When Computer Technologies Meet the Learning Sciences: Issues and Opportunities

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This article explores how insights from the learning sciences can guide the effective use of computer technologies to promote learning and how these technologies make new types of learning opportunities possible. The discussion is organized to provide three illustrations of how the introduction of new technologies can have "ripple effects" that influence many different aspects of the teaching and learning processes. We discuss these examples from the perspective of a framework for thinking about teaching and learning based on principles from the 1999 book by Bransford, Brown, and Cocking, *How People Learn.* Finally, we explore how rapid advances in technology both require and support changes in how we as researchers and teachers do our work.

Our goal in this paper is to explore how insights from the learning sciences can guide the effective use of computer technologies to promote learning, and how these technologies make new types of learning opportunities possible. Our discussion builds on information in a report written by the National Research Council's Committee on Developments in the Science of Learning entitled *How people learn: Brain, mind, experience, and school* (Bransford, Brown, & Cocking, 1999). The first part of *How People Learn* (HPL) discusses the nature and organization of knowledge that supports expertise (see especially chap. 2), plus information about the processes involved in helping people acquire knowledge that supports understanding and subsequent transfer (see especially chaps. 3 & 4). In the second part of HPL, the Committee uses knowledge about expertise, learning, and transfer to suggest a set of design principles for creating effective learning environments (see especially chap. 6). It also reviews the role of technology in helping people learn (see chap. 9).

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In the present discussion we examine issues of technology and learning that were not explicitly discussed in HPL, yet are compatible with the committee report. Included in our discussion is a description of an undergraduate course we taught that attempted to use important design principles from HPL to teach about how people learn. Our discussion is organized as follows. First, we provide three illustrations of how the introduction of new technologies can have "ripple effects" that influence many different aspects of the teaching and learning process. Second, we discuss these examples from the perspective of a framework for thinking about teaching and learning based on principles from HPL. Third, we explore how rapid advances in technology both require and support changes in how we as researchers and teachers do our work. Last, we summarize our arguments.

Three Examples of Educational Technologies and Their Effects on the Ecology of Classrooms

In Chapter 9 of HPL, the committee notes that one of its members had attended his senior year in high school in a country where there were no textbooks in many of the classes. Class time was spent with the teacher writing on the board and the students copying the information into their own notebooks—in essence they were transcribing their own texts. As soon as printed textbooks became available, the teachers were able to rethink their practices. It was no longer necessary to use class time simply to write statements on the board for the students to copy. Instead, time could be spent on more interactive activities like asking questions for clarification, discussing the text, and elaborating on the text.

The addition of textbooks did not cause teachers to give up their old technologies like paper, pencils, blackboards, and chalk, but the teachers and their students now used these old technologies differently. It is also noteworthy that the addition of textbooks did not guarantee that teachers would use their class time more effectively. But it provided the potential for them to change.

In this section we describe three analogous examples where the introduction of new technologies (in this case, new computer technologies rather than textbooks) made it possible to transform classrooms into places that are less sources of one-way transmission and more interactive. We focus on simple transformations of familiar environments (e.g., changes in typical classroom environments) rather than on futuristic scenarios like captivating simulations and wireless tutors and scribes that help students note, understand, and capture knowledge as they work in "real" environments. These futuristic possibilities are exciting and important (e.g., De Jong & van Joolingen, 1998; Georgia Tech Future Computing Group, http://www.cc.gatech.edu/fce/). Nevertheless, our present goal is to show how even modest implementations of new technologies can impact how teachers teach and students learn.

The three technology examples we describe were chosen for several reasons. First, we wanted to cover a variety of age ranges (from college to early high school to fifth graders.). Second, we looked for cases where the essence of the technology interventions was relatively easy to describe—at least at a general level. Third, we chose examples where we had the benefit of seeing the technologies used in classrooms. There are many additional examples of technology applications that are exciting and worthy of attention, but that we are unable to discuss in any detail (e.g., see Bereiter & Scardamelia, 1993; Cognition and Technology Group at Vanderbilt [CTGV], 1997; Dede, 1998; Bransford et al., 1999, chap. 9; Lin & Hsi, 1999; Roschelle & Pea, 1999; Williams et al., 1998).

Transforming Large Lecture Classes

The introduction of textbooks to "textbookless" classrooms made it possible for teachers to do something other than spend class time having students create their own books by copying from the board. In today's textbook-plentiful classrooms, teachers often deliver lectures about the main points of the readings, elaborate on the readings, and, to a smaller extent, ask students questions and allow them to ask questions. Especially in large classes like those found in many introductory courses in college, it is difficult to teach in any other way.

It's almost a sport to make fun of boring lectures, and the media does this brilliantly. An excellent example is the "Anyone, anyone?" teaching scene from the movie *Ferris Buehler's Day Off.* None of the Committee members who wrote HPL advocates the kinds of boring lectures and fill-in-the-blank questioning methods shown in the "Anyone, anyone?" scenario. Nevertheless, there is nothing in the cognitive literature that argues against the idea that lectures are *inherently* ineffective for promoting learning. In particular, it is not the case that lecturing violates the constructivist idea that learning involves the use of currently available knowledge to construct new understandings (e.g., Cobb, 1994; Piaget, 1952; Vygotsky, 1978). Sometimes, a lecture is just what students need to organize their knowledge and propel them to a new level of understanding (Schwartz & Bransford, 1998). At other times, lecturing is a poor way to help people learn.

Figure 1 illustrates a variety of strategies that teachers can use to promote learning (Donovan, Bransford & Pellegrino, 1999, p. 18). Knowledge of how people learn helps bring order to a seeming cacophony of choices by clarifying why, when, and how various teaching strategies may or may not be appropriate (analogous to clarifying why, when, and how to use different tools such as a hammer, screwdriver, saw). Consider lecturing as an example. A major problem with lectures is that the understandings (representations) that students construct may seem fine to them, yet (a) include assumptions (preconceptions) that are problematic but undetected (e.g., see Mestre, 1994; Redish, this volume); (b) omit crucial distinctions intended by the lecturer (see Schwartz & Bransford, 1998), and (c) fail to specify the conditions under which the knowledge is useful (Bransford, Franks, Vye, & Sherwood, 1989; Simon, 1980; Whitehead, 1929). Unless the assumptions and thoughts of students are made visible, it is very easy for them to understand only superficially, miss the opportunity to confront their preconceptions, and fail to learn the conditions under which new knowledge is applicable (i.e., fail to "conditionalize" their knowledge). In HPL, the Committee used Lionni's *Fish is Fish* story to illustrate how misunderstandings can arise because attempts to construct new knowledge depend on what people already know (see boxed text).

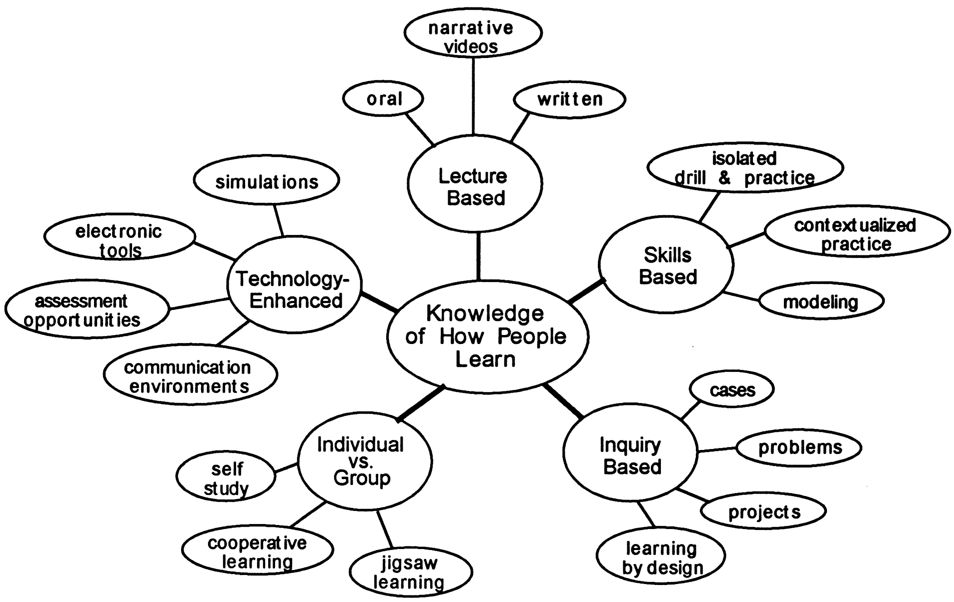

Figure 1. A Cacophony of Possible Teaching Techniques

> "Fish is Fish" (Lionni, 1970) describes a fish who is keenly interested in learning about what happens on land, but the fish cannot explore land because it can only breathe in water. It befriends a tadpole who grows into a frog and eventually goes out onto the land. The frog returns to the pond a few weeks later and reports on what he has seen. The frog describes all kinds of things like a bird, cow and people. The book shows pictures of the fish's representations of each of these descriptions: each is a fish-like form that is slightly adapted to accommodate the frog's descriptions—people are imagined to be fish who walk on their tailfins, birds are fish with wings, cows are fish with udders. This tale illustrates both the creative opportunities and dangers inherent in the fact that people construct new knowledge based on their current knowledge. (Bransford et al., 1999, p. 11)

Typical lecture classes often fail to make students' thinking visible to both the students and the instructor. The professor lectures and the students take notes. Students are usually allowed to ask questions, but they often don't know they are misunderstanding (Schwartz & Bransford, 1998), are too confused to know the exact question to ask, or are too embarrassed to take class time on a point that, as far as they know, is problematic only to them. Professors can have trouble knowing how much time to spend on a student's question because the knowledge state of the person who asked it does not necessarily represent the class as a whole.

In addition, frequent question-askers may be those students who are especially outgoing. Over time, they may have too much influence on how class time is spent.

New technologies make it possible to make students' thinking much more visible by transforming one-way-transmission classes into interactive sessions. By using networked desktop computers or wired or wireless palm size devices, students can respond electronically (and anonymously) to questions posed by the course instructor. All the responses can be compiled almost instantaneously and both the instructor and the students can have a picture of the *knowledge state* of the class as a whole. Most of these systems require that students respond to multiple choice questions—and that is often less than ideal, of course. Nevertheless, as discussed in HPL (see especially chap. 6), carefully constructed multiple choice questions can go a long way toward helping professors assess what students understand (Mestre, 1994).

Professors at the University of Massachusetts Amherst have been using a classroom communication technology called Classtalk for a number of years (e.g., see Dufresne, Gerace, Leonard, Mestre, & Wenk, 1996; Mestre, Gerace, Dufresne, & Leonard, 1997; Wenk, Dufresne, Gerace, Leonard, & Mestre, 1997). It is comprised of hand-held devices (either Hewlett Packard palmtop computers or Texas Instruments calculators) wired via phone jack ports to a computer in the front of the room. The existence of multiple phone-jack ports throughout the auditorium allows students to sign onto the system, with groups of up to four students sharing one hand-held device. The software and hardware allows for the presentation of questions for students to work on collaboratively and for the collection and anonymous display of students' answers in histogram form.

This simple new technology has had a number of ripple effects on the ecology of the classrooms in which it was used. Video interviews with students from a physics class taught with Classtalk suggest some intriguing ways in which their classroom experiences have been transformed.

Several students noted how Classtalk made class more of an active learning experience.

> In class I really don't learn anything by lecture. I'm more of a person that reads. That's how I learn. I go to class all the time but it's a waste of time. I'll take notes, but when I leave the class I won't have any idea what the professor has just talked about. With Classtalk you're forced to pay attention, you're forced to process all the information right there.
>
> You're not just writing down notes then leaving class; you're actually applying what you're learning as you and others are thinking.

Another student emphasized the benefits of seeing what others in the class were thinking about problems. If many other students were confused, it was nice to see that she wasn't the only one. If she did understand but many others didn't, she could appreciate why the professor needed to take the time to make things clearer to those who needed help. And when different groups explained their reasoning behind different answers, it helped her better appreciate the range of possible ways to think about problems that were posed.

Still another student talked about the bonds formed by working in groups to answer via Classtalk. She then noted how working in groups had helped her meet new people, and how her Classtalk group also met outside of class to help one another:

> I think working in groups has helped us meet other people in our major and our classes. It turns out I meet with those same people outside of class. We practice tests together.

One student began her interview by stating how Classtalk made her physics class exciting. After a moment she amended her statement and, in the process, formulated a potentially important principle about formal education:

> Even with Class Talk [sic] that doesn't mean the class isn't going to have its boring moments. I mean, that's impossible. You have to be bored to be in school.

Additional information about Classtalk and its uses is available in Dufresne et al. (1996), Mestre et al. (1997), and Wenk et al. (1997). Data presented in these articles indicate that the vast majority of the students believed that, compared with traditional courses, Classtalk improved their abilities to understand the subject matter that they were trying to learn.

Transforming High School Algebra Courses

As a second illustration of the transformative potential of new educational technologies, consider the computer-based algebra tutoring programs developed by John Anderson, Ken Koedinger and their colleagues (e.g., Koedinger, Anderson, Hadley, & Mark, 1997). This new generation of tutoring programs is very different from older forms of computer-assisted instruction where students essentially did the same activities as they had done with textbooks (e.g., answered problems at the end of the chapter), except that they did them on the computer. For example, the Algebra Tutor supports students in constructing graphical and symbolic solutions to real-world problems. Students not only learn the fundamentals of algebra, they also gain experience in using software tools, like spreadsheets, equation calculators, and graphic programs, which are becoming as commonplace as pencil and paper in the modern workplace.

For many people, the image of using educational tutoring programs involves students working alone at the computer, proceeding at their own pace, and becoming more technical and less social. And for some people, this image is accompanied by the thought that computer tutors can replace teachers.

After one of us (JB) had the opportunity to visit classrooms in Pittsburgh where the Algebra Tutor is being used, we developed a very different image of the role of tutors from the one described above. Students did indeed work individually on the computer and at their own pace. But this was only part of what they did during their algebra classes. Much of their time was spent working with the algebra teacher to understand important concepts. The computer provided students an opportunity to work through these concepts at their own pace. As they did, the students were not confined to solitary interactions with the tutor. They often asked questions of one another and collaborated—much as students help one another learn to master video games. The computer labs were very social environments—there was not dead silence with each student working in isolation from everyone else. Furthermore, everyone seemed engaged and on task.

Especially interesting was the opportunity to talk with the algebra teachers at some of the Pittsburgh high schools. Many had experienced situations that are typical of many schools—each teacher does his or her own thing, usually behind closed doors. Teaching is a private rather than public act, and it is rarely discussed (e.g., see Bray, 1998; Elmore, Peterson, & McCarthey, 1996). The introduction of the Algebra Tutor provided the teachers with a common ground (anchor) for collaboration that generated sustained enthusiasm and discussion. The teachers formed what many would call a *learning community*, where they discussed how to integrate the tutors with the broader algebra curriculum and where they continually helped one another improve their students' learning (e.g., see Bray, 1998; Talbert & McLaughlin, 1993). These ripple effects of the tutoring program were very different from the typical image of computer tutors that comes to mind.

The introduction of the Algebra Tutor into schools has made it possible for students who normally would have great difficulty with algebra to gain substantial mastery of the subject matter. Overall, data show that algebra students who have the benefit of the tutoring programs do considerably better than typical students who do not have the programs (see Koedinger et al., 1997; Schofield, 1995)

Transforming the Experience of Mentoring

As a third example of the transformative potential of new technologies, consider the dual goals of (a) letting inner-city fifth graders (most of whom had never visited a college campus) visit a college class to learn about norms and expectations at the college level and (b) letting the college students (most of whom were going to be teachers) get to know fifth graders and how to interact with them. Simply to have the fifth graders sit in on a college class would be far from ideal—they could easily feel lost and intimidated. To have them make some sort of presentation to the college students would be better, but this format still allows only limited opportunities for interaction. What other options exist? One possibility is to have the college students attempt to solve some sort of challenging problem and receive help from the fifth graders. This type of problem-solving interaction could be highly beneficial for both groups.

A project headed by Burgess (see CTGV, in press) created successful problem-solving interactions. Fifth graders from inner-city classrooms visited a college class that was studying cognition and instruction. The fifth graders came prepared with valuable knowledge. Earlier in the semester they had solved one of the video-based Jasper adventures, Rescue at Boone's Meadow (see CTGV, 1997). In the adventure, a character named Jasper discovers a wounded eagle while on a camping trip to Boone's Meadow, which is in the wilderness with no access by road. Jasper radios Emily and asks for help. Emily has access to maps, a truck, ultralight, and other possible rescue vehicles. She has to take into account a number of factors like presence versus absence of roads in various areas, dimensions of possible landing areas, issues of speed, payload, and fuel capacity on the ultralight, and so forth.

The challenge at the end of the video is to help Emily find the best and fastest way to rescue the eagle. The problem is challenging even for college students, and there are multiple possible solutions. Because Jasper is presented as a video story, and because interactive software makes it easy to return to the story as needed to find relevant embedded data (e.g., the fuel capacity of the ultralight or the size of the flat field at Boone's Meadow where Jasper found the eagle), fifth-grade students are able to solve the problems—usually by working collaboratively with their teacher's guidance over a period of five class periods or more (see CTGV, 1997).

Burgess arranged for the fifth graders to visit a Vanderbilt class where the college students would see *Rescue at Boone's Meadow* for the first time and attempt to solve it. The fifth graders knew that their role was not simply to give the answers to the problem; instead it was to keep the college students from getting too far off track, plus help them use the software to revisit embedded data and embedded teaching scenes that were relevant to their task (see CTGV, 1997).

Before visiting the college classroom, we interviewed the fifth graders. They were understandably nervous but also very excited. As soon as they began helping the college students solve the adventure, they discovered that they had insights to offer and that the college students appreciated their help. By the end of the class the middle school students knew that they had genuinely helped the college students, and the college students were both appreciative and impressed.

In interviews conducted after the class sessions, the fifth graders explained that they learned some important lessons from their opportunities to interact with the college students. First, the fifth graders were impressed that the college students actually asked them questions and valued their opinions. Second, the fifth graders noticed that the college students only occasionally had to revisit a Jasper adventure to review relevant facts, and that this was different from their experiences in their own classrooms. When asked to explain this fact, they decided that it was a result of the college students "paying better attention when they watched the adventure." And they stated "we should do that too." The fifth graders were also impressed that the college students knew their math facts and knew how to work together and stay on task. This led to them valuing these skills.

Insights gained from observing college students found their way back to the fifth graders' classrooms and to the students' homes. Interviews with teachers and parents indicated that the middle school students frequently explained to their classmates that "we should be more like college students and pay attention." Parents reported that the students talked about the excitement of their visit to Vanderbilt and about the knowledge that they had taught the college students. All the fifth graders wanted to come back and solve another Jasper with the college class. As noted above, the fact that the fifth-grade students came to the college class prepared with knowledge appears to be very important for the success of these interactions. Opportunities to feel that they contributed to the class also appear to have freed students to learn more from their experiences. Data from a number of different studies indicate that students remember and highly value Jasper and Jasper-like experiences and that the experience of solving Jasper problems increases their abilities to solve new problems, as well as increasing their confidence and enthusiasm for challenging problems that require them to think mathematically (e.g., see CTGV, 1997; Vye, Schwartz, Bransford, Barron, Zech, & CTGV, 1989)

Behind the Scenes: How Learning Theory Comes Into Play

In this section we go behind the scenes and explore issues about learning that were tacit in the previous discussions of Classtalk, the Algebra Tutor, and Jasper. Issues about learning are often invisible in discussions of the implementation of new technologies in educational settings, but they are always present. They include assumptions about *what* students need to learn, *how* they learn, and *what counts as evidence* for their learning. When tacit assumptions about learning are made explicit, they can be analyzed for coherence as a system and correspondence to the literature on how people learn.

How People Learn provides a framework for analyzing the design of learning environments that captures insights from the extensive literature reviewed by the committee. The HPL framework helps make tacit assumptions explicit and builds on what is known about learning and transfer (see Figure 2). It highlights four perspectives on effective learning environments—perspectives that are highly interrelated (note the overlapping circles in Figure 2) and must be kept in balance. Each of these perspectives, and their interrelations, is discussed below.

Knowledge Centeredness

The knowledge-centered perspective focuses attention on *what* is to be taught and why it is important. At first glance, it seems obvious that all courses are knowledge centered. However, research discussed in HPL (chap. 2) indicates that expertise is based on the acquisition of a great deal of specific knowledge that is organized around important concepts (e.g., in physics an important organizing concept is Newton's second law). In addition, research indicates that transfer is enhanced when students learn with understanding rather than merely memorize facts and formulas (see Bransford et al., 1999, chap. 3). The idea of teaching the kind of knowledge that supports understanding is different from simply teaching disconnected facts and formulas.

The HPL emphasis on the importance of being knowledge centered is compatible with recommendations in the book *Understanding by Design* by Wiggins and McTighe (1998). They argued that teachers must begin with an analysis of what students need to know and be able to do and work backward to choose teaching tools and strategies. Often we do the opposite; we pull out our favorite readings, experiments, and demonstrations but put little thought into how to help students develop a coherent organization of skills and knowledge that will support particular types of competencies on course completion. Wiggins and McTighe also emphasized the value of organizing what should be taught into three different levels of knowledge and skills; namely, those that (a) support enduring understanding; (b) are important to know and do; and (c) are worth being familiar with. Their emphasis on analyzing the levels and functions of knowledge is very compatible with arguments and data presented in HPL.

Knowledge Centeredness and Classtalk, Tutors, Jasper. A look behind the scenes reveals that issues of what to teach were extremely important for the three examples of technology discussed earlier (Classtalk, the Algebra Tutor, and uses of the Jasper program for two-way mentoring). Classtalk was used in a physics class where the primary goal was to help students learn with understanding, which includes understanding why many seemingly intuitive ideas about the physical world don't fit the evidence from science (e.g., see Mestre, 1994; Minstrell, 1989; Reddish, this issue). The Algebra Tutor is based on a detailed analysis of what is important to understand about algebra (e.g., National Council of Teachers of Mathematics, 1989, 1991) and of the kinds of representations and technology tools that will allow students to "work smart" in everyday settings. The Jasper two-way mentoring project was of much briefer duration than the previous two, but it too was based on assumptions about what is valuable for students to learn. One assumption was that the inner-city fifth graders needed to learn that colleges are not foreign places that are totally out-of-bounds for them, that college students are human and need and appreciate help in dealing with complex problems, and that they (the fifth graders) had the potential to develop expertise that could help the college students. A second assumption was that the college students (many of whom will become teachers) needed to see first hand some of the competencies of children who often seem like failures when discussed by the media or viewed only from the perspective of scores on standardized tests.

Knowledge Centeredness in a Course on HPL. For any subject, the major challenge from the knowledge-centered perspective is to be able to articulate what we want students to know *and be able to do* at the end of the course. The importance and complexity of this point became especially clear to us in the context of designing a course that we cotaught in the spring of 1999. The course was a small undergraduate seminar (14 students) on "How People Learn." We used HPL (the preprint edition) as the text.

The easy solution to what students needed to learn was simply to expect them to be able to recite the main points of each of the chapters in HPL. But we knew from research that the mere ability to remember main points provides no guarantee that people can do much with that knowledge other than recite it (e.g., see Bransford et al., 1989, 1999). Because our seminar was small and experimental, we discussed possible learning goals with the students. We jointly decided that our goal for this class would be to help students develop the expertise to analyze cases of teaching and learning (either on video or through text descriptions) from the HPL perspective and make recommendations for improvement. This meant that the course needed to include cases of teaching practices that students could watch and analyze. The benefits of these kinds of experiences have been explored by a number of researchers (e.g., see Barrows, 1985; Michaels, Klee, Bransford, & Warren, 1993; Williams, 1992). By using cases, our course became quite different from one where the goal was to memorize the textbook and readings for the course.

Assessment Centeredness

Effective learning environments also require frequent opportunities to make students' thinking visible to see what they are learning. When students' thinking is assessed at the end of a course or a unit it involves *summative assessment*; in contrast, *formative assessment* involves attempts to assess students' thinking during the process of learning (before summative assessments). Each of these types of assessments (summative and formative) is discussed below.

Summative Assessments and the Technology Examples. Summative assessments involve attempts to measure what students have learned at the end of a course or at the end of specific units that comprise a course. Summative assessments must be aligned with learning goals; otherwise they can provide misleading information. For example, if the goal is to learn physics or algebra with understanding, assessments must go beyond the ability of students simply to repeat facts and manipulate formulas (see Bransford et al., 1999, especially chap. 6). The Classtalk and Algebra Tutor examples discussed earlier both included items that assessed student understanding. The Jasper two-way mentoring project used a different type of assessment—tracking what the fifth-grade students spontaneously said about their experiences to their other classmates, teachers, and parents, and asking the college students to discuss what they had learned from the experience.

Measures of transfer are an important way to assess the quality of students' understanding (see Bransford et al., 1999, chap. 3). Both the Classtalk and Algebra Tutor projects included these kinds of transfer items. As discussed in HPL, there are also important differences between assessments of static versus dynamic transfer. For example, certain kinds of experiences may not help students do better on a static test of transfer, yet can help them on dynamic tests of transfer such as the ability to *learn* a new area more effectively when they are given chances to study and practice (e.g., Singley & Anderson, 1989). New ways of conceptualizing learning and transfer have a number of implications for ways to assess the quality of what students have learned (e.g., Bransford & Schwartz, in press; Pellegrino, Baxter, & Glaser, in press).

Formative Assessments and the Technology Examples. Formative assessments are designed to help teachers and students monitor the progress being made toward the courses' learning goals. Earlier we noted how Lionni's *Fish is Fish* (see boxed text) illustrates the need for frequent formative assessments that make students' thinking visible to themselves, their peers, and their instructors. Without formative assessment, the fish's image of birds, cows, and people would remain very different from what her friend the frog intended to convey.

The three technology examples discussed earlier included frequent opportunities for formative assessments. Classtalk is especially designed for this purpose—it allowed the instructor to pose questions and challenges frequently and see what students were understanding, and it made the process fast and efficient. The Algebra Tutor also provided multiple opportunities for formative assessment. The computer includes an expert and student model, which allows it to assess where students are in their thinking about algebra and to provide feedback. These opportunities for feedback are markedly lacking in other environments such as lecture classes, where students simply listen and take notes during class.

The Jasper two-way mentoring project also included provisions for ongoing formative assessments, although these were conducted by the organizers and college instructor rather than by computer technology. For example, the organizers carefully monitored the feelings of the fifth graders as they drove toward the college, and they intervened when students seemed too nervous. The college instructor also continually monitored the interaction between the fifth graders and the college students as the latter attempted to solve the Jasper adventure. If the fifth graders had looked uncomfortable or seemed to have been ignored by the college students, the instructor would have intervened. After the class, the organizer of the event also provided opportunities for the students to reflect on their experiences and talk about what they had found valuable (one example was the fact that the college students actually asked them questions and appreciated their help). Discussions with the fifth graders' teachers and parents also provided opportunities for assessing the experience of the fifth graders with an eye toward improving things next time around. In this case, one can consider the discussion as part summative assessment and part formative assessment for improving things later.

Assessment in the HPL Course. Our undergraduate course on how people learn helped us see that formative assessments contributed to our learning as instructors, which in turn helped us improve the students' learning. As a "low tech" formative assessment exercise, we asked students to turn in very brief (one- or two-page) thought papers on selected readings. They were asked to answer questions such as: (a) What do you see as the main point of the reading?; (b) What especially connects to your experiences and what doesn't?; and (c) What do you find confusing or want to learn more about?

The thought paper assessments helped us realize a number of points that were extremely informative to us. For example, after reading Chapter 2 in HPL on expertise, almost every student indicated strong agreement with the point that having content knowledge does not guarantee that one has developed the expertise needed to teach it to novices (which requires what is called *pedagogical content knowledge*; Shulman, 1986, 1987). Students noted that they experienced this issue almost daily in college.

Students' thought papers on the expertise chapter provided us with additional insights into their thinking. Several summarized their understanding of the main points of the chapter by noting that chess experts seemed to have good pattern recognition and memory skills (e.g., deGroot, 1965); physics experts noted the deep structure rather than the surface structure of physics problems (Chi, Feltovich, & Glaser, 1981); history experts were metacognitive and showed signs of adaptive expertise (Wineburg, 1998) and so forth.

The students' comments helped us realize that, as written, Chapter 2 could easily be misinterpreted. We wanted students to realize that experts in any domain demonstrated a range of competencies including pattern recognition, abilities to remember domain-specific information, abilities to understand at the level of deep rather than surface structure, abilities to adapt to novel situations by being metacognitive, and so forth. However, the HPL chapter used studies of different types of experts to emphasize different points about expertise. For example, discussions of chess masters primarily emphasized pattern recognition and schema-based abilities to remember. Chess masters were not discussed in the context of other issues such as adaptive expertise; instead this discussion focused on history experts and experts in systems design. In short, the chapter provided an incomplete mapping of domain knowledge (physics, chess, etc.) with types of competencies (pattern recognition, understanding, etc.). The students' thought papers made the incomplete mapping problem visible to us. We were then able to help them develop a more complete picture of the wide range of competencies that are characteristic of expertise in any content area. But without access to the students' thoughts, it would never have occurred to us that we needed to emphasize this point.

A third point revealed in the students' thought papers on Chapter 2 was particularly surprising to us and had a major impact on our teaching. In response to the question about how the chapter connected to the students' personal experiences, most noted that it was difficult to connect to the chapter because "we aren't experts in anything." As soon as we saw these comments we realized that the chapter set the students up for this assumption. Nearly every example involved experts who were much more senior and accomplished than the students in the class (the studies discussed world-class chess masters, professional historians, physicists, etc.).

Thanks to their thought papers, we were able to help students understand that there were many levels of expertise and that they indeed had developed at least midlevel expertise in a number of areas—including everyday language, the ability to drive a car (and carry on a conversation at the same time), keyboarding (for most of them), and so forth. After reading the thought papers, we encouraged students to identify areas where they had acquired at least midlevel ranges of expertise. Examples included football (complete with outstanding pattern recognition and memory for what happened in the games), soccer, waiting tables, dance, and public speaking. As the first summative assessment, students chose to take their area of expertise and discuss it from the perspective of the concepts discussed in Chapter 2 of HPL. How and under what conditions would their expertise affect their pattern recognition, memory, understanding, and problem solving? To what extent did they think they were adaptive experts, and to what extent did they think they had developed pedagogical content knowledge?

The essays written by the students were extremely interesting and revealed a strong understanding of many points in Chapter 2 plus a few persistent areas of confusion (especially with respect to the concept of adaptive expertise). We worked to clarify these confusions and gave students a chance to rewrite their essays if they chose to do so (nearly all of them did). Thus our *summative* assessment was formative as well.

One additional point we learned was that the types of questions asked of the students had a strong effect on what we learned from them. If we had simply asked students to write down the five main headings of the chapter, we would have failed to obtain most of the information discussed above. Professors who have used Classtalk make a similar point. They discuss the kinds of questions that are most likely to yield fruitful discussions and reasoning (see Mestre et al., 1997; Dufresne et al., 1996).

Learner Centeredness

The learner-centered perspective focuses on the knowledge, skills, goals, and cultural beliefs that each person brings to the learning situation. The more that a teacher knows about each student, the better that he or she can adapt teaching strategies to students' specific needs and goals.

Learner-centered environments overlap with assessment centeredness when efforts are made to assess students' preconceptions about the subject and address them directly, plus assess their sense of how their own learning is progressing. Learner-centered environments overlap with knowledge centeredness when they help students acquire knowledge and skills that are important for their future and that prepare them for future learning. In addition, being learner centered overlaps with knowledge centeredness when teachers look for special expertise that students can bring to the classroom or purposely develop that expertise so that students can contribute as well as learn (see Brown & Campione, 1994, 1996; Moll, Tapia, & Whitmore, 1993).

Learner Centeredness and Classtalk, Tutors, Jasper. Much of the previous discussion of formative assessment included a learner-centered perspective. The use of Classtalk in large lecture classes can allow instructors learn about and address students' thoughts and concerns in a way that is helpful yet also preserves their anonymity. The use of the Algebra Tutor allowed students to proceed at their own pace and provided feedback that was just for the student and hence not publicly embarrassing. The two-way mentoring project involving Jasper was learner centered in the sense that it specifically armed the fifth graders with important expertise before their visiting the college class.

Learner Centeredness and the HPL Course. Additional aspects of learner centeredness became clear to us as we taught our undergraduate course on *How People Learn.* We began to see that student involvement increased as we purposely built on their individual strengths and interests. For example, after discovering that there was a football player in the course and after discovering the need to help students see they too had developed expertise in various areas (see the previous discussion), we showed the class a clip from a football game and asked everyone to state what they noticed. Class members were amazed at how much the football player noticed about the video clip compared with everyone else; the football player was surprised and elated to see that his football expertise had relevance in an academic context.

In other cases that supported learner centeredness, we helped students generate paper topics in areas that were relevant to their careers after graduation. An E-mail statement from one of the students illustrates the value of tailoring assignments:

> I want to thank you for allowing us to individualize our second assessments. I personally found this very rewarding, because it allowed me to pursue a subject in which I have much

> interest. I was not constrained to write about a topic someone else found intriguing, which really hit the learner-centered bullseye.

We also gave students feedback on initial drafts of their papers and then provided opportunities to revise based on that feedback—an activity that was simultaneously knowledge- assessment-, and student-centered. A number of students noted that they had never before been given the chance to see feedback from an instructor and then revise their paper based on that feedback. In all cases, the post-feedback papers were substantially improved (except for one case where the initial draft was so good that no revisions were necessary).

Extensive use of electronic communications with students also helped us make the HPL course learner centered. Instructors received E-mail queries from at least one student almost every day throughout the semester. The electronic conversations let us explore a number of issues such as helping students see how their career plans could be enhanced by the type of paper topic they chose to write about, helping them cope with uncertainties about their writing or classroom performance, and so forth. In addition to the advantage of convenience, electronic communications seem to make it easier for students to talk about emotionally charged issues—provided that they had first developed a sense of trust for the instructor in face-to-face interactions inside or outside of class.

Community Centeredness

The fourth HPL perspective on the design of effective learning environments involves the degree to which they are community centered. Like all the other perspectives, this one overlaps with the others. Its unique contribution is to focus explicitly on the goals of the teacher and the norms of the classroom environment and its connectedness (or lack thereof) to the school or college program as a whole.

Classroom environments can reflect a number of different goals and assumptions. One involves the teacher's assumption that "I am the gatekeeper to graduate school, medical school, and so forth, and my goal is to *select* talent." An alternative assumption is that "anyone in this class deserves to be here and my role is to *develop* talent to its fullest."

In most courses instructors try to keep both goals in mind, but there are differences in the degree to which talent development is a high priority goal of many institutions. This affects the climate of the classroom and school community, which in turns affects how students feel about the classroom and how they perform academically (e.g., see Bateman, Goldman, Newbrough, Bransford, & CTGV, 1997).

Community Centeredness and Classtalk, Tutors, Jasper. Interactive technologies such as Classtalk could be used to support either a talent selection or talent development environment. The classroom environment could be one of intense competition and students could compete to see who responded to most of the answers asked by the instructor during class time. In contrast, the norms of the classroom could emphasize collaboration, and the policy of the instructor could be that "everyone deserves a high grade IF you reach high standards, and my goal as an instructor is to help you do that as much as is possible. But you have to do your part as well." The latter assumption characterizes the use of Classtalk in physics classes at the University of Massachusetts Amherst. Students worked collaboratively to help one another do their best. And the instructor was clearly "on the students' side" while also maintaining high standards.

Technologies such as the Algebra Tutor or the Jasper problem-solving series can also be used in a context of talent selection and intense competition versus talent development. The algebra tutoring environments that we observed in Pittsburgh seemed to reflect the norms of talent development for everyone. So did the Jasper two-way mentoring project. For example, the fifth-grade teachers did not pit all the students against one another to see who could best solve the Jasper adventure and then receive the reward of going to the college class. Instead, a concerted effort was made to help all students reach a threshold of mastery on Jasper that would allow them to work successfully with the college students. In several cases, students who had math weaknesses but could clearly profit from the college experience were paired with another class member who could compensate for these weaknesses—hence creating a distributed-expertise environment. Overall, the goal was to help all the students develop competence and confidence rather than simply select the top performers and leave the others out in the cold.

Community Centeredness and the HPL Course. The HPL course that we taught was explicitly built on the premise that we wanted to create a classroom environment where everyone achieved at an exceptionally high level (e.g., everyone had the chance to receive an "A"), where standards were very high, and where we would do everything within reason to help the students achieve. The students did not appear to believe us at first, but their perceptions changed as we began to help them see that our assessments were not simply "tests," but were formative and allowed us to help them learn better. By midsemester there was a strong feeling in the class that we were all in this together and all learning from one another. The earlier discussion on formative assessment in the HPL class (see above) provides examples of what we as instructors learned from the students. And we made our learning clear to the class.

Another way that we attempted to build a sense of community in the classroom was to let students see how much they were learning over the course of the semester (this involves a combination of assessment- and community-centeredness). We did this by letting the students experience the same event on multiple occasions and experience changes in what they noticed and understood as a function of the expertise they were developing in the course. The "event" that they experienced was a 45-minute video of a multimedia lecture that covered the essentials of *How People Learn.* After viewing it, students wrote down what they noticed and understood about the lecture. They did this on three different occasions: at the beginning of the course, midway through the course, and near the end of the course.

What we had hoped would happen—and it did—was that students would notice and understand new information each time they saw the lecture and, in the process, see how much they were learning. After seeing the lecture for the first time, most students mentioned that it was a lot to digest and that the stories and video examples were particularly easy to remember. The second time they saw the lecture they began to talk about the concepts that the stories and video examples were illustrating. By the third time they saw the video the students were able to articulate the organization to the overall talk and they could elaborate based on knowledge acquired during the semester. Overall, the event helped students experience the development of their own expertise. As one student stated:

> . . . viewing the video three times (as much as I disliked watching it over and over and over again) was very helpful. . . . I was able to see exactly how much I had learned over the semester, which was very heartening to me.

The content in HPL helped us align the students' experiences and expectations for the course with our goals and methods as instructors. Especially important was the idea of expertise and its development (including the fact that they, too, were becoming experts), the idea that we needed to know how they were understanding the materials to help them learn effectively (the *Fish is Fish* story helped illustrate this point; see boxed text), and the concept of adaptive expertise (see Hatano & Inagaki, 1986; Bransford et al., 1999, Chapter 2) as a goal for them as students and us as instructors.

The idea of aligning students' expectations with the instructor's is an important part of the community-centered perspective in the HPL framework. Without this alignment, attempts to change teaching practices can be met with disappointment, resistance, and even hostility. One of us (JB) learned this lesson in a course on "Cognition, Culture and Technology" taught jointly with Xiaodong Lin and Jan Hawkins (Jan served as a virtual professor who visited occasionally and interacted a great deal on line). At the end of the course, a student wrote in her evaluation that she loved the course except for one thing that made it very disappointing. She explained that the course description included the term *technology*, and that to her that meant that she would be able to learn HTML programming. But we never discussed HTML in the class and that disappointed her tremendously. At first glance we were shocked that a student would make the assumption that *technology* in a course title meant HTML programming. At second glance we were shocked that we could have gone an entire semester without knowing what the student was expecting. We have since learned that simple technologies such as E-mail can go a long way toward continually assessing students' sense of how the course is going for them and helping them feel part of a community that cares about their perceptions. In this instance, community-, learner-, assessment-, and knowledge-centeredness all overlap.

The importance of aligning the expectations of students and instructors is further illustrated by a study of Vanderbilt's Peabody College faculty as they attempted to use new technologies to change their teaching processes (Williams Glaser, 1998). One of the professors in the study noted how he had been asked to teach a course outside his area of expertise, plus he attempted to be innovative by using new technologies to support his teaching. Both factors resulted in him frequently telling his students that he did not know the answer to a question right now (to a question about content or technology) but would find out for the next class. Student ratings at the end of the course were quite brutal in pegging him as a novice who didn't have much knowledge. In actuality, the professor was an outstanding model of an adaptive expert who had the courage to try new things and learn along with the students. However, the students in his course had no concept of adaptive expertise. To them, experts should know all the answers. They interpreted statements about the need for the professor to learn as a sign of weakness. In our HPL course, the idea that the instructors and the students were fellow learners became valued by the class as a whole. The instructors learned how their statements and readings were interpreted by the students; the students learned from one another and from the instructors. Interactions in the class were fun, yet high standards were maintained.

E-mail comments from students after the course was completed provided some perspective on their feelings about the standards and sense of community:

- First of all I loved this course. I learned so much. . . .
- . . . The three of you treated us with respect at all times, which makes a major difference in my life at least. Too often I have been treated as a student who does not know anything and who could not possibly have anything worthwhile to contribute. You valued what I had to say, and you took my opinions into consideration. Thank you so much!
- Thank you for caring enough about your students to make sure that we truly understood the material.

The HPL framework does not imply that students and teachers must always form the type of community that we developed in the HPL class. The important point of the community-centered part of the HPL framework is that the classroom norms be made explicit and that teachers attempt to create a community where their goals become aligned with the students'. Bateman et al. (1997) showed how middle-school students' sense of community is related to their academic achievement. Lin and Hsi (1999) showed that opportunities for students to see a multimedia case about their professor's goals and life experiences can have powerful effects on creating an alignment of goals and norms that foster an effective classroom community.

The Learning Sciences, Collaboration, and Connectivity

The primary focus of the preceding discussion was on ways that the HPL framework (see Figure 2) can guide the design of effective learning environments, with or without the use of modern technologies. Our goal in this section is to shift the figure–ground relationship and explore how new technologies can make it easier to implement the kinds of ideas suggested by the HPL framework. We explored this issue at two levels: (a) additional technologies that we would like to add to our HPL course (plus other courses) to make learning more effective and (b) uses of technology to help us as teachers and researchers increase our abilities to learn from one another and collaborate.

Additional Technologies That Can Enhance Student Learning

In HPL, the Committee discusses many more examples of technology than we have explored in this chapter (see Bransford, 1999, chap. 9). An especially important

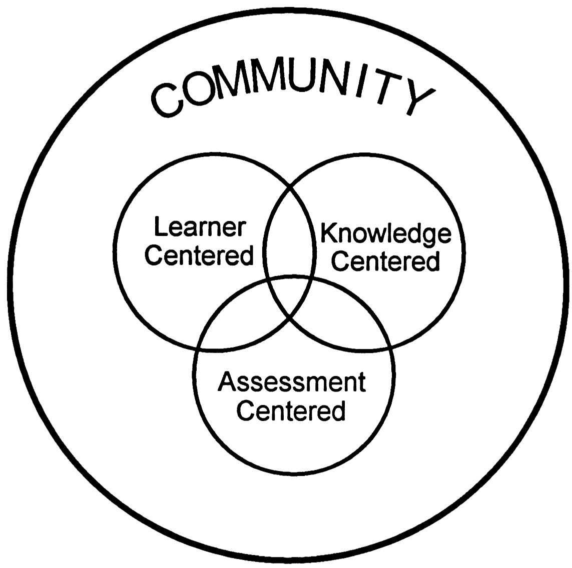

Figure 2. Four Perspectives on the Design of Effective Learning Environments

part of the Committee's discussion is the presentation of data showing how appropriate uses of new technologies facilitated students' learning of important subject matters (see chap. 9). Increasingly, data from technology-based programs are being used not simply to prove that the programs work, but also continually to improve the programs. Some of these continuous improvements efforts are designed to increase students' abilities to learn with understanding and be more flexible in their abilities to transfer to new situations (e.g., Bransford, Zech, et al., in press; Linn & Hsi, 1999). Other improvements are designed to provide the kinds of support that teachers need to use new technologies effectively (e.g., CTGV, in press; Mestre et al., 1997).

Many of the technology applications discussed in Chapter 9 of HPL would have enhanced the course on HPL that we discussed earlier. We used electronic communications and case-based technologies analogous to Jasper (these were cases of classroom teaching that the students learned to analyze from the HPL perspective). Nevertheless, we would have loved to use additional technologies like Classtalk (even for a small class) and tutoring environments that could help students work through particular learning and design issues. And the course would have benefited from opportunities for on-line discussions. But this was the first time we had taught the class. In addition, because it was small, we were able to do many things without technology that, in a larger class, require technology.

An especially important concept that will be incorporated in our next course on HPL is technology support for helping students self-assess their own learning. Even with our small class size, having technology-enhanced environments for self-assessment would have saved us considerable class time that could have been used for other activities. Technology-supported environments for self-assessment include traditional multiple choice and true-or-false options plus newer programs that link students to resources when they need them (see Pfaffman & CTGV, 1999); diagnostic programs that help students identify misconceptions and understand how to think differently about situations (Hunt & Minstrell, 1994); automatic essay scorers that let students test their mettle by writing essays and receiving feedback (e.g., Landauer, Foltz, & Laham, 1998); concept-mapping software (e.g., Inspiration by Inspiration Software Inc., 1997; Project Integration Visualization Tool (PIVit) by Krajcik, Soloway, Blumenfeld, & Marx, 1998); software that provides feedback about students' overall problem solving (Stevens & Wang, 1996); and *teachable agent* software that lets students learn by teaching computerized agents, seeing how they perform in specific environments (a form of assessment), and reteaching the agents as needed (e.g., Brophy, Biswas, Katzlberger, Bransford, & Schwartz, 1999). Many of these examples appear in HPL (Bransford, 1999, chap. 9). Others are discussed in Means, Brophy, and Bransford (1999).

Rapid developments in wired and wireless connectivity also have the potential to change how teachers teach and students learn. In our next round of the HPL course, we want to give students opportunities to access the latest information about HPL over the Internet, get in touch with experts and other groups of students as appropriate, and create products (papers, cases, etc.) that can be shared with others across the country and the world. Having a real outside audience for one's work as a class is an especially powerful way to develop a sense of a learning community that is doing important work (e.g., see CTGV, 1997). A major challenge for us as teachers and researchers is to keep abreast of the rapidly developing changes in technology so that we can use them. That brings us to the next issue of technology and learning, which is discussed below.

Enhancing Our Own Learning as Teachers and Researchers

New technologies can enhance not only students' learning, but also the learning of teachers and researchers. Changes in technology are occurring so rapidly that it is difficult to keep current. Relying solely on print-based publications is too slow. New opportunities for digital connectivity enable us to create collaborative learning environments that help teachers and researchers change how they learn. But collaboration doesn't just happen because of the connectivity. Other factors must be put in place (see especially Langemann, 1997).

Efforts to capitalize on technology to improve collaboration and to learn from the experience are already underway. For example, the National Science Foundation has funded three distributed centers designed to accelerate collaboration around issues of technology and learning: The Center for Innovative Learning Technologies (CILT; http://www.CILT.Org); The Center for Learning Technologies in Urban Schools (LeTUS; http://www.letus.nwu.edu/); The Center for Interdisciplinary Research on Constructive Learning Environments (CIRCLE; http://www.pitt.edu/~circle/). The web sites of each of these centers provide up-to-date information about their activities. One of the centers, CILT, provides seed grants that link together groups who can learn from one another but would otherwise probably never collaborate.

The Department of Education's Office of Educational Research and Improvement (OERI) is also supporting collaboration. Its Challenge Grant program links universities with school systems and, ultimately, with one another (http://www.ed.gov/Technology/challenge/). As we finish this article, the OERI is ready to announce winners of a funding competition designed to prepare future teachers to use technology to improve student learning (http://www.ed.gov/offices/OERI/). The idea of having these projects collaborate and learn from one another is a major part of the OERI plan. Other examples of important collaborative efforts include a National Science Foundation project to link professors at community colleges to improve technology education (http://www.nsti.tec.tn.us/seatec/), and a new National Science Foundation center that links learning scientists with bioengineers to enhance bioengineering education (see erc.netlearning.org).

As noted earlier, worldwide connectivity made possible by the Internet enhances the potential for fruitful collaboration, but it definitely does not guarantee it. There are trends among members of the research, development, and publishing communities that are making efforts to collaborate easier to achieve.

One important trend is the idea of creating software components that are interoperable and can be assembled into unique configurations that fit specific needs. Instead of the monolithic word processor, web browser, or tutor, people will be able to access, configure, and use just those components that they need. Roschelle and Pea (1999) provided an insightful overview of many of the potentials and challenges that exist.

The idea of creating interoperable software components is part of a larger idea of modular design in general (Baldwin & Clark, 1997). In the music industry, the ability to download single songs is replacing the album as the prime unit of packaging and marketing. Similar trends are beginning to appear in the print industry. The monolithic textbook will be replaced by access to modules that can be reassembled to fit specific needs. Furthermore, these modules will contain audio, video, and interactive simulations, not only text.

Concepts of *flexibly adaptive design* (e.g., Schwartz, Lin, Brophy, & Bransford, 1999) fit well with an emphasis on modularity. For example, one of CILT's synergy projects (see CILT.org) involves a collaborative effort to find ways to help students learn about rivers and water quality by using new technologies. Design teams in different locations of the country soon learned that there are problems with a one-size-fits-all approach. For example, students in the Berkeley group were within walking distance of Strawberry Creek and could use it as the primary anchor for their activities. Students in inner-city Nashville were a long, expensive bus ride from the river and could afford to go only once. Compared with the Berkeley students, they needed to rely much more on simulations to prepare them for their actual river trip.

Software environments are being developed that help integrate modular resources into pedagogically sound units complete with opportunities for formative assessments. Examples include the Knowledge Integration Environment (KIE) and Web-Based Integrated Science Environment (WISE; http://wise.berkeley.edu/WISE/index.html) developed at Berkeley, and the STAR.Legacy environment developed at Vanderbilt (Schwartz et al., 1999). These environments provide frameworks for teaching in ways that are consistent with the HPL framework discussed earlier.

One of the most promising trends that can facilitate collaboration involves uses of technology to change how data are shared (e.g., Pea, 1999) and transformations of the art of teaching into inquiry and scholarship (Shulman, 1999). Historically, teaching has been a private act that takes place behind closed doors. It stays this way from kindergarten to college and graduate school. This emphasis on privacy is distinctly different from the norms of scientific inquiry, which emphasize the importance of making ideas public and subject to review, analysis, and experimentation. Teaching can benefit from a similar transformation from private to public. Technology can help display the kinds of data that allow teachers to analyze and communicate their work (e.g., Pea, 1999).

The simple act of putting one's syllabus on the web begins to make teachers' activities more public. But more is needed—especially fruitful ways to think about teaching and learning that help people develop ways to improve the learning of their students continually. The principles in HPL provide an excellent starting point for framing questions about learning and teaching that can be studied and help everyone improve.

Summary and Conclusions

Our goal in this chapter was to explore how insights from the learning sciences can guide the effective use of computer technologies to promote learning and how these technologies make new types of learning opportunities possible. The primary focus of our discussion was on ways that new technologies can enhance the formal learning that takes places in elementary school, high schools, and colleges.

First, we explored how some "simple" technologies such as textbooks, Classtalk, the Algebra Tutor, and Jasper made it possible to transform classroom environments into ones that were less of one-way-transmission and more interactive. Second, we went behind the scenes and explored how issues of learning are involved in any attempt to implement new technologies. In most discussions of technology implementation, the learning issues remain relatively tacit. By making them explicit, it becomes possible to assess their coherence as a system (see Brown & Campione, 1996) and their correspondence with what is known about human learning. We argued that the framework presented in HPL (see Figure 2) was useful for thinking about the design of effective learning environments. We applied it to four different settings: Classtalk, the Algebra Tutor, Jasper, and our recent undergraduate course on "How People Learn" that used HPL as a text.

Third, we discussed how the rapid developments in technology provide us with both challenges and opportunities. Opportunities include the ability to enhance student learning further; for example, we discussed how our HPL course could be improved by making greater use of new technologies. Challenges including finding the time to learn how to incorporate the new technologies well and to ensure that they continually work as planned.

In addition to the effects of technology on student learning, we briefly discussed its effects on teachers and researchers. The increased ability to communicate electronically is changing how professionals do their work. But there is still a great deal to learn about ways to make this work well. We discussed several virtual centers that are engaged in collaborative attempts to improve education through effective uses of new technologies. Important trends in thinking about software and curricula are also affecting the ease of collaboration. These include the idea of moving away from monolithic texts, software programs, and curriculum units and instead designing modules that are interoperable (Roschelle & Pea, 1999). Software shells are being developed that allow modules to be combined into flexible curriculum units that allow flexibly adaptive design (e.g., Schwartz et al., 1999).

We ended by noting a particularly exciting trend in education: the transformation of teaching into an area of inquiry and scholarship (Shulman, 1999). The idea of making teaching practices public, sharable, and subject to analysis and experimentation is very exciting. New technologies provide the HPL framework with a way to begin thinking about teaching from the perspective of how students' learning can be improved.

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