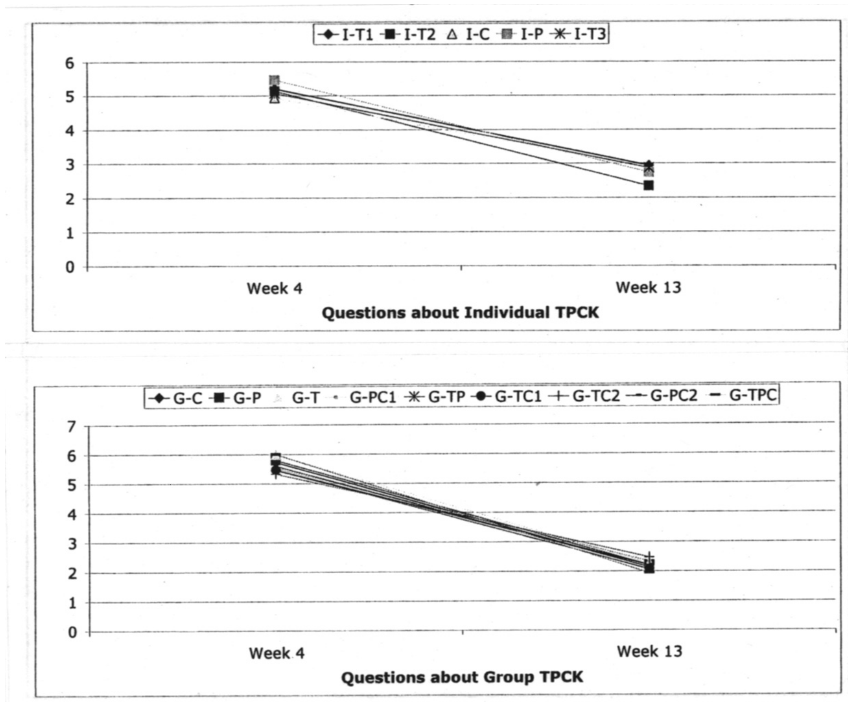

Figure 4. Average rating by week for survey questions about individual and group thinking about TPCK.

CONCLUSION

The idea of TPCK has significant implications for teacher education and teachers' professional development. In order to go beyond the simple "skills instruction" view offered by the traditional workshop approach, we have argued that it is necessary to teach technology in contexts that honor the rich connections between technology, the subject-matter (content) and the means of teaching it (the pedagogy). We have offered one possibility (the *learning by design* approach), that explicitly foregrounds these connections. By participating in design, teachers are confronted with building a technological artifact while being sensitive to the particular requirements of the subject matter to be taught, the instructional goals to be achieved, and what is possible with the technology. The idea of learning by design is not a new one. However, we believe that the TPCK framework provides yet another argument for the pedagogical value of such activities, especially when considering the integration of educational technology in pedagogy. In particular, the findings of our study indicate that participants find learning by design approaches as being challenging, and fun.

More importantly, our data clearly show that participants in our design teams moved from considering technology, pedagogy and content as being independent constructs toward a more transactional and co-dependent construction that indicated a sensitivity to the nuances of technology integration. In other words they showed a significant shift toward developing Technological Pedagogical Content Knowledge, involving the development of deeper understandings of the complex web of relationships between content, pedagogy and technology and the contexts within which they function.

There are certain fundamental challenges in representing teacher knowledge around technology (Fenstermacher, 1994), particularly as it develops in "learning-by-design" seminars. The first challenge is that any representation of teacher knowledge needs to reflect its collaborative, co-constructed nature. Furthermore, TPCK develops by doing and through the dialogues and interactions between the participants in design teams as they grapple with issues surrounding content, pedagogy and technology. Consequently, knowledge in such settings is not static or fixed. In our previous work (Koehler, Mishra, Hershey, & Peruski, 2004; Mishra & Koehler in press a, b) we offered some representations of teacher knowledge around technology. However there were often based on detailed and time-intensive qualitative research. In this article we extend our work by developing a survey questionnaire that allows us to observe both the process and product of learning by design seminars. We see this survey instrument as being a useful tool for future research on the development of TPCK as well as allowing us to develop a better understanding of how design teams function.

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