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THE NATURE AND SHARING OF TEACHER KNOWLEDGE OF TECHNOLOGY IN A STUDENT TEACHER/MENTOR TEACHER PAIR

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This study had two purposes. The first was to explore teacher knowledge of educational technology through the lens of three components of Shulman's model of teachers' knowledge—content, pedagogical, and pedagogical content knowledge. A second purpose was to investigate the ways in which teacher knowledge was acquired, shared, and used by student teachers and their mentors. By using Shulman's model, a comprehensive depiction of teacher knowledge was constructed and considered. Data for the study were drawn from a 3-month intensive observation period. Results indicate that employment of Shulman's model revealed a set of knowledge derived from and applicable to practice with educational technology. Impact on the field includes a broadening sense of the nature of knowledge of educational technology as well as increased attention to the importance of the student teaching placement and student and mentor teachers' roles within that environment.

Keywords: *teacher knowledge; educational technology; teacher preparation; teacher education*

When student teachers and their mentors use educational technology in classroom and professional settings, they instantiate a body of knowledge. This body of knowledge is fluid and continuously developing, drawn from a variety of sources, and applicable in a variety of settings. Within the context of their practice, teachers modify their understanding of educational technology, much as they modify their understandings of other factors that influence

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teaching and learning. In the process, they evolve a "wisdom of practice" (Shulman, 1987, p. 4) that enhances and expands their knowledge base. If teachers are to use technology to further their efforts to be effective facilitators of student learning, it is essential that their knowledge of educational technology encompass not just content knowledge—the technological capacities of hardware and software—but pedagogical and pedagogical content knowledge as well.

This article examines the nature and acquisition of knowledge of educational technology by a student teacher and her mentor working in the shared professional context of Madrid Middle School,[1] a medium-sized middle school in a working-class suburb of a large midwestern industrial city. The initial product of this examination was a set of three cases of pairs of practicing teachers and the student teachers with whom they work. This article reports the results of one of those cases, a pair of science teachers referred to as Helen Johnson (student teacher) and Anna Lloyd (mentor teacher). From March through June of 1999, I observed, talked with, and in some instances worked alongside these teachers as they interacted with students and used technology for teaching, learning, and achieving their own professional ends. By depicting this particular case, I create a narrative portrait of teacher knowledge of educational technology in this individual setting. This portrait is informed by and structured according to a comprehensive general model of teacher knowledge that includes content knowledge, pedagogical knowledge, and pedagogical content knowledge of educational technology. Placing this depiction within the literatures surrounding teacher knowledge and educational technology, this article seeks to contribute to the field's understanding of teacher knowledge as it impacts and is impacted by both educational technology and the mentor/student teacher relationship.

Questions for Study

Two major questions guided the design, conduct, analysis, and writing of this study. The first question was

> *Research Question 1:* What knowledge of educational technology can be inferred from observing the practice of and conversing with student and mentor teachers in the context of their professional lives?

To address this question, this study took a broad view of teacher knowledge, adapting Shulman's (1987) model for teacher knowledge to educational technology. The second question for study was

> *Research Question 2:* How is knowledge of educational technology acquired, employed, and shared by the participants?

Running parallel to the depiction of educational technology knowledge in this study were considerations of the role that knowledge plays in instantiating educational uses of technology and the means by which educational technology knowledge was promulgated in the setting.

Operational Definitions

This study employed an operational definition of teacher knowledge that is close to what Fenstermacher (1994) would call a "grouping" sense. This grouping sense of knowledge posits that teachers "generate ideas, conceptions, images, or perspectives when performing as teachers" (p. 31). It is these ideas and perspectives that are described in this study.

In reviewing the literature, the term *educational technology* tends to be implicitly defined. Ely (1995) wrote that "Educational technology is a term widely used in the field of education, . . . but it is often used with different meanings. . . . Educational technology properly refers to a particular approach to achieving the ends of education" (p. 1). This definition, like others found in the literature, can be seen as focusing on processes for teaching and learning as much as they are about pieces of hardware or software. Teachers' use of technology can furthermore be viewed through the use of a definition explored by Hickman (1990), in which the roots of the term *technology* are traced to the Greek *techne*. Hickman wrote that

> for Aristotle and Plato alike, *techne* was said to imitate nature by modifying and bringing to completion natural events and objects for the sake of human pur-

> pose and use. At the same time it was said to perform the quasi-divine function of establishing order where there had been only chance. (p. 17)

Applying this to educational technology, concepts to be learned by students might be thought of as "natural events" with technology serving to help order those concepts for learning purposes. For purposes of this article, the definition of the phrase *educational technology* was operationalized as follows: applications and processes that employ electric or electronic devices to enhance teaching, learning, or the professional ends of teachers. Primarily these were information technologies. Participants used these technologies to aid in student and teacher presentations (e.g., equipment demonstrations, video cameras, and laser disks), create information-based products (e.g., student word processing to create texts), locate information and curricular resources (e.g., World Wide Web sites and CD-ROM materials), and assess and record student understanding of information (e.g., quizzes taken via computer software and grade-keeping programs used to create a record of learning).

RATIONALE

Educational technology, especially the use of computers and associated information technology, is rapidly solidifying a prominent role in education. The computer has the capacity to be employed for instance as a cognitive tool (Salomon, Perkins, & Globerson, 1991), a memory tool (Swan, 1996), a motivational tool (Means & Olson, 1995b), a communication tool (Doucette, 1994), or a project support tool (Marx, Blumenfeld, Krajcik, & Soloway, 1997)—understanding the range of possibilities, the appropriate applications, and the relevant pedagogical strategies requires an array of knowledge on the part of the teacher. This knowledge can be acquired from a variety of sources.

For both student teachers and mentor teachers, the sharing of knowledge of educational technology in the context of the student teaching placement may be a contributor to professional development (Easdown, 1994). Preservice teachers have reported that their student teaching experience is a very consequential portion of the teacher preparation process (Dowrick, 1997). Mentor teachers play a contributing role in the value to the student teacher of the student teaching experience (McIntyre, 1988). Their classroom experience, subject matter knowledge, and familiarity with particular teaching settings cause them to be viewed as a respected source of knowledge for the student teacher.

Mentor teachers for their part report that student teachers are a valued source of knowledge (Easdown, 1994; Margerum-Leys & Marx, 1999; Tatel, 1996). Sharing of knowledge is important for teacher preparation and development generally; it may be especially important in the acquisition of educational technology knowledge. Educational technology is an area in which mentor teachers are eager to access content knowledge held by student teachers. Mentor teachers view student teachers by virtue of their relative youth as members of a generation that holds more knowledge of technology than they themselves do. They also perceive that students' teachers teacher education coursework will have contained more educational technology information than their own coursework (Lundeberg, Zeon, Brown, Ingebrand, & Bieging, 2001; Margerum-Leys & Marx, 2000). An additional motivation for studying the knowledge of teachers regarding technology is that the role of educational technology, especially computers in education, is changing rapidly. In the early days of computer use in education, computers were thought to be useful for the teaching of logic through programming (Papert, 1993). Subsequently, there was a conceptualization of computers as standalone information processing and document production tools. More recently, the computer has been thought of as a communication tool; computers are now used and viewed as portals to an ever-expanding array of information through electronic mail and the World Wide Web (Jonassen, 2000; Tiene & Ingram, 2001). Paralleling these changes in our perceptions of the utility of technology has been a steady movement toward more student-centered learning environments and activities. This has implications for the preparation and development of teachers. To use technology in ways that are congruent with our current understandings of teaching and learning as well as of technology itself, teachers need to be familiar with an expanding variety of pedagogical techniques (Forcier, 1999; Jonassen, 2000; Marx et al., 1997; Means & Olson, 1995a; Mergendoller, 1996).

Relevant Literature

In recent years, there has been an explosion in the number of computers available in America's schools. Between 1983 and 1995, the students per computer ratio nationwide plummeted from 125 students per computer in the average school to 9 students per computer (Glennan & Melmed, 1996). Current initiatives in the state of Michigan (Michigan Department of Education, 2001) will equip classroom teachers with laptop computers and other hardware, bringing this ratio down even more. As the educational community passes through a phase in which acquisition of hardware is a paramount concern to one in which educationally sound applications of new technologies are at the forefront, focus on the role of teachers is increasing (Corcoran, 2000; Wenglinsky, 1998). Teachers play a vital part in the success or failure of any educational innovation; the use of technology is no exception. Computer use is not the "unalloyed good" (Beasley & Sutton, 1998) that politicians and the media sometimes portray. Computer use can be associated with either increased or decreased student learning (Wenglinsky, 1998). The difference between computer uses that are associated with poor academic performance and uses of classroom technology that are associated with higher student learning lies in large measure in whether teachers are prepared and how they use technology in their teaching. Teachers who use technology in the service of higher order thinking skills are associated with students whose standardized test scores are higher (Wenglinsky, 1998).

To make effective classroom use of technology, teachers require knowledge regarding the incorporation of educational technology into the K-12 academic milieu (Office of Technology Assessment, 1995; Wenglinsky, 1998). Knowledge forms the basis for sound decision making; specialized knowledge is required for the fluent handling of the complex teaching and learning situations that arise as teachers instantiate applications of technology in their teaching practice (Bransford et al., 1986).

Knowledge as a Construct in the Educational Research Literature

Fenstermacher (1994) pointed out that literature that deals with teacher knowledge, including some of the literature explored in this article, in certain instances neglects to define the standards by which it judges information or statements to be knowledge. This is a legitimate criticism; to have a discourse about *knowledge*, the term needs to be defined so that there is some shared sense of meaning. The information on which teachers act and that some literature treats as knowledge is often at the level of what has traditionally been called *beliefs* rather than knowledge. Beliefs is defined by Goodenough (1963) as implicit or explicit propositions that are held to be true and are "accepted as guides for assessing the future, are cited in support of decisions, or are referred to in passing judgment on the behavior of others" (p. 151). Crucial to this definition is the role of beliefs in determining courses of action and in shaping knowledge structures, sometimes in opposition to what might be looked at as objective "truth." Teachers act with conviction on their beliefs, basing these beliefs on their own experience and preparation (Alexander, Schallert, & Hare, 1991). Different teachers operating in very similar settings would be expected to have different beliefs regarding appropriate pedagogical approaches. Although there are generally accepted guidelines for teaching, it is possible that each of these teachers might be correct for his or her own practice; pedagogically effective choices for one might be ineffective for the other.

Knowledge as the Construct Used in This Study

In this article, the inferences made regarding teacher knowledge of educational technology are in a grouping sense (Fenstermacher, 1994).

We do not make an epistemic distinction between knowledge and beliefs, preferring to carefully describe participants' practice and our inferences regarding their knowledge and to allow the readers to draw their own conclusions. For descriptive purposes, we use Shulman's (1987) model as a form on which to fit these findings. Shulman embraced a broad range of knowledge components drawn from a variety of sources. In applying Shulman's model to educational technology though, we retain some sense of the epistemic. Knowledge to be considered knowledge here is information that exists "in the world." It is shared and its warrant validated by one or more communities; these may be teachers, researchers, professional organizations, or bodies of related literature. In addition, knowledge may be warranted as such through improvements in repeated practice. When a teacher alters his or her instruction to correct for perceived shortcomings in his or her plan or students' abilities, the teacher evidences accrual of pedagogical (in the case of general strategies) or pedagogical content (in the case of specialized understandings of the use of technology for teaching and learning) knowledge.

Teacher knowledge, as laid out by Shulman (1987), has multiple components and draws from multiple sources. Each of these components and sources can be seen operating in and on educational technology. Each influences how teachers teach with technology as well as how teacher education students might be helped to develop the ability to teach with technology. This study focused on the following three components of teacher knowledge: content knowledge, pedagogical knowledge, and pedagogical content knowledge.

METHOD

The object of this study was a description of knowledge as it was acquired, used, and shared by a student teacher and her mentor teacher in the context of their teaching and other professional practice. Knowledge can be difficult to observe—as defined in the previous section, it is a theoretical construct that must to some extent be inferred. Although inferences about knowledge are by nature subjective, sufficient warrant must be given for inferences drawn and substantiation made for the selection of some evidence for inferences over others. The primary goal of the methods employed in this study was to link teachers' knowledge as spoken of in interviews and instantiations of that knowledge as observed in their classroom practice as well as to show educational technology knowledge, acquisition, and sharing by the student teachers and their mentors. By linking interviews and observations systematically, this study's methods build an argument for a complex description of teacher knowledge of educational technology. A guiding assumption is that student teachers and their mentor teachers may serve as sources of knowledge for each other. For both student teachers and mentor teachers, sharing knowledge of educational technology is a mechanism that fuels professional development. The methods used sought to provide evidence for this assumption through conversations with the participants and observations of their classroom and other professional practices. In addition to defining knowledge of educational technology richly, I sought to document the acquisition and sharing of knowledge by student teachers and their mentors.

Research Design

Case study research, with its ability to describe individuals and their settings richly, was the natural choice for this study. Yin (1989) argued that case studies are the method of choice for describing current phenomena over which the researcher has relatively little control, in which the boundaries between phenomena and context are unclear, and for which the researcher will have access to multiple data sources.

Procedure

This study relies on the following two main data sources: classroom observations and interviews. The classroom observations, which included observations of planning periods and informal conversations with participants, took place from March 1 through June 21, 1999. Concurrent with the classroom observations were a series of three interviews with each participant. During this 3-month period, I gradually became a part of the Madrid Middle School environment, allowing me to make observations, if not from an insider's perspective, at least with an insider's access to the setting.

The object of the classroom observations was to follow the teachers as they used technology in their teaching. By attending to their practice, I was able to draw inferences about the implicit knowledge displayed. During instruction as well as during out-of-class interactions, I also noted the give and take between cooperating teacher and student teacher. From these interactions, I was able to create a picture of the sharing of educational technology knowledge within the teacher pairs.

Data on classroom observations were collected using a field notes database devised iteratively during the first 2 weeks of data collection. This database allowed the individual observations to be focused along systematic lines. Using the reporting functions of the database, it was also possible to remain cognizant of the larger structure of the data being collected. Each observation (i.e., a class period or a conversation) was represented by a record in the database, with organizational and observational information entered into fields within the record.

Paralleling the observations, a series of three interviews with each participant served as the other major component of the data set. These interviews helped to create a more complete picture of teacher knowledge as it played out at the research site. Teachers were able to narrate their perspective on their practice as well as add value to classroom observations by explaining things I did not understand or could not see. I was interested in both the knowledge held by the teachers and their perspective regarding that knowledge. Following a format suggested by Seidman (1991), I conducted three semistructured interviews with each of the 6 participants. Each interview lasted approximately 1 hour. All interviews were conducted at the research site, with most of them held in the participants' classrooms. By locating the interviews in the classrooms, the participants and I were able to use the surroundings to aid in recall and to spark conversation.

Analysis

Methodologically, there were six links that led from the events to this report. The first was the events themselves. From March 1 to June 21, 1999, a set of events occurred at Madrid Middle School. The second link was what I chose to observe from within the universe of what occurred. As I developed my role as a participant-observer, I focused my attention on teachers' uses of technology with the goal of making inquiries and inferences about the knowledge base that was reflected in the teachers' practices. The organization of my field notes and the transcription of the interviews formed the third link in the chain. By being systematic about what was noted in each observation and how transcripts of the interviews were created, I was able to accrue a set of data in which connections could be made and themes observed. The field notes were a subset of my observations, which were in turn a subset of the events themselves and the observations that could have been made. Similarly, the interview transcripts lost the audible sound of the voices of the participants, but the transcription process allowed for coding of the transcripts as well as connection with the observation notes. Coding of the notes was the fourth link. The coding used in this study was thematic, rising from the observation field notes and organized in part along conceptual lines. Although the process of code development was guided by previous research and suggestions from the literature (Chi, 1997; Margerum-Leys & Marx, 1999), the structure and particular set of codes were unique to this study. Thematic analysis of the coded data formed the fifth link in the chain. The final link was the form of report used for the study. Following guidelines suggested by Yin (1989), I present a case study that illuminates the study setting and its participants.

In systematically performing observations, interviews, data collection, analysis, and reporting, I was able to reach conclusions that respect the intricacy of the phenomena being described while yielding comprehensible conclusions. The purpose of data analysis was to allow the systematic reduction of data in such a way that trends could be seen and results derived while honoring the complexity of the underlying data and presenting a supportable argument. Data analysis keyed on the classroom observations. From this standpoint, the classroom observation field notes were the central component of the data set as it was in this setting that teachers instantiated their knowledge. Themes from the observations were developed first, with the interview transcript coding tied to these themes.

Data coding was accomplished through a recursive process of identifying themes in the classroom observation field notes and interview transcripts, followed by a process of creating narratives describing sections of the data rich in thematic information. During a first pass through the data, a process known as bootstrapping was employed; emerging themes and categories were recorded in the database. These became the basis for the coding structure. The compiled list of emerging themes was compared with each other, and redundant themes were merged. Codes relating to teacher knowledge were organized along conceptual lines suggested by Shulman (1987) in his descriptions of the structure of teacher knowledge. With the coding structure in place, the data were again examined and coded at the paragraph level for field notes and the line level for interviews. This process was similar to verbal analysis coding (Chi, 1997) in which a researcher's subjective impression of a data set is used to create a structure that can be partially quantified to aid in the identification of larger themes.

RESULTS

As identified in the literature (Glennan & Melmed, 1996), lack of access to technology can be a barrier to its use in educational settings. An additional barrier is a dearth of teacher preparation (President's Committee of Advisors on Science and Technology Panel on Educational Technology, 1997). Helen Johnson and Anna Lloyd's case represented what can be accomplished when a student teacher has constant access to technology for her professional use as well as the potential that can be realized when an in-service teacher acquires educational technology knowledge through professional development and ongoing interaction with student teachers.

Classroom Environment

Lloyd and Johnson cultivated a classroom atmosphere of collaborative student scholarship. Analysis of field notes indicated that class sessions often took the form of labs or other student-centered projects. Lloyd emphasized science content in these projects, insisting that students use scientific vocabulary and emphasizing that understanding of the science content was more important than mastery of lab techniques or computer equipment.

Technology took center stage among the objects in the classroom. Lloyd's classroom computer was in the middle of the front of the room; she and Johnson used it frequently during the class period, primarily for Web searches and record keeping. A VCR and television were also present in the room, along with a laser disk player. At the front of the classroom was an overhead projector. The projector was in daily use for the question of the day as well as for directions for classroom activities. Both Lloyd and Johnson were frequent and enthusiastic users of and learners concerning technology. The physical arrangement of the room highlighted their incorporation of technology in their everyday teaching practice.

Desk space for students in the classroom was provided by a set of freestanding lab tables. Each table seated two (for teacher-directed instruction) or more (for project work) students. On three sides of the perimeter of the room, a set of six workstations—each with gas, electricity, and sink—provided space for conducting science experiments or participating in other projects. Small windows along the exterior wall provided light to the classroom, as did fluorescent overhead lights.

Students generally performed to Lloyd's expectations. It was unusual for the class routine to be disrupted by discipline or other classroom management problems—there were only four instances of this during the time that I spent at Madrid Middle School. Even during project sessions, the classroom tended to be quiet and well ordered. Students rarely abused the relative freedom to move about in the room during labs and projects. Only once during the data collection period did a student need to leave the classroom due to inability to follow class norms.

Throughout the observation field notes, Lloyd's daily classroom routine was structured and predictable. Each instructional period in the classroom began with a question of the day projected onto a screen at the front of the classroom. Students spent the first 5 minutes of class individually answering this question, then discussing their answer with the rest of the class. Following the question of the day, the remainder of the period was usually given over to a mix of direct instruction and project-based education, with labs and other projects predominating.

Approaches to Teaching With Technology

By March, when the observation period started, Johnson's and Lloyd's teaching styles were nearly identical. Timed scripting of their lessons showed that each instantiated lesson plans along timelines that differed very little, with student activities facilitated in the same ways by both members of the pair. In interviews, both espoused similar philosophies of science teaching and working with middle school students. Their philosophies were enacted in a shared setting, with the same student population and district curricular goals.

In May, I observed Johnson and Lloyd teaching a lesson on plant cells using a Web site as a source for scanned microscopic images. There were five repetitions of the same lesson, with Johnson (the student teacher) leading the first two and Lloyd (the mentor teacher) the remaining three. Each began with approximately 5 minutes of direct instruction, including bringing to students' attention some relevant terms from the Web site. Each used a whiteboard at the front of the room to project images from the Web site. Each walked students through the first three questions on their accompanying worksheet, then allowed students to work in independent pairs for the remainder of the period. Time allotted for the introductory and direct instruction portion of the period was as followed: third period (Johnson), 26 minutes; fourth period (Johnson), 20 minutes; fifth period (Lloyd), 20 minutes; sixth period (Lloyd), 20 minutes; seventh period (Lloyd), 21 minutes. Johnson, the student teacher, had planned the lesson. The stacked histogram in Figure 1 shows how closely their instructional sequence matched during these five instantiations of the same lesson plan. Period 5 is the lunch period at Madrid: The extra exploratory time was an artifact of the school schedule.

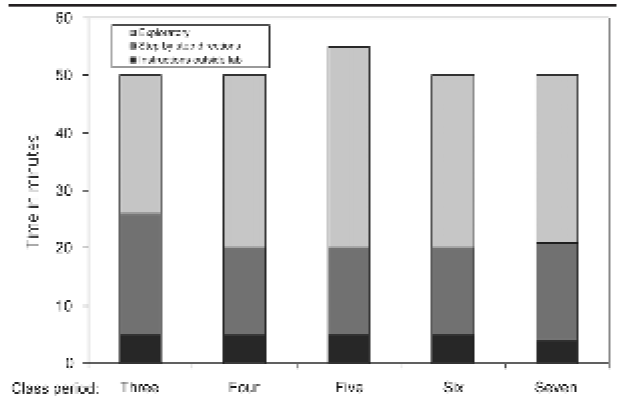

FIGURE 1: Web Cell Lab Times
NOTE: Periods 4 and 5 were led by Helen Johnson, the student teacher. Periods 5 through 7 were led by Anna Lloyd, the mentor teacher.

It was common for Johnson and Lloyd to do what I came to think of as twin team teaching. Rather than each taking a different role, they would share the role of lead teacher during the directed instruction segment of the class, then share the role of activity facilitator during student-centered time. On many days, a visitor unfamiliar with the pair of them would be hard pressed to say who was the mentor and who was the student teacher based on their instructional practice. Lloyd saw Johnson as an indispensable partner in doing the kind of science teaching that she valued, particularly when incorporating technology into her teaching.

Nonetheless, a more analytical examination of their teaching exposed subtle differences in their approach, both with and without technology. These differences seemed in part related to Lloyd's greater experience as a classroom teacher. When introducing new content through direct instruction, Lloyd frequently used examples drawn from her teaching experience. Lacking illustrations from personal experience, Johnson asked students to contribute examples from their own life experiences. Both approaches seemed effective, with students remaining engaged in the lesson and appearing to gain from the examples provided, whether from the teacher or from fellow students.

Lloyd's approach to teaching with technology. Lloyd's views on teaching science and her practices as a science teacher were in alignment with a pedagogical philosophy that teaching science involved creating rich environments for students and providing them with authentic tasks (Cognition and Technology Group at Vanderbilt, 1990). Technology's role was to motivate students and provide a content-rich environment. To this end, Lloyd used laser disks for small group work and CD-ROM-based software as a source of content material.

Students were held to scientific standards when participating in class activities. Lloyd put more emphasis on scientific concepts than on technology or lab technique knowledge. Students were encouraged to experiment and not be concerned about technological failures. When students had trouble with equipment, they were encouraged to be problem solvers. Lloyd would guide them to a solution by asking them to think about what the trouble might be and how they would go about solving it.

Outside the classroom, Lloyd used e-mail to extend her reach as a science teacher, both for her own students and for students who contacted her through an America Online program in which teachers agreed to act as content experts and field questions. On several occasions during the observation period, she reported that she fielded science content and school-related questions.

In employing technology in her teaching, it was clear that Lloyd was enamored of science education first and viewed technology as an interesting toolbox for enhancing her teaching and her students' learning of science. Technology was a motivator and a provider of content and communications capability, but science and student learning were the primary goals.

Johnson's approach to teaching with technology. Both Johnson and Lloyd valued student inquiry and relative student autonomy in which students pursued questions provided by the teacher but had some flexibility regarding the steps to be taken in addressing those questions. This philosophical perspective contrasted with school lab personnel's view of effective instructional practices, which tended to be more conservative and teacher centered. When Johnson discussed her plans for the Web-based cell biology lesson with the lab personnel, there was a difference of opinion as to how the lesson should be implemented. The paraprofessional recommended that Johnson take students through the instructions for the lab step by step. Johnson disagreed, but as a student teacher she consented to implement the lesson as recommended.

Prior to the student teaching experience, Johnson had acquired knowledge of technology by a different route than had Lloyd. By almost a decade the oldest of the 3 student teachers who participated in the larger study, Johnson had a considerable background in banking before turning to classroom teaching. Of the 6 participants, she was the only one who carried a laptop computer. Through her work experience and her constant access to a computer, she had become very proficient with productivity applications such as word processors, spreadsheets, and presentation software. In the following passage, she related how her access to the laptop computer impacted her teaching practice:

> Because [technology] was there, I tend to use it . . . [for] everything. I use it for word [processing] . . . I mean, I use it to make signs on the door to tell them we're going somewhere else, I use it to make quizzes and tests, I use it to make worksheets, I use it to take

the worksheets that are in the [teacher's edition] that comes with our book, and change them so that the special ed. class has more room to write. I have done that frequently where I'm looking at a worksheet going "Okay, I don't like this format" and I completely redo it. . . . Sometimes it's the way questions are asked . . . I think a lot of the questions, sometimes the way they're asked don't make sense, or wouldn't make sense to some of our students, so sometimes it is completely editing or partially editing. (Johnson, third interview)

The aforementioned example is an instance of a teacher applying pedagogical knowledge to her use of educational technology. It may seem simple to change a worksheet to better fit with one's students, but Johnson did so far more often than the other participants. For Johnson, constant access to technology enhanced her teaching practice, allowing her to improve the usability of curriculum materials for her particular students.

Approach to Learning About Teaching With Technology

For Lloyd, formal professional development was an ongoing, planned process with improvement of her classroom teaching practice as the goal of her development efforts. Lloyd's approach to professional development in teaching with technology was consistent with her professional approach to other types of teaching. When she realized that the Internet was becoming important, she enrolled in a university course to learn more about its use.

A benefit of the knowledge acquired through the course was Lloyd's increased ability to connect with her students electronically during nonschool hours. The knowledge acquired from the course itself was content knowledge: knowledge of the capacities and operating procedures of specific pieces of hardware and software.

Lloyd referred in conversations to the value of student teachers as sources of educational technology content knowledge. In aggregate, she considered them a renewable resource, with each year bringing a fresh set of ideas.

It's one of the reasons I love getting [student teachers]. It instantly updates me. It's like, they know the newest stuff. . . . If I'm stuck on something and I'm not sure how to do it, a lot of times they do. (Lloyd, third interview)

Acquisition of educational technology knowledge was a two-way street for Lloyd and Johnson; Lloyd was both a recipient and a provider of educational technology knowledge. Particularly in terms of pedagogical and pedagogical content knowledge, Lloyd viewed herself as a source of knowledge for her student teachers. In a passage following the earlier passage, Lloyd says,

I think the [teacher education] students come in probably knowing a lot more about computers than I do. But, I probably can show them some things about classroom management and what to do when it breaks, and how to have the alternate plan B, and those kinds of things are the things that I can pass on. So definitely, we pass things back and forth. (Lloyd, third interview)

Over the course of the observation period, Lloyd acquired technology knowledge from Johnson; in some cases, this knowledge had in turn been acquired from Johnson's methods class and from her university educational technology class. An example of this was the Web-based cell biology activity that Johnson discovered. Johnson found the activity on the Web, planned for implementing the activity, and implemented it in the computer lab. She had input from Lloyd and from the computer lab personnel, but the primary responsibility for developing and delivering the lesson was hers. Lloyd observed the lesson and taught it herself—as noted earlier, her delivery was remarkably similar to Johnson's. In the coming year, Lloyd intended to use the lesson herself. The potential exists for a subsequent student teacher to gain from the knowledge Johnson brought to the setting, with the benefit of Lloyd's contribution of pedagogical content knowledge gained through experience and applied to the activity through her own instantiation of it.

Johnson's Use of Technology in the Job Search Process

The availability of computer-based and Internet-connected technology factored into

Johnson's search for a first teaching position. By using online resources from the school site, Johnson was able to keep her job search moving forward without being absent from the school site. She monitored district Web-based job listings, retrieved academic grade reports from the university to be forwarded to potential employers, and contacted the employers via e-mail. This was uncharted territory, although Johnson's experience in the office environment helped her to negotiate it.

Professional Relationship

Johnson and Lloyd shared a considerable amount of educational technology knowledge during the 3 months that I observed them. Lloyd picked up a new curriculum piece—the cell biology Web activity—that she intended to use with her students in the following year. Johnson observed Lloyd using educational technology as an integral part of her teaching practice. As a student teacher, she was able to see firsthand what the pedagogical issues were when using technology and to increase her own pedagogical and pedagogical content knowledge of educational technology.

On a few occasions, I observed Lloyd and Johnson working with technology during their planning period. At various times they discussed the cell biology activity, worked to solve technical problems with the FlexCam, and talked with me about software capabilities and recommended activities for students. For the most part though, technology knowledge was shared through having joint use of curriculum materials and working together to implement new activities. In the course of preparing to implement the cell biology activity, Lloyd took the materials found and adapted by Johnson and studied them at home. She then observed Johnson teaching the materials and was able to enact the activity herself. Although planning time provided some opportunity for sharing knowledge, it was more common for knowledge acquisition to occur in the context of the classroom.

DISCUSSION

Sharing Knowledge of Educational Technology

As the basis for other forms of knowledge, content knowledge is a vital component of the knowledge base for teaching with technology. In the case reported in this study, a student teacher served as a source of content knowledge for her mentor teacher, bringing to the site knowledge of the existence of various technologically infused activities. With her recent teacher education experience and lifelong experience as a technology user, Johnson had at her fingertips a breadth of technology knowledge. Content knowledge of technology gives teachers choices about what applications to choose for their students (Betts & Frost, 2000); Johnson was able to help her mentor by expanding her awareness of the choices available when using technology.

In line with reports in other studies (e.g., Hall, 1996), Lloyd was also a source of content knowledge, sharing applications of which she had become aware through sources at the schools. In some instances, she had acquired this knowledge through previous student teachers as well as through more traditional educational technology professional development experiences. A factor seen in this study that has not been reported elsewhere was the mentor teacher's integration of the content knowledge brought in by her student teacher, enriched by infusion with the pedagogical and pedagogical content knowledge held by dint of her classroom experience. In terms of sharing knowledge, the pair brought to life the mentoring envisioned by Lundeberg et al. (2001), Knight and Albaugh (1997), and Loucks-Horsley, Hewson, Love, and Stiles (1998). Where those authors and others in the professional development literature focused on university personnel and other readily identified professional developers, this case showed that student teachers and their mentors can each fulfill the role of mentor for the other, depending on the knowledge to be acquired and the abilities of the participants. There are a number of advantages to content knowledge sharing by student teachers and their mentors; among them are extended exposure to each other and a shared context, both technologically and instructionally.

Constant Access to Technology and Its Impact on Technology Knowledge

Russell (1996) identified adaptation as a high level of technology use. He drew a connection between adaptation and "immersion in the situation" (p. 635). Constant access to technology allowed Johnson to adapt curriculum materials for use in her classroom. The access afforded by a laptop was necessary but not sufficient to encourage adaptation of materials. Length of experience with technology and deeper content knowledge were important as well. Even with constant access, increases in knowledge take time to accrue and manifest themselves as increased capacity. There is a developmental process of integrating educational technology into practice (Gallo & Horton, 1994). Access to technology when combined with experience is a contributing factor to increased knowledge and improved practice (Dwyer, Ringstaff, & Sandholtz, 1991; Hannafin & Freemand, 1995).

The Foundational Nature of Pedagogical Knowledge

General pedagogical knowledge (Shulman, 1987) is foundational and can be observed in many decisions regarding practice with technology. In this area, Lloyd took the lead. Her experience in the classroom gave her a store of pedagogical knowledge from which to draw. As with content knowledge, possession of a wealth of pedagogical knowledge gave Lloyd not only options but strategies for choosing among those options.

Pedagogical knowledge is foundational to educational technology teaching practice along the following two axes: the general pedagogical nature of teachers' goals when using technology and the relative sizes of the spheres of teaching with and teaching without the use of educational technology. Johnson and Lloyd were for the most part following the President's Committee of Advisors on Science and Technology Panel on Educational Technology (1997) advice to teach with, not about educational technology. Their primary teaching goals were student understanding of science content; secondary goals included general teaching/learning goals such as improving student motivation for learning and scaffolding student social skills. To achieve these goals, Johnson and Lloyd developed and applied general pedagogical strategies drawn from throughout their teaching practice. These strategies were employed when using technology as this teaching was a subset of their general teaching. Because the goals of their technology use were general teaching and learning goals, it follows that general pedagogical strategies would be employed.

Related to this is the issue of the relative infrequency of technology use. Only a fraction of a teacher's day is spent in settings in which he or she uses technology to pursue teaching and learning goals. The teaching practices that a teacher develops are created throughout his or her teaching practice, in whatever context he or she finds himself or herself. It is not surprising that the practices he or she develops for teaching generally are also used when technology is present. It would be much more surprising if his or her teaching changed dramatically when using technology. Although there are observable differences and special strategies for teaching with technology, general pedagogical knowledge plays a crucial role.

Pedagogical Content Knowledge of Educational Technology

Although pedagogical content knowledge is a well-studied construct in the teacher education literature (Fenstermacher, 1994), it has received relatively little attention in the area of educational technology. As I have defined it in this study, pedagogical content knowledge of educational technology arises from experiences in teaching with technology. It is a knowledge of appropriate instructional strategies specific to the implementation of technology-enhanced learning activities. This definition is consistent with the work of Kong and Kwok (1999), who explored the pedagogical content knowledge needed to teach with a piece of graphing software, though this study is more broadly focused than theirs. van Driel, Beijaard, and Verloop (2001) wrote that pedagogical content knowledge is "a transformation of the subject matter knowledge, used by teachers in the communication process with learners" (p. 143). When thinking about this definition in terms of educational technology, it is clear from this study that teachers' understanding of educational technology is "developed through an integrative process rooted in classroom practice" (van Driel et al., 2001, p. 143).

At Madrid Middle School, development of pedagogical content knowledge was based on existing content and pedagogical knowledge. Teaching experiences played a key role in its development, with pedagogical content knowledge generated in answer to teaching problems that arose in situ. In addition, pedagogical content knowledge development was proximal (Vygotsky, 1987); to understand the nature of a teaching problem and work toward its solution, thereby generating pedagogical content knowledge, teachers required extant knowledge of technology, authentic experience teaching with the technology, and enough understanding to derive new strategies, predict their likely effectiveness, and make adaptations on first and repeated enactment.

The literature on pedagogical content knowledge is largely domain based. Technology use is not a domain and is generally construed to be in service of domain-based instruction. However, effective teaching with technology requires knowledge that can be described independently of the domains. This article speaks to an evolving sense (Keating & Evans, 2001; Wallace, 2000) that a teacher needs to know things about technology use that are not technological content knowledge (e.g., which boxes connect with which wire) and that are not general pedagogical knowledge (e.g., how does one go about structuring activities for adolescents). Rather, teachers have a special understanding of technology that allows them to teach effectively.

Implications for Teacher Preparation in Educational Technology

There has been some progress since Willis and Mehlinger (1996) wrote,

> Much of the literature on information technology and teacher education could be summarized in one sentence: Most preservice teachers know very little about effective use of technology in education. (p. 978)

In the present study, Johnson entered her teacher preparation program with prior knowledge of technology, especially as it concerned applications that were of personal benefit to her, such as e-mail. As teacher preparation moves forward, continuing attention needs to be paid to students' prior knowledge. At the same time, increasing teacher salaries and a pressing need for new teachers will bring more older, second-career students into teacher education. At Eastern Michigan University, the number of such students has increased by 53% in the past 3 years (Lancaster, 2002). Some of these students will lack the technology skills of their younger counterparts, leading to an educational version of the digital divide (Clinton, 1998) based in part on the age differences among prospective teachers. Attention to the promise of the student teaching placement in preparing preservice teachers to use technology in their practice will be of benefit to both of these groups. Younger students will have the opportunity to see firsthand how their technological content knowledge can be employed in the classroom setting. Nontraditional students bring with them experiences that may serve to mitigate against a lack of technology content knowledge, giving them opportunities to apply their experience to pedagogical settings.

Regardless of student age or prior technology experience, the student teaching placement is a source of pedagogical knowledge and a site for exploring mentoring relationships (Easdown, 1994). Teacher preparation in educational technology has traditionally focused on either standalone university coursework or technology infused into teacher education courses such as educational psychology or teaching methods. To capitalize on the benefits accruable in K-12 settings, teacher preparation programs should incorporate field experiences. As preservice teachers move into their student teaching placements, attention should be paid to the technology available in those placements and to intentionally linking university preparation with the opportunities that students are likely to encounter. This is in line with constructivist principles of teacher education. Richardson (1997) observed that constructivism describes not how teacher education students should learn but in fact how they do learn. Meaning is constructed based on the intersection between learners' existing knowledge and their experiences. From the standpoint of acquiring knowledge of educational technology, a constructivist perspective would argue that opportunities for authentic experiences are a necessary condition for learning to occur.

In a later work, Richardson (in press) wrote about the difficulty of adding more coursework to already crowded teacher education programs. This is a valid criticism—the pressure to add more coursework comes from a variety of sources urging that teachers should know more about topics ranging from women's studies to the traditional canon to education of students with severe disabilities. At the same time, the pressure to remove coursework is also considerable, arising from a pragmatic and political need for more teachers in the workforce as well as ever-increasing competition to traditional teacher preparation from for-profit institutions and alternative certification programs. Mindfulness of the opportunities for student teachers to acquire knowledge of educational technology in their student teaching placements affords teacher education the opportunity to capitalize on an authentic learning environment without adding to the already large burden of coursework faced by teacher education students.

Implications for Professional Development

In general, professional development in educational technology lacks an empirical or theoretical basis and is in need of a more theoretically grounded approach (Fishman & Marx, 2001). Although this dissertation study was not a professional development effort per se, the participants made mutual gains in educational technology knowledge and the mentor teachers unanimously felt that our work together constituted professional development for them. By being situated entirely in context, the work of the student teachers, mentor teachers, and myself together was pedagogically aligned with the teaching goals of Madrid Middle School's written and enacted curricula. Both longer time frame and awareness of classroom context are useful for professional development (Cognition and Technology Group at Vanderbilt, 1996). Viewing student teachers as professional development partners gives the opportunity for extended contact and immersion in context.

CONCLUSION

Use of educational technology is becoming more evident in American schools (Glennan & Melmed, 1996). Every year, more schools are becoming connected to the Internet, more computers are finding their way to classrooms, and more parents are demanding that technology be included in their children's education. The ability to incorporate the use of educational technology into the broad spectrum of teaching and learning, once the province of a few dedicated enthusiasts, is becoming a substantial requirement for new teachers.

The use of technology in education is being embraced in part because it is associated with the implementation of reform-oriented teaching and learning practices (Means & Olson, 1995a, 1995b). Teacher preparation and development plays a crucial role in helping teachers to use technology for these reform-oriented purposes (Willis & Mehlinger, 1996). Research also supports a link between teacher preparation and enhanced student achievement. Students of teachers who have had professional development in technology use and whose teachers use technology for teaching higher order thinking have higher levels of achievement than students whose teachers have not been prepared or who do not stress higher order thinking (Wenglinsky, 1998). Because teacher professional development is associated with enhanced student performance, it follows that teachers increase their knowledge through such development. Knowledge forms the basis of rational decision making (Borko & Putnam, 1996; Bransford et al., 1986), allowing teachers to pursue fruitful courses of action.

NOTE

1. All participant and place names are pseudonyms.

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