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# DISCIPLINED INQUIRY AND THE STUDY OF EMERGING TECHNOLOGY

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Few developments have piqued researchers' interest as has the growth of computers in their various hybrid forms as educational tools. A seemingly infinite range of methods and strategies has evolved to exploit the potential of technology. The problem has not been a scarcity of research. Literally thousands of studies related to computers and learning have been published during the past three decades. The problem has been one of making sense of the enormous, and growing, body of available research.

This dilemma is compounded by the continuous metamorphosis of technologies—hardware, software and design—and the relatively short shelf-life of what is considered "state of the art." Present-day technologies often bear little resemblance to the computers of even a decade ago; new hardware and design technologies continue to emerge. During the past 40 years alone, computers have evolved from cumbersome, expensive room-size machines with typewriter displays to inexpensive hand-held devices of substantially greater power, flexibility, and ease of use. Applications have shifted from primitive tutorials to tools for individual inquiry, from typed text to high-fidelity visual images and immersive three-dimension CAVEs (computer-aided virtual environments), and from systems that present information to systems in which individuals construct knowledge. Indeed, the construct of "emerging" technology seems apropos in a field of such rapid and continuous change. The purpose of this chapter is to present one way of making sense of the vast body of educational technology research by organizing and categorizing research related to technology in education along a number of facets. As part of this organization, we examine how differences in the values and assumptions underlying teaching and learning research, theory, and practice have influenced disciplined inquiry related to emerging technologies.

## 13.1 PERSPECTIVES ACROSS RESEARCH COMMUNITIES

Different communities emphasize different perspectives—at times modest, at times profound. The problems and issues related to teaching, learning and emerging technologies, as well as the methods of study, develop along different paths. Much "educational technology" research focused on the effectiveness of technology in improving test scores, using past achievement as evidence of a problem or need (e.g., Wenglinksy, 1998). "Learning science research," in contrast, might address misconceptions by allowing students to hypothesize, test and reconcile naïve individual beliefs. Each adopts a different epistemological perspective, which influences the questions studied, the literature

| | | Considerations of Use? | |
|---|---|---|---|
| | | No | Yes |
| Quest for fundamental understanding? | Yes | Basic and foundational research (Foundation Research) | Use-inspired basic research (Theory-building Research) |
| | No | X | Pure applied research (Application Research) |

FIGURE 13.1. Quadrant model applied to educational technology research

base used to frame and interpret the problem, and the methods of study (Hannafin, Hannafin, Land, & Oliver, 1997).

While it is important to understand goals and distinctions unique to different perspectives, it is beyond the scope of this chapter to do so comprehensively. Rather, we have chosen to highlight particular research processes that characterize particular approaches, then look across the work of researchers from different "schools," to identify patterns and implications not apparent within any single approach. As illustrated in Fig. 13.1, Stokes' (1997) model contrasts research on understanding and use as the key dimensions, each of which is considered as being either central or not central to the aims of the researcher. The extent to which research manifests each dimension (i.e., the pursuit of fundament understanding and use) determines the quadrant (or focal point for impact) of the research.

Basic (or foundation) research, in this context, is concerned with developing principles and standards that may be drawn upon in other settings. In contrast, application research focuses on technology use in a given setting and/or meeting a particular need. Application researchers focus on how the tools work in a particular setting. Rather than attempting to derive principles, application researchers often try to answer practical questions about the use or implementation of an innovation. Theory builders conduct what Stokes terms "use-inspired basic research." They are interested in both practical questions and the development of fundamental understanding. However, their research typically focuses not on the technology (though the technology is important), but on understanding theories about learning as well as ideas for supporting learning. Theory builders are concerned with how well theories embodied in innovations work in practice. (Note. Stokes does not attempt to legitimize research perceived as advancing neither fundamental understanding nor use implications to warrant detailed attention in his presentation of Pasteur's Quadrant. For our purposes, we adopt similar distinctions in our application of Pasteur's quadrant to instructional technology research.)

## 13.2 PASTEUR'S QUADRANT AND EMERGING TECHNOLOGY RESEARCH

In education—and particularly in educational technology—the dimensions of Fig. 13.1 relate questions about *using* innovations with *developing principles* for designing and developing the innovations. The distinctions are important to establishing important conceptual distinctions among the growing universe of research, and researchers, related to teaching, learning and emerging technology. The matrix shown in Table 13.1 provides a common set of perspectives across three key research communities represented in Pasteur's Quadrant: foundation, application, and theory building, or use-inspired, research. Throughout this chapter, each column of Table 13.1 will be elaborated into its own matrix focused on a wide range of sample projects within the research perspective. Each matrix provides a means for exploring the kinds of questions posed, the evolution of research threads, differences among the focus and methods of contrasting communities, and distinctions as to the goals and audience of different research communities, classifying seemingly disparate educational technology research. It should be noted that the matrices, as well as the text accompanying them, attempt to broadly define the research field rather than offer a comprehensive review of the literature for that research perspective.

### 13.2.1 Foundation Research

Analogous to Stokes' pure basic research quadrant, *foundation research* identifies underlying principles and processes that provide core principles to guide, influence, or direct other researchers' efforts. The research appropriate to this quadrant focuses on basic information about an innovation independent of setting. Foundation research focuses on developing fundamental knowledge about technology and its use that is necessary before an innovation or instructional approach can be considered for use in educational settings, while concurrently defining underlying principles and processes for use-inspired research. For the educational technology field, foundation researchers include psychologists, engineers, programmers, and others interested in issues related to how technology can work and what happens when people use it.

***13.2.1.1 Goals of the Research.*** As implied by their placement in the quadrant model, foundation researchers are interested in fundamental knowledge independent from real-world application. For example, Abnett, Stanton, Neale, and O'Malley (2001) examined the consequences of young children working in pairs using more than one mouse. They found that students sharing mice while engaged in a collaborative writing activity exhibited greater levels of shared input and produced higher

TABLE 13.1. Framework for Considering Research on and with Learning Technologies

| Community | Foundation (Psychology, Computer Science, Information Management, Engineering) | Application (Educational Technology, Instructional Design) | Theory Building (Learning Sciences) |
|---|---|---|---|
| **Nature of the Research** | Basic and foundation research—focused on developing fundamental understanding about the technology itself or about affective aspects of technology use (e.g., motivation or efficacy). | Application research—focused on how people interact with and learn from an innovation. Often concerned with innovation in use in a particular setting. | Theory Application & Development (use-inspired basic research)—focused on learning with technology acting as a vehicle. Combination of other two as focus is on developing understanding about learning while focusing on questions about learning in context. |
| **Problem Definition** | Concerned with whether the technology is achieving a desired effect. Foundation research provides principles and processes that can be adopted and adapted in other settings. | Concerned with the user's experience. Typically concerned with supporting decision-making regarding adoption and adaptation. | Concerned with implementation and refinement of theory embodied in or captured by technology tools. Often leads to further refinement and retesting of theories and tools. |
| **Research Question Categories** | Can people learn from this technology?<br>How does this technology work best?<br>What happens when people use this technology?<br>How do we overcome problems inherent to this technology? | How do users benefit from this innovation?<br>Is the innovation practical?<br>What is the innovation's return on investment?<br>Is the innovation usable?<br>Is the innovation worth using? | How do certain theories enacted in the innovation work?<br>Is the theory underlying my innovation/implementation appropriate?<br>What happens when I test this theory/innovation in context? |
| **Target Audience(s) for the Research** | Developers<br>Engineers<br>Programmers<br>Instructional designers | Policy makers<br>Evaluators<br>Decision makers<br>Practitioners | Researchers<br>Instructional designers<br>Practitioners |

quality stories. While this research could be considered application research, the intent of the research was to build a body of baseline evidence of a need that might warrant further inquiry, not a solution to a defined problem. Foundation research can also serve as initial steps in the development of educational applications of technology. The work undertaken by Dede's (e.g., Dede, Salzman, & Loftin, 2000) and Winn's (e.g., Winn et al., 1997) virtual reality groups provided insight into whether students could learn from virtual reality as well as how they interacted with the virtual environments but without the expectation of addressing a manifest need or a common classroom problem. Their work served as foundation for subsequent researchers interested in educational virtual reality environments.

The goals of the foundation research are typically twofold: (1) The researchers are interested in particular technology innovation, and (2) more importantly, they are interested in testing a hypothesis related to some facet of that innovation. Often, hypothesis testing drives the research. Investigators may be interested in increased motivation related to the use of technology, information search processes on the Internet, or patterns of reading in a hypermedia environment (see Table 13.2 for a snapshot of the variety of questions and issues addressed in foundation research). Researchers set out to test or reveal focused, but potentially generalizable, principles. Once conclusions are drawn, the foundation researcher or other researchers may embody the findings in later work that is more explicitly contextualized. For example, Antonietti, Imperio, Rasi, and Sacco's (2001) work with hypermedia and virtual reality was focused on a single learning task—learning about lathes. However, their research questions were focused on the hypothesis that seeing the virtual reality version of the lathe before interacting with related hypermedia information would yield different results than interacting first with the information, then with the virtual tool. In the end, their research yielded a principle about using virtual reality and hypermedia that is largely context-independent—that is, users with no previous mental model seem to benefit from interacting with the virtual environment before reading about it, whereas the users with previous experience benefit more from interacting with the hypermedia materials followed by the virtual experiences.

Various foundation researchers' work reflects different assumptions about learning or interaction. For example, many questions are concerned with information processing issues such as how young students navigate using CD-ROMs (e.g., Large, Beheshti, & Breleux, 1998). However, some are interested in sociocultural theories as evidences by their work focused on the role of an instructor in a learning environment (e.g., Hmelo, Nagarajan, & Day, 2000). Often, foundation researchers concentrate on sets of closely linked questions of a highly interdependent nature, such as the research on information processing and human memory. Foundation researchers often develop more inclusive, generalizable theories and principles through

TABLE 13.2. Sample Questions and Findings from Foundation Research

| Selected Research Questions | Studies | Findings |
|---|---|---|
| *Scaffolding* | | |
| How is a joint problem space constructed? How is the process influenced by incoming knowledge levels? | Hmelo, Nagarajan, & Day, 2000 | Low incoming knowledge students and high incoming knowledge students used different processes to solve a problem. However, both relied on computer tools to structure their activity and to prompt them to consider certain factors. |
| Do different versions of a concept-mapping system affect performance? | Chang, Sung, & Chen, 2001 | Students using a scaffold that was a partially completed expert concept map scored better on performance outcomes than those who created their own maps. |
| Do students who take notes have better achievement than those who do not? | Trafton & Trickett, 2001 | Found that students using note taking answered more questions correctly than those who did not. Found different levels of scaffolding in note taking affected both use of learning strategy and task performance. |
| *Hypermedia/Multimedia* | | |
| Can students learn using a virtual lathe? Given a virtual and hypermedia environment, which is better for students to encounter first? | Antonietti, Imperio, Rasi, & Sacco, 2001 | Students can learn from virtual lathe. Trend emerged that it was beneficial to experience VR condition before hypermedia if students do not know about lathes. The opposite is true if they do have a prior mental model for a lathe. |
| Do users react better to more or less information in a hypertext system? | Dimitroff, Wolfram, & Volz, 1995 | Found complex relationships between maneuverability and usability in the systems. In the system with more information, users felt it was usable, but rated it low for accessing the information they wanted. |
| Does a hypertext system better support information location than a print-based system? | Egan, Remde, Landauer, Lochbaum, & Gomez, 1995 | Found hypertext users had better search accuracy, fewer erroneous responses, and produced superior essays than those using print-based system. |
| Is there evidence that the brain processes various media types differently? | Gerlic & Jausovec, 1999 | Used EEG readings to determine that the brain reacts differently to images and movies than to text. |
| *Information Organization/Seeking* | | |
| What strategies do young novices use when seeking information? | Marchionini, 1989 | Older searchers were able to find information faster and with more success. Younger searchers generally used whole sentence searches indicating a lack of understanding of information organization. |
| What kinds of strategies do adults use in searching for information? | Van Der Linden, Sonnentag, Frese, & Van Dyck, 2001 | Systematic efforts led to better task performance. Trial and error can be effective, but also leads to a number of negative errors. Noneffective strategies lead to lower self-evaluation. Repeating unsuccessful searches or excessive searches led to low performance. |
| *Usability of Innovations/Human Factors* | | |
| Does using two mice influence student collaboration? | Abnett, Stanton, Neale, & O'Malley, 2001 | Presence of second mouse did not impact communication amount. Gender of students in pair influenced kind of communication, but second mouse seemed to promote equity.<br>Quality of student work was improved. |
| How do users react to and use a "programming by example" system? | Cypher, 1995 | Subjects were uncomfortable giving up control to automated system. There were important interface flaws that kept users from understanding what was happening. |
| What kinds of virtual reality cues lead to the most learning in an immersive VR environment? | Dede et al., 2000; Dede, Salzman, & Loftin, 1996 | Found that three-dimensional representations were more effective than two-dimensional representations. Found that users preferred multimodal cues (haptic, sound, & sight). |
| *Motivation* | | |
| How do student motivation, inquiry quality, and the interactions between these develop? | Hakkarainen, Lipponen, Jarvela, & Niemivirta (1999) | Student motivation was no different in computer environment than on self-report. Significant differences emerged between motivation orientation and knowledge production. |
| How are student and teacher motivation related in a design and technology project? | Atkinson, 2000 | Found a positive correlation between teacher motivation and student motivation for project. |

TABLE 13.2. Continued

| Selected Research Questions | Studies | Findings |
|---|---|---|
| What is virtual reality's potential as a motivating learning tool? | Bricken & Byrne, 1992; Byrne, Holland, Moffit, Hodas, & Furness, 1994 | Found that students were motivated in virtual environments—particularly those they created themselves. |
| *Learning from Technology* | | |
| Can students learn content in an immersive virtual reality environment? | Winn et al., 1997;<br>HITL, 1995;<br>Winn, 1995 | Yes, students can learn content. Lower achieving students may particularly benefit. |
| Can VR aid in eliminating student science misconceptions? | Dede et al., 2000 | Found that students learn correct content and that they seem to have their incoming misconceptions challenged by participation in immersive environment. |

multiple studies related to a single topic. These studies, however, are not inherently related except by topic strand—a researcher may choose to focus on motivation, for instance, and conduct a number of separate motivation studies over a period of years. Further, this research tends not to be iterative in nature or self-correcting. After all, making revisions in the conditions during a study removes the controlled environment that basic research requires to develop understandings about the phenomenon of interest.

***13.2.1.2 Questions Asked.*** Research questions asked in foundation research tend to be tightly focused, discrete, and largely unconcerned with specific contextual factors except those variables that impact the theory. To-be-learned content, for example, is often described more in terms of characteristics and complexity (e.g., problem solving, inquiry) than as specific to a domain (e.g., determining how far light waves travel, use of specific pedagogical approaches in scientific inquiry). Whereas an application researcher may study the practical value of tool use in a particular domain or setting, and theory builders may attempt to study how (or if) an innovation supports learning in particular ways, foundation researchers study whether and how an idea works—under particular circumstances and with a particular subject pool.

Foundation researchers study questions such as whether or an innovation works, under what conditions it works, and how people work with the innovation, but not questions about the users' experience with the innovation or whether the innovation was worth using. Often, the research questions require the innovation be compared against a control group so that researchers can determine the statistical reliability of the observed differences. In some cases, foundation questions focus on a specific prototype. For example, Chang, Sung, and Chen (2001) created a concept-map scaffolding system to support their inquiry. In other cases, questions rely on a specific innovation only as a vehicle for understanding a phenomenon, such as Marchionini's (1989) early hypertext research on student search strategies. While some structure was provided for the search activity, there was no overt attempt to test a particular product; rather, Marchionini attempted to understand how children of different ages conducted an information search. Table 13.2 presents a representative selection of foundation research studies related to emerging technologies, many of which are elaborated throughout this section.

***13.2.1.3 Methodologies.*** Research conducted by foundation researchers is often experimental or quasi-experimental in nature. This is largely related to the historical roots of the instructional technology field, where experimental designs dominated most of the foundation research dome prior to the 1990s, and questions typically asked: *whether* the innovation works and *to what extent* it works. From the perspective of the emerging technology research community, it provides a baseline from which to chart growth or measure change. Foundation researchers often do not know the extent to which an innovation or idea is effective without also knowing what performance would be elicited from similar subjects who have not interacted with the innovation.

*How* questions examine the ways in which people interact with an innovation. In these studies, quasi-experimental studies are often employed (or in many cases should be employed), often featuring pre/postmeasures or other within-group or within-subject measures rather than the between-groups measures often appropriate for other questions. Typically, though not exclusively, data collected during these studies tend to be objective in nature. Participant surveys, pre/postmeasures, and observational checklists are commonly employed in these studies, and hypotheses are tested using data are analyzed statistically to establish objective baseline indicators and threshold data. Interestingly, however, recent efforts have adapted approaches from usability testing and observational qualitative approaches, broadening both the methodological toolkit of the researcher and the question and method options for inquiry.

***13.2.1.4 Audience.*** Foundation researchers provide information about people and innovations for a wide spectrum of technology-related research. Instructional developers use foundation research for decision making; educational technologists use it for selecting appropriate classroom materials; while learning scientists use this research to formulate and test their contextualized hypotheses. Foundation researchers also inform one another. Programmers, engineers, and psychologists deepen their understanding of relevant principles from their own or other disciplines to design future studies or implement future innovations. Research agendas emerge by linking together separate foundation studies that center on a hypothesis and refine it over time through progressive refinements in underlying principles.

#### *13.2.1.5 Examples of Foundation Research.*

*13.2.1.5.1 Virtual Reality Usability Research.* Early VR researchers were interested in whether learning could occur in virtual environments and to what extent it occurred as well as on the usability issues of such systems. Dede's (e.g., Dede et al., 2000; Dede, Salzman, & Loftin, 1996) research, for example, centered on ScienceSpace, a series of immersive microworlds designed to promote the learning of physical science principles, but considered questions that were not specific to that tool. In addition to student satisfaction and learning, the researchers studied what happens as learners attempt to use an immersive VR program. These and related studies helped to provide principles about VR learning that can be used in a wide array of settings. For example, these early studies found that users prefer multimodal (haptic, sight, and sound) systems and that there is a tendency for disorientation sickness. These studies, and the findings from them were not related to the mastery of particular content or the use of the tools in a particular setting, rather they focused on foundational questions about the potential of VR.

Further VR research focused on understanding frames of reference—an issue unique to immersive technologies. One study indicated the importance of using the egocentric view to see details and the exocentric view to understand the big picture (Salzman, Dede, Loftin, & Ash, 1998). Another study found that students in the 3D environment could construct two-dimensional representations of the concept, however those in the two-dimensional space were unable to create a 3D representation (Dede et al., 2000)—important principles related to learning in immersive environments developed through foundation research.

*13.2.1.5.2 Hypermedia Research.* As alluded to thus far in the discussion of foundation research, much hypermedia research can be considered foundation research. From the early hypermedia studies that attempted to determine differences in the use of hypertext versus linear text (see McKnight, Dillon, & Richardson, 1996, or Thompson, Simonson, & Hargrave, 1996, for overviews of early hypermedia research) to the current research focused on understanding factors that impact learning with hypertext, there has been a consistent focus on foundation questions related to what makes hypertext work best and what happens when people use it.

Shapiro (1999), for example, has studied the relevance of hierarchies and other organizational structures on the way people learn information. In her study, Shapiro offered adults information on a made-up topic (life forms on another planet) organized in different ways. The same body of information was available to each participant, however, some saw it hierarchichally organized, some saw it clustered, others saw it in a linear form, and the final group saw the information unstructured. Her findings indicated that there was no difference in the amount of factual knowledge learned across the three groups, but that there was a bias for structured groups, particularly the hierarchical group, in cued association tests and information mapping. In fact, she found that those who were given the hierarchy used it readily while those who were not given the hierarchy tended to try to develop their own hierarchical organization as they moved through the tasks.

Dimitroff, Wolfram, and Volz (1995) studied the effects of different factors on participant information retrieval using a hypertext system. While their methods varied considerably from Shapiro's, they had at least one finding in common—that participants' mental model, or lack thereof, impacted their interactions with a hypertext system. In their study, Dimitroff and colleagues looked at a basic and enhanced version of their hypertext information retrieval system. The enhanced system varied from the basic system only in that it included additional hyperlinked information. The abstract and titles of materials were included in a keyword link. The researchers assigned their 83 adult participants to either a basic system group or an enhanced system group and asked them to complete five searches (known item, keyword, descriptor, and two different subject searches) then complete a user survey. In their factor analysis of the survey results, the researchers found that for both conditions maneuverability was rated quite low. This included factors such as the fun and frustration levels the participants reported, whether the system was easier than other systems they had used, and whether the system was confusing. In fact, 74 percent of the negative comments reported in both groups were related to system maneuverability. Conversely, the participants found the system to be quite useful. They reported it was easier to use than they expected and felt the navigation was not overwhelming. While these are only two of a host of hypermedia research efforts, they demonstrate how foundation research has moved our understanding forward.

### 13.2.2 Application Research

*Application* research focuses on in-context technology innovations and issues of practice. Application researchers include instructional developers, educational technologies, and educational evaluators, as well as teachers conducting action research in their own classrooms. In terms of Stokes' model, the research is applied in nature; questions are mainly concerned with the application of principles in the real-world rather than the development of underlying design or learning theories to guide future use or development. Further, questions often focus on the user's experience with the innovation rather than the innovation itself. Often, the work of the application researchers supports decision making ranging from the actual cost of instructional technology for a school district (Keltner & Ross, 1995) to whether an EPSS system is effective for supporting teachers in conducting their day-to-day activities (Moore & Orey, 2001).

***13.2.2.1 Goals of the Research.*** Often, application research focuses primarily on whether innovations are effective and worthwhile in a given context. Application research questions vary widely, tending to focus on whether technology should be used in a given setting or by a particular audience. This research transcends experimental settings, focusing on technology as used in classrooms such as WebQuests or computer aided instruction systems, and performance technologies, such as electronic performance support systems and training simulations. For example, the Moore & Orey (2001) research included in Table 13.3 focused on whether EPSS systems were effective in supporting teachers as they conducted everyday activities. The researchers found that only elements of the EPSS were used and, consistent with the applied nature of the research, the investigators identified some key attributes that impacted the innovation's effectiveness in practice.

Another common goal of application research is to improve the implementation of an innovation rather than focusing on improving the innovation itself. For example, the research will address whether the innovation is worthwhile, as well as factors that impaired or facilitated the innovation's utility or value, speculations on elements that might make it more effective, and principles of broader implications. Stuhlmann and Taylor (1999), for example, in their examination of factors influencing student-teacher technology use, identified both factors that impacted the student-teachers and hypothesized about effective ways of supporting student-teacher technology integration during classroom experiences.

*13.2.2.1.1 Questions Asked.* Application research is most concerned with understanding the practical issues related to the use of technology by learners—whether in classrooms, informal settings, or just-in-time training situations. In simplest terms, this area of research is concerned with the kinds of questions summarized in Table 13.3: "Did it work?" "How will it work best?" and "What matters to the users as they use it?" To this end, researchers are concerned with questions of effectiveness as measured through defined criteria, such as return on investment, cost effectiveness, and usability. Often, the questions answered by research out of this group have straightforward "yes," "no," or "it depends" answers. While the researcher generally provides clear rationales and foundations for the questions asked the way they are considered, the answer is a clear one. For example, Wenglinsky's (1998) review of NAEP data asked questions about how technology could be used to support achievement in mathematics. His study yielded simple guidance on the effectiveness of computers for supporting mathematics achievement. Findings included suggestions that drill and practice do not increase student achievement and, in some cases, may actually lower achievement. Further, Wenglinsky found a correlation between teacher professional development and reported effectiveness of technology used in the classroom.

***13.2.2.2 Methodologies.*** Unlike foundation research, application research tends to be concerned with users and their experiences with technologies—particularly as their experience relates to specified goal attainment. Because of this, much of the research takes the form of case studies or of evaluations of particular innovations in use. Another common approach to application research is analysis of standardized test results to determine whether set goals were achieved through the use of the innovation.

Research focused on practical use, however, may also use approaches such as teacher (or action) research, evaluation, think-alouds, cost modeling, or usability studies. Given the goal of determining whether an innovation is efficient or effective, almost any approach to research that allows measurable growth to be witnessed or allows the researcher to interact with the learners as they are experiencing an innovation becomes a viable method for conducting the research.

***13.2.2.3 Audience.*** The audience for application research includes any of a variety of decision makers. These may include administrators or financial agents in education or business, teachers, curriculum specialists, or other people placed in the position of selecting or implementing instructional materials in any school district, university, corporate, or military setting.

***13.2.2.4 Examples of Application Research.*** Cost effectiveness research. One form the "did it work?" question has taken focuses on the return-on-investment versus cost of developing technology innovations. This has been considered as the measure for defining effectiveness (see Niemiec, 1989, for a review of several early cost effectiveness studies related to computer-based instruction). As an historical example of application research, cost effectiveness as a research area evolved to meet a series of locally bound needs. Early in the evolution of computer-assisted instruction, it became clear that developing courseware and acquiring needed hardware would be an expensive proposition. To achieve useful results to research considering costs, researchers have taken different approaches. For example, some researchers applied "value-added" models, where the gains associated with such systems were evaluated relative to the additional costs incurred in obtaining them (see, for example, the methods described by Levin & Meister, 1986, and Niemeier, Blackwell, & Walberg, 1986, in Kappan's issue on the effects of computer-assisted instruction). This approach rarely yielded favorable results. Another perspective considered cost-replacement approaches to evaluate the relative costs associated with learning via "traditional" approaches—usually teacher-led, textbook-based methods—versus computer-aided methods. The underlying question shifted from assessing the marginal gains of "add-on" technologies, to one in which the costs of replacing existing methods were assessed (e.g., Bork, 1986). Judgments as to the true value of computers versus traditional classroom-based teaching on learning could then be assessed, appropriate designs and models could be implemented, true costs (immediate, recurring, long-term) associated with each could be identified, and the relative effectiveness of each method could be benchmarked without undue confounding.

There are countless ways researchers can consider effectiveness of innovations. They range from reasonable to questionable (e.g., media comparison studies) and provide a variety of information to the audience for which they are intended.

TABLE 13.3. Sample Questions and Findings from Application Research

| Selected Research Question | Studies | Findings |
|---|---|---|
| *Tool Use & Design* | | |
| Are first graders able to make productive use of a synchronous collaborative workspace? | Tewissen, Lingnau, Hoppe, Mannhaupt, & Nischk, 2001 | Synchronous workspace can be effective in literacy development if the students are properly prepared to use it. |
| What are the critical success factors for implementing MOOSE (a virtual reality MUD) into classrooms? | Bruckman & DeBonte, 1997 | Case study showed that the 4 critical success factors were student access to computers, presence of peer experts, student freedom to choose to use versus being told to use, and teacher tolerance for productive chaos. |
| What kinds of interface elements are best suited to multimedia for primary school children and do multimedia tools have a role to play in the classroom? | Large, 1998 | Students showed confidence in navigation in each product, but were hesitant to use searching. Children are not naïve users and can discern between attractive interfaces and useful tools. Multimedia should only be used when there is a clear need for it. |
| How can a problem-based learning tool be best used in a classroom? | Laffey, Tupper, Musser, & Wedman, 1998 | Found that for successful use, teacher must be philosophically aligned with pedagogical approach and the tool must fit with the authentic activity of the classroom. |
| How did participants use an asynchronous conferencing tool to support learning in an online problem-based environment? | Orrill, 2002 | Found that students tended to use tool for logistics and often did not provide rationales for comments. Students were persistent in getting their point across. Recommendations about ways to promote meaningful interactions are provided. |
| *Performance* | | |
| Can a custom-designed EPSS support teachers in carrying out day-to-day activities? | Moore & Orey, 2001 | The teachers were able to use it to facilitate certain record keeping. There was a strong relationship between usage of the system, performance on teacher tasks, and attitudes toward the system and technology. |
| Does EPSS use by instructional designers lead to high learning and/or better performance on an analysis task? | Bastiaens, 1999 | EPSS users had lower levels of learning, but exhibited higher levels of performance. There was no difference in time on task or satisfaction with training in two groups. |
| How can we best structure student experiences with information seeking? | Bowler, Large, & Rejskind, 2001 | Provides findings about how students seek information as well as a list of issues that determine student success with information finding, interpretation, and use. |
| *Usefulness/Utility Research* | | |
| What factors influence student teachers' experience with technology integration? | Stuhlmann & Taylor, 1999 | Identified 3 factors that influence student teachers' experience (computer availability, technological attitude and competency of cooperating teacher, and attitude of principal toward use). Also made recommendations about supporting student teachers. |
| Do navigational assistants improve search experiences? | Mazlita & Levene, 2001 | Novice users were able to navigate with this system more easily than traditional search engines. Expert searchers who were about the same on both. Users found the interface too complex. |
| How do student frustrations with an online learning environment inhibit their learning experience? | Hara & Kling, 1999 | Three main areas caused frustration: technological problems; minimal and untimely feedback from instructor; ambiguous instructions. Impacted course because students gave up on learning content. |
| *Return on Investment* | | |
| What is the Return on Investment (ROI) for a set of EPSSs? | Hawkins, Gustafson, & Nielson, 1998 | Provides a rationale and model for determining ROI. |

TABLE 13.3. Continued

| Selected Research Question | Studies | Findings |
|---|---|---|
| What does it cost to have a K-12 technology program? | Keltner & Ross, 1995 | Considered all related costs as well as effectiveness. Provided figures between $142 per student to over $400 per student. |
| *Meta-analyses of Implementation/Application Studies* | | |
| What does research say about the impact of technology on student achievement? | Schacter, 1999 | According to the research reviewed, students with access to various kinds of learning technologies see gains on a variety of outcome measures. |
| Does small group learning enhance student achievement? What features moderate small-group success? Are there optimal conditions for using small groups with computer technology? | Lou, Abrami, & d'Apollonia, 2001 | Small group learning had positive effects on individual performance and small group performance. The best outcomes occurred when tasks were difficult, groups had 3–5 members, and no or minimal feedback was available from the computer. |
| What is the observed effectiveness and efficiency of computer simulations for supporting scientific discovery learning? | De Jong & van Joolingen, 1998 | Findings indicate that students do not perform better on outcome tests, but do exhibit indicators of deeper understanding and implicit application than those who did not use simulations. Also included outcomes of particular designs. |

*13.2.2.4.1 Computer-Supported Collaborative Learning.* Computer-supported collaborative learning (CSCL) research, like many other research strains reported here, spans across the three major research groups of interest in this chapter. Numerous studies of CSCL consider when, how, and under what conditions students use CSCL tools (e.g., Kynigos, Evangelia, & Trouki, 2001; Laffey, Tupper, Musser, & Wedman, 1998). Consistent with application research, these questions focus on whether "it" worked—whether "it" was an instructional approach or a tool. For example, as shown in Table 13.3, Laffey et al.'s (1988) work on the PBLSS examined issues of use with online tools for supporting problem-based learning. Their research indicated that, for technology to scaffold authentic inquiry in school, the tool must align with the teacher's assessment needs work as well as the students' needs in their inquiry process. Kynigos and colleagues (2001) explored how elementary-aged Greek students used CSCL. In their study, students in two classrooms were to work together via email to plan a trip to each other's location. Their findings indicated that collaborating this way promoted greater student attention to written communication; students learned that they could not make basic assumptions in their communications. They also found that the students, perhaps because of the teacher, often focused on school questions rather than personal questions. As a result the students learned about each other's locations, little was learned about the other students and their cultures. Finally, the authors described a "question and answer game" that emerged. This was a pattern of communication where students answered incoming questions and asked new questions. Typically, students did not offer alternatives to the questions asked. For example, one of the classes asked the other about routes to travel to visit their city. The queried students immediately identified that there was another possible route, but chose not to share that information because they had not been asked about it. In another example of the question and answer game, the students were encouraged by their teacher to generate new questions if they received a response that did not include questions. This indicated that the teachers' roles in the communication impacted the students' experiences. Clearly, these studies offered advice about what it means for CSCL to work and under what conditions it may work.

Another group of CSCL application questions focus on the ways in which participants use the tools to communicate. In one study of collocated CSCL learning, Lipponen, Rahikainen, Lallimo, and Hakkarainen (2001), analyzed the patterns and quality of participation among 12- to 13-year-old Finnish students as they worked individually or in a dyad or triad to complete a unit on human senses. Lipponen et al. found that 39 percent of the class participated in the online tool and posted between 7 and 39 notes (mean = 16, s.d. 8.02). They found that the thread size—that is, the number of messages posted in a continuous thread—ranged from 2 to 11 notes (mean = 3.4, s.d. 2.13). They differentiated among central participants and isolated participants by analyzing the number of responses to postings. Of the on-topic postings (63 percent overall), they found that 75 percent provided information and 25 percent asked for clarification. Overall, even younger students could benefit from online communications. Overall, these findings suggested that students can and will use CSCL to share relevant information—particularly to share information with one another.

In a study of the ways students use CSCL tools, education graduate students used an online tool to support distributed problem-based learning (Orrill, 2002). The research showed that students used rationales only 34 and 41 percent of the time even though rationales should provide the basis for agreeing on a problem definition and a plan of action. Perhaps related, the same students were often reluctant to take a stance most of the time, preferring to label messages in neutral ways almost 52 percent of the time. While the students were able to apply labels to their messages, more than one-third of the time, the label was not used in an anticipated way (e.g., "Summary" was used to label a question), but that socially negotiated meanings for the labels emerged. This was complicated by the presence of multiple ideas in each message. Orrill also detected two ways that students used the collaborative space. Some groups used it to engage in problem definition discussions focused on the issues, while others used the space to coordinate effort and tasks. The findings from this research indicate that students can use distributed, online tools to identify problems and plan for their solution, but that the depth and meaningful nature of the conversation is tentative.

Interestingly, Jonassen and Kwon (2001) considered some similar aspects of adult student problem solving using four conditions: online or face-to-face as well as ill-structured or well-structured. In their analyses, the instance of off-task messages was lower for online groups than face-to-face. This suggests that perhaps Lipponen et al.'s (2001) students would have been more off-task if they had worked face-to-face rather than online. Like Orrill, Jonassen and Kwon (2001) found a high degree of "simple agreement" postings in their computer-based groups, that is, postings that simple state a position ("I agree") with no further elaboration or moving forward of the conversation. Here, findings indicated that adult learners may be more focused using CSCL than in a face-to-face group, though the interaction dynamics are quite different.

In a study of how and whether CSCL supports a particular goal, problem solving, Hurme and Järvelä (2001) considered emergent metacognitive processes in the CSCL environment as students construct solutions for math problems. Finnish students, ages 12 and 13 years varied in their use of the CSCL space to work based on the task they were given but very little metacognition was present in their work regardless of the situation. Only the highest-level group in the class was able to use the discussion features for this project; the remaining students posted only their final plan. Consistent with the findings presented above, factors not yet identified seem to impact student success in the use of these tools for higher-level thinking. This collection of application research studies provides insight into the body of CSCL literature examining how students actually use CSCL software in a variety of classroom settings.

Another branch of CSCL research focuses on effectiveness studies. In application research, effectiveness refers to the degree to which an approach meets the needs of the local learners. In short, this research considers whether an innovation is practical and worthwhile. Goldman (1992) considered whether online learning was practical and worthwhile. She found that, as a result of CSCL tool use, student discourse was often rich, involving a variety of materials, resources, and methods. The findings indicated that the environment supported student exploration, investigation, and communication, where the "social glue" served as a mechanism for promoting deeper understanding. This study indicated that the social element appeared to be an important factor in student performance.

Similarly, in a study concerned with implementation of a CSCL software package to support writing skills, Neuwirth and Wojahn (1996) described the importance of instructor–student discourse when using a CSCL writing software to improve writing and reduce frustration. The inquiry centered on the effectiveness of the system for supporting student writing skills. Then software not only allowed many iterations of feedback, but also supported instructor coaching of peer reviews and supported students' articulation of knowledge about revisions. Students and teacher were able to track editorial changes and use their comments on the screen as a basis for communicating and reflecting on their ideas. Findings indicated that students liked using the tools, were able to see the editing process as one of two-way communication rather than one-way feedback, and were able to make meaningful improvements to their work. In short, the tools proved to be practical and effective for meeting a set of needs.

In a separate effectiveness study, Muukkonen, Lakkala, and Hakkarainen (2001) compared a computer-supported, shared journaling effort with maintaining a written journal. Effectiveness was determined by the extent to which students were engaged in the inquiry process. Students in the CSCL group were asked to post a message where it became public as part of a shared module. The journal group was asked to keep a journal in which they recorded working theories and had peers comment regularly on entries. The results indicated very different entries between the two groups. While both had more working theories than other kinds of note (Control 65.2%, online 40.4% ) and similar numbers of scientific explanation notes (11.5% in online group, 10.7% in control), the online group had far more quotes from others (10.3 vs. 3.8% in the control group), more meta-comments (16.8 vs. 9.0% in the control group), and more problem presentations (20.9 vs. 11.3% in the control group). The findings indicated that the journal group was more focused on explaining their own understanding whereas the online group had many interlinked ideas. In short, the online journal fostered a socially shared understanding of the content. In their results, the authors recommended the use of either tool, noting that both bring valuable benefits. These three studies offer insight into application research aimed at answering questions of effectiveness. That is, they all define what it means for the CSCL environment to be considered effective and how their environment did or did not meet those criteria in implementation.

### 13.2.3 Theory-Building Research

Theory-building research converges where application and foundation knowledge overlap—what Stokes labels as "use-inspired research." Like application researchers, theory builders attempt to address real-world issues; like foundation researchers, they develop fundamental understanding about learners and learning. Theory builders, such as researchers in the learning sciences, are primarily concerned with enacting theories so that hypotheses about learning and learning environments may be tested. However, this group is highly concerned with contexts and the interaction between tools and learning in complex settings such as real classrooms. In theory-building research, technology is viewed as a tool that can support, scaffold, capture, and promote student and teacher thinking, communication, and archival of ideas. The work of the theory builders has fostered long-term, iterative development efforts to better understand learning, teaching, and design.

TABLE 13.4. Common Characteristics of Theory-Building Research

Theory-Building research efforts:

- Feature a research and design process that is intertwined and iterative
- Embody one or more explicit theories about learning and aim to evolve those theories
- Aim to inform design, learning, and instructional theories
- Use a variety of research approaches including case studies and quasi-experimental designs
- Span considerable lengths of time
- Stay within their design group—the tools may be used by others, but the research agenda remains with the developers

As exemplified in significant R& D undertakings such as *The Adventures of Jasper Woodbury* (Jasper) and CSILE, theory builders have created a host of tools and complex systems to support learners in developing conjectures, testing hypotheses, critiquing ideas, and articulating understandings (Stahl, 1999) as they engage in learning activities. Collectively, these systems have become known as "knowledge building environments" (KBEs) and are typically technologically enhanced environments concerned with a specific facet of learning. KBEs are grounded in a particular theory or theories about learning and knowledge; research refines that theory and leads to other theories, such as theories about instruction and school change (See Table 13.4). [In addition to the examples discussed in this chapter, see research from the CoVis (Edelson, Gordin, & Pea, 1999; Edelson, Pea, & Gomez, 1995; O'Neill & Gomez, 1994) and Inquiry Learning Forum (Barab, MaKinster, & Sheckler, in press; Barab, MaKinster, Moore, Cunningham, & ILF Team, 2001) projects for other detailed examples of the theory-based development and research-centered evolution of KBEs.]

***13.2.3.1 Goals of the Research.*** Theory-building research has a variety of goals subsumed within a single research agenda. Whereas foundation and application research often focus on individual studies and attends to technology and/or human-technology interaction, theory-building efforts focus on extended, in-depth exploration centering on a single theory or hypothesis. Theory-building research focuses on innovations and design that embodies central theories about teaching and learning in authentic situations. Such theories may be broad, such as the theories underlying CSILE: (1) Learning should be intentional; (2) Expertise is a process, not just a performance; and (3) Intentional learning, necessary for building expertise, requires a reframing of schools into knowledge-building communities (Scardamalia & Bereiter, 1996). Similarly, the theories may be well-defined and easier to enact, such as those embodied in the KIE/WISE project: (1) choose topics and models that are accessible to students; (2) use visual representations and help make students' thinking visible; (3) students need opportunities to learn from each other; and (4) science instruction should promote the development of autonomous lifelong learning skills (Linn, 2000; Linn & Hsi, 2000). Regardless of the set of theories the researchers are interested in, the very existence of rich, interconnected ideas underlying a single intervention requires a different approach to research—one that simultaneously considers interrelationships among the parts of the underlying theory set, yet takes the necessary steps to understand the impact of the various facets of that set by themselves and in context.

Research goals, guided by the underlying theoretical biases, often focus on developing understandings of the learning, teaching, and designing processes. Consistent with application research, the goals of theory-building research center not only on the viability of the theories and processes in controlled settings, but extend to consider the viability and nuances of the theories and processes as they are enacted in the context for which they were intended. The fundamental difference between application research and theory building is the intent. Theory building is concerned with the enactment and refinement of generalizable theories while application research is concerned with considering effectiveness of single implementations of an innovation. Further, theory builders are concerned with the processes involved with the design and implementation of the innovation as well as the outcomes of that implementation. For example, in one report of Jasper, the authors cautioned, "It is emphasized that the research has not been done to 'prove that Jasper works.' Rather, it has been undertaken to understand the kinds of thinking and problem solving that students engage in when they tackle the Jasper challenges . . . " (CTGV, 1992b, p. 118).

***13.2.3.2 Questions Asked.*** Theory-building research looks both inward and outward simultaneously. That is, the research typically informs the design of interest, typically a KBE, itself while simultaneously evolving the community's understanding of generalizable issues related to theories of teaching and learning. For example, KIE research led to the development of several new tools as specific student needs have emerged from classroom-based experiments and case studies (Bell & Linn, 2000; Bell & Davis, 2000). *Sensemaker* was developed to help students organize arguments about science-related controversies, and to sort links to Web sites into categories of "Evidence" in support of their arguments. Simultaneously, these studies led to a fuller understanding about supporting students as they develop the processes and skills necessary to become lifelong science learners.

Findings from theory-building research efforts often spark new questions about the innovations as well as about the theories upon which innovations are built. In the case of Jasper Woodbury, for example, there were many evolving and new themes that emerged. In the assessment research effort, early implementation studies focused on classrooms already invested in the reform ideas championed by national mathematics organizations (e.g., Pellegrino, Hickey, Heath, Rewey, & Vye, 1992); however, later studies focused on schools that were not complying with recommended standards (Hickey, Moore, & Pellegrino, 2001). The research shifted to examine the implementation requirements in environments that were not philosophically or epistemologically aligned with problem-based approaches. Similarly, findings from the nine-state implementation effort for Jasper led to the development of new assessment tools and approaches including the evolutionary development of a "Challenge Series" which allowed students in one classroom to "compete" against students in other classrooms on extension questions related to the Jasper series (CTGV, in press). The evolution of the Challenge series led to simultaneous development of new research questions and development of new design ideas.

Because of the nature of design research, theory-building research efforts tend to evolve over time, and involve multiple collaborators including instructional designers, psychologists, teachers, and programmers. Research questions evolve to make them more responsive to the emerging realities of classroom use as they arise during iterations of research. The Jasper Project, for example, initially focused on several related issues: (1) changes in the students' abilities to solve complex problems over time; (2) effects of different approaches to using Jasper in classroom settings; (3) assessment of problem-solving ability and attitudes about mathematics; and (4) ways of supporting teachers as they implemented these new materials (Cognition and Technology Group at Vanderbilt, 1992a). Over time, however, the research shifted to examine the implementation requirements in environments that were not philosophically or epistemologically aligned with problem-based approaches. Similarly, research was broadened to develop an understanding not only of how learning and instruction principles influence learning in classrooms, but also to compare that to informal learning settings.

***13.2.3.3 Methodologies.*** Because theory-building research and design efforts are intertwined, research efforts are typically iterative, with successive efforts focusing on different aspects of learning, design, and educational change as they are embodied in the KBE of interest. Design experiments (Brown, 1992; Collins, 1992), formative research (Reigeluth & Frick, 1999), and development research (Reeves, 2000) are commonly employed in the theory-building research efforts. Design-based approaches utilize both traditional quantitative and qualitative research methodologies, often creating and testing new ways to analyze and collect data. The iterative nature allows questions of various scope and complexity to be studied; the findings of successive implementations form a rich base of information to refine theories about learning, design, and teacher change (Edelson, 2002). For example, in a theory-building research effort, an early implementation of a KBE may focus on its use in an after-school club to learn how students interact with a single facet of the KBE environment. Later studies in the research effort may include larger groups (such as whole classes or schools), more specific questions (e.g., "How does this tool support the development of problem-solving strategies?") or more general questions (e.g., "What kinds of changes occur in classrooms using this innovation?"). Hoadley (2002) outlines an evolution of research on one facet of WISE. He provides a roadmap of design decisions, iterations of research and design, research questions that emerged, and participant groups—starting from a pilot study that included graduate students and focused on proof-of-concept issues, through final iterations that considered how to support middle school students in reveling their identity in their postings. This was relevant because research efforts had uncovered a tendency for students to post anonymously in cases where others had done so.

***13.2.3.4 Audience.*** Because of the nature of theory-building research, the audiences for the work varies. The attention given to design processes and theory development in theory-building research informs communities of developers (e.g., software designers, programmers, instructional writers) as well as theorists (e.g., psychologists and sociologists). The focus on innovations in use, on the other hand, appeals to decision makers, teachers, and other practitioners who are concerned with whether they should adopt a given innovation for their classroom.

***13.2.3.5 Examples of Theory-Building Research.*** CSILE/ Knowledge Forums The Computer-Supported Intentional Learning Environment (CSILE) is an online information organization and evolution system that supports student learning by capturing information, allowing users to organize it, and sharing the information among participants. CSILE, now known as Knowledge Forums (available at http://www.learn.motion.com/lim/kf/KF0.html), uses an interface that allows users to communicate about their own learning as well as to support others in learning-by-doing activities such as attaching notes to images, displaying notes in a threaded format, and creating "rise-above" notes that allow users to group ideas together (Hewitt, 2000).

Consistent with theory-building research, CSILE was initially developed to research and support students as they learned how to learn, set cognitive goals, and applied comprehension, self-monitoring, and knowledge organization strategies (Scardamalia et al., 1989). The design group held strong beliefs about learning as process rather than product which, in turn, influenced CSILE's affordances. (e.g., Bereiter, 1994; Bereiter, Scardamalia, Cassells, & Hewitt, 1997).

Consistent with design-based research, CSILE's creators employed iterative research cycles to stimulate the refinement of existing tools and the development of tools as student needs were clarified (Scardamalia & Bereiter, 1991). The initial research agenda centered on three main issues: supporting students engaged in intentional learning; transitioning from novice toward expertise; and fundamentally changing schools. The problems were contextualized in actual classrooms, but the researchers aimed to build a more generalizable theory as well: "Nobody wants to use technology to recreate education as it is, yet there is not much to distinguish what goes on in most computer-supported classrooms versus traditional classrooms" (Scardamalia & Bereiter, 1996, p. 249).

CSILE research has focused on learning, pedagogy, and design as well as refining the original theory upon which it was based. A series of case studies and experimental studies were undertaken in a variety of classrooms, from fifth grade through graduate school, and included students who were new to the environment as well as those who had used it for multiple projects. CSILE researchers have explored student goal-setting behaviors (Ng & Bereiter, 1991) as well as conversational interaction among students using CSILE (Cohen & Scardamalia, 1998).

Pedagogically, research has explored whether and how students learn using CSILE (e.g., Bereiter & Scardamalia, 1992; Hewitt & Scardamalia, 1998; Scardamalia & Bereiter, 1993). Research has yielded both generalizable strategies for supporting knowledge building and a range of use-inspired questions about CSILE in the classroom, such as providing multiple entry points to a conversation (e.g., allowing notes to be text-based, graphical, etc.), emphasizing the work of the community over the work of the individual, and encouraging students to participate by both adding notes and exploring the information already present.

CSILE's evolution has been tightly linked to ongoing research on learning and pedagogy, that is, design requirements evolved by watching students use the CSILE system. Design changes were examined to determine not only whether they improved learning, but also how they influenced the students' abilities to engage in intentional knowledge building. Hewitt's research (e.g., Hewitt, 1997, 2000; Hewitt & Scardamalia, 1998; Hewitt, Webb, & Rowley, 1994) has been particularly relevant to the design and development of communal knowledge systems. Hewitt examined the interaction between students and CSILE's affordances to better understand how information is organized, inter-connected, and reused in the service of learning. These efforts resulted in the development of new CSILE functionalities (e.g., an annotation tool) and guided the transition of CSILE to WebCSILE and ultimately Knowledge Forums.

*13.2.3.5.1 The Adventures of Jasper Woodbury.* Jasper is a videodisc-based mathematics curriculum that serves as an enactment of anchored instruction. Consistent with the design experiment approach, Jasper arose from an identified need in the schools, was based on a series of design principles, enacted and tested a learning theory, relied on and evolved because of partnerships with practitioners, and was studied through a series of experiments and case studies that, combined, offer a holistic image of the effectiveness of the tool, but separated represent a variety of grain sizes, questions, and approaches (e.g., CTGV, 1994, in press).

*13.2.3.5.2 The Adventures of Jasper Woodbury,* in its final form, includes 12 episodes that fall into four categories of mathematical activities: trip-planning, statistics and business plans, geometry, and algebra. Consistent with the Jasper design principles, the episodes are divided evenly among these categories (see Table 13.5 for a list of the Jasper Design Principles). Each episode is designed to present a problem to the students grounded in a real-world context. For example, in the "Journey to Cedar Creek" episode, the students watch as Jasper Woodbury purchases a boat, buys gas for the boat, gets it repaired, and spends time with a friend. They are provided with a variety of relevant and irrelevant data that would be common to someone actually in a boat on a lake or river. The students are asked at the end of the scenario what time Jasper must leave to get home before dark and whether he has enough fuel to make the trip. Each problem, as shown in this example, includes a number of subproblems that the students must complete in order to answer the episode problem.

Jasper was originally developed to address shortcomings in student problem-solving ability identified in previous research by members of the Jasper team. In work leading to Jasper, Bransford's group identified a need for meaningful contexts for mathematical problem solving (e.g., Bransford et al., 1988). Through a series of experiments using commercial videos (e.g., *Raiders of the Lost Ark* ), then low-fidelity prototypes, the research team was able to develop and refine a set of design principles as well as develop an understanding about the benefits of anchored instruction (CTGV, 1992b, in press).

In the first round of studies on Jasper, the goals of the research were focused on understanding whether Jasper was, indeed, addressing an actual need. To this end, the researchers presented the Cedar Creek episode to high-achieving sixth graders and college students, then asked a series of increasingly-prompting questions about the main problem and the subproblems ranging from Level 1 (What problems did he have to solve?) to Level 3 (What is the distance from the Marina to get home?) (Van Haneghan et al., 1992; CTGV, 1992b, in press). Findings showed that as the researchers asked more explicit questions, both college and middle schools students were more able to provide reasonable answers to the questions. However, at both college and middle school level, the students showed a very low ability to identify subproblems and solve them. Once this baseline data had been set, the researchers attempted to determine whether short-term instruction with Jasper would impact learning. To this end, both a field-test and a controlled study were undertaken to determine the effects of Jasper on student learning and attitude. Results from the field tests indicated that Jasper was liked by the teachers and students and that students were able to engage in the Jasper activities in a sustained way. Further, students reported that the problems were challenging, but not too hard and students, parents, and teachers reported instances of students thinking about the problems outside of math class. The controlled study posed questions about whether anchored instruction with Jasper would produce learning and transfer that was not experienced by students instructed in word-problem solving activities as instructed in a traditional curriculum. This study of fifth grade students found that, on posttests, both the Jasper and the control group were equally able to solve unrelated context problems. This was surprising given that the control group students had received more instruction related to this skill. Further, Jasper students showed significant gains in the ability to match pertinent information to problems that needed to be solved while the control group did not. Finally, Jasper students we more able than the control students to identify the main problem and subproblems in a similar Jasper activity both in prompted and unprompted cases. From this work, the researchers were able to determine a set of research issues that drove the next phases of development and research on Jasper. These included a need to work with a larger variety of students,

TABLE 13.5. Seven Design Principles Underlying *The Adventures of Jasper Woodbury*

| Design Principle | Hypothesized Benefits |
|---|---|
| Video-based | a) more motivating;<br>b) easy to search;<br>c) support complex cognition;<br>d) good for poor readers, yet can support reading. |
| Narrative with realistic problem (rather than a lecture on video) | a) makes situation easier to remember;<br>b) more engaging for students;<br>c) promotes student realization of relevance of mathematics and reasoning. |
| Generative (the story ends and students generate problems to be solved) | a) motivates students to determine ending;<br>b) teaches students to find and define problems to be solved;<br>c) provides enhanced opportunity for reasoning. |
| Embedded data design (all necessary data is included in the story) | a) permits reasoned decision making;<br>b) motivating to students to find the information in the episode;<br>c) all students have the same knowledge to work from;<br>d) clarifies that relevant data depends on specific goals. |
| Problem complexity (each problem is at least 14 steps) | a) promote persistence—overcome student tendency to try for a few minutes, then quit;<br>b) introduce students to levels of complexity seen in real, everyday problems;<br>c) help student learn to deal with complexity;<br>d) develop student confidence in abilities. |
| Pairs of related adventures (the Jasper adventures were originally all paired by key activities) | a) extra practice with core mathematical ideas;<br>b) helps students clarify what is or is not transferable;<br>c) illustrates analogical thinking. |
| Links across the curriculum | a) helps extend mathematical thinking to other areas;<br>b) encourages knowledge integration;<br>c) support information finding and publishing. |

*Note*. This table adapted from CTGV, 1992a.

to provide professional development to teachers, and to develop assessment tools.

The next generation of Jasper work focused on a nine-state implementation that involved over 1300 students, included a 2-week professional development component for teachers, and collected large amounts of Jasper and control data from a subset of the implementation sites (e.g., CTGV, 1992c,1994, in press). The research goals at this phase were to better understand student abilities to represent and solve complex problems; to determine the effects of different teaching approaches on the experiences with Jasper; to assess instructional outcomes on problem solving and student attitudes toward math; and to better understand how to support teachers as they learned the new materials (CTGV, 1992a). Research on these questions included qualitative, quasi-experimental, and anecdotal evidence. The findings indicated that in the development of complex problem solving skills Jasper students made significant gains in their abilities to generate subproblems and subgoals as well as to determine which subproblem a calculation belonged with while control group students did not. Jasper students also outperformed control group students on one-step, two-step, and multistep word problems. Changes in student attitudes toward mathematics and their perceived abilities during the implementation year were significantly higher in Jasper groups except on questions of the students' abilities. It should be noted that while Jasper students saw mathematics as being more relevant and felt more self-confidence, their overall ratings of these items were still not particularly high. Further measures of mathematical skills indicated that Jasper had a positive impact on basic concepts and skills in most classrooms. Further, findings indicated that Jasper had a small, but not significant, positive impact on student scores on standardized tests.

Jasper research on teacher professional development focused on the same nine-state implementation. Teachers attended a summer workshop as members of triads that included two teachers from each participating school and a corporate partner who would help support the teacher in the implementation of the series. The professional development focused on solving Jasper adventures, providing teachers with the opportunity to develop some basic computer skills, and the opportunity for teachers to learn some multimedia skills. The teachers rated the workshop very highly and felt confident in their abilities to implement Jasper. As the implementation occurred, the researchers determined, based on artifacts they were receiving, that the implementation was very different based on implementation site. Further, they found that teachers did little more than focus on the adventures—they did not use the multimedia materials. In the follow-up workshop, researchers learned that the teachers felt strongly that they needed more support in the initial implementation and that they saw the use of the multimedia elements as a new idea to implement in Year 2. Based on the findings from this effort, the Jasper team developed plans for ongoing professional development (CTGV, 1994, in press).

Finally, the assessment strand of the implementation research was concerned with not only finding ways to determine what kinds of learning was occurring, but to do so in ways that the students and teachers approved of. In the initial implementation, teachers reported significant negative reaction to the paper-and-pencil assessments developed by the Jasper team (CTGV, 1994, in press). In response to this negative attitude, the team developed a new approach to assessment called the "Jasper Challenge Series" which was like a call-in game show in which classrooms of students competed against each other. A succession of design experiments were undertaken to develop and refine the challenges beyond the initial implementation (e.g., CTGV, 1994).

Like all of the major research projects discussed in this theory-building research section, Jasper has proven a fertile ground for experimenting with new ideas, refining them, and understanding their impact on student thinking and mathematical ability. The research that has grown out of the Jasper effort has shown not only that Jasper might be construed as "effective" but also attempts to add to the dialogue about what "success" means, what it looks like when students learn, and how we can promote meaningful experiences. Even now, more than a decade after the initial premier of the Jasper series, we are seeing worthwhile studies of learning being published ranging from those considering the interplay of a number of variables on trying to understand Jasper's success (Hickey, Moore, & Pellegrin, 2001) and those concerned with what elements of cooperation impact the success of group problem solving (Barron, 2000). Also, consistent with good design research, Jasper simultaneously developed solutions and looked for problems, partnered with teachers, and focused on the theories and beliefs that the solutions were built on.

*13.2.3.5.2 Web-Based Inquiry Science Environment (WISE).* WISE (http://wise.berkeley.edu) is a 3rd generation technology built upon enabling projects: Computers as Learning Partners (CLP) (Linn & Hsi, 2000), which focused on knowledge integration and teaching as design, and the Knowledge Integration Environment (KIE) (Linn, Bell, & Hsi, 1998; Slotta & Linn, 2000), which focused on scaffolding knowledge integration with technology. WISE was designed to embody the principles of "scaffolded knowledge integration" (Linn & Hsi, 2000) by "engag(ing) students in sustained investigation, providing them with cognitive and procedural supports as they make use of the Internet in their science classroom" (Slotta & Linn, 2000, p. 193).

WISE research has focused simultaneously on questions of use and the development of fundamental understanding about learning. WISE researchers have studied and developed tools and supports to help students learn science, support online collaborative learning, make thinking visible, and search for information (Bell, 1996; Slotta & Linn, 2000). Recent work has focused on supporting teachers as they develop modules—from developing a partnership program to developing discipline-specific support tools within the system (Linn & Slotta, 2000; Linn, Clark, & Slotta, in press). As shown in Table 13.6, the research questions asked in a theory-building line of research require a variety of research methods be employed. In the case of WISE, these include methods commonly associated with the fundamental research group such as quasi-experimental, comparison designs (e.g., Clark & Slotta, 2000; Hoadley, 2000), as well as methods more common to application research such as analysis of longitudinal data collected through authentic use of the system (e.g., Bell & Davis, 2000).

Characteristic of theory-building research, the WISE effort has informed design, learning, and pedagogy. WISE technology and curriculum have evolved continuously through research resulting in easy-to-use software. WISE scientists, teachers, and educational researchers projects have developed a library of teaching and learning activities. As WISE matured from its earlier versions in KIE and CLP, researchers confronted new questions focusing on professional development, teacher practice, and curriculum and assessment. Over the past several years, thousands of teachers and tens of thousands of students have participated in WISE activities (Slotta, 2002). WISE research demonstrates the value of intertwining iterative tool development, curriculum design, and theory building and the importance of longitudinal approaches to theory-building research.

## 13.3 THE FUTURE OF RESEARCH AND EMERGING TECHNOLOGIES

This chapter has attempted to provide a representative rather than exhaustive review of contrasting, and in some cases complementary, community perspectives advanced by emerging technology researchers. It seems to us naï ve and perhaps impossible to examine research in terms of hardware per se—computers, video, CD-ROM, and the like. By design, we have avoided attempts to organize these trends in terms of technological "things." Rather, we focus our perspectives and analysis on the kinds of questions researchers from diverse epistemological backgrounds pose and address related to technology. Our matrix attempts to overlay a framework on emerging technology research to better understand the kinds of questions asked, the communities who ask them, and the underlying beliefs on which they are based. We build on the distinctions made by Stokes and others who describe research in terms of the underlying intent of the research community—whether concerned with solving real-world problems of use or developing fundamental building-block knowledge across settings.

Are there really "new" research questions, or are they variations of existing themes? To be certain, the questions posed and the methods employed vary as a function of the epistemological biases, contextual factors, social and community values and mores of the researchers. So, perhaps conventional wisdom—the problem and question drive the method—is oversimplified: The very same "things" are often examined in dramatically different ways—different questions, different theoretical frameworks, different methods and measures. It is the unique lens through which innovation is viewed that influences what is studied and how it is studied. To refine and understand one's lens is to define the researchers frame; to communicate this frame effectively is to reveal the basic foundations, assumptions and biases underlying a research study or program of research.

TABLE 13.6. Sample Questions and Findings from WISE Research

| Selected Research Questions | Design or Pedagogical Strategy from Research Findings | Selected Studies | Findings |
|---|---|---|---|
| *Make Science Accessible* | | | |
| How can we use Internet resources to make learning accessible? | Setting appropriate scope and goals | Slotta & Linn, 2000; Linn, 2000 | Advance guidance helps students use Internet materials effectively |
| How do we help students connect a variety of ideas | Build from current ideas, provide richer models | Linn, Bell, & Hsi, 1998; Clark & Linn, in press | Depth of coverage leads to more coherent understandings |
| *Make Thinking Visible* | | | |
| How do we support students in engaging in scientific learning process? | Development of activity checklist—leads to integrated learning rather than memorizing | Linn, Shear, Bell & Slotta, 1999 | Controversy-based curriculum can introduce ideas about the nature of science |
| How do we support students in modeling expert thinking? | Ways to use advance organizers with student arguments | Bell & Linn, 2000 | Technology scaffolds can enable richer arguments |
| How can we support students in engaging in knowledge integration through debate? | Development and refinement of SenseMaker argumentation tool | Bell & Linn, 2000; Bell & Davis, 2000 | Design of debate activities includes use of evidence, critique of peers, revision of arguments |
| *Help Students Learn from Each Other* | | | |
| How do we engage all students in meaningful conversation | Development and refinement of SpeakEasy online discussion tool | Hoadley, 2000; Hsi & Hoadley, 1997 | Student participation increases dramatically in online forums |
| How can students learn from debate? | Research use of online discussions in inquiry projects | Hsi, 1997; Hoadley & Linn, 2000 | Social representations add value to discussions Careful design is required to integrate online discussions with curriculum |
| *Promote Lifelong Science Learning/Promoting Autonomy* | | | |
| How do we help students become lifelong science learners? | Development of principles for supporting student knowledge integration | Linn & Hsi, 2000; Clark & Slotta (2000) | Articulated a set of design principles for knowledge integration activities |
| How do we support students in conducting their own knowledge integration? | | Linn & Clancy, 1992; Linn and Hsi, 2000; Slotta and Linn, 2000 | A case study approach benefits students. Explored the use of personally relevant topics |
| How do we support students in integrating knowledge through reflection? | Development of Mildred—an online scaffolding & reflection system | Davis & Linn, 2000; Bell, & Davis, 2000; Davis, 2000 | Explored the nature of effective prompts |
| How does perceived credibility impact student use of evidence? | Development of principles for selecting media to support all learners | Clark & Slotta, 2000; Slotta & Linn, 2000 | Manipulated evidence credibility in studies of student argumentation Showed that critiquing skills can be promoted by advance guidance |

## References

Abnett, C., Stanton, D., Neale, H., & O'Malley, C. (2001). *The effect of multiple input devices on collaboration and gender issues.* Paper presented at EuroCSCL 2001: Maastricht, Netherlands. Available online http://www.mmi.unimaas.nl/euro-cscl/presentations.htm [2002, November 4].

Antonietti, A., Imperio, E., Rasi, C., & Sacco, M. (2001). Virtual reality and hypermedia in learning to use a turning lathe. *Journal of Computer Assisted Learning, 17*, 142–155.

Atkinson, S. (2000). An investigation into the relationship between teacher motivation and pupil motivation. *Educational Psychology, 20*(1), 45–57.

Barab, S., MaKinster, J., & Sheckler, R. (in press). Designing system dualities: Building online community. In S. A. Barab, R. Kling, & J. Gray (Eds.), *Designing for virtual communities in the service of learning*. Cambridge, MA: Cambridge University Press.

Barab, S. A., MaKinster, J. G., Moore, J. A., Cunningham, D. J., & The ILF Design Team (2001). Designing and building an on-line community: The struggle to support sociability in the Inquiry Learning

Forum. *Educational Technology Research & Development, 49*(4), 71–96.

Barron, B. (2000). Achieving coordination in collaborative problem solving groups. *The Journal of the Learning Sciences, 9*(4), 403–436.

Bastiaens, T. J. (1999). Assessing an electronic performance support system for the analysis of jobs and tasks. *International Journal of Training and Development, 3*(1), 54–61.

Bell, P., (1996). *Designing an activity in the Knowledge Integration Environment.* Paper presented at the Annual Meeting of the American Educational Research Association: New York.

Bell, P., & Davis, E. A. (2000). Designing Mildred: Scaffolding students' reflection and argumentation using a cognitive software guide. In B. Fishman & S. O'Connor-Divelbliss (Eds.), *Fourth International Conference of the Learning Sciences* (pp. 142–149). Mahwah, NJ: Erlbaum.

Bell, P. & Linn, M. C. (2000). Scientific arguments as learning artifacts: Designing for learning from the web with KIE. *International Journal of Science Education, 22*(8), 797–817.

Bereiter, C. (1994). Implications of postmodernism for science, or, science as progressive discourse. *Educational Psychologist, 29*(1), 3–12.

Bereiter, C., & Scardamalia, M. (1992). Two models of classroom learning using a communal database. In S. Dijkstra (Ed.), *Instructional models in computer-based learning environments*. Berlin: Springer-Verlag.

Bereiter, C., Scardamalia, M., Cassells, C., & Hewitt, J. (1997). Postmodernism, knowledge building, and elementary science. *The Elementary School Journal, 97*(4), 329–340.

Bork, A. (1986). Let's test the power of interactive technology. *Educational Leadership, 43*(6), 36–37.

Bowler, L., Large, A., & Rejskind, G. (2001). Primary school students, information literacy, and the web. *Education for Information, 19*, 201–223.

Bransford, J., Hasselbring, T., Barron, B., Kulewicz, S., Littlefield, J., & Goin, L. (1988). Uses of macro-contexts to facilitate mathematical thinking. In R. I. Charles & E. A. Silver (Eds.), *The teaching and assessing of mathematical problem solving* (pp. 125–147). Hillsdale, NJ: Erlbaum & National Council of Teachers of Mathematics.

Bricken, M., & Byrne, C. (1992). Summer students in virtual reality: A pilot study on educational applications of virtual reality technology. In A. Wexelblat (Ed.), *Virtual reality applications and explorations*. Cambridge, MA: Academic Press Professional.

Brown, A. L. (1992). Design experiments: Theoretical and methodological challenges in creating complex interventions in classroom settings. *Journal of the Learning Sciences, 2*(2), 141–178.

Bruckman, A., & De Bonte, A. (1997). *MOOSE goes to school: A comparison of three classrooms using a CSCL environment.* Paper presented at Computer Support for Collaborative Learning: Toronto. Available online: http://www.oise.utoronto.ca/cscl/papers/bruckman.pdf [2002, November 4].

Byrne, C., Holland, C., Moffit, D., Hodas, S., & Furness, T. A. (1994). *Virtual reality and "at risk" students* (R-94-5). Seattle: University of Washington.

Chang, K. E., Sung, Y. T., & Chen, S. F. (2001). Learning through computer-based concept mapping with scaffolding aid. *Journal of Computer Assisted Learning, 17*, 21–33.

Clark, D., & Linn, M. C. (in press). Scaffolding knowledge integration through curricular depth. *The Journal of Learning Sciences*.

Clark, D. B., & Slotta, J. D. (2000). Evaluating media-enhancement and source authority on the internet: The Knowledge Integration Environment. *International Journal of Science Education, 22*(8), 859–871.

Cognition and Technology Group at Vanderbilt (CTVG) (1992a). The Jasper experiment: An exploration of issues in learning and instructional design. *Educational Technology Research & Development, 40*(1), 65–80.

Cognition and Technology Group at Vanderbilt (CTVG) (1992b). The Jasper Series. A generative approach to improving mathematical thinking. In K. Sheingold, L. G. Roberts, & S. M. Malcolm (Eds.), *This year in school science1991: Technology for learning and teaching*. Washington, DC: American Association for the Advancement of Science.

Cognition and Technology Group at Vanderbilt (CTVG) (1992c). The Jasper Series as an example of anchored instruction: Theory, program description, and assessment data. *Educational Psychologist, 27*(3), 291–315.

Cognition and Technology Group at Vanderbilt (CTVG) (1994). From visual word problems to learning communities: Changing conceptions of cognitive research. In K. McGilly (Ed*.), Classroom lessons: Integrating cognitive theory and classroom practice*. Cambridge, MA: MIT Press/Bradford Books.

Cognition and Technology Group at Vanderbilt (CTVG) (in press). The Jasper series: A design experiment in complex mathematical problem solving. In J. Hawkins & A. Collins (Eds.), *Design experiments: Integrating technologies into schools*. New York: Cambridge University Press.

Cohen, A., & Scardamalia, M. (1998). Discourse about ideas: Monitoring and regulation in face-to-face and computer-mediated environments. *Interactive Learning Environments, 6*(1–2), 93–113.

Collins, A. (1992). Toward a Design Science of Education. In E. Scanlon & T. O'Shea (Eds.), *New Directions in Educational Technology*. Berlin/New York: Springer-Verlag.

Cypher, A. (1995). Eager: Programming repetitive tasks by example. In R. M. Baecker, J. Grudin, W. A. S. Buxton, & S. Greenberg (Eds.), *Readings in human-computer interaction: Toward the year 2000*, 2nd ed. (pp. 804–810). San Francisco: Morgan Kaufman Publishers, Inc.

Davis, E. A., & Linn, M. C. (2000). Scaffolding students' knowledge integration: Prompts for reflection in KIE. *International Journal of Science Education, 22*(8), 819–837.

De Jong, T., & van Jooligen, W. R. (1998). Scientific discovery learning with computer simulations of conceptual domains. *Review of Educational Research, 68* (2), 179–201.

Dede, C., Salzman, M., Loftin, R. B., & Ash, K. (2000). The design of immersive virtual learning environments: Fostering deep understandings of complex scientific knowledge. In M. J. Jacobson & R. B. Kozma (Eds.), *Innovations in science and mathematics education: Advanced designs for technologies of learning* (pp. 361–414). Mahwah, NJ: Lawrence Erlbaum Associates.

Dede, C., Salzman, M. C., & Loftin, R. B. (1996). *ScienceSpace: Virtual realities for learning complex and abstract scientific concepts.* Paper presented at the IEEE Virtual Reality Annual International Symposium, New York.

Dimitrof, A., Wolfram, D., & Volz (1995). Affective response and retrieval performance: Analysis of contributing factors. *Library and Information Science Research, 18*, 121–132.

Edelson, D. C. (2002). Design research: What we learn when we engage in design. *The Journal of the Learning Sciences, 11*(1), 105–121.

Edelson, D. C., Gordin, D. N., & Pea, R. D. (1999). Addressing the challenges of inquiry-based learning through technology and curriculum design. *The Journal of the Learning Sciences, 8*(3 & 4), 391–450.

Edelson, D. C., Pea, R. D., & Gomez, L. M. (1995). Constructivism in the collaboratory. In B. G. Wilson (Ed.), *Constructivist Learning Environments: Case Studies in Instructional Design* (pp. 151–164). Englewood Cliffs, NJ: Educational Technology Publications.

Egan, D. E., Remde, J. R., Landauer, T. K., Lochbaum, C. C., & Gomez, L. M. (1995). Behavioral evaluation and analysis of a hypertext browser. In R. M. Baecker, J. Grudin, W. A. S. Buxton, & S. Greenberg (Eds.), *Readings in human-computer interaction: Toward the year 2000*, 2nd ed. (pp. 843–848). San Francisco: Morgan Kaufman Publishers, Inc.

Gerlic, I., & Jausovec, N. (1999). Multimedia: Differences in cognitive processes observed with EEG. *Educational Technology Research & Development, 47*(3), 5–14.

Goldman, S. V. (1992). Mediating microworlds: Collaboration on high school science activities. In T. Koschmann (Ed.), *CSCL: Theory and practice of an emerging paradigm* (pp. 45–82). Mahwah, NJ: Lawrence Erlbaum Associates.

Goldman, S. V. (1996). Mediating microworlds: Collaboration on high school science activities. In T. Koschmann (Ed.), *CSCL: Theory and Practice* (pp. 45–82). Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Hakkarainen, K., Lipponen, L., Jarvela, S., & Niemivirta, M. (1999). The interaction of motivational orientation and knowledge-seeking inquiry in computer-supported collaborative learning. *Journal of Educational Computing Research, 21*(3), 263–281.

Hannafin, M. J., Hannafin, K. M., Land, S., & Oliver, K. (1997). Grounded practice and the design of constructivist learning environments. *Educational Technology Research and Development, 45*(3), 101–117.

Hara, N., & Kling, R. (1999). Students' frustrations with a web-based distance education course. *First Monday, 4*(12). Available online: http://firstmonday.org/issues/issue4_12/hara/index.html [2002, November 4].

Hawkins, C. H., Gustafson, K. L., & Neilsen, T. (1998). Return on investment (ROI) for electronic performance support systems: A Web-based system. *Educational Technology, 38*(4), 15–21.

Hewitt, J. (1997). *Beyond threaded discourse.* Paper presented at the WebNet '97, Toronto.

Hewitt, J. (2000, April). *Sustaining interaction in a Knowledge Forum classroom.* Paper presented at the American Educational Research Association, New Orleans.

Hewitt, J., & Scardamalia, M. (1998). Design principles for distributed knowledge building processes. *Educational Psychology Review, 10* (1), 75–96.

Hewitt, J., Webb, J., & Rowley, P. (1994, April). *Student use of branching in a computer-supported discussion environment.* Paper presented at the American Educational Research Association, New Orleans.

Hickey, D. T., Moore, A. L., & Pellegrino, J. W. (2001). The motivational and academic consequences of elementary mathematics environments: Do constructivist innovations and reforms make a difference? *American Educational Research Journal, 38*(3), 611–652.

HITL (1995). *The US West Virtual Reality Roving Vehicle program*. HITL. Available: http://www.hitl.washington.edu/projects/education/vrrv/vrrv-3.95.html [2002, June 1].

Hmelo, C. E., Nagarajan, A., & Day, R. S. (2000). Effects of high and low prior knowledge on construction of a joint problem space. *Journal of Experimental Education, 69*(1), 36–56.

Hoadley, C. M. (2000). Teaching science through online, peer discussions: SpeakEasy in the Knowledge Integration Environment. *International Journal of Science Education, 22(* 8), 839–857.

Hoadley, C. M. (2002). Creating context: Design-based research in creating and understanding CSCL. In *Proceedings of CSCL 2002*. Boulder, CO. January, 2002.

Hoadley, C. M., & Linn, M. C. (2000). Teaching science through online peer discussions: SpeakEasy in the Knowledge Integration Environment. *International Journal of Science Education*, Special Issue(22), 839–857.

Hsi, S. (1997). *Facilitating knowledge integration in science through electronic discussion: The Multimedia Forum Kiosk.* Unpublished doctoral dissertation, University of California, Berkeley, CA.

Hsi, S., & Hoadley, C. M. (1997). Productive discussions in science: Gender equity through electronic discourse. *Journal of Science Education and Technology, 6*, 23–36.

Hurme, T., & Järvelä, S. (2001). *Metacognitive processes in problem solving with CSCL in math.* Paper presented at Euro CSCL 2001. Maastricht, Netherlands. Available: http://www.mmi.unimaas.nl/euro-cscl/presentations.htm.

Jonassen, D. H., & Kwon, H. I. (2001). Communication patterns in computer-mediated versus face-to-face group problem solving. *Educational Technology Research and Development, 49*(1), 35–51.

Keltner, B., & Ross, R. L. (1995). *The cost of school-based educational technology programs*. RAND Corporation. Arlington, VA. Available: http://www.rand.org/publications/MR/MR634/. [2002, November 5].

Kynigos, C., Evangelia, V., & Trouki, E. (2001). *Communication norms challenged in a joint project between two classrooms.* Paper presented at Euro CSCL 2001. Maastricht, Netherlands. Available: http://www.mmi.unimaas.nl/euro-cscl/presentations.htm.

Laffey, J., Tupper, T., Musser, D., & Wedman, J. (1998). A computer-mediated support system for project-based learning. *Educational Technology Research & Development, 46*(1), 73–86.

Large, A., Beheshti, J., & Breuleux, A. (1998). Information seeking in a multimedia environment by primary school students. *Library & Information Science Research, 20*(4), 343–376.

Levin, H., & Meister, G. (1986). Is CAI cost-effective? *Phi Delta Kappan, 67*, 745–749.

Linn, M. C. (2000). Designing the Knowledge Integration Environment. *International Journal of Science Education, 22*(8), 781–796.

Linn, M. C., Bell, P., & Hsi, S. (1998). Using the Internet to enhance student understanding of science: The Knowledge Integration Environment. *Interactive Learning Environments, 6*(1–2), 4–38.

Linn, M. C., & Clancy, M. J. (1992). The case for case studies of programming problems. *Communications of the ACM, 35*(3), 121–132.

Linn, M. C., Clark, D., & Slotta, J. D. (in press). WISE design for knowledge integration. In S. Barab & A. Luehmann (Eds.), *Building sustainable science curriculum: Acknowledging and accommodating local adaptation, Science Education*.

Linn, M. C., & Hsi, S. (2000). *Computers, teachers, peers: Science learning partners*. Mahwah, NJ: Lawrence Erlbaum Associates.

Linn, M. C., Shear, L., Bell, P., & Slotta, J. D. (1999). Organizing principles for science education partnerships: Case studies of students' learning about 'rats in space' and 'deformed frogs'. *Educational Technology Research and Development, 47*(2), 61–85.

Linn, M. C., & Slotta, J. D. (2000). WISE science. *Educational Leadership, 58*(2), 29–32.

Lipponen, L., Rahikainen, M., Lallima, J., & Hakkarainen, K. (2001). *Analyzing patterns of participation and discourse in elementary students' online science discussion.* Paper presented at Euro CSCL 2001. Maastricht, Netherlands. Available: http://www.mmi.unimaas.nl/euro-cscl/presentations.htm.

Lou, Y., Abrami, P. C., & d'Apollonia, S. (2001). Small group and individual learning with technology: A meta-analysis. *Review of Educational Research, 71*(3), 449–521.

Marchionini, G. (1989). Information-seeking strategies of novices using a full-text electronic encyclopedia. *Journal of the American Society for Information Science, 40*(1), 54–66.

Mazlita, M. H., & Levene, M. (2001). Can navigational assistance improve search experience? *First Monday, 6*(9), online: http://firstmonday.org/issues/issue6_9/mat/index.html

McKnight, C., Dillon, A., & Richardson, J. (1996). User-centered design of hypertext/hypermedia for education. In D. H. Jonassen (Ed.), *Handbook of research for educational communications and technology* (pp. 622–633). New York: Simon & Schuster Macmillan.

Moore, J. L., & Orey, M. (2001). The implementation of an electronic performance support system for teachers: An examination of usage, performance, and attitudes. *Performance Improvement Quarterly, 14*(1), 26–56.

Muukkonen, H., Lakkala, M., & Hakkarainen, K. (2001). *Characteristics of university students' inquiry in individual and computer-supported collaborative study process.* Paper presented at Euro CSCL 2001. Maastricht, Netherlands. Available: http://www.mmi.unimaas.nl/euro-cscl/presentations.htm.

Neuwirth, C. M., & Wojahn. P. G. (1996). Learning to write: Computer support for a cooperative process. In T. Koschmann (Ed.), *CSCL: Theory and Practice* (pp. 45–82). Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Ng, E., & Bereiter, C. (1991). Three levels of goal orientation in learning. *The Journal of the Learning Sciences, 1*(3), 243–271.

Niemeier, R., Blackwell, M., & Walberg, H. (1986). CAI can be doubly effective. *Phi Delta Kappan, 67*, 750–751.

Niemiec, R. (1989). Comparing the cost-effectiveness of tutoring and computer-based instruction. *Journal of Educational Computing Research, 5,* 395–407.

O'Neill, D. K., & Gomez, L. M. (1994). *The collaboratory notebook: A networked knowledge-building environment for project learning.* Paper presented at the Ed-Media, Vancouver, B. C.

Orrill, C. H. (2002). Supporting online PBL: Design considerations for supporting distributed problem solving. *Distance Education, 23*(1), 41–57.

Pellegrino, J. W., Hickey, D., Heath, A., Rewey, K., & Vye, N. (1992). *Assessing the outcomes of an innovative instructional program: The 1990–1991 implementation of "The Adventures of Jasper Woodbury Program"* (Tech. Rep. No 91–1). Nashville: Vanderbilt University, Learning & Technology Center.

Reeves, T. C. (2000). Socially responsible educational technology research. *Educational Technology, 40*(6), 19–28.

Reigeluth, C. M., & Frick, T. W. (1999). Formative research: A methodology for creating and improving design theories. In C. M. Reigeluth (Ed.), *Instructional-design theories and models: A new paradigm of instructional theory* (Vol. II, pp. 633–651). Mahwah, NJ: Lawrence Erlbaum Associates, Publishers.

Salzman, M., Dede, C., Loftin, R. B., & Ash, K. (1998). *Using VR's frames of reference in mastering abstract information.* Paper presented at the Third International Conference of the Learning Sciences, Atlanta.

Saye, J. W., & Brush, T. (2002). Scaffolding critical reasoning about history and social issues in multimedia supported environments. *Educational Technology Research and Development, 60*(3), 77–96.

Scardamalia, M., & Bereiter, C. (1991). Higher levels of agency for children in knowledge building: A challenge for the design of new knowledge media. *The Journal of the Learning Sciences, 1*(1), 37–68.

Scardamalia, M., & Bereiter, C. (1993). Technologies for knowledge-building discourse. *Communications of the ACM, 36*(5), 37–41.

Scardamalia, M., & Bereiter, C. (1996). Computer support for knowledge-building communities. In T. Koschmann (Ed.), *CSCL: Theory and practice of an emerging paradigm* (pp. 249–268). Mahwah, NJ: Lawrence Erlbaum Associates.

Scardamalia, M., Bereiter, C., McLean, R. S., Swallow, J., & Woodruff, E. (1989). Computer-supported intentional learning environments. *Journal of Educational Computing Research, 5*(1), 51–68.

Schacter, J. (1999). *The impact of education technology on student achievement: What the most current research has to say*. Santa Monica, CA: Milken Exchange on Education Technology: Available: http://www.mff.org/publications/publications.taf?page=161 [2002, November 5]

Selman, R. L. (1980). *The growth of interpersonal understanding*. New York: Academic Press.

Shapiro, A. M. (1999). The relevance of hierarchies to learning biology from hypertext. *The Journal of the Learning Sciences, 8*(2), 215–243.

Slotta, J. D. (2002). Designing the Web-based Inquiry Science Environment. In S. Hooper (Ed). *Educational technology, 42*(5), 5–28.

Slotta, J. D., & Linn, M. C. (2000). The Knowledge Integration Environment: Helping students use the internet effectively. In M. J. Jacobson & R. B. Kozma (Eds.), *Innovations in science and mathematics education: Advanced designs for technologies of learning* (pp. 193–226). Mahwah, NJ: Lawrence Erlbaum Associates.

Stahl, G. (1999). *Reflections on WebGuide: Seven issues for the next generation of collaborative knowledge-building environments.* Paper presented at the CSCL, Stanford.

Stokes, D. E. (1997). *Pasteur's Quadrant: Basic science and technological innovation*. Washington DC: Brookings Institution Press.

Stuhlmann, J. M., & Taylor, H. G. (1999). Preparing technologically competent student teachers: A three-year study of interventions and experiences. *Journal of Technology and Teacher Education, 7*(4), 333–350.

Tewissen, F., Lingnau, A., Hoppe, U., Mannhaupt, G., & Nischk, D. (2001). *Collaborative writing in a computer-integrated classroom for early learning.* Paper presented at EuroCSCL 2001: Maastricht, Netherlands. Available online: http://www.mmi.unimaas.nl/euro-cscl/Papers/161.pdf [2002, November 4].

Thompson, A. D., Simonson, M. R., & Hargrave, C. P. (1996). *Educational technology: A review of the research* (2nd ed.). Washington, DC: Association for Educational Communications and Technology.

Trafton, J. G., & Trickett, S. B. (2001). Note-taking for self-explanation and problem solving. *Human-Computer Interaction, 16*(1), 1–38.

Van Der Linden, D., Sonnentag, S., Frese, M., & Van Dyck, C. (2001). Exploration strategies, performance, and error consequences when learning a complex computer task. *Behavior & Information Technology, 20*(3), 189–198.

Van Haneghan, J. P., Barron, L., Young, M., Williams, S., Vye, N., & Bransford, J. (1992). The Jasper series: An experiment with new ways to enhance mathematical thinking. In D. F. Halpern (Ed.), *Enhancing thinking skills in the sciences and mathematics* (pp. 15–38). Hillsdale, NJ: Lawrence Erlabum Associates, Inc.

Wenglinsky, H. (1998). *Does it computer: The relationship between educational technology and student achievement in mathematics* . Princeton, NJ: Educational Testing Service.

Winn, W. D. (1995). The Virtual Reality Roving Vehicle project. *Technological Horizons in Education, 23*(5), 70–74.

Winn, W., Hoffman, H., Hollander, A., Osberg, K., Rose, H., & Char, P. (1997). *The effect of student construction of virtual environments on the performance of high- and low-ability students.* Paper presented at the Annual meeting of the American Educational Research Association, Chicago.