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Not “what” but “how”:
Becoming design-wise about educational technology

Punyashloke Mishra[1]
Matthew J. Koehler[2]

Michigan State University[3]

INTRODUCTION

Educational technology is here to stay. Although arguments about the promises and perils of educational technology abound, no one seriously questions that computers and other new information technologies will play an important role in the lives and learning of teachers and students. New technologies are already a significant presence in classrooms and schools. The numbers tell the story in no uncertain terms. Becker (1999) reported that between 1992 and 1998 the numbers of computers in U.S. schools grew over 150%—from 3.5 million to 8.6 million. The ratio of students to computers dropped from 14 students for every computer in 1992 to 6 students per computer in 1998. Over 90% of schools have Internet access, with more than a third having direct access in classrooms.

How these computers are used is another matter. Despite the increased availability of computers and access to network resources, instructional use of new technology is quite limited. Less than half of the teachers with classroom Internet access in Becker's (1999) survey had students use the web as a research tool on at least three occasions

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during the academic year. Only 7% of these teachers allowed students to use the computers to send e-mail as an instructional tool, and "even fewer involved the students in cross-classroom collaborative projects or in Web publishing" (p. 4).

Cuban (1999) found that fewer then two out of ten teachers is a serious user of technology in the classroom. However, this is not because teachers are luddites or lack training. The “technology puzzle” according to Cuban is that, “of those same 10 American teachers, about seven have computers at home and use them to prepare lessons, communicate with colleagues and friends, search the Internet, and conduct personal business. In short, most teachers use computers at home more than at school.”

What stands between the now and the vision of teachers creatively using technology in the classrooms of the future? The answer to this problem may seem straightforward— teachers need to know more about technology and how to use it in their classroom. We argue that the problem is more complex – it’s not simply a matter of WHAT teachers need to know, but HOW they are supposed to learn it.

The WHAT

Much has been written about what teachers need to know about technology to be effective teachers in the information age. Journal articles (Thomas, 1994; Widmer & Amburgey, 1994), state technology plans, and national standards have compiled a long list of the competencies that teachers will need to know in order to become skillful in technology rich classrooms. These sources aptly list a wide range of competencies for teachers to master, including concrete skills (e.g., keyboarding, connecting a computer to the network, etc); software application (e.g., word processing, spreadsheets, etc.); key technology concepts (e.g., networking, distributed computing, etc.); and transformative uses of technology in the classroom (e.g., learner-centered inquiry, using real-time data, etc.).

The voices are many, including national, state, and local organizations, licensing agencies, professional organizations, and teacher preparation programs (Handler & Strudler, 1997; Hirumi & Grau, 1996; National Council for Accreditation of Teacher Education, 1997; Petrakis, 1997; US Congress Office of Technology Assessment, 1995; Wiebe & Taylor, 1997). Kent & McNergney (1999) report that the teacher certification process in over 32 states in the U.S includes 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).

Technology standards, like other educational standards, tend to shape the curriculum and requirements of teacher preparation programs. Early versions of such technology standards for teachers have been criticized as being laundry lists of functional skills and knowledge that often ignored the situational and contextual realities of using technology for learning and teaching (Bruce, 1999). Such standards often interpret technology proficiency as the acquisition of technical skills--the ability to use current versions of hardware and software. 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. Underlying these lists was the implicit assumption that teachers who can demonstrate proficiency with software and hardware will be able to incorporate technology successfully into their teaching.

Some recent standards initiatives of note have moved away from this list of technology proficiencies view. The International Society for Technology (ISTE) and the National Council for Accreditation of Teacher Education (NCATE) are good examples of moving beyond advocating basic skills. The ISTE standards do contain a list of foundational skills for all teachers. However, these standards also enumerate a series of higher order goals that are essential for effective pedagogy with technology. 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 curriculum in the US primarily because NCATE is the only body officially sanctioned by the U.S. Department of Education to accredit schools of education. As Thomas, Taylor, and Knezek (1993) reported, the combined power of the ISTE standards and NCATE recognition had a significant impact both on developing programs and on promoting change in the educational structure within three years of their first being proposed. The ISTE standards have also become the basis for receiving funding and continued support of a variety of programs. For instance, the U.S. Department of Education's Preparing Tomorrow's Teachers to Use Technology (PT3) program, now in its third year, has allocated millions of dollars to enhance teachers' use of technology. Proposals for these funds are evaluated in part for their drawing on licensing, certification, and accreditation standards developed by state agencies, and national associations, with ISTE and NCATE being mentioned by name. The ISTE/NCATE standards have been recognized as being de-facto standards in other countries as well (Thomas, Taylor, & Knezek, 1993).

The newer standards (such as the ISTE/NCATE standards) have gone beyond advocating basic skills by emphasizing the pedagogical role that technology can play and the nature of teacher knowledge that is required to fully utilize technology for teaching and learning. That said, we believe that even these improved standards do not provide a complete answer to the problem at hand, and meet just part of the challenge of helping teachers become smarter and better users of technology.

The HOW

HOW are teachers supposed to learn WHAT the standards say they need to know? Teachers have often been left to go it alone – Kent & McNergney (1999) reported that a mere 15% of US teachers had 9 hours or more of technology training, despite an increased emphasis on teacher training and teacher professional development. Clearly, time, money and opportunities are part of the equation, but so are values, goals and methods.

Teacher education approaches must find ways to give teachers a wide range of skills that lead to a technological. Moreover, approaches must address how to help teacher develop a “deep understanding” of the concepts and skills that are not limited to specific instances of technology. For example, training teachers to use specific software packages not only makes their knowledge too specific to be applied broadly, but it also becomes quickly outdated. Technology is changing so fast, that any method that attempts to keep teachers up to date on the latest software, hardware, terminology is doomed to create knowledge that is out of date every couple of years.

We argue that traditional methods of technology training for teachers – mainly workshops and courses – are ill-suited to produce the “deep understanding” that can insulate teachers from the changes brought on by rapidly changing technology. Inevitably, these approaches rely on a process whereby teachers become consumers of knowledge about technological tools, with the hope that chances to learn about today's hardware and software packages will allow teachers to use them in their classrooms. 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. Teachers must reconsider their way of thinking about technology and their relationship to it. Teachers need ways to think about their relationship towards technology as being complex, dynamic and continuously evolving, through which they develop sophisticated and nuanced understandings of the capabilities of technology as well as its constraints.

We believe that effective technology users often find innovative and conceptually sophisticated (though not necessarily technologically sophisticated) solutions to authentic pedagogical problems through the creative reinterpretation and re-purposing of existing technologies. Doing so requires a willingness and ability to critically examine new tools in terms of their implications for standards-based teaching and learning in the classroom. Our concept of teachers need to know also includes a belief that teachers' professional development is a career-long commitment and that developing a plan for continued development is essential to maintaining proficiency.

We propose an approach whereby teachers work in groups to as designers and producers of educational technology. This approach, which we call learning by design, allows teachers to learn in ways that ties their knowledge of technology to its' educational uses (i.e., authentic problem solving). Teachers focus on an educational issue or problem, and seek to find ways to use technology to address the problem. In the traditional workshop/class approach, teachers are trained in the use of the newest tools that they might be able to use in their classroom. In the learning by design approach, in the context of solving a problem, teachers become the designers of the tools. Because their explorations of technology are tied to their attempts to solve educational problems, teachers learn "how to learn" 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 active designers technology.

The structure of the rest of the chapter is as follows. We begin by offering our conceptualization of the design process and how it should be taught. Three case studies are provided as examples of how we have used the learning by design approach in our classes of practicing teachers. We conclude with a description of how these three case studies are similar and different from each other as well as what lessons we can learn from them.

LEARNING BY DESIGN

> "Technology presumes there's just one right way to do things and there never is. And when you presume there's just one right way to do things, of *course* the instructions begin and end exclusively with [one predetermined product]. … But if you have to choose among an infinite number of ways to put it together then the relation of the machine to you, and the relation of the machine and you to the rest of the world, has to be considered, because the selection from among many choices, the *art* of the work is just as dependent upon your own mind and spirit as it is upon the material of the machine …" (Pirsig, 1974, p. 160)

Why design?

Design activities are one class of activities that fall under the broader category of project-based activities that has learners design complex interactive artifacts to be used by others for learning a particular subject (Harel, 1991). Design-based projects have involved the development of presentations, instructional software, simulations, publications, journals, and games (Carver et. al, 1992; Kafai, 1995; Kafai & Resnick, 1996; Lehrer, 1991). With such projects, students learn both about design – through the process of developing complex artifacts – and a variety of academic disciplines, such as programming, social studies, language arts, etc.

Research and theory suggest that design-based activities provide a rich context for learning. Within the context of social constructivism (Cole, 1997; Vygotsky, 1978) or constructionism (Harel & Papert, 1991), design projects lend themselves to sustained inquiry and revision of ideas. Other scholars have emphasized the value of complex, self-directed, personally motivated and meaningful design projects for students (Blumenfeld et. al. 1991, Harel & Papert, 1990, Kafai, 1995). Such design-based informal learning environments offer a sharp contrast to regular classroom instruction, the effectiveness of which has been questioned by many scholars (Harel & Papert, 1991; Papert, 1993; Pea, 1993; Lave & Wenger, 1991). As one might imagine, adapting such open-ended problem solving situations into the structure and organization of the conventional classroom is often difficult.

Design, broadly speaking, can be seen as "structure adapted to a purpose" (Perkins, 1986, p. 2). Perkins' definition captures elegantly an essential quality of design: it is a process of constructing artifacts that exhibit "goodness of fit." The notion of fit is particularly appealing to us, because evaluating fit requires a more nuanced view of the conceptual domain – a view that is sensitive to complex set of interrelationships between artifacts, users, tools and practice. Design can be seen both in material artifacts, such as a hammer or a piece of software, as well as in non-material artifacts, such as a poem, a theory or a scientific experiment.

Unfortunately, design has often been viewed as being the formulaic application of a series of predetermined steps that must be accomplished in order to achieve a particular, pre-specified goal. At the heart of this assumption is what Donald Schon calls the "model of technical rationality" (Schon, 1983, p. 21). This model assumes that developing technology consists of "instrumental problem solving made rigorous by the application of scientific theory and technique" (Schon, 1983, p. 21). Dasgupta (1996) makes a similar point about the subservient relationship of technology to pure science when he says that too often technology is seen to be "merely the application of the relevant basic sciences to the making of artifacts" (Dasgupta, 1996, p. 4).

More recently, it has been argued that design is more than the rote application of scientific knowledge to a given real world problem (Dasgupta, 1996; Gelernter, 1999; Mishra, Zhao & Tan, 1999; Schon, 1983; Winograd, Bennett, De Young & Hartfield, 1996). As Mishra, Zhao, & Tan (1999) say:

> Design is a creative activity that cannot be fully reduced to standard steps, and should not be thought of as mere problem solving. A designer lacks the comforting restraints of a well-organized discipline because designing is inherently a messy endeavor. It includes, but goes beyond, the ability to be

> creative in solving problems. A host of techniques and skills come into play during design. Many of the techniques and skills are explicit and publicly available, while others may be tacit and unspoken. According to Smith and Tabor (1996), design is as much an art as it is a science–spontaneous, unpredictable, and hard to define (p. 221).

Design requires a balancing act between a wide range of factors that often work against each other (features vs. cost, ease of use vs. advanced features, time to market vs. product quality, etc.). It requires the application of a wide array of knowledge, including algorithms, understanding of users, rules of thumb, scientific "facts," and multidisciplinary connections. This inherent "messiness" of design is further complicated when we consider the design of an abstract artifact, such as an after-school program (Vyas & Mishra, in press) or an online course (Mishra, Koehler, Hershey, & Peruski, 2001).

Vygotsky (1978) and Dewey (1934) emphasize the role of dialogue or interplay in learning – as the individual acts on the environment, the environment also acts upon the individual. Design activities bring this interplay directly into focus. It is fundamentally about ideas and transforming oneself and the world through the process of working with those ideas. That is, the environment constrains and thereby acts upon the artifact (and therefore the designers), and the introduction of new artifacts changes the environment. This is especially true of technological artifacts – they both are designed according to the constraints of the environment and change the environment. E-mail, is a good example of this. E-mail's features, conceptual metaphors, and core operations are adopted from the environment of traditional ("snail") mail. Likewise, E-mail has changed the nature of text-based communication in the information age. Hence, design is essentially a dialogue between ideas and world, between theory and its application, a concept and its realization, tools and goals. We see this dialogue as being at the heart of true inquiry, involving as it does the construction of meaning and the evolution of understanding through a dialogic, transactional process.

Teaching design

Despite our optimism around learning by design, we should also acknowledge that teaching design requires a shift in understanding. In fact Schon (1987) lists a range of reasons arguing that design cannot be "taught" in conventional ways. He argues that: (a) Designing is a holistic skill. It must be grasped as a whole, by experiencing it in action; (b) Design depends a great deal on recognition of design qualities. This recognition is not something that can be described but rather must be learned by doing; (c) 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; (d) Descriptions of designing are likely to be perceived initially as confusing, vague, ambiguous, or incomplete; their clarification depends on a dialogue in which understandings and misunderstandings are revealed through action; and finally (e) The gap between a description of designing and the knowing-in-action that corresponds to it must be filled by reflection-in-action. Moreover 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 as to what pedagogical value exists in doing so.

The sum of these arguments points towards learning about design by "doing" design, and less reliance on overt lecturing and traditional teaching. Thus our courses rely more on "implicit" learning through an active engagement in the class activities. We have designed a number of activities that teachers do (both in and out of class) that address the subtleties of the design process while developing technological fluency in teachers. We present three cases our use of the learning by design approach to teaching masters' level educational technology courses. Following the cases, we conclude with an overview of what teachers learn in our approach.

These examples were drawn over 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. Early in the courses 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. These courses had the usual assigned readings, discussion, and writings, but all of these are aimed at supporting the main activity of the class – the design and evaluation of the artifacts created by the design teams.

Direct instruction or training about a particular software or technology was rare, and when conducted, depended upon being requested by the participants. Though we did have a limited number of lectures, they were limited to short periods (20 to 30 minutes). These mini-lectures occurred for two reasons. First, a piece of software or hardware would be demonstrated if the whole class would need to do something repeatedly in the class (e.g., FTP to their webspace or operate a digital camera). Second, there were short discussions focused on big and powerful ideas about computing technology, such as the idea of a client-server relationship, internet protocols, file formats and hierarchical file structures, digitization. The emphasis here was on understanding basic concepts and on connecting these concepts to the projects teachers were working on. In addition these lectures often came towards the middle of the semester after teachers felt the need for a better understanding of these topics.

Instead of instructor-driven teaching about technology, the participants were free to choose (and often did so) any software or technology they felt was important to solving their unique set of problems. This de-emphasis on particular computer programs or platforms meant that teachers often used a wide range of technologies and this in turn significantly changed the role of the instructor, since it was impossible for the instructor to be knowledgeable about all of the technologies being used by the different groups. The instructor was no longer a lecturer, and instead became a facilitator and a resource (albeit limited by his or her knowledge).

We offer below three instantiations of these ideas. The cases present some diversity around the theme of learning technology by design. Although these courses build on a similar set of principles and ideas, they do differ from each other in some respects. These differences, we believe, are not differences in philosophy about the design approach. Rather, they are the result of a three main factors: (a) differences within faculty members in charge of the courses; (b) differences in course content and instructional goals; and finally (c) differences in institutional constraints, such as meeting-times, number of meetings in a week, and availability of electronic discussion groups. The three case studies allow us to see the same ideas play out across multiple contexts and identify commonalities and exceptions.

Case I: Faculty development & online learning

In the fall of 2001, Michigan State University began offering a Master's degree program available entirely online. In order to prepare university faculty to meet the demands of teaching and learning in an online environment, institutions of higher education, such as Michigan State University, must find ways to develop the expertise needed to teach in the online world, while meeting several very real constraints (e.g., limited faculty time, limited college budgets, fear of technology, etc.). The standard approach to confronting these problems is to enlist the help of technical experts (e.g., web-programmers) for the technical aspects of online course development, and leave the pedagogy to the experts in their chosen fields. Unfortunately, in this approach, the web-programmers may end up making decisions that have unintended pedagogical consequences. Pedagogical experts, unfamiliar with the technology, may not recognize the subtleties of how technical decisions can affect pedagogy. We attempted to solve this problem of developing online courses *and* of faculty professional development using the learning by design approach. Instead of handing the web-programmers a set of materials that worked in the face-to-face classroom, we advocate that the expert teachers take a hand in the design of the technology to support the learning. We relied on the process of design to develop the necessary skills and relationships for understanding the nuances of integrating technology and pedagogy and the complexities of applying the knowledge thus gained to the complex domain of real world practice.

This faculty professional development was achieved through a regular Master's level course in educational technology co-taught by the authors. We extended membership in this course to include six tenured faculty members. These faculty members enrolled as "students" in the design course. Teams consisting of one faculty member and three or four masters students worked on designing an online course that would be taught by the faculty member in the following year. The major activities of the course consisted of readings, explorations with technology, prototyping of the online course, online and in-class discussions, and peer review and feedback. A typical class period had a whole group component that was used to discuss readings and issues that applied to all groups, and a small group component in which the design teams worked on their projects.

In many ways, this design course was a typical graduate class experience for the teachers – they read articles, discussed ideas, and were responsible for meeting course deadlines. However, there were some important differences. Like faculty members, teachers were exposed to several technologies, assessed their usefulness, and potentially used them in the design of the online class. In more traditional technology courses, all teachers explicitly learn the same target technologies as part of the course (e.g. web design, digital video, etc). In contrast, the design approach made learning about technology implicit – teachers learned about technologies as they needed to in order to fulfill some desired feature of the course they were designing. However despite this "implicit approach" teachers were exposed to a range of different technologies and managed to focus their attention on particular technologies that were most appropriate for the task at hand. The choices of technologies used by the groups varied, depending on the design of their online course. One group, for instance focused a great deal on understanding how a faculty member could provide audio feedback to his students. Another group investigated the use of PowerPoint presentations via the web to offer overviews of the lessons to be covered. Groups also explored a range of pedagogical issues such as developing techniques for developing a learning community online as well as strategies for problem-based learning. All the groups learned about the nature of effective web design as part of putting their course online for review and feedback. Apart from issues of technology the faculty-student groups also learned about other issues of online course design such as 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.

The task of designing an online course was a unique opportunity for most teachers. None of the students had previously had the opportunity to design a graduate course from scratch. Opening up the process of graduate teaching for students gave them the chance to apply their knowledge of educational theory to a real context, and to further their own development as future lecturers, instructors, and professors. As one studentparticipant said, “This class has been one that I will never forget. From how much work building, maintaining, and revising an on line 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.”

Also, the chance to work with tenured faculty provided novel experiences for most of the students. Too often, graduate students’ experiences with their professors seem opaque – they only get to see final products of their thought processes (e.g., research papers, courses they take, etc.). By working with expert educators, they got to interact with ideas in ways that they are seldom allowed – they worked over a whole semester with these ideas, got to influence the experts’ ideas, and apply them to a real problem. Most student participants reported that this course was one of the best courses 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 before.

Case II: Making movies in Switzerland

As the capstone sequence towards a master’s in educational technology, the second author and Dr. David Wong taught a nine-credit, educational technology sequence to 28 teachers. Their goals were to give teachers additional insight into the fields of educational psychology and educational technology and how the two fields interact in expert practice. Again, much of the course was traditional – the participants had assigned readings, discussion groups about readings, some lecturing about educational issues, and action research projects to do. However, part 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. The instructors decided to accomplish this goal with the learning by design approach.

Teachers had to make two movies, called iVideos (idea-based videos) to communicate an idea of education importance to a wider audiences. The videos had to inspire others with passion for the idea. The first video had to complete the sentence: “Teaching is ______.” The second video was up to the groups (with the approval of the instructors). Topics included, the role of technology in the library sciences, communicating online, and appropriate uses of technology. Instead of teaching teachers how to do digital video, the teachers had to learn the technology in the context of communicating a broader educational idea.

Teachers were provided with digital cameras, tapes, tripod, software, and computers. They also received a one-hour demo of how to use a camera, capture video, edit it, and produce a digital movie. Most of their time was spent in groups discussing/debating their idea, storyboarding, filming, digitizing, editing, revising, and soliciting feedback. The instructors scheduled regular times for teachers to preview their works in progress to the whole class in order that feedback was a consistent part of the process (although many objected to showing their uncompleted work). Versions of their iVideos were posted to a website so that feedback from other masters' level courses could also serve as an impetus to change and re-design. Once the movies were complete, they were shown to an audience of approximately 80 people (involved in the summer session) and were posted to the website 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, argue, screen, and preview video. These activities went well beyond classtime, teachers worked late into the night in the lab, in their dorms, and through the weekends.

The instructors did hardly any lecturing about the "nuts" and "bolts" of digital video, instead they spent most of their time circulating among the teachers, acting as a coach, guide, and mentor. Occasionally some advanced technical assistance was given by the instructor, but for the most part the teachers learned "how to learn" without the help of the instructors. They began to rely more and more on their fellow teachers, and undertook responsibility for their own learning by playing with the software and hardware, seeking out on-line resources and tutorials, and sharing their knowledge outwards to the other teachers. It is our hope and belief that learning about "how to learn" will carry out with them beyond the realm of making iVideos as they are confronted with changing educational technologies in their schools in the years to come.

Given that their was no list of skills teachers needed to learn, nor was their grade based on learning specific skills, the list of technologies that some (to all) learned was impressive. These included, operating a digital camera, learning about cabling, file formats, protocols, digitizing video, video production software (e.g., Adobe Premiere, iMovie), video compression (CoDecs), bandwidth considerations, FTP (File Transfer Protocol) for sharing large files with other group members), graphics programs (Photoshop, Fireworks), web searching (for picture resources), web page design (for sharing and distributing movies and documents), data-base driven websites (for maintaining movie versions and user feedback), animation programs (e.g., flash and director), and troubleshooting.

More important than the individual technologies skills was their learning about subtleties and relationships between and among tools, actors, and contexts. Technology was learned in the context of expressing educational idea and metaphors. For example, seven different metaphors were used and discussed for the "Teaching is ____" assignment. 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, working together in groups, giving and receiving feedback, and communicating with audiences.

Case III: Learning Technology through Design

This course, Master's seminar in Educational Technology offered by the first author, dealt with technical, pedagogical, and social issues around design and educational uses of web based technologies. Most participants in this graduate class were practicing k-12 teachers who brought their rich professional knowledge of teaching and learning to this course. Participants in this class were expected not only to learn interactive web-based technology but also generate abstract knowledge (about designing educational technology) through working in groups on four different design projects. In the learning process, each member of the communities 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. Like the other two cases, teachers in this class did plenty of readings and discussion (both in-class and on-line).

The tasks assigned to this group were different from the projects in the two courses described previously. Participants in the previous courses were involved in the task of developing movies or online courses from scratch. In contrast, participants in this course were involved in the re-design 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 re-design tasks: (a) Re-design of virtual tour of the College of Education; (b) Re-design of a web publishing course for middle school students; (c) Re-design of a children's computer clubhouse web site to make it more accessible to children and parents; and finally (d) Re-design of a database on educational psychology theory and practice (currently available at http://tip.psychology.org). Each of these projects had a different audience, ranging from middle school students to visitors to the college of education web site; from parents of students at a computer clubhouse to master's or doctoral students in educational psychology. Teachers in their class regularly participated in group projects, whole class discussion, group collaboration, project presentation and critique, asynchronous on-line discussion, journals, and final 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 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.

Though one of the goals of these courses was to have participants learn technologies, the instructors did not specify what software programs the teachers were to use. Also, teachers were offered no explicit training on learning specific computer programs. Though this approach generated some frustration at the beginning, throughout the course, teachers had learned a wide number of technologies to complete their projects. For instance the virtual tour group learned Quicktime VR, the web-publishing group used Javascripts in their web pages, the database group focused on database driven websites, 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 a-priori determined the range of software packages that would be covered.

An important part of the class were electronic discussions through either a bulletin board or through a web-archived listserv. Teachers were asked to write two or three journals through the semester. The timings of the journals were staggered in order to have regular postings to the group throughout the semester. Teachers were not constrained in anyway about the topics that they may raise through they were encouraged to connect the journals to issues currently being raised in the class. Teachers were also asked to supply constructive criticisms of the products being developed by the other groups. This helped develop a sense of community as well as allow for in-depth discussions on topics—something not necessarily possible in the regular class time.

What was learned

The three cases studies presented here all used the learning by design approach to help teachers learn about educational technology. Though there were some important differences between these courses, they do capture the spirit of the learning by design approach. Across the three settings, we argue that the teachers learned quite a bit about technology, about design, and about learning.

Learning about technology – In each of the three case studies, it's clear that teachers (and instructors) covered a wide range of technology skills and concepts. If all the skills learned were listed together, the list would be impressively long. Rather than focus on WHAT hardware and software skills were learned, we wish to speak to WHAT teachers learned about 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 (Norman, 1993; Gibson, 1986). 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 layout 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 websites.

Technologies are context sensitive – In the design activities, technologies are investigated, evaluation, and applied in order to accomplish a goal. Hence, technologies were always learned within the context of the task. In some sense, the context was the same for all teachers – they were learning about technology within the larger context of a Master's course (or courses). However, because of differences in the personnel, goals, resources available, and the faculty involved, the context could vary significantly. This is particularly important when we consider the "protean" nature of the digital computer (Papert, 1980) that affords multiple uses depending on the context. For example, in case one (online course development) one group learned how to use PowerPoint to communicate their progress to other groups. A second group explored advanced features of PowerPoint to make online lectures come alive by synchronizing audio with bulleted topical summaries of key points. In short, in design activities such as these, providing context is never a problem because context provides the grounding for all learning.

Technologies are social actors **–** In design approaches, technologies are never passive, they are a part of the larger design context. 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 (1986) 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 that 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 stereotypical ways. However, an immediate consequence of the idea that the computer is a protean machine is the fact that it is a malleable device. The overarching goal of design is to get the artifact to "do the job" within the constraints of time and resources available. Since resources or time are limited designers often have to creatively re-purpose what they have to make their designs work. There were many such examples of re-purposing visible during the design projects. Freely downloadable javascripts that were meant to display random quotes were re-designed to display random images instead. Since sharing large amounts of video data over the network was not feasible the teachers making iVideos came up with the creative solution of "dumping" their partially edited materials back to tape and digitizing it again on to 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 haven't been considered yet).

Technology means breakdowns – In the technology rich design environments we described, opportunities for teachers to learn about the breakdowns associated with technology were not hard to find. For example, every day the video design teams constantly faced breakdowns, minor bugs, and major flaws associated with Adobe Premiere. Teachers had to learn ways around these bugs to complete their projects and often shared tips with their fellow teachers (defragmenting the hard drive, configurations of memory and virtual memory, suggested sequences of actions to take in the software to avoid crashes, etc.). Teachers in the website re-design 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 were wonderful teachable moments allowing the instructors to talk about larger and bigger issues of file formats, hierarchical file structures, client-server relationships. A previously abstract and abstruse discussion on file naming conventions becomes important when Teachers are faced with the immediate problem of images not showing up on their web pages. And it was not that the instructors were immune to such breakdowns. These happened often and were another instance where a possible problem could be seen as being instructionally valuable. These situations allowed the instructors to model appropriate responses – how to trouble shoot, 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. It is learned best through the active process of creating and doing. That said, design is hard to learn. It can be extremely motivating and enjoyable and frustrating at the same time. The fact that there are no magic solutions, and even the solutions that emerge are compromises at best is often a difficult message to swallow. 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, to experiment with technologies and ideas.

Design is for a purpose -- An important lesson to learn is that design is always for a purpose. Thinking of this forces designers (as it did the participants in our courses) to take on a variety of perspectives on their design. Continual feedback (both formal and informal, from the instructors and from their fellow teachers) forced them to think of their work from the point of view of the users (be they students, or teachers or parents). This perspective taking is an extremely important part of design. For example, teachers in the web re-design 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.

Design is done in cycles – Participants also developed a better understanding of the conversational and dialogic nature of design. An important part of design is that of redesign—of going back to the first principles and thinking about every decision them made. Participants became sensitive to the consequences of their initial decisions since the consequences of these initial decisions could ripple through their work and sometime constrain 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 wreck havoc on the final design (as did happen to the group redesigning the clubhouse web site). 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.

That is, 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. Most teachers in these design-oriented courses became sensitive to these issues as they became more involved in their projects, hoping to develop a perfect product. They realized that their projects could, in some sense, go on forever but that often the best that can be achieved, or maybe even needs to be achieved is “satisficing” (Simon, 1969). The deadline of the final presentation to a large group urged them to complete their projects. Though 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. It is a process that makes the designer to marshal all the resources currently available to them and leverage them to generate solutions. The goal is to create something that works. In this, design is eclectic, and does not respect traditional disciplinary boundaries. This is because real-world problems are often not contained with such boundaries either and hence coming up with a solution requires thinking outside of these restrictions. For instance participants in the web redesign course had to think about the psychology of human computer interaction, the nature of the content they were covering with as well as the constraints of the technology (i.e. software and hardware) and more. Any decision in one area (say the choice of a navigational structure for the site) would have consequences for all of these domains. A special javascript pulldown 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 un-intended consequences. Design thus is not so much a process of planning and executing, as it is a conversation. It is a conversation in which the conversing partner—the designed object itself, generates unexpected interruptions and contributions. The process of design can be fruitfully seen as an ongoing series of experiments in which the self and the object to be constructed are in continuous dialogue. The designer has to listen to the emerging design, even while shaping. This dialogue often happens at multiple levels, between theory and practice, between constraints and tradeoffs, between the designer and the materials and between participants in the group.

Learning about Learning – The classrooms these teachers found themselves in looked a lot different than the classrooms they typically encounter. Instead of sitting in rows, facing the instructor, these classrooms have multiple foci of activity, as teaches 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. While a lot could be said about what the impact that learning by design has upon teachers' beliefs and process of learning, we would like to briefly mention a few aspects of our experience. It is our hope that the process of learning emphasized here is one that carries with the teachers, so that future learning carries with it many of the values described below.

Learning is frustrating and challenging – Design projects involving technology can be extremely frustrating. There are 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 unsetting 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 often 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 lessons on what to do, which menu to pull down, 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's hard to characterize – there's 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 courses such as these they were put in the role of generating knowledge not just consuming it. They had to come up with answers to questions and dilemmas that arose during the design process. Instructors are put in the role of coaches and guides, and less in the role of the keeper of answers. Initially, many teachers felt uncomfortable with this position – often wondering why the instructors won't simply tell them the answer. Over time, teachers begin to investigate potential technologies for themselves, use the web to search for resources and ideas, and learn to ask questions to the entire group. In short they begin to understand that learning is a community of practitioners (in which they are an equal part), and not a process 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 begin 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 in and out of class – One of the most interesting consequences of the learning by design projects was that 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 the 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 in best in the journal postings (and responses) in the website re-design course. 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 impact of new technologies on schools. This allowed deeper and wider conversations than could have been possible through the regular class meetings.

CONCLUSION

We began this paper with the question of what do teachers need to know. We argued that though we are increasingly become sensitive to WHAT teachers need to know we need to get a better sense of HOW they are to learn it. Understanding technology is more than the accumulation of skills, and that skillful teaching is more the science of applying the right tool for the job. We have offered above one possibility – the idea of "learning by design" – where teachers learn educational technology by doing educational technology. Design, we argued was necessarily a complex interplay between tools, artifacts, individuals and contexts. Design activities allow teachers to explore the ill-structured domain of educational technology and develop flexible ways of thinking about technology.

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