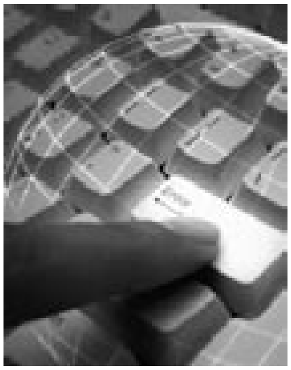

Teachers Learning Technology by Design

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Abstract

Although there has been much debate about what *teachers need to know about technology, less attention has been paid to* how *they are supposed to learn it. Teacher preparation programs need to go beyond merely training teachers in how to use specific software and hardware tools, and instead focus on developing an understanding of the complex set of interrelationships between artifacts, users, tools, and practices. In this paper, we introduce and advocate a* Learning By Design *approach that can help teachers develop a flexible and situated understanding of technology. In this approach, inservice teachers work collaboratively in small groups to develop technological solutions to authentic pedagogical problems. We introduce the Learning by Design strategy and provide examples of its use in three different courses. We summarize what teachers learn in this approach, focusing on learning about technology, learning about design, and learning about learning.*

Much has been written about what teachers need to know about technology to be effective teachers in the information age. Journal articles (Bielefeldt, 2000, 2001; Implementing the NETS*T, 2003; Thomas, 1994; Thomas & Knezek, 2002; Widmer & Amburgey, 1994; Wetzel, 2001; Zhao 2003), state technology plans, and state and national standards (CEO Forum on Education and Technology, 2000; Hirumi & Grau, 1996; US Department of Education, 2003; US Congress, Office of Technology Assessment, 1995) have compiled a long list of competencies that teachers will need to know to become skillful in technology-rich classrooms. Kent and McNergney (1999) report that the teacher certification processes in more than 32 states in the United States include an explicit technology requirement. Most states have also developed technology plans that offer detailed idealized and prescriptive views of how technology should be used in classrooms (Zhao & Conway, 2001).

Early standards conceptualized technology proficiency as a wide range of competencies for teachers to master (Wiebe & Taylor, 1997), including concrete skills (e.g., keyboarding, connecting a computer to the network), software application (e.g., word processing, spreadsheets), key technology concepts (e.g., networking, distributed computing), and transformative uses of technology in the classroom (e.g., learner-centered inquiry, using real-time data). Lankshear (1997) described this emphasis as a form of applied technocratic rationality, a view that technology is self-contained, has an independent integrity, and that to unlock its potential and power requires merely learning certain basic skills. It is assumed that teachers who can demonstrate proficiency with software and hardware will be able to incorporate technology successfully into their teaching.

In contrast, more recent educational technology standards such as those developed by the International Society for Technology in Education (ISTE) and the National Council for Accreditation of Teacher Education (NCATE, 1997, revised in 2001) have moved away from an emphasis on basic skills alone, and have enumerated a series of higher-order goals that are essential for effective pedagogy with technology (Glenn, 2002a, 2002b; Handler & Strudler, 1997; Wise, 2001). In doing so, ISTE has provided glimpses of what can and should be achieved with these basic skills. These current standards are powerful influences on teacher education curricula in the United States, primarily because NCATE is the official body for accrediting teacher preparation programs and ISTE is the professional education organization responsible for recommending guidelines for accreditation to NCATE for programs in educational computing and technology teacher preparation. The Teacher Education Accreditation Council (TEAC) also offers accreditation to teacher education programs. Though TEAC does not currently endorse any specific technology standards, it accepts technology as being an important tool for liberal education (Teacher Education Accreditation Council, 2004). ISTE's National Educational Technology Standards (NETS) have also become the basis for receiving funding and continued support for a variety of programs. For instance, the U.S. Department of Education's "Preparing Tomorrow's Teachers to Use Technology" (PT^3) program has allocated millions of dollars to enhance teachers' use of technology. Proposals for these funds are evaluated, in part, for specifically citing licensing, certification, and accreditation standards developed by state agencies and national associations, with ISTE and NCATE being mentioned by name.

We have argued elsewhere (Mishra & Koehler, 2003) that these standards only answer part of the question regarding technology integration. In other words, though these standards tell us *what* teachers need to know, they often do not tell us *how* they are supposed to learn it. Most scholars working in this area agree that traditional methods of technology training for teachers—mainly workshops and courses—are ill-suited to produce the "deep understanding" that can assist teachers in becoming intelligent users of technology for pedagogy (Brand, 1997; Milken Exchange on Education Technology, 1999; US Department of Education, 1999). A survey by the Milken Family Foundation and ISTE found that teacher-training programs, in general, do not provide future teachers with the kinds of experiences necessary to prepare them to use technology effectively in their classrooms. Specifically, they found that formal stand-alone IT coursework does not correlate well with technology skills and the ability to integrate technology into teaching. They recommended that teacher preparation programs should increase the level of technology integration in their own academic programs (Milken Exchange on Education Technology, 1999).

Inevitably, traditional approaches lead to teachers becoming *consumers* of knowledge about technological tools, with the hope that teachers will be able to apply this general knowledge to solving problems particular to their classroom situations. In this view, the role of technology is to create more tools for teachers and students to use, and the role of teacher preparation is to train teachers in the proper use of these tools. There is more to teacher preparation than training teachers how to use tools—it requires appreciation of the complex set of interrelationships between artifacts, users, tools, and practices. What is needed, we argue, is an approach that helps teachers develop deeper understandings of the nuances and complexities of technology integration.

The issue of how technology is to be covered in preservice teacher education and inservice teacher professional development has received significant attention recently. A review of the recent teacher education research around technology will show numerous examples of teacher education programs that have implemented instructional technology in ways that encourage integration (for examples see, Fulton, Glenn, Valdez, & Blomeyer, 2002; Fulton, Glenn, & Valdez, 2003; Hacker & Niederhauser, 2000; Loucks-Horsley, Hewson, Love, & Stiles, 1997; Neiderhauser, Salem, & Fields, 1999; Neiderhauser & Stoddart, 2001; Strudler & Wetzel, 1999). Most of these approaches have involved providing teachers and teacher candidates with experiences with real educational problems to be solved by technology.

Learning by Design & Teaching Learning by Design

Our work with inservice teachers reported in this paper falls into this tradition of involving teachers in authentic problem solving with technology. Over the past few years we have been involved in a design experiment (Design-Based Research Collective, 2003) to develop a framework for technology integration in teacher education. This framework attempts to capture some of the essential qualities of teacher knowledge required for technology integration in pedagogy. Teacher knowledge, as we know, is complex, multifaceted, and situated. We argue that intelligent pedagogical uses of technology require the development of a complex, situated form of knowledge we call Technological Pedagogical Content Knowledge (TPCK). Our approach extends Shulman's (1986) idea of pedagogical content knowledge to include technology, and this regard is consistent with work by other scholars in this area who have argued for a similar construct (for other work on TPCK, see Keating & Evans, 2001; Lundeberg, Bergland, Klyczek, & Hoffman, 2003; Margerum-Leys & Marx, 2002; Zhao, 2003). Our conceptualization of TPCK is described in greater detail elsewhere (Koehler, Mishra, Hershey, & Peruski, 2004; Mishra & Koehler, in press). At the heart of TPCK is the dynamic, transactional relationship between content, pedagogy, and technology. Good teaching with technology requires understanding the mutually reinforcing relationships between all three elements taken together to develop appropriate, context specific strategies and representations.

Viewing teacher knowledge for technology integration as being a transaction between the three factors of content, pedagogy, and technology 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 offer one approach, that of *Learning by Design*, that honors these connections by creating an environment in which teachers naturally confront them. 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). Therefore, every act of design is always a process of weaving together components of technology, content, and pedagogy. The Learning by Design approach seeks to put teachers in similar roles as they work collaboratively in small groups to develop technological solutions to authentic pedagogical problems (Mishra & Koehler, 2003).

In a traditional workshop or technology class, teachers are trained to use the latest tools with the hope that they can apply them to their practice. In contrast, in the Learning by Design approach, teachers focus on a problem of practice, and seek ways to use technology (and thereby learn about technology) to address the problem. Because their explorations of technology are tied to their attempts to solve educational problems, teachers learn "how to learn" about technology and "how to think" about technology. Hence, teachers go beyond thinking of themselves as being passive *users* of technological tools and begin thinking of themselves as being *designers* of technology—i.e. they learn to use existing hardware and software in creative, novel, and situation-specific ways to accomplish their teaching goals.

Our use of Learning by Design approach to learn about educational technology has been influenced by a number of theoretical traditions suggesting the potential of design-based activities for learning. Within the context of social constructivism (Cole, 1997; Vygotsky, 1978) or constructionism (Harel, 1991; Harel & Papert, 1991), design projects lend themselves to sustained inquiry and revision of ideas. Other scholars have also emphasized the value of complex, self-directed, personally motivated and meaningful design projects for students (Blumenfeld et. al, 1991; Harel & Papert, 1990, Kafai, 1995). Design-based informal learning environments offer a sharp contrast to more traditional classroom instruction, the effectiveness of which has been questioned by many scholars (Greeno, Collins, & Resnick, 1996; Harel & Papert, 1991; Lave & Wenger, 1991; Papert, 1993; Pea, 1993). Research has shown that general problem-solving strategies have little demonstrable effectiveness outside of the immediate context in which this learning occurs (Larkin, 1989). In contrast, several researchers have successfully documented the rich learning that occurs under a diverse set of design-based activities, including the development of presentations, instructional software, simulations, publications, journals, and games (Carver, Lehrer, Connell, & Erickson, 1992; Kafai, 1995; Kafai & Resnick, 1996; Kolodner, 2002; Lehrer, 1993).

Design-based approaches are also informed by the research and theory of problem-based learning, as both approaches share common elements in their respective learning environments: They often occur across extended periods of time, they are learner centered, interdisciplinary, ill-structured, and they have real-world relevance and engage students in authentic inquiry (Blumenfeld et al., 1996; Krajcik et. al., 1998). In both approaches, meaningful learning is possible when learners are given opportunities to leverage prior knowledge and experience as they engage in tasks that are meaningful to them. Hence, authentic learning opportunities maintain a balance between the learning activity and the relevance of the activity to the lives of the students and real-world practitioners.

The process of design in such environments is about finding solutions through an active engagement with relevant materials, artifacts, tools, and ideas (Dasgupta, 1996). The act of design is essentially a dialogue between ideas and the world, theories and their application, concepts and their realization, tools and goals (Dewey, 1934, Mishra, Zhao, & Tan, 1999). This dialogue lies at the heart of true inquiry, involving as it does the construction of meaning and the evolution of understanding through a dialogic, transactional process (Bruce, 1997; Dewey & Bentley, 1949; Rosenblatt, 1978).

Clearly design is a messy and complex process that seeks to find solutions to ill-structured problems. As Jonassen (1997, 2000) has argued, ill-structured problems often possess multiple solutions, with a greater "uncertainty about which concepts, rules, and principles are necessary for the solution or how they are organized and which solution is best" (Jonassen, 1997, p. 65). This makes the act of teaching design even more difficult. Schon (1987) identifies some key problems in teaching design:

- Designing is a holistic skill. It must be grasped as a whole, by experiencing it in action. It cannot be broken down into parts that can be understood in isolation from each other.
- Design depends a great deal on recognition of design qualities. This recognition is not something that can be described. It must be learned by doing.

- Designing is a creative process in which a designer comes to see and do things in new ways. Therefore, no prior description of it can take the place of learning by doing.
- Descriptions of designing are likely to be perceived initially as confusing, vague, ambiguous, or incomplete. The clarification of these ambiguities depends on a dialogue in which understandings and misunderstandings are revealed through action.
- There are multiple gaps between the initial conceptions of design (description of design) and the process of achieving the final design (knowing in action). These gaps are recognized when breakdowns occur or things do not go exactly as planned. In such a situation a designer has to move to a reflective mode—consciously thinking, analyzing, and learning (reflection in action).

These arguments point toward learning about design by *doing* design, and relying less on overt lecturing and traditional teaching. Design is learned by becoming a practitioner, albeit for the duration of the course, not merely by learning about practice. Not all design (or project-based) activities have equal educational value—merely giving students "something to construct" may keep them busy but it is unclear what pedagogical value exists in doing so. We can identify certain key principles that are important for teaching design (see also Barab & Duffy, 2000). In brief, students should engage in challenging problems that reflect real-world complexity. The problems should be authentic and ill-structured; that is, they should not have one predetermined, foregone solution but rather be open to multiple interpretations and multiple "right answers." Students should engage in actively working on solving the problem over an extended period of time in collaborative groups to reflect the social nature of learning.

This approach requires a shift in the roles of both students and teachers. The student becomes a cognitive apprentice, exploring and learning about the problem in the presence of peers (who may know more or less about the topic at hand). The teacher, on the other hand, must shift from being the "knowledgeable other" towards becoming a facilitator, who manages the context and setting, and assists students in developing an understanding of the material at hand (Blumenfeld et. al. 1991; Marx et. al. 1997; Savery & Duffy, 1995).

Three Examples of the Learning by Design Approach

In this section we offer three examples, drawn from three different Master's level courses in an Educational Technology Master's program. This is followed by an overview of what teachers learn through our approach. These three examples were drawn from three different courses during a two-year span. Although each class had different course goals, there were a number of similarities across the examples. Most of the participants in these courses were working teachers, often with years of experience in the classroom. In each class, we divided participants into working groups that were responsible for defining, designing, and refining a solution to a problem throughout the course of the semester. In each of the courses, students were required to complete assigned readings, participate in class discussion, and complete their writing assignment, typical of masters'-level coursework. All of the course requirements were aimed at supporting the main activity of the class—the design and evaluation of the artifacts created by the design teams.

In these courses, there was little direct instruction about particular software programs or technology. More common were spontaneous tutorial sessions (both student-to-student and instructor-to-student) driven by the immediate requirements of the groups. Though we gave a few short lectures (rarely longer than 30 minutes in duration), they were limited to instances in which there was a need to address a software or hardware issue that was repeatedly coming up in class or to spark discussion focused on big ideas about educational technology (e.g., client-server relationships, the challenges of compressing digital video, etc.). These lectures typically came during the middle of the semester after teachers felt the need for a better understanding of these topics. Hence, lectures were used to emphasize basic concepts connected to the work teachers were doing on their design projects.

As instructors, we rarely suggested or required the use of any specific technology—the emphasis on design required teachers to propose software and hardware solutions to their problems. This de-emphasis on particular computer programs or platforms meant that teachers often used a wide range of technologies, making it impossible for the instructor to be knowledgeable about all of the technologies being used by the different groups. Consequently, the instructors' role as purveyor of knowledge was replaced with the more appropriate roles of coach and mentors.

We offer below three instantiations of the Learning by Design model. Although these courses build on a similar set of principles and ideas, they do differ from each other in some respects, allowing us to see how the same ideas play out across multiple contexts.

Example I: Faculty Development & Online Learning

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

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

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

Example II: Making Movies in Switzerland

As the capstone sequence towards a master's in educational technology, the first author and a colleague taught a nine credit, educational technology sequence to 28 teachers. Their goals were to give teachers additional insight into the fields of educational psychology, educational technology, and how the two fields interact in expert practice. One of the course goals was to learn some concrete, advanced technology skills. In this course, the teachers were to learn the ins and outs of digital video.

A design-based approach was used to accomplish these goals. Teachers worked in groups to make two iVideos (idea-based videos) to communicate an educationally-important idea (Wong, Mishra, Koehler, & Siebenthal, in press). Topics for the videos included the role of technology in the library sciences, affective communication online, and appropriate uses of technology. Instead of learning the de-contextualized skill of creating and editing digital video, the teachers had to learn the technology within the context of communicating their understanding of larger ideas that form the basis of their profession.

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

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

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

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

Example III: Learning Technology through (re)Design

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

In contrast to the previous two cases, participants in this course were involved in the *redesign* of existing Web sites or Web resources. This emphasis on redesign was to ensure that the participants would not spend a lot of time researching the topic but instead would focus on the process of design. Sixteen teachers were divided into four groups. Each group did one of the following redesign tasks: (a) redesign of the virtual tour of the College of Education; (b) redesign of a Web publishing course for middle school students; (c) redesign of a children's computer clubhouse Web site to make it more accessible to children and parents; and finally (d) redesign of a database on educational psychology theory and practice (currently available at http://tip.psychology.org). Teachers in this class also participated in whole class discussion, project presentations and critiques, asynchronous online discussion, journals, and final written group reflection on design process.

The fact that the teachers were engaged in authentic design activities around educational technology compelled them to seriously study the complex relationships between technology and education. The redesign projects forced the participants to think deeply about evaluating the needs of the audience and to configure their design to meet these needs. Thus, by the end of the semester teachers had learned valuable and self-affirming lessons about managing and learning in situations that were often ambiguous, confusing, and frustrating.

As in the other cases, participants learned about technologies as and when they needed to. For example, the virtual tour group learned QuickTime VR, the Web-publishing group used JavaScript in their Web pages, the database group focused on database-driven Web sites, and the clubhouse group utilized a variety of site building and image manipulation tools. They did this by studying manuals, talking to each other, talking to the instructor, and seeking out other locally available experts. The range of technological knowledge these projects brought to bear often outstripped the knowledge of the instructors. In fact, this would be one of the few classes where the instructors learned as much from the teachers as the teachers learned from the instructor! This would not have been possible if the instructors had determined a priori the range of software packages that would be covered.

Learning in the Design Approach

The three course examples presented here all used the Learning by Design approach to help teachers learn about educational technology and develop their TPCK. Though there were some important differences between these courses, they do capture the spirit of the Learning by Design approach.

Design by its very nature is about finding optimal (not perfect) solutions through the process of "satisficing" (Simon, 1969). Applying this knowledge is a complex process that is often riddled with contradictions and tensions. For example, the imperatives of pedagogy can conflict with the capabilities of the technology or the nature of the content to be covered. Likewise, the affordances and constraints of the technology can place constraints on how the content is to be represented or the kinds of pedagogy possible. Consider, for instance, attempting to replicate a full-class discussion through an online-chat. Participants in the design teams have to resolve these contradictions and tensions by considering all three factors (T, P, *and* C). Situations that call for reasoning about interactions (e.g., between technology and pedagogy) are an inherent feature of the learning by design approach. Furthermore, these interactions are always brought up in meaningful, context-bound situations. We do not discuss the specific development of TPCK through Learning by Design in this paper. (Interested readers can refer to other publications where these matters have been discussed in greater detail, for instance, Koehler, Mishra, Hershey, & Peruski, 2004; Mishra & Koehler, in press).

In this paper we focus on three specific aspects of Learning by Design that seem to emerge from the three examples: What the teachers learned about technology, about design, and about learning.

Learning about Technology

In each of the three case studies, it is clear that teachers (and instructors) covered a wide range of technology skills and concepts. As the course descriptions above indicate, the list of skills and technologies (both hardware and software) learned are impressively long. Additionally, participants and the instructors also discussed important ethical and legal issues relevant to digital ownership and copyright that emerged as the students worked on their projects. What is important here is to note that, for the most part, students learned on their own initiative, with little if any direct training. However, instead of focusing on what hardware and software skills were learned, (which, although important, could have been learned through other more traditional ways), we wish to speak to what teachers learned about the subtleties and complexities of technology in education. These are briefly summarized below.

Technologies have affordances and constraints. One feature of Learning by Design is that, as designers, teachers must confront the affordances and constraints of technology (Gibson, 1986; Norman, 1993). The design tasks enforce some constraints, including the time to complete the project, the expected audience, and the tools available to complete the job. Most decisions that a design team makes have to consider these strengths and limitations of particular technologies—deciding whether to lay out an online course conceptually or chronologically, whether to use one teacher's idea or another's for imagery in an iVideo, or whether to use a particular graphical editor in designing the Web sites.

Technologies are context sensitive. The computer, in and of itself, is an extremely malleable technology (Papert, 1980) in that it affords multiple, general-purpose uses. However, the problem of applying these general-purpose technologies to specific educational purposes requires an understanding of context. By proposing design activities in which every group has different members, goals, resources, and audiences, a different context is created for each design activity. Teachers come to learn that the "right" use of the technology really does depend on the particulars of the situation.

Technologies are social actors. In design approaches, technologies are never passive, and they are a part of the larger design context. Scholars of technology (Callon,1992; Latour, 1987) argue that thinking of technology as being a passive factor in design may be mistaken. They have argued that technology is as much an "actor" in the social network of interactions between people and technologies as people. As Brey (1997) says, "Artifacts can have effects because they can act, just like human beings. Consequently, they can also have unintended effects, just like an individual can perform actions that were neither intended nor anticipated by others." Schon (1996) talks about the idea of backchat, where the design talks back to the designer. As Schon describes it, the designer needs to listen to the design and to determine their next moves based on this knowledge. It is while in the process of designing that the designer learns about the kinds of moves that need to be made to solve the problem. In certain situations, this may lead to redefining the problem itself. For instance, as the educational psychology database group continued to work on their design, they realized that users would often want to print out the contents of the pages. This required them to rethink the design in a very fundamental manner and to offer the option of printer-friendly pages. Thus, the process of design becomes a conversation—a mutually constituted negotiation between the developing artifact and evolving conceptions of the designers.

Technologies are malleable. Naïve users of technology often use technology in naïve, stereotypical ways. In the design approach, teachers creatively re-purpose the tools and resources in hand if they are to achieve their goals. There were many such examples of re-purposing visible during the design projects. For example, due to network storage limits, the teachers making iVideos came up with the creative solution of "dumping" their partially edited materials back to tape and digitizing it again onto another computer. Hence, the camera and tape became re-purposed to serve as a mass storage device. To these teachers, a piece of technology is no longer viewed as a tool for doing just one thing; it has a range of potential uses (even some that have not yet been considered).

Technology means breakdowns. In the technology-rich design environments we described, opportunities for teachers to learn about the breakdowns associated with technology were not difficult to find. For example, teachers in the Web site redesign course faced innumerable problems due to incompatible software programs, where work done by one teacher with FrontPage (for example) would not be accessible by another teacher with Dreamweaver, and when a perfectly designed Web page would "vanish" when uploaded. These breakdowns happened often, and were another instance of a situation where a seeming problem could be seen as being instructionally valuable. These situations allowed the instructors to model appropriate responses, such as: how to troubleshoot, how to work through a problem, when to ask for help, and when to stop and fall back on another technology.

Learning about Design

Design is not something that can be taught by lectures and demonstrations. Design is a process that is best learned by experiencing it. That said, design is difficult to learn—it can be extremely motivating, enjoyable, and frustrating at the same time. Finding out that there are no easy or direct solutions, and that the solutions that do emerge are compromises at best, is often a difficult message for teachers to accept. By involving teachers in these design projects, we offered them an opportunity to explore and play within the relatively "consequence-free" zone of a classroom. In some sense, the classroom became a laboratory for teachers to experiment and try out different concepts, and to experiment with technologies and ideas. In doing so, we argue that they have learned a lot about the process of design.

Design is for a purpose. Teachers learned that design is always for a purpose. Continual feedback (both formal and informal, from the instructors and from their fellow teachers) forced them to think about their work from the point of view of the users (be they students, teachers, or parents). Considering the purpose of a design is critical to helping teachers develop as designers. For example, teachers in the Web redesign groups tested their designs on groups of potential users, and this feedback was invaluable in revealing assumptions and gaps that they were not aware of initially (Perkins, 1986).

Design is iterative. Participants in our courses learned that to design is to redesign. That is, design is an iterative process continually cycling back to first principles and re-thinking decisions. Participants became sensitive to the fact that consequences of their initial decisions could ripple through their work and sometimes constrained them in ways they had not initially envisaged. For instance, the choice of a software program for Web design, if not thought through carefully, could wreak havoc on the final design, as did happen to the group redesigning the clubhouse Web site. They initially chose a free Web editor to design their pages. However, as they worked on their design they realized that the software often renamed files, or placed them in different directories. Editing the site became an immense chore, and they finally had to redesign their site from scratch using a commercial, but less idiosyncratic, software program. Thus, design became a series of ongoing experiments—a process of intentional variation and selective retention of those experiments that worked and rejection of those that did not.

Design is best characterized as a cycle—it never really ends. There are temporary points of closure, often dictated by external constraints such as the time available. Participants realized that their projects could, in some sense, go on forever but that often the best that can be achieved, is "satisficing"—doing the best they could with what they had in the time available (Simon, 1969). The deadline of the final presentation to a large group urged them to complete their projects. Although the design teams were often quite critical of their own work, it was always interesting for them to see how people outside the class viewed their work. It was rarely, if ever, seen as being incomplete.

Design is eclectic. Design is a pragmatic exercise, a search for solutions that work. In attempting to find solutions, teachers learned that design is eclectic—it does not respect traditional disciplinary boundaries and requires thinking outside of these restrictions (Dasgupta, 1996). For instance participants in the Web redesign and faculty development courses had to think about the psychology of human computer interaction and the nature of the content they were presenting, as well as the constraints of the technology (i.e., software and hardware) and more. Any decision in one area (e.g., the choice of a navigational structure for the site) would have consequences for the other components of the project. For example, a special JavaScript pull-down menu could possibly solve the problem of navigation and use of space on the screen but would restrict the kinds of browsers that could view the site.

Design is complex. Teachers became sensitive to the fact that every choice made by a designer has both intended and unintended consequences. Thus, design is not so much a process of planning and executing, as it is a conversation in which the conversing partner—the designed object itself—generates unexpected interruptions and contributions. This dialogue often happens at multiple levels: between theory and practice, between constraints and tradeoffs, between the designer and the materials, between participants in the group, and between content, technology, and pedagogy.

Learning about Learning

The classrooms these teachers found themselves in looked a lot different than the classrooms they had typically encountered. Instead of sitting in rows and facing the instructor, these classrooms had multiple foci of activity, as teachers worked in groups. When teachers talk about problems they are facing in their designs, fellow teachers are just as likely to have ideas for solutions as instructors. We hope that this view of learning and teaching will be something that the participants in our classroom will carry with them even after they graduate. We list below some of the key aspects of the Learning by Design experience.

Learning is frustrating and challenging. Design projects involving technology could be extremely frustrating. There were many reasons for this. One reason was that teachers were concurrently learning the very technologies they were using to develop their final projects. This, when combined with the tendency of technology to break down, could make the process quite unsettling and frustrating. Design is also difficult because solutions are not easy to develop: Every potential solution has competing solutions, and deciding between the possibilities is not easy. Being left, for the most part, on their own and responsible for their own learning was not something most of the participants had expected or had much experience with. Despite the fact that these were practicing teachers and Masters' students, many of them expected to be given direct instruction on what to do, which menu to pull down, and which buttons to click to complete a particular task. Re-orienting their view about what teaching and learning looks like (even at the Masters' level) was not always easy.

Learning is fun. Despite the fact that design was frustrating, it was also intensely motivating and fun. In the Learning by Design approach, the classrooms we described all generated a buzz that is difficult to characterize—there is a certain energy and mood to the classroom that becomes part of the context. Learning becomes fun again. As one teacher noted, "I think, in most situations, people don't want to learn, or don't like learning because learning is boring and monotonous. However, in this class, learning is meaningful and also fun and enjoyable."

Learning is an active process. Teachers often came into these courses expecting to learn to use technology. This meant that they often perceived themselves as being consumers of knowledge. However, in our courses they were put in the role of generating knowledge, not just consuming it. In design-based courses, students have to create answers and encounter dilemmas, and the instructors are put in the role of coaches and guides. Initially, many teachers felt uncomfortable with this position, often wondering why the instructors would not simply tell them the answer. Over time, teachers began to investigate potential technologies for themselves, they used the Web to search for resources and ideas, and learned to pose questions to the entire group. In short, they began to understand that learning takes place in a community of practitioners (in which they are an equal part), and not as a result of communicating knowledge from a few experts (the instructors) to the novices (the teachers). After a while, many teachers picked up the new rhythm of the classroom and began to see the power of their being in charge. Comments like the following were not uncommon: "This experience has been one that has reshaped many things that I have held to or thought about teaching."

Learning happens in a range of contexts, both inside and outside of classrooms. In the Learning by Design approach, learning was no longer restricted to the classroom. Teachers often met outside of the classroom in groups or brought their own individual investigations and experiments to share with the group. These courses changed from being just the completion of a set of requirements for receiving a Master's degree to becoming something they looked forward to. This aspect of learning outside of class can be seen best in the journal postings (and responses) in the Web site redesign and faculty development courses. Discussions on the listserv were wide-ranging and engaging, and delved deeply into issues such as the aesthetics of design, design and its relationship to teaching, and the effect of new technologies on schools. The discussions around the journal postings on the listserv allowed deeper and wider conversations than would have been possible during the regular class meetings.

Conclusion

We began this paper with the question of what do teachers need to know about educational technology. We argue that although educational researchers are becoming increasingly sensitive to *what* teachers need to know, we have paid less attention to the issue of *how* teachers are to learn about educational technology. We argue that understanding the role of technology in pedagogy is more than the accumulation of technology skills, and that skillful teaching is more than finding and applying the right tool. In short, traditional methods of technology education miss the fact that teacher knowledge is complex (Carter, 1990; Cochran-Smith & Lytle, 1999), situated (Greeno, 1998), and multifaceted (Shulman, 1986).

As an alternative, we have offered the idea of Learning by Design––whereby teachers learn about educational technology by engaging in authentic design tasks in small collaborative groups. Our approach goes beyond the simple acquisition of skills (something that has been criticized in the teacher education literature). The acquisition of skills approach does not address what we and others believe is a critical issue: that teachers need to develop pedagogical understandings if they are to integrate technology into their instructional practices in ways that will benefit students. Clearly, teacher change cannot be achieved merely through direct instruction. It requires teachers to experience, as learners, the kinds of novel learning environments that can facilitate and enhance learning through the appropriate use of technology (Salomon, 1998). The Learning by Design approach requires teachers to navigate the necessarily complex interplay between tools, artifacts, individuals, and contexts. This allows teachers to explore the ill-structured domain of educational technology and develop flexible ways of thinking about technology, design and learning, and thus develop Technological Pedagogical Content Knowledge.

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