WHAT TEACHERS NEED TO KNOW ABOUT TECHNOLOGY? FRAMING THE QUESTION

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Modern information and communication technologies (ICT) are rapidly entering schools in the hope that these expensive tools will improve student learning, increase teachers' productivity, and prepare our children to live and work in an information society, where ICT play an essential and ubiquitous role. The ratio of students to instructional computers connected to the Internet in American public schools, for example, dropped from 12:1 to 7:1 in a matter of two years between 1998 and 2000. The percentage of American public schools connected to the Internet increased from 35% in 1994 to 98% in 2000 (Cattagni & Farris, 2001). The increased presence of ICT in schools has been accompanied by increased pressure for teachers capable of using these supposedly powerful tools so as to realize their educational potentials. Technology competency has been increasingly viewed as a necessary element of a teacher's professional qualifications (The CEO Forum on Education and Technology, 1999; National Council for Accreditation of Teacher Education, 1997; U.S. Congress Office of Technology Assessment, 1995). Today as attested to by the technology requirements issued by government teacher licensing agencies, teacher education program accreditation agencies, and international professional organizations, technology professional development programs for in-service teachers initiated by schools, and the addition and expansion of the technology component in teacher education programs, it is no longer a question whether teachers should know something about technology.

The question has changed from whether to what. In order for school districts and licensing agencies to assess whether practicing teachers are technologically competent, for teacher educators to prepare technologically competent teachers, and for all teachers to develop their own technology proficiency, a good understanding of what that something is that teachers need to know about technology is necessary. The quest for such an understanding is as challenging a task as is the attempt to understand what makes effective teachers and efficient teaching (Borko & Putnam, 1996; Calderhead, 1996; Edelfelt & Raths, 1999; Gage, 1963; Richardson, 2001; Shulman, 1987; Travers, 1973; Wittrock, 1986).

Difficult though it may be, many people have embarked on this journey. This collection of papers reports findings from some of the efforts to define teachers' technology competency that have been undertaken at multiple levels from various perspectives. It is hoped that what is learned from these pioneering efforts will help light the paths to follow and dead ends to avoid in the future. In this essay, I discuss the major issues considered by the included chapters with the intention to develop a framework for understanding teachers' technology knowledge.

From Artifact to Tool: What Teachers Need to Know to Use Technology?

When considering what teachers need to know about technology in order to use it, I found the following story told by the wise man Aesop extremely enlightening and relevant:

> A thirsty crow found a pitcher with some water in it, but so little was there that, try as she might, she could not reach it with her beak, and it seemed as though she would die of thirst within sight of the remedy. At last she hit upon a clever plan. She began dropping pebbles into the pitcher, and with each pebble the water rose a little higher until at last it reached the brim, and the knowing bird was enabled to quench her thirst. (Aesop, 1912, p. 17)

In this story, Aesop illustrates the essence of technology. The pebbles were simply irrelevant physical objects until four things happened: a) the crow felt thirsty, b) the crow saw a pitcher of water, c) the water is too low for her to reach, and d) she realized that the pebbles could be used to raise the water level. Connecting the pebbles to her need for water, the crow turns irrelevant objects into a tool, a technology—a solution to her problem. At this moment, the pebbles are no longer pebbles but a powerful tool for the thirsty crow. What turns the pebbles into a tool is the crow's knowledge of the relationship between a problem and the quality of an object.

Teachers' uses of technology are certainly more complex than the thirsty crow's using pebbles to help her get to the water but they have some striking similarities. While computers and the Internet are much more sophisticated and created more purposefully than Aesop's pebbles, they are as irrelevant and useless as pebbles until they are used to solve a problem. Unless they are used, computers remain a man-made object, or an artifact. They only become a tool, a means to an end, when they are connected to a problem.

Admittedly, technology is different from natural physical objects such as the crow's pebbles in that they are made to solve practical problems. However, a technological object is quite often other people's solutions to other people's problems. A word processor application is the software developer's solution to the perceived problems of composing and editing texts. It only becomes a tool for a specific user when she uses it to solve her problems of composing and editing texts. In order to turn the word processor application from an artifact into a tool, the user must first know that she needs to compose and edit, and then realize that the word processor can help her compose and edit. Since most technologies introduced to schools have not been developed as educational tools—tools that solve problems teachers face in their work—very often they remain expensive artifacts rather than useful tools because teachers do not consider them solutions to their problems. This is one of the main reasons that most school technologies have been unused or underused (Becker, 1999; Cuban, 1986; Cuban, 1999; Cuban, 2001; Loveless, 1996; Smerdon, Cronen, Lanahan, Anderson, Iannotti, & Angeles, 2000).

A technology has its built-in functions. These functions represent the developer's knowledge of the connection between a problem and a solution. In other words, technology is a knowledge system (Hickman, 1990). Thus technology is not neutral or unbiased. Rather, it has its own propensities, biases, and inherent attributes (Bromley, 1998; Bruce, 1993). Its inherent attributes or functions suggest to its perspective users what problems a particular technology might solve. For example, the functions of an e-mail program make a strong suggestion that it is designed to solve communication problems through electronic means. Hence for teachers to use a technology, they need to know its inherent functions. Knowledge of the functions of a technology helps teachers not only make the connection between the technology and existing problems but also identify new problems.

However as mentioned earlier, the problems identified by the developer may not be the same problems that teachers face. Thus the built-in functions of a technology are often considered irrelevant by teachers unless they are presented as solutions to educational problems. For instance, most word processor applications today have the function for embedding annotations in the document. This function represents a solution to the problem of leaving notes within a document but the problem is not necessarily an educational one. Until it is connected to educational problems such as inserting comments into student writings or having students engaged in peer editing, this function is not a considered useful by teachers. Therefore for teachers to use technology, they need to develop knowledge that enables them to translate technological potentials into solutions to pedagogical problems, which are very local and deeply situated in the teacher's own contexts.

This view of teacher technology knowledge is fairly consistent with findings of cognitive research on teacher knowledge and teacher learning (Putnam & Borko, 2000). A number of cognitive psychologists have argued that human cognition is situated (Greeno, Collins, & Resnick, 1996). According to the situative perspective:

> The physical and social contexts in which an activity takes place are an integral part of that activity, and that the activity is an integral part of the learning that takes place within it. How a person learns a particular set of knowledge and skills, and the situation in which a person learns, become a fundamental part of what is learned. Further, whereas traditional cognitive perspectives focus on the individual as the basic unit of analysis, situative perspectives focus on interactive systems that include individuals as participants, interacting with each other as well as materials and representational systems. (Putnam & Borko, 2000, p. 4)

Teachers' knowledge about technology is situated in the context where technology is used. The knowledge is not only about what technology can do but also (and perhaps more importantly) what technology can do for them. The usefulness of a technology lies only in its uses. Thus teachers' technology knowledge consists of three elements: (a) knowledge of problems that can be solved by technology, (b) knowledge of a technology that can solve their problems, and (c) knowledge of how technology can solve their problems. Teachers who are sufficiently equipped with this knowledge should be able to decide when to use technology and when not to. They should also be able to select technologies appropriate for the current problems.

This discussion leads us to further questions. First, given the situated nature of teacher technology knowledge and the long list of possible technologies, what technologies should teachers know about? Second, how much should teachers know about specific technologies? Finally, in what ways should teachers learn about technology? I discuss the questions in detail in the following sections.

Pencils and Microscopes: What Technologies Should Teachers Know?

Technology is a very broad and ill-defined term. It can mean any application of human knowledge to practical problems. Even when technology is interpreted as only mechanical objects, the range of objects is almost inexhaustible: from simple things such as the overhead projector and pencil to complex systems such as the computer and Internet. Even when we narrowly define technology as computers, the list of things teachers need know is still not easy to create.

A useful way to develop such a list might be to first think about the categories of technology teachers may use in their teaching. There are multiple dimensions by which one can group educational technologies: technical capacity, specificity of functions, and pedagogical roles.

In terms of technical capacities, technologies can be grouped into word processing/publishing (e.g., Microsoft Word), data processing (e.g., Access), presentation (e.g., PowerPoint), communication (e.g., e-mail), and information accessing (e.g., web browsers). This way of categorizing currently dominates the discourse in educational technology and teacher education. Many teacher education programs and professional development programs in educational technology are organized around this categorization and teach teachers specific computer applications. Even many state technology requirements for teachers follow this orientation and define teacher technology competency as mastery of applications in these areas (Zhao & Kendall, this volume). However, this orientation is too techno-centric, with little consideration of how technology may be used by teachers to solve problems inherent to teaching and learning. In other words, it categorizes technology as artifacts, not tools.

Another way to think about technology is in terms of the types of problems it addresses. Some technologies, such as word processors and web browsers, are content free, multi-purpose tools. They can be used in many contexts for a myriad of purposes. In other words, they are like pencils, which can be used for drawing and writing in a variety of situations. On the other hand, some technologies, such as student record management systems and a software program that simulates gravity are designed for specific purposes. Like microscopes, they are often used in limited situations.

The specificity and versatility of technologies are two opposing qualities. When specificity increases, versatility decreases. Thus, the more specific are the problems a technology is designed to address, the less likely it is that it can be used to address other problems. Specific technologies provide more explicit and constrained connections between functions and problems and thus are easier for teachers to see how they can be used. For example, a student-record management program tells the user clearly what it can do because what it can do is very limited. Consequently, it would be fairly easy for teachers to see how it can be used. However, a more generic technology, such as the word processor, while it allows more creativity, does not suggest any direct connection to an educational problem, making it more difficult for teachers to see how it can used in their teaching.

The third dimension by which technology can be categorized is its educational function. A number of scholars have proposed categorizations from this perspective. Means (1994) classified educational technology into four categories: used as a tutor, used to explore, applied as a tool, and used to communicate. Technologies used as a tutor are systems designed to "teach by providing information, demonstrations, or simulations in a sequence determined by the system." On the contrary, technologies used to explore are systems that designed to "facilitate student learning by providing information, demonstrations, or simulations when requested to do so by students." Technologies that are applied as a tool are "general-purpose technological tools for accomplishing such tasks as composition, data storage, or data analysis" while technologies used to communicate are systems that allow "groups of teachers and students to send information and data to each other through networks or other technologies." (p. 11). Bruce and Levin (this volume) proposed a similar taxonomy of educational technology. Based on John Dewey's works, they treat technology as media and put educational technologies in four categories as well: technology as media for inquiry, media for construction, media for communication, and media for expression. Salomon (1993) categorized technology into two groups: performance tools and pedagogical tools. Performance tools are technologies that enhance or change how a task is accomplished while pedagogical tools are technologies that focus on changing the user's competencies.

These categorizations of educational technologies are useful for different purposes, but they are not connected to research on teachers' knowledge and beliefs. Without connecting technology to teachers' pedagogy, these categorizations view technology as a separate force in the classroom, while research suggests that the effects of technology are significantly mediated by teachers' existing pedagogical knowledge and beliefs (Becker, 2000; Bruce, 1993; Dwyer, Ringstaff, & Sandholtz, 1991; Fisher, Dwyer, & Yocam, 1996; Zhao, Pugh, Sheldon, & Byers, in press). Thus what technologies teachers should know should interface directly with what teachers do in their teaching. In other words, teachers technology knowledge should be integrated with their pedagogical knowledge. Technology knowledge should be considered part of a teacher's knowledge and beliefs about teaching and derived from what he does. Only when such integration is made can technology move from artifact to tool for teachers. And only when technology "disappears" into teachers' practices (Bruce & Hogan, 1998) and becomes part of their overall knowledge of teaching and learning can technology function to support teaching and learning on a regular basis. Thus, we should consider teachers' technology knowledge in light of teachers' pedagogical knowledge and consider what technologies teachers should know in light of what teachers already know and need to know about teaching and learning. The abundant literature on teacher knowledge and teacher learning lends us a conceptual framework for considering teachers' technology knowledge.

There are just as many different categorizations of teacher knowledge and beliefs as categorizations of technology (Borko & Putnam, 1996; Calderhead, 1996; Shulman, 1987). In a review of literature on teacher learning, Borko and Putnam (1996) discussed "three domains of knowledge that are particularly relevant to teacher's instructional practices: (a) general pedagogical knowledge and beliefs, (b) subject matter knowledge and beliefs, and (c) pedagogical content knowledge and beliefs." (p. 675). The two most relevant domains where technology can be applied to are general pedagogical knowledge and pedagogical content knowledge. The domain of general pedagogical knowledge and beliefs, according to Borko and Putnam:

> … encompasses a teacher's knowledge and beliefs about teaching, learning, and learners that transcend particular subject matter domains. It includes knowledge of various strategies and arrangements for effective classroom management, instructional strategies

> for conducting lessons and creating learning environments, and more fundamentally knowledge and beliefs about learners, how they learn, and how that learning can be fostered by teaching. (p. 675)

Pedagogical content knowledge, first proposed by Shulman (1987), includes “the ways of representing and formulating the subject that make it comprehensible to others,” and “an understanding of what makes the learning of specific topics easy or difficult” (p. 9).

This articulation of teacher knowledge and beliefs suggests a number of directions for identifying what technologies teachers need to know. First, there is technology for classroom management: databases for record keeping, communication technologies for exchanges with parents, and project management tools for developing and managing class projects. Second, there is technology for instruction: presentation tools to provide multi-media information and simulations, communication tools for students to collaborate on projects, and information accessing technologies for student research. Third, there is technology for teachers to know more about their students: simulation technologies to identify students’ misconceptions, technologies for communicating with students, and assessment technologies to better and more accurately gauge student learning. Fourth, there are specific technologies for different subject matters. For example, web-based archives of historical documents can be used for teaching history, live data from the Internet for teaching weather and earthquakes, computer simulations for teaching abstract scientific concepts, writing tools for literacy, and speech technologies for foreign languages.

This articulation of teacher knowledge not only points out that technology knowledge should not be limited to using technology as a tool, but also strongly suggests that teachers understand how technology affects students as well. Today’s students grow up in a technology-mediated world and their thinking, behavior, and emotions are heavily influenced by new technologies (Tapscott, 1998). Many students today spend much of their time interacting with technological objects or in technology-mediated environments: watching TV, playing video games, chatting on the Internet, writing on the computer, and reading on the Web. Teachers' knowledge of technology should be expanded to include technologies that students interact with as well.

In summary, instead of treating technology knowledge as a separate entity of teacher knowledge, I suggest that we view it as an integrated part of teacher pedagogical knowledge and pedagogical content knowledge[1]. In other words, technology becomes an element of instructional strategies and classroom management strategies. Knowledge of teaching, learning, and content includes knowledge of technology.

From Adoption to Invention: How Much Should Teachers Know About Technology?

There are two dimensions of knowledge: breadth and depth. Breadth indicates the quantity of technologies teachers need to know while depth refers to how much teachers need to know about technology. Thus far, I have discussed the breadth of technology knowledge. In this section I discuss the issue of depth of technology teacher should develop.

Teachers' technology knowledge can have three levels: mechanical, meaningful, and generative. At a mechanical level, users' understanding of a technology is fragmented, limited, and superficial, focusing more on form than function. Teachers who are at this level of proficiency hold relatively stereotypical views of the functions of the technology—similar to what is conceived in popular media or by the manufacturer. Typical behaviors of teachers who understand technology at a mechanical level include following strictly prescribed steps of action when approaching technology, attempting to memorize specific instructions on how to use a particular technology, and inability or reluctance to use new and unfamiliar technologies.

At the meaningful level, users begin to separate functions from forms. They can think of or accept alternative ways to achieve the same function. Though they begin to gain a certain situational awareness about technology, they are still limited in their ability to use or re-purpose the tools in new or different contexts. At the generative level of technology proficiency, users have a deep understanding of the technology, which enables them to disassociate form from function and break away from stereotypical uses of technology. These users also have a good understanding of the contextual implications of the technology and are sensitive to appropriate and inappropriate uses of technological tools.

The depth of teacher technology knowledge significantly affects their uses of technology (Zhao et al., in press). Teachers at the mechanical level of understanding often try to repeat what technical manuals prescribe or what they are taught and by whom. They are less inclined to repurpose technology for their own uses. On the other hand, teachers at the generative level of knowledge are creative and frequently reinterpret technology for their purposes. They adapt technology instead of simply adopting it.

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[1] There are different ways to conceptualize teacher technology knowledge in relation to pedagogical knowledge. In other chapters of this volume, the authors hold different perspectives on what teacher technology knowledge is, for example see Margerum-Leys and Marx (this volume) and Conway and Zhao(this volume).

The Apple Classroom of Tomorrow (ACOT) project (Fisher et al., 1996), one of the most extensive and first large-scale experiments with infusing technology in all aspects of teaching, found that teachers go through a five-stage evolution in their uses of technology: entry, adoption, adaptation, appropriation, and invention (Sandholtz & Ringstaff, 1996; Sandholtz, Ringstaff, & Dwyer, 1997). In the entry stage, teachers did not have much experience with technology—it could be said that their technology knowledge was at a mechanical level. Their focus was on changes in the physical environment and "typical first-year-teacher problems such as discipline, resource management, and personal frustrations" (Sandholtz & Ringstaff, 1996, p. 286). Their use of technological resources was simple and limited.

In the adoption stage, teachers began to develop more fluency with technology. They become more focused on the functions of technology. "Their concerns shifted from connecting the computers to using them" (Sandholtz & Ringstaff, 1996, p. 286). When they moved into the adaptation stage, "teachers increasingly incorporated technology in their instruction" (p. 286). They began to observe improved efficiency of the instructional process and notice changes in student learning and engagement.

The last two stages, appropriation and invention, saw more creative uses of technology to accomplish real tasks. Teachers at these stages should have reached the generative level in terms of technology knowledge. "They came to understand technology and used it effortlessly to accomplish real work—their roles began to shift noticeably and new instructional patterns emerged … teachers began to reflect on teaching, to question old patterns, to speculate about causes behind the changes they were seeing in their students" (Sandholtz & Ringstaff, 1996, p. 287). This indicates freedom from technology. Teachers are no longer constrained by the prescribed mechanical functions of technology. They invent and reinvent the uses of technology in their own teaching. In these last stages technology has become part of teacher knowledge and pedagogy.

In summary, how much teachers know about technology makes a big difference in their uses of technology, as suggested by the ACOT study. Once technology is truly integrated, teachers' beliefs and knowledge are changed as well. New pedagogical knowledge and practices emerge from the integration of technology, but only when teachers reach a certain level of technology understanding. Thus when considering what teachers should know about technology, we cannot only think about what and how many technologies but also how much.

From Addition to Integration: How to Teach Teachers Technology?

As teacher education programs are asked to prepare technologically proficient teachers, they are faced with the practical problem of how to teach teachers to use technology. The first and usual response is to offer a new course, as we have always done when something new needs to be taught. Actually many teacher education programs have been offering educational technology course for a long time, although the content of the course has changed many times. (Lumsdaine, 1963) reported that in some states, teachers were required to take a lab course to learn about how to use films for teaching in the 1960s. As technologies changed over the years, the emphasis in lab courses moved from films to instructional television, personal computers, multimedia authoring, and the Internet.

Adding a new course on technology to an existing program has a number of benefits. First it ensures that the content, whatever it is and whoever defines it, has a place in the curriculum. Someone is responsible for this part of teacher knowledge. Second, it is fairly easy to implement. A program needs only to find one or two instructors and hand them this job. It does not affect the rest of the faculty, thus causing minimal disruption to existing practices. Finally, it is more noticeable to the accreditation agency and the public that the program has addressed the issue of preparing teachers to use technology.

This addition approach, however, is quite problematic in at least two ways. First, today's school technology is rather different from its predecessors such as films and overhead projectors. Computer-based technologies are much more complex than older technologies and encompass a wider range of applications. One course is no longer sufficient to help teachers reach the level of knowledge needed for creative uses. Adding more courses is at the same time next to impossible because most teacher programs already have a crowded curriculum. Second, and more importantly, as discussed earlier in this essay, technology should be considered part of teachers' pedagogical knowledge. Teaching technology separately could easily result in a focus on technological skills instead of technology uses.

An alternative approach that is gaining popularity is to integrate technology into the existing courses. Instead of offering separate technology courses, some teacher education programs have started to infuse technology into the current curriculum. Every teacher education course becomes a place where future teachers can learn how to use technology. The integration approach should theoretically be more effective than the addition approach. It enables teacher educators to demonstrate how technology can be used in authentic teaching situations, and provides opportunities for preservice teachers to explore and use technology throughout their collegiate years. It provides possibilities for connecting technology to content knowledge, pedagogical knowledge, and pedagogical content knowledge, which is the main focus of most teacher education courses. For this reason, the integration approach is more likely to teach technology uses rather than technical skills.

However, the integration approach is much more challenging to implement than the addition approach because it requires instructors of all teacher education courses to be able to use technology to teach and understand how technology can be used for classroom management and instruction. This is no easy task however, as many teacher educators are no better prepared to use technology than are K-12 teachers (The CEO Forum on Education and Technology, 1999). Taking the integration approach requires teacher education programs to invest much more on professional development for their teaching staff and provide sufficient technical support as well as access to facilities. Further, integration could mean disappearance—the technology component can be easily ignored or taken out by instructors who are not prepared to teach with technology or are pressured for time to teach "more important" things for teachers. The effectiveness of the integration approach relies heavily on the readiness of the teacher education faculty.

Conclusion

What I have done so far is to unpack the question "what should teachers know about technology?" To reach a useful answer to this question we need to address at least four more questions: What is the nature of technology use? What technologies should teachers know? How much should teachers know about technology? Finally, how can teacher education programs teach technology knowledge? These four questions constitute the main components of a framework for future inquiries about teacher technology knowledge.

I have attempted to propose some tentative answers to these questions:

1. Technology use is essentially a process whereby the user turns an artifact into a tool, an object into a solution to a local problem.

2. Technology should be considered an integral part of teacher knowledge. Teacher pedagogical knowledge and beliefs should include knowledge of how technology can be used to solve their own problems. Therefore, a good source of directions for identifying what technologies teachers should know is what they already do and know.

3. Teachers can have different levels of technology understandings. The levels of understanding matter in teaching practices.

4. Teacher education programs could take two different approaches to teach technology: separate technology courses or integration of technology into the existing curriculum. Each approach has its merits and problems.

These answers are summaries of current understandings and meant to serve as a starting point for future research. Many of the ideas discussed in this essay are speculative in nature and await further verifications. The papers included in this volume address these issues in more detail through a variety of perspectives and methods.

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