THE JOURNAL OF THE LEARNING SCIENCES, *13*(1), 43–76

Creating a Framework for Research on Systemic Technology Innovations

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This article examines why cognitively oriented technology innovations, designed to foster deep thinking and learning, have not become widespread in K–12 schools. We argue a key reason is that most design-based research does not explicitly address systemic issues of usability, scalability and sustainability. This limitation must be overcome if research is to create usable knowledge that addresses the challenges confronting technology innovations when implemented in real-world school contexts. This is especially important in an era when political forces push schools away from the cognitively rich, inquiry-oriented approaches espoused by the Learning Sciences. We suggest expanding our conception of design-based research to include research on innovations in the context of systemic reform as a potential solution to the problem. To that end, we introduce research questions and issues arising from our own experiences with a technology-rich innovation in the context of a systemic reform initiative as a starting point in the creation of an expanded design-based research agenda. These questions and issues have important implications for both the continued viability of research on technologies for learning and on the future of technology use in schools that stems from such research.

Over the past decade, the Learning Sciences have built on knowledge of how people learn (Bransford, Brown, & Cocking, 1999) and made major investments in the design and development of learning environments that employ technology to foster

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thinking and understanding with demonstrated positive effects on learning (Roschelle, Pea, Hoadley, Gordin, & Means, 2000). Despite the fact that technology is now considered commonplace in K–12 education (Becker, 1999), most innovations derived from Learning Sciences research, which we refer to as cognitively oriented technology innovations, have not found their way into widespread classroom use. Instead, for a variety of reasons including teacher capabilities (CEO Forum on Education and Technology, 1999), technology infrastructure (Carvin, 2000), school culture (Cuban, 1986) and organizational constraints (Cohen, 1988), the primary uses of technology in schools remain drill and practice, word processing, and web surfing (R. E. Anderson & Ronnkvist, 1999). These uses of technology may be important initial steps for schools, but they fall short of the tremendous potential of technology to support the rich, inquiry-oriented learning called for in national standards documents (e.g., American Association for the Advancement of Science, 1993), and embodied in Learning Sciences research (Bransford et al., 1999).

Appropriately, the public demands a great deal from its education investment. Technology is an expensive and therefore popular target for criticism, particularly because demonstrating widespread benefits from its use in schools is a challenging problem for research (Means, Wagner, Haertel, & Javitz, 2000). Researchers have long understood that for technology to contribute to learning requires much more than simply installing it in schools. As one research group puts it, in order to be effective, "technology needs to be part of a coordinated approach to improving curriculum, pedagogy, assessment, teacher development, and other aspects of school structure" (Roschelle et al., 2000, p. 78). In other words, the most effective uses of technology are interwoven with the challenges and problems of school reform itself. However, much of the design-based research that is targeted toward the development of cognitively oriented technological innovations has focused on classroom-level or multi-classroom testbed implementations (Gomez, Fishman, & Pea, 1998) and not the larger contexts in which innovations are, or are not, actualized when used across entire school systems.

This article explores the question of why there is not more widespread use of technologies to foster deep learning aligned with national standards, and how we, as a research community, can learn more about how to foster, sustain, and scale these uses of technology. In particular, we explore the use of cognitively oriented technologies within systemic reform contexts, using our own experiences to frame new research questions and issues for exploration that shed light on the problems of creating scaleable, sustainable, and usable technology innovations. Additionally, we shed light on interrelating system variables that should be considered when conducting design-based research.

Why are cognitively oriented technology innovations not widely used in schools? Why aren't they scaleable or sustainable? We believe an underlying explanation to be that we, as a scholarly community, have not focused our research on the development and use of cognitively oriented technologies in a way that addresses the fundamental needs of school *systems*. Instead, research on cognitively oriented learning technologies has focused primarily on students, teachers, and classrooms as the primary unit(s) of analysis. Though we recognize the need to link technology and reform, the field lacks a bridge between focused research and development of learning technologies and the broad-based systemic use of these innovations in schools. Shepard (2000) recognized this as problem for the broader educational research community in her AERA Presidential Address, when she advised researchers to develop methodologies that embrace "dilemmas of practice." Such work "would advance fundamental understandings at the same time that they would work to solve practical problems in real-world settings" (p. 13). This focus would lead to the production of more readily "usable knowledge" (Lagemann, 2002). As researchers, we have developed rich understandings of how technology can foster learning in specialized situations; we now need to develop knowledge about widespread appropriation and use of cognitively oriented technologies by schools and school systems as part of real-world reform efforts. Ultimately, this calls for an augmented research agenda designed to enhance the usability of technology innovations developed by the research community, with positive consequences for scalability and sustainability. To address this issue requires that we introduce new questions and ways of thinking about problems into our research agendas. The framework that guides these questions must combine the best of what we currently understand about learning and teaching with technology with what is already known about the challenges of creating systemic reform and the implementation of innovations in reform contexts.

We begin by clarifying the nature of cognitively oriented technology innovations in school and research contexts. Next we reflect on what is known about fostering the widespread use of technology innovations in schools, and provide a framework for considering the usability of innovations. We then turn to research questions arising from our own experiences in working in systemic reform to frame a systemic research agenda that addresses issues of sustainability, scalability, and usability of cognitively oriented technology innovations, concluding with reflection on issues for the research community that are related to carrying out our proposed research agenda.

COGNITIVELY ORIENTED TECHNOLOGY INNOVATIONS

In our thinking, cognitively oriented technology innovations focus on inquiry and approaches to learning as embodied in national standards documents (e.g., National Council of Teachers of Mathematics, 1989; National Research Council, 1996). These innovations include technology as a core component, but are rooted in cognitive and constructivist learning theories (Bransford et al., 1999; J. S. Brown, Collins, & Duguid, 1989). Cognitively oriented technology innovations range from intelligent tutoring systems that help students learn mathematics (e.g., J. R. Anderson, Corbett, Koedinger, & Pelletier, 1995) to environments that foster communal knowledge-building and support for writing (e.g., Scardamalia & Bereiter, 1991) to tools that scaffold deep explorations in science (e.g., Linn & Hsi, 2000). In these innovations, technology is employed as a tool to support teaching and learning, as opposed to the object of learning. These innovations often use technology to scaffold teaching and learning practices that would be difficult to achieve otherwise, such as making complex causal modeling accessible to students (e.g., Jackson, Stratford, Krajcik, & Soloway, 1994).

There is a continuum of ways that technology is employed in cognitively oriented technology innovations. Instruction can be delivered via computer, as is the case with intelligent tutoring systems, or computers can be used as resources and "learning partners" in classrooms where much learning takes place "off line." Cognitively oriented technology innovations may be designed to cover a relatively short period of time, or they may be comprehensive, intended to be used throughout an entire year or across multiple years of instruction. Our focus, however, is on cognitively oriented technology innovations that are closely tied to the regular curriculum and tightly integrated with teaching and learning practices. In instances where this is not the case, such as after-school computer clubs (e.g., Zhao, Mishra, & Girod, 2000), there may be high-quality learning and excellent uses of technology, but we do not include these instances in our consideration of cognitively oriented technology innovations for teaching and learning because such extracurricular uses of technology side-step the challenges of systemic reform and are not designed or intended to influence teaching and learning by teachers in regular school subjects as part of the school day.

The Knowledge Integration Environment (KIE; Bell, Davis, & Linn, 1995; Linn & Hsi, 2000) is an example of a cognitively oriented technology innovation. KIE combined a range of networked software tools with constructivist pedagogical principles in order to foster use of evidence and argument in middle school science. In KIE, learning is organized around generative questions in science, such as whether light travels forever or dies out. Students conduct research collaboratively on the Internet to gather evidence or view evidence developed expressly for KIE, and use argument-support software to organize their evidence and make supportable claims. Students then debate their claims and use of evidence in face-to-face classroom discussion as well as through the use of asynchronous on-line discussion tools. The technological aspects of the learning environment in KIE are designed to complement the face-to-face learning facilitated by the classroom teacher, who must orchestrate collaboration, guide students in their learning, and provide assessment and feedback to students. KIE is challenging for teachers in that they need to understand not only the content embedded in this project (which is just one of several in a broader KIE-enabled science curriculum), but also how to help students use the technology, how to foster collaboration, and how to conduct appropriate assessments. As with many cognitively oriented technology innovations, access to the Internet is crucial. If the Internet connections or computers are not working, it is difficult to use KIE curriculum. In this way, cognitively oriented technology innovations are often demanding of both the instructional and technology infrastructures of schools. Recently, research on KIE has evolved into a larger effort called the Web-based Inquiry Science Environment (WISE; Linn, Clark, & Slotta, 2003), that is attempting to address issues of scalability and sustainability.

Design-Based Research

Many cognitively oriented technology innovations are developed using design-based methodologies in which researchers work closely with teachers and students to design, develop, implement, and evaluate an innovation in real classroom settings (A. L. Brown, 1992; Collins, 1990). Design-based research has great potential for creating "usable knowledge" (Lagemann, 2002) principally because it is intertwined with practice and makes an attempt to study the complex influences of context on teaching and learning (The Design-Based Research Collective, 2003). Design-based research combines inductive qualitative approaches with quantitative and quasi-experimental approaches, varying the method to suit research questions that present themselves over the life of the collaboration. Research staff generally establish a regular presence in the classroom to support the use of the innovation, sometimes modeling or co-leading instruction with the teacher (Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003). In part, this serves to temporarily establish conditions that are favorable to the innovation's success. Without these conditions, it would not be possible to study the phenomena or ideas of interest. However, if the conditions depend heavily upon an infusion of extra support from researchers, this may pose a challenge to scalability and sustainability.

Another characteristic of design-based research on cognitively oriented technology innovations is the nature of the participants. As Means (1998) put it,

> In the majority of cases (but not always), teachers are voluntary participants, and hence likely both to buy-in to the philosophy of the project and to see the connection of the technology used in the project to something they want to do with their students … . The disadvantage innovative technology-supported projects often face is the fact that they may not be a good match to priorities with an individual school or district. (p. 7)

Design-based research, which has been a major methodology within the Learning Sciences, has the advantage of grounding the lessons of research on cognitively oriented innovations firmly in dilemmas of practice (Shepard, 2000), but in a specialized way that does not necessarily lead to the sustainability or scalability of the innovations. Work to date, and design-based efforts in particular, have helped researchers to better understand the constraints and contexts for classroom uses of learning technologies. But what happens when the innovation is used by dozens or hundreds of teachers who do not share co-ownership of the design with the researchers and may lack specialized knowledge generated from the collaborative research process?

Design-based research focuses on studying an innovation's use within a classroom or several classrooms, and not necessarily on "external" factors that are necessary for the innovation's support. Writing about methodological issues in design research, Collins, Joseph, and Bielaczyc (this issue) point to the importance of including a school or institutional analysis among the ways that a particular design can be studied. They also argue that system variables, such as ease of adoption, sustainability, and spread, are key dependent variables that should be measured in design-based research. We agree, but believe that if design-based research is going to provide guidance for systemic reform, such variables need to be treated as more than outcome measures, but as a central part of the intervention. If we are to foster truly sustainable innovations, there is a pressing need for an extension of classroom-based design research that focuses on schools and school systems as the primary units of analysis (Snipes, Doolittle, & Herlihy, 2002). As we work to build upon the lessons learned from classroom-oriented design-based research, we need to define questions that explicitly address issues of scalability and sustainability, if we hope for innovations to enter into widespread use beyond their original research contexts. To this end, we now turn our attention in this article to the constraints and needs of school *systems*.

SUSTAINABILITY, SCALABILITY, AND SYSTEMIC REFORM

Developers of cognitively oriented technology innovations want their innovations to be sustainable and scalable. The Learning Sciences is a field rooted in cognitive science, but with practice-oriented objectives. Ideally, the use of innovations will extend beyond the time that researchers are directly involved in the classroom. This is the essence of sustainability. Ideally, the pedagogical ideas and uses of technology that are encompassed in the innovation will spread to teachers' general repertoires. If school systems are able to support the practices embodied in the innovation, then their use will also spread to other teachers within or across schools. This is the essence of scalability.

There are various mechanisms employed in attempts to create sustainability and scale. We have chosen to work in the context of urban systemic reform, in which an innovation is intended to reach many teachers and students within a single school system. A fundamental challenge of work in systemic reform contexts is creating alignment across the components of school systems, such as administration and management, curriculum and instruction, assessment, policy, and technology (Smith & O'Day, 1991). If the challenge of alignment can be met, an innovation has a better chance of being both sustained and scaled because the alignment of the system creates a stable structure and provides needed support. Moreover, cognitively oriented technology innovations that are well matched to systemic reform goals of school systems, such as standards-based instruction, are more likely to be sustainable, and more likely to be scalable to widespread use. These challenges are not new to the domain of cognitively oriented technology innovations, but have been studied in the context of, for example, the more general problem of curriculum implementation (Snyder, Bolin, & Zumwalt, 1996).

Much has been written about the difficulties of creating systemic instructional innovations in general, such as the nested complexities of school organization, family and community concerns, and professional and regulatory agencies (Cohen & Ball, 1999), and problems related to the adaptation of innovations as they are adopted in new contexts (McLaughlin, 1990). Technology introduces additional issues and challenges that are not as well documented, but which we propose need to become the focus of research. Cognitively oriented technology innovations force researchers, schools, and districts to think across conceptual and organizational boundaries in ways that other innovations typically do not. This is because technology used for curricular purposes is often maintained by organizations in the school district that traditionally have not been involved in classroom learning, and new technologies, such as the Internet, require a high level of coordination between classroom users and central network managers (Fishman & Gomez, 2000; Fishman, Lento, Gomez, & Despenza-Green, 1997; Schofield & Davidson, 2002). Because they draw upon resources that are uncommon in nontechnology curricular innovations, cognitively oriented technology innovations can place stress on the alignment of a district's systemic reform agenda, uncovering areas where alignment is insufficient for the demands of the innovation. We elaborate on these issues below.

Systemic Reform and Technology Innovations: What Works

In their study of successful technology implementation efforts, Means et al. (1993) identified the following six common features: Ready technology access and technical support; instructional vision and a rationale linking the vision to technology use; a critical mass of teachers in technology activities; a high degree of collaboration among teachers; strong leaders; and support for teacher time for planning, collaboration, and reporting technology use. Though Means and her colleagues were not explicitly studying implementations of technology in systemic reform, their description of the conditions for success resonates with systemic notions of alignment. In later work, Means found that cognitively oriented technology projects were more successful at a small scale. In trying to explain why this should be, she concluded that, "many of the features associated with successful technology-supported reform efforts within individual schools are often missing from large-scale technology implementations" (Means, 1998, p. 11). This is likely also a function of the volunteer nature of the participants, who are able to work as independent (and idiosyncratic) actors within the larger system, and the effect of the intensive but highly localized investment in capacity by researchers. In widespread use, it becomes an order of magnitude more difficult to maintain alignment of all the needed organizational components and participants.

Knapp (1997) argued that a key to successful reform is that the major ideas be grasped by participants at all levels of the school system. This requires investment in professional development, teacher leaders, curriculum, and logistical support. Reform efforts are not successful when they are implemented "top down," as a function of policy implementation, largely because this perspective does not value organizational learning (Fullan & Miles, 1992). The most successful systemic reform efforts are where the local organization either invents or assumes ownership of the core ideas in the reform (Honey & McMillan-Culp, 2000). This was the case in Union City, NJ, a successful urban systemic reform effort involving cognitively oriented technologies (Center for Children and Technology, 2000). In Union City, the school system itself designed the core of the reform initiative in response to state policies that would have led to the takeover of the district. Union City school administrators invited researchers to join them as consultants, but they never ceded control of the core ideals of the reform. This was also the case in the Hanau Model Schools Project (McNamara, Grant, & Wasser, 1998), where researchers worked with a DoDEA school in Germany to integrate technology throughout the curriculum, developing a comprehensive approach to professional development for the district as a key component of the reform.

A FRAMEWORK TO INSPECT THE SCALABILITY, SUSTAINABILITY, AND USABILITY OF INNOVATIONS

Some of the conditions under which reform and technology within reform become successful have been identified (e.g., Knapp, 1997; Means, 1998; Means et al., 1993), and so have many of the problems that are encountered when trying to use technology at scale in schools (Means, Penuel, & Padilla, 2001). But there is little guidance in the literature for those interested in establishing those conditions or resolving those problems. In order to take this critical next step, it is necessary to conduct systematic research on cognitively oriented technology innovations in a variety of settings. Research on such innovations, as a design-oriented enterprise, attempts to understand the interaction between innovations and their contexts of use in order to increase the *usability* of the innovation. We take the term "usability" from human-computer interaction (Nielsen, 1993), where it connotes a measure of the extent to which those who take up innovations or products are able to employ them to accomplish their work. If a reform innovation is not usable, it is unlikely to be adopted, and will be neither sustained nor scaled. To understand how to enhance the usability of cognitively oriented technology innovations, it is necessary to frame questions that directly address issues of scalability and sustainability. Our goal is to develop research that enables the linkage of current knowledge to dilemmas of practice (Shepard, 2000) in school systems.

A feature of research on systemic reform and large-scale studies of technology is that researchers normally have an outsider or *etic* perspective on the object(s) of study. The researchers or evaluators are almost never the same people who have worked to create the reform. By contrast, a feature of research on cognitively oriented technology innovations is that the researchers are usually the developers of the innovation (ideally codevelopers with the school participants), and thus have an insider or *emic* perspective. Being "on the inside" fundamentally changes one's perspective on the reform process. Research to date has told us much about where to look for problems in the systemic uses of technology or reform more generally, but it has not provided guidance about how to *create* or *enable* change. *Etic* approaches attempt to understand and explain, but *emic* perspectives, such as design-based research, struggle to influence and shape the change process in order to create a desired outcome as part of the understanding process. Developing a research agenda that fosters the creation of cognitively oriented technology innovations that are usable in systemic reform contexts is, we believe, the key contribution of this work, building upon earlier research that has described problems and conditions for success.

A core question that needs to be addressed is just what is the definition of a "usable" cognitively oriented technology innovation? A basic answer is that an innovation is usable if a school organization can adapt the innovation to local context, enact the innovation "successfully" (as jointly defined by the school and the developer), and sustain the innovation. This question may also be turned on its head, and answered by examining what aspects of innovations or school systems create challenges for usability.

In earlier work (Blumenfeld et al., 2000), we have argued that there are three dimensions within school systems to which one must attend in order to create usable innovations: school culture, capability, and policy/management. We arrayed these dimensions in the form of three axes originating from a common point (the origin, which represents the current capacity of the district) to form a three-dimensional space we call the "usability cube" (see Figure 1). An innovation can be placed in the space created by these three axes, where the "distance" between the innovation and the origin represents the gap that exists between the capacity required to successfully use the innovation and the current capacity of the district. The creation of usable innovations (and successful reform), conceptualized in this manner, is a process of working to "close the gaps" that exist. This might involve increasing district capacity through professional development or changes in policy, or re-

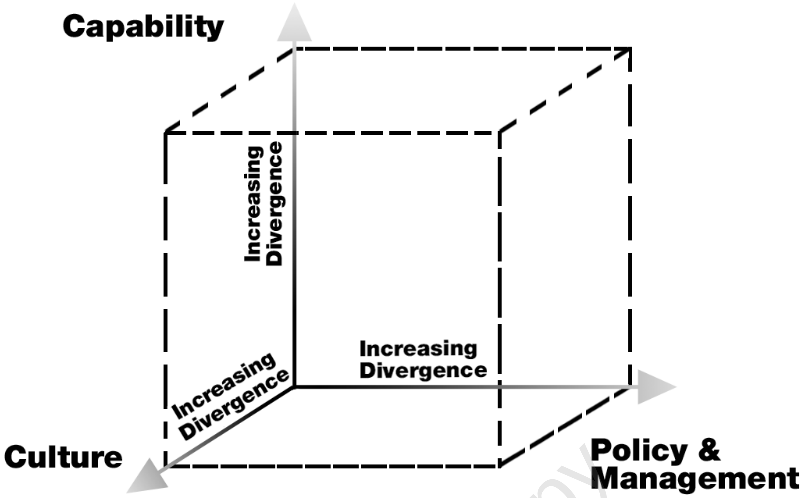

FIGURE 1 Framework to evaluate the usability of innovations (Blumenfeld et al., 2000).

working the innovation so that it better matches existing capacity. We argue that both types of changes are ultimately required in the creation of usable innovations that foster reform. Understanding the opportunities for and processes by which one closes gaps is the area for research that we propose in this article.

To illustrate how this "usability cube" model can be used to describe and even predict the difficulty any particular innovation faces in the adoption process, we have selected two examples from research on cognitively oriented technology innovations that demonstrate two different approaches to becoming scalable and sustainable. The first of these is the work of the Pittsburgh Advanced Cognitive Tutor (PACT) Center work with Cognitive Tutors in mathematics (Corbett, Koedinger, & Hadley, 2001), which have become widely used by schools nationally. The second is the reform effort of the Union City, NJ, public schools (Center for Children and Technology, 2000), which represents a pedagogical, curricular, and technological innovation that has been scaled throughout an entire school district.

Example: Cognitive Tutors

Cognitive Tutors, which were developed at Carnegie Mellon University using Anderson's theory of human and machine learning (J. R. Anderson, 1983), have been used successfully to teach high school mathematics to students in a variety of settings (Corbett et al., 2001). These systems have been commercialized by an organization called Carnegie Learning Corporation, and are currently being used in hundreds of school districts throughout the country, though not necessarily system-wide within individual school districts (Corbett et al., 2001). By most measures, the Cognitive Tutors can be said to have successfully reached scale.

Viewed from the perspective of the usability cube (Blumenfeld et al., 2000), we would say that Cognitive Tutors are a likely candidate for such success. For example, knowledge of the common errors that students make in a domain, and how to correct them, is an instance of crucial pedagogical content knowledge for teachers (Shulman, 1987). Because Cognitive Tutors are constructed around a model of learners' common errors and paths to understanding, they provide support to teachers in this difficult area, thus reducing a potentially challenging capability gap for teaching mathematics. Many teachers express concern about their ability to facilitate students moving at their own pace through material when using tutors, as opposed to in unison as is typical in more familiar didactic approaches to instruction. This potential capability gap is also reduced by the software, as its design "provides just the support students need to move successfully at their own pace" (Corbett et al., 2001, pp. 241–242), thus allowing teachers the flexibility to focus on other issues, such as spending more time with students who are struggling. It is important that schools have capability in the form of technical support to keep the computers that run the tutors working, and Carnegie Learning Corporation has focused some efforts in this direction (Corbett et al., 2001). However, because the tutors utilize standard computers available in most schools, and do not require access to networks, the range of technical problems is reduced. In early stages of development, the tutors required much greater computational power than was typically available in schools, but recognizing this as a problem, the designers worked to close this particular capability gap (Corbett et al., 2001). Cognitive Tutors are a good fit with school culture, because they supplement but do not replace mathematics teachers, and are flexible with respect to whether computers are located in the math classroom or in a separate computer lab. Furthermore, Carnegie Learning sells the Cognitive Tutors in conjunction with complete mathematics curricula that are designed to fit directly into existing categories of high school math subjects (e.g., Algebra, Geometry, etc.). In terms of the policy/management dimension, Cognitive Tutors speak directly to a felt need of school administrators, as they have demonstrated success at helping students achieve in mathematics, an area that many school districts find challenging and which is highlighted in the current state and federal policy environment by the No Child Left Behind Act (U.S. Department of Education, 2001).

Because the demands of Cognitive Tutors do not overly stress schools' capability, policy/management structures, or culture, they do not present a large usability challenge to schools, and are therefore good candidates for scalability and sustainability. At this point, one might ask why all technology innovations are not created in the mold of Cognitive Tutors? The reason is that, while the learning theory upon which Cognitive Tutors are based (J. R. Anderson, 1983) can be readily applied to domains such as mathematics, computer programming, or other relatively well-bounded problem spaces where designers can anticipate likely student errors, the theory has a much harder time with open-ended domains, such as humanities. For the same reason, Cognitive Tutors are not currently a good fit with open-ended, inquiry-oriented pedagogies because the content and direction of student learning cannot usually be predicted in advance, though some progress is being made in this direction (e.g., Koedinger, Suthers, & Forbus, 1999).

Example: Union City, NJ

The cognitively oriented innovation developed by the Union City, NJ, public schools as part of their decade-long reform effort (Center for Children and Technology, 2000) represents almost complete adoption of an innovation within a single school district, as opposed to broad adoption by schools spread across the country as was the case with Cognitive Tutors. Union City transformed itself from a district on the verge of a state takeover due to low test scores into the highest-performing urban district in their state. The core of the Union City innovation is a redesign of their curriculum with a focus on second-language literacy (they serve a mostly Spanish-speaking population), with complementary pedagogical reforms to create a student-focused and literacy-based approach with an emphasis on collaboration and communication. Technology plays a central role in the Union City reforms, as students create a wide variety of computer-based writing and multimedia projects as part of the communication objectives of the district, and rely heavily on the Internet as a source of texts for use in all subject areas (Honey, Carrigg, & Hawkins, 1998). When Union City embarked on their innovation, they faced tremendous challenges in terms of all three dimensions of the usability cube: capability, culture, and policy/management. The process of reform used by Union City is a good example of how these dimensions interrelate, and how solutions on any particular dimension can require that one simultaneously address other dimensions.

An initial challenge faced by Union City was to address gaps in teachers' capabilities, both with respect to the new pedagogy and the new technologies. The district made use of extensive professional development, a typical approach to reduce capability gaps. However, they simultaneously made changes in policy/management by focusing the reform on early grades first, and allowing teachers who were not willing to participate to either move up grades (where the reforms were not yet installed) or to switch to schools in the district that were not in the first wave of reforms. The district also focused on changing the culture of both the classroom and professional development by inviting teachers to bring students with them to workshops. Students were asked to focus on the technologies, and then act as classroom aides to help alleviate teachers' capability concerns. By having students integrally involved in the enactment of the innovation, and by starting with younger grades, Union City created a situation where the students *themselves* acted as change agents, expecting their middle school instruction to be similar to what they experienced in the early grades, thus exerting an internal force for change that affected school culture (Center for Children and Technology, 2000). This is in stark contrast to projects that inadvertently work against the students' pedagogical expectations by altering a single "experimental" classroom in the older grades (e.g., Gomez et al., 1998). At this point, the district made it possible for teachers who were *still* resistant to the changes to either retire or leave the district, a strong show of policy/management support with implications for school culture. Because the Union City innovation was "home grown," and led by district administrators, it was never much of an issue to reduce gaps in policy/management. By focusing on that dimension, the district was able to create conditions for closing the gaps in capability and culture. What worked in Union City is extremely specific to its context, but it provides a telling example of working to reduce gaps between district capacity and the demands of an innovation in order make the innovation usable, achieving both district-wide scale and sustainability.

In the remainder of this article, we turn to an examination of our own experiences in working collaboratively with schools to create scalable and sustainable cognitively oriented technology innovations within the context of systemic reform. We draw upon these experiences to outline a proposed research agenda. We build upon findings from earlier research that identify places where the demands of innovations and the capacity of school contexts are likely to diverge, and suggest new questions that help us understand how to close the gaps. We examine issues that pertain to the capacity of school organizations with respect to creating usable cognitively oriented technology innovations in systemic reform, and questions that pertain to the organization of the research community. An additional challenge for any such research agenda is that, working from an inside or *emic* perspective, the questions asked should have utility for *both* the research and practitioner communities. Our hope is that, in pursuing this proposed agenda, the field will develop a body of examples of how cognitively oriented technology innovations come to be usable in a range of systemic contexts. This research will ideally reveal a range of strategies employed by researchers and practitioners to reduce gaps between the capabilities of schools and the demands of innovations, yielding information that others can employ to create the needed conditions for the successful scaling and sustainability of cognitively oriented technology innovations.

A RESEARCH AGENDA FOR EXPLORING SCALABILITY, SUSTAINABILITY, AND USABILITY OF INNOVATIONS

Perhaps because the success of any instructional innovation is closely linked to teaching practices, much research in the Learning Sciences has focused on classroom teaching and student learning. But educators at all levels of the system are key to the eventual success of classroom-level innovations. Thus, a focus on the capacity of the larger school organization is critical when seeking to increase the usability of cognitively oriented technology innovations. We argue that the following areas are critical components of a research agenda on the usability of cognitively oriented technology innovations in systemic reform contexts: teacher learning, assessment, technology planning, and organizational structure and leadership. We explore each area below in the context of our own experiences in developing a cognitively oriented technology innovation with an urban school district.

Our work in the Center for Learning Technologies in Urban Schools[1] provides a window into the challenges of conducting design-based research on creating usable cognitively oriented technology innovations as part of systemic reform. Our goal is to develop and integrate inquiry-based science curricula with embedded technology in the Detroit Public Schools. This involves extensive curriculum development (Singer, Marx, Krajcik, & Clay-Chambers, 2000), design and integration of technologies to support student and teacher learning (Marx, Blumenfeld, Krajcik, & Soloway, 1998), broad-based professional development (Fishman, Best, Marx, & Tal, 2001), and collaboration with teachers and school and district administrators (Murray, Fishman, Gomez, Williams, & Marx, 2001).

Our work began in the fashion of most cognitively oriented technology innovations. We developed materials using focused design-based approaches (Krajcik, Blumenfeld, Marx, & Soloway, 1994). When we believed that our innovation was working well (Krajcik et al., 1998), we attempted to expand our work to include many settings as part of Detroit's systemic reform initiative. In the process, we encountered multiple challenges to the usability of our innovation. These included (aside from challenges related to technology use, which we will discuss in depth below), the educative design of the curriculum (Schneider & Krajcik, 2000), the effectiveness of the professional development (Fishman, Marx, Best, & Tal, 2003), and the relationship between school and community (Moje, Collazo, Carrillo, & Marx, 2001). In working to resolve these challenges, we developed and began to employ our "usability cube" model to gauge the "fit" of our innovation to the capacity of the school district's culture, capabilities, and policy/management structures (Blumenfeld et al., 2000). Through this process, we uncovered a broad range of "gaps" between the capacity of the district and the demands of the innovation, which when taken together comprise the dimensions that a research agenda on cognitively oriented technology innovations needs to address. Below, we consider the major gaps that we encountered and propose specific research questions to address, and hopefully narrow, each gap. The four issues we choose to highlight (see

[1]More information about LeTUS can be found at http://www.letus.org/. More information on hi-ce can be found at http://www.hi-ce.org/.

Table 1) are likely to be relevant to cognitively oriented technology innovations in a broad range of systemic reform contexts.

Creating Scalable and Sustainable Teacher Learning

There is little doubt that professional development is a key component of successful systemic reform initiatives (Supovitz, 2001). Gaps in teacher capabilities in terms of content knowledge and pedagogical knowledge present a serious hurdle to reform. Recent research has provided evidence on the value of focusing professional devel-

TABLE 1
Key Issues to Explore in Design-Based Research on Cognitively Oriented Technology Innovations in Systemic Reform Contexts

Issue	*Areas for Research*
1. Teacher learning	How can PD to enhance teachers' capability be made usable for teachers with a broad range of motivation, skill, and working contexts?
	How do district policies and cultures shape the participation of teachers in PD?
	How can PD be scaled to reach thousands of teachers and maintain high quality standards?
	How can teacher learning be linked to student learning and standards-based accountability systems?
2. Assessment	How can instructionally useful forms of assessment inform standards-based accountability systems?
	How can urban school systems balance the time demands of high-stakes testing with the demands of cognitively oriented innovations?
3. Planning for technology	What are the characteristics of successful technology planning practices?
	How can district policies for acquiring, distributing, and maintaining technology be aligned with instructional needs for technology?
	How can different innovations effectively leverage and share technology resources within a district?
4. Organizational structure and leadership	How can schools examine their organizational structures to promote realignment around the demands of cognitively oriented technology innovations?
	How should school organizations be realigned to better support innovations?
	How can distributed leadership be fostered in school organizations?
	What forms of professional learning help school leaders build capacity to support reform and innovations?

Note. PD = professional development.

opment on teacher content knowledge (Wilson & Berne, 1999), on student learning (Kennedy, 1999), on the importance of extended participation, and alignment with broader reform agendas (Garet, Porter, Desimone, Birman, & Yoon, 2001; Supovitz, Mahyer, & Kahle, 2000). Cognitively oriented technology innovations complicate the picture further, adding knowledge of technology and how to teach with it to the list of capabilities teachers must master (Margerum-Leys & Marx, in press). Though many projects have focused on professional development and technology, relatively few have focused on technology integrated with core curricular goals (President's Committee of Advisors on Science and Technology, 1997). Notable exceptions that have focused on professional development in systemic settings include the work with the Hanau Schools in Germany (Wasser & McNamara, 1998), the work in Union City, NJ (Center for Children and Technology, 2000), and work to integrate calculators comprehensively throughout mathematics curriculum in Montana (Zucker & Marder, 1998). Cognitively oriented uses of technology often employ challenging pedagogical approaches, such as project-based learning (Blumenfeld et al., 1991). Teachers may need to learn new content or new approaches to managing instruction with technology, thus widening the usability gap in terms of the capabilities needed to employ the innovation. A further challenge comes from the large numbers of teachers in urban districts. How can a successful professional development program be scaled to hundreds or potentially thousands of teachers and still maintain quality and focus? One proposed solution has been to employ on-line learning environments, and there is promising work in that area, though more is needed (Shrader et al., 2002).

Our work in Detroit attempts to provide rich professional development opportunities for teachers that focus on the curriculum instead of on the technology. To do this, we have employed a wide variety of approaches, including extended summer and monthly Saturday workshops, teacher study groups, in-classroom support, educative curriculum materials, and on-line professional development tools. This broad-based effort was intended to allow us to explore the range of opportunities for teacher learning in order to better understand linkages between particular professional development practices and changes in student outcomes (Fishman et al., 2003). We also realized that such an intensive professional development enterprise was ultimately unsustainable, and so sought to document both costs and benefits of different approaches in order to provide guidance to the district for future investment of effort, in particular attempting to link professional development to student outcomes. If these efforts are to be sustainable and scalable, it is important that the district assume responsibility for organizing and operating the professional development, a process which is now underway (Fishman, Fogleman, Kubitskey, Peek-Brown, & Marx, 2003; Margerum-Leys et al., 2003). We are also exploring the use of on-line learning environments as a means of creating sustainable and scalable teacher learning opportunities (Fishman, 2003).

In working to close the gaps between teachers' capabilities and the demands of our innovation, we uncovered a range of challenges to the usability of the professional development components of our innovation that were related to both the culture and the policy/management dimensions of our usability cube (Blumenfeld et al., 2000). For example, an extended program of professional development must account for teachers who have different (and changing) capability levels and who will therefore be on different learning trajectories. There will be differences in motivation and participation (Supovitz & Zeif, 2000), problems with teacher turnover and mobility, problems created by teachers teaching out of the subject area of their credentials, and the problem of finding time in teachers' work days to engage in teacher learning. All of this must be reconciled against the backdrop of organizational culture that favors one-day or other short term approaches to professional development. What we wish to highlight is that what at first appears to be a usability or design challenge on the dimension of teachers' capability is in fact a multifaceted problem that involves district policy/management practices with respect to teacher learning as well as organizational culture. Below we present areas for further research on teacher learning with respect to cognitively oriented technology innovations that will provide information about how to close the gaps that arise, and potentially lead to design-based research that on innovations intended to be used beyond those schools where the researchers are guiding the implementation process.

Proposed areas for further research. There is much needed research in the area of policy/management challenges that arise in attempting to develop systemic cognitively oriented technology innovations. How can teachers who do not have ready access to computers in their own classrooms gain confidence and skill in using computers as part of their teaching? How can teachers' time constraints be overcome in order to create sufficient time for extended participation in professional development? How can district and building administrators create sufficient incentives for teachers to participate in professional development beyond normal working hours? How can districts create professional development that reduces gaps in teachers capability to employ technology as part of cognitively oriented curricular innovations, integrating knowledge of technology with knowledge of content and pedagogy? How can high-quality professional development be extended to potentially thousands of teachers district-wide while maintaining quality and focus? What role does or should on-line professional development play in addressing these questions?

Linking Cognitively Oriented Technology Innovations to High-Stakes Assessment

A key "feature" of systemic reform is new assessment and accountability measures that place tremendous pressure on schools and present a critical alignment challenge for systemic reform programs (Goertz, 2001), creating gaps between the policy/management structures of the district and the innovation. This pressure has increased with the introduction of the "No Child Left Behind Act" (U.S. Department of Education, 2001), which increases the amount of testing and raises the stakes for underperforming schools. Developers of cognitively oriented technology innovations must understand how their innovations fit with federal, state, and local policy initiatives, and make such linkages transparent for schools. New technologies present both new forms of student work and new means for conducing assessment (Pellegrino, Chudowsky, & Glaser, 2001). What kinds of assessments are both consistent with the goals of cognitively oriented technology innovations *and* with the demands of standards-based accountability? Goldman (2002), in her AERA Division C Vice-Presidential address, argued that it is the responsibility of the cognitively oriented technology research community to create new forms of assessment that bridge this gap.

We have attempted to address this issue in our work by explicitly connecting our curricular materials to district and state frameworks for science education (Singer et al., 2000). However, this approach does not resolve all of the potential problems, as state testing itself can be out of alignment with the standards (Goertz, 2001; Porter & Smithson, 2001). This is because standardized testing is a distal measure with respect to local teaching and learning in schools (Ruiz-Primo, Shavelson, Hamilton, & Klein, 2002). Paradoxically, the time districts devote to standardized assessment activities cuts into the amount of extended time available for focus on inquiry-oriented learning as called for in the standards (e.g., National Research Council, 1996). In our experience in Detroit, as political pressures and public opinion created a press for more accountability through the use of standardized assessment, increasingly more classroom time was given over to preparation for and taking a range of assessments such as the state mandated tests and comprehensive batteries, which created both a policy/management and a culture challenge to the usability of cognitively oriented technology innovations. As more of the school year in Detroit was devoted to external assessment (in noncontiguous blocks), our cognitively oriented technology innovation had to compete for the limited time remaining. In such an environment, it became increasingly difficult for teachers to carry out extended inquiry-projects during certain months of the school year. Further research in this area is crucial. If we do not help schools find ways to address assessment needs productively, cognitively oriented technology innovations become less usable in light of the culture of standards-based assessment to which all urban schools must respond.

Proposed areas for further research. How we might shape or align the instructionally useful forms of alternative assessment employed in many cognitively oriented technology innovations to meet the accountability needs of districts, thus reducing a major policy/management gap in the usability of cognitively oriented technology innovations? Many cognitively oriented technology innovations have developed rich means of portfolio or artifact assessment as part of their research

(Pellegrino et al., 2001), but how might these approaches be applied across an entire school district? This is a key scalability issue for assessment. Can we find ways to conduct rigorous and meaningful assessment tasks, aligned with cognitively oriented innovations, in ways that are scalable within and comparable across schools and districts? How can the content and learning strategies embodied in the technology use(s) be represented in high stakes tests? From a policy/management perspective, how can school organizations balance the time demands of high-stakes testing with the time demands of inquiry-oriented teaching and learning?

Planning Effectively for Cognitively Oriented Technology Innovations

Teachers require ready access to technology in order to use cognitively oriented technology innovations. This is a usability issue for innovations that spans school culture and policy/management issues. If school and district technology plans are not aligned with goals for teaching and learning, teachers and students will not be able to gain necessary access to technology. Unfortunately, this is frequently the case, as technology plans rarely focus on teaching and learning and instead read like shopping lists for hardware and software, functioning more as a bureaucratic placeholder than a real plan for action (Fishman & Pinkard, 2001). Research on effective technology planning processes emphasizes the importance of forming a planning group with representatives from all constituencies within the school community, and of having a strong focus on curricular goals (Regional Technology in Education Consortia, 1996). However, much of the work in this area still approaches the technology planning process independently from the particulars of school reform (L. S. Anderson, 1999). Furthermore, the planning processes advocated in much of the literature are designed to fit within existing organizational structures, not to challenge them or seek reciprocal changes between the capabilities of extant structures and desired innovations (Fishman & Pinkard, 2001).

Technology must be acquired before it can be used, but the purchasing and distribution of technology is a hazy area of school policy at best. In Detroit, for example, curriculum decisions are centralized, but technology acquisition, although guided by district standards, is decentralized and building principals make individual decisions about technology purchases. The result is that computer capabilities are not uniform, and machines are difficult to maintain and upgrade. Issues such as these are normally overlooked by researchers, but they are serious impediments to the use of cognitively oriented technologies, which typically place high demands on computers.

Teachers and students need access to technology. Administrators need help in understanding the implications of placing computers in labs versus classrooms. Either solution has problems, because computers distributed throughout classrooms are difficult to secure and maintain, while centralized computer labs create scheduling conflicts between teachers that make it difficult to utilize technology as a tool to be used throughout the curriculum. Technology breaks down frequently, and few schools have computer technicians on staff to provide maintenance. Labor rules in urban school districts are tricky regarding personnel who are not certified to teach, especially when those positions demand high salaries. The result is that teachers cannot get the help they need when they need it, which becomes a strong disincentive to using technology. A national survey of technology use in schools found that more than two-thirds of teachers nationally reported not being able to get timely technology help (Ronnkvist, Dexter, & Anderson, 2000). Furthermore, the survey indicated that support was less available in low than in high-SES districts, reflecting yet another dimension of the "digital divide." Everyone seems to recognize this problem, but the cost of solving it is so high that no solution is forthcoming. Temporary solutions such as the "e-rate" telecommunications discount program (Carvin, 2000) can provide some relief to urban districts, but these programs are temporary fixes, and do not represent mature thinking about technology whereby ongoing costs become line items in a school budgets, not special expenses supported by external grants and awards.

In our work with Detroit, we attempted to help schools think strategically about their technology acquisitions, both at the building and at the district level. This proved challenging in that there were several different organizations with responsibility for technology (see next section), but no clear chain of authority that connected them together. Another challenge was that our particular cognitively oriented technology innovation had to coexist with ongoing uses of technology in the district (many of which were drill-and-practice type of activities), and there was frequent competition for resources. This was in part due to the lack of a unified district-level plan for technology that assigned clear priorities to different initiatives, leaving principals on their own to make decisions in this regard. Finally, even in situations where everything was properly aligned for the use of our cognitively oriented technology innovation, there were still serious maintenance problems that could prevent activities from proceeding. Our intermediate solution to this challenge was to place our own technology support personnel in the schools to ensure that technology would be in working condition when teachers needed it, temporarily (but not sustainably) reducing the gap in capability for using the technology associated with our innovation.

Proposed areas for further research. Researchers working with cognitively oriented technology innovations need to conduct research to determine the characteristics of successful technology planning practices. What planning approaches create opportunities to evaluate gaps in existing capacity and the demands of cognitively oriented technology innovations? How can districts align their plans for acquisition of, access to, and support of technology with their teaching and learning goals? How can different technology-related innovations effectively share resources within a school or district? How can school budgets and contracts be realigned to support ongoing infrastructure costs for technology? What conditions are needed in order for a technology plan to be implemented effectively, and how are those conditions fostered?

District Organization, Leadership, and the Usability of Technology Innovations

As alluded to in the previous section, we have found that the structure of the district organization itself can facilitate or impede the usability of cognitively oriented technology innovations. Much classroom technology is designed to be "stand alone," to be used by students working in isolation on tasks such as drill and practice or working with multimedia presentations. Cognitively oriented technology innovations, however, often make use of networks to facilitate collaboration and data sharing among students and teachers. The introduction of networks brings to the surface many areas where district organization does not align well with the goals of school reform or cognitively oriented technology innovations.

The Internet is both one of the most promising and at the same time the most challenging technologies to be employed in classrooms (Fishman & Gomez, 2000; Schofield & Davidson, 2002), making organizational communication problems apparent. This is because the Internet connection to the classroom is dependent upon cooperation and coordination with multiple organizations within the school system. A teacher can plan a lesson using stand-alone software and, assuming that the computers are working and available, be confident that the tools will work when called upon. There is no way, however, for a classroom teacher to predict whether or not the Internet will be available when needed. In K–12 settings, especially urban settings, the Internet is "down" more than it is "up," making such planning a gamble. This introduces challenges to usability, in that the classroom can no longer operate in isolation from its surrounding school or district context. In order to use the cognitively oriented technology innovation, teachers are dependent upon a broad range of district personnel beyond the classroom.

In many large school districts, responsibility for technology management is assigned to centralized management and information services (MIS) departments. These departments were responsible for computers and networks for district business functions long before the classroom use of computers became popular (Hodas, 1993), and were obvious candidates for overseeing the instructional uses of these networks. The key problem is that MIS departments generally do not have "support for learning" as a central part of their mission. In our work, we discovered that curriculum and technology administrators had not previously had occasion to discuss how their two organizations should interact. The introduction of our cognitively oriented technology innovation provided the impetus for these discussions, in which it was discovered that in fact the two parts of the organization had divergent goals and missions. In large part, what is needed is a "tightening" of the "loose coupling" for which educational organizations are well known (Weick, 1976), such that different elements of the organization (central administration, school administration, and classroom teacher) are accountable to one another and have clear chains for reporting problems and seeking resolutions (Elmore, 2000).

Because cognitively oriented technology innovations require support, input, and knowledge from so many diverse components of school organizations, they stand to benefit from an emerging view of school leadership called "distributed leadership" (Spillane, Halverson, & Diamond, 2001). This view posits leadership as an emergent property of how organizations operate, instead of as traits held by individual actors. In an environment that values distributed leadership, knowledge, feedback, and most importantly, decision making authority can be shared among those who are most integrally involved in enacting the innovation, thus decreasing usability issues by dealing with potential barriers as they emerge. In making this argument, we are not calling for "site-based management" or other forms of decentralizing school organizations. Indeed, research on what works in school reform among large urban districts indicates that a strong central voice and direction for reform is a key to success (Snipes et al., 2002). However, having a strong centralized vision for district change is not the same thing as consolidating the necessary leadership and knowledge to drive the reform in a centralized authority. Indeed, reforms on the whole are more likely to succeed when people at all levels of the organization share ownership of that core vision and feel empowered to act on its goals (Elmore, 2000).

In our work with Detroit, the need for a distributed view of leadership became apparent in efforts to establish classroom Internet connectivity. Central office personnel with decision-making authority for Internet access had no established avenues for learning about how the Internet was to be deployed in individual school buildings, and building-level administrators were often unaware of the specific network-connectivity demands of teachers using the LeTUS curriculum materials. This led to situations where school personnel believed that they had done what was required to enable classroom use of the Internet, but had no way of knowing whether their solutions matched with the needs of those below them in the organization. In an attempt to resolve these disconnects and encourage a distributed approach to leadership within the district, we worked to create contexts where administrators could meet with their peers and others in the system, including teachers, to uncover and discuss the issues they were facing related to the use of cognitively oriented technology innovations (Murray et al., 2001).

Proposed areas for further research. Organizational structure issues create serious usability gaps for innovations along dimensions of both district culture and policy/management. How can districts best be helped to examine their organizational structures in light of the demands of cognitively oriented technology innovations? How should organizations be realigned to increase the usability of cognitively oriented technology innovations? How can schools foster distributed leadership for technology innovations that spans the organization? What forms of professional learning help school leaders build their capacity to support reform?

ISSUES RELATED TO THE RESEARCH COMMUNITY'S CAPACITY

The challenges for schools and school organizations that we describe above will sound familiar to anyone who has studied the integration of technology into K–12 classrooms, and probably also to those who have worked with instructional innovations in general. What makes research on the use of cognitively oriented technology innovations in systemic reform different is that one is forced to consider issues of school capability, culture, and policy/management simultaneously in order to come to an understanding of potential challenges to usability. Thus far, our discussion may seem as if we place the burden for closing usability "gaps" on schools and school personnel. To the contrary, we wish to highlight a point we made in describing our "usability cube" framework (Blumenfeld et al., 2000), which is that reducing barriers to usability is a two-way street. It is as critical for us, as researchers, to learn how to adjust the demands of our cognitively oriented technology innovations as it is for school organizations to embark upon changes to meet innovations' demands, while preserving the core principles of the innovation. It is in this way that the boundaries of design-based research go beyond the technical structures of the innovation. There are also issues that, while perhaps not areas for research in themselves, are important with respect to the ability of the research community to carry out systemic research on cognitively oriented technology innovations. Below we discuss two of these issues: How researchers consider the nature of an "innovation," and the critical issue of collaborative relationships between schools and academic research organizations.

The Nature of Innovations

To make cognitively oriented innovations more usable, researchers must reconsider just what, exactly, *is* an innovation in a systemic reform environment. The research literature on curriculum innovations describes two primary perspectives: "fidelity" and "mutual adaptation" (Snyder et al., 1996). The fidelity perspective seeks to keep innovations intact, and measures success of implementation in terms of divergence from the intended innovation. The essence of this perspective is captured in the very name of the "technology transfer" offices in many universities. The mutual adaptation perspective, which was first highlighted by the Rand "Change Agent" study (Berman & McLaughlin, 1975) recognizes the importance of local re-invention of innovations in order to better match the norms (and capacity) of the adopting organization. We entered into our collaboration with Detroit knowing that we did not want to employ a "fidelity" perspective towards our innovation, but we were unprepared for the number and range of changes to our innovation that became necessary as we negotiated to reduce the capability challenges involved in making our innovation usable. We began with a view of diffusion for our innovation where we hoped to work with early adopters in order to build a critical mass for widespread adoption throughout the district (Rogers, 1995). As we realized that our initial attempts to create capacity within the district were not going to be successful, we shifted our perspective towards mutual adaptation. In doing so, we faced an inherent challenge of this approach – variations that cause innovations to become very different than originally envisioned, potentially weakening the impact of the innovation (McLaughlin, 1990). A key challenge in systemic research on cognitively oriented technology innovations is to understand when modifications violate core principals of the innovation, and to make sure that these changes are avoided. Schools will "push" on innovations to conform to business-as-usual (Cuban, 1986). At the same time, researchers need to push back on the school to preserve the core principles of their innovations. For example, administrators may be reluctant to grant science teachers greater or more flexible access to the computer lab than other teachers. Innovation designers may be reluctant to alter the demands their innovation make on access to computers. Finding a compromise is likely to engage both policy/management structures and school culture issues.

How can researchers create flexibility in their innovations to allow for mutual adaptation that preserves core principles? An example of how *not* to do this comes from past efforts to create "teacher proof" innovations. This is done either by attempting to direct the teacher's every action, or through the use of technology, remove the teacher from the role of instructor altogether. More recently, developers of cognitively oriented technology innovations have moved to create flexibly adaptive materials, in order to enhance their fit with divergent classroom contexts (Squire, MaKinster, Barnett, Leuhmann, & Barab, 2003) and encourage mutual adaptation. But precisely how to do this is still an open question. An approach taken by many projects is to under-specify the curriculum, perhaps presenting only a loose framework of goals and suggested activities, but leaving it to teachers to define the details. This approach caters only to a minority of teachers who are able to invest effort in such development (Cohen & Ball, 1999). Teachers are unlikely to be willing to develop a whole curriculum around an underspecified innovation, as Cuban and colleagues found in their examination of why technology in schools is not well utilized even when broadly available (Cuban, Kirkpatrick, & Peck, 2001). More specification around how the innovation "should" be used is necessary, but within broad parameters. In addition, for many teachers in systemic reform contexts, the curriculum materials themselves can carry crucial information about how to use the technology, as in the vision of "educative" curriculum materials called for by Ball and Cohen (1996).

In our work, we attempted to create materials that were educative, highly developed, and specific about how teaching might proceed (Schneider & Krajcik, 2000). In professional development, we attempted to stress with teachers that our materials *could* serve as a complete guide if teachers wished, but if they wanted to adjust activities to better suit their own particular goals and contexts (especially for scheduling constraints), they should feel free to do so. In practice, novice teachers often felt uncomfortable deviating from the printed curriculum, and as a consequence were often unable to complete it. Alternatively, when teachers *did* feel comfortable enough to make modifications, the changes sometimes undercut the intention of the innovation, such as when teachers would omit technology use altogether due to lack of comfort with or availability of technology (Blumenfeld et al., 2000).

How Can Collaborative Partnerships Enhance the Usability of Innovations?

Strong collaboration between school systems and the developers of cognitively oriented technology innovations is critical for addressing gaps of culture, capability, and policy/management. All parties must own and be committed to the innovation (Honey & McMillan-Culp, 2000). This goes further than simple endorsement by the central office. It involves creating a common vision and plans to achieve it. It means that researchers need to work with educators to specify and develop plans for enactment that account for divergences between the capacity of the school system and demands of the innovation. Plans for enactment must be developed at all levels of the system with mechanisms aimed at integration and coordination so that everyone sees the innovation as part of district rather than outside efforts and strives to make it work. Researchers need to explore the dimensions of these partnerships. What are the components of a successful partnership? How are such partnerships fostered? Confrey and her colleagues found that failure to establish partnerships and create a shared understanding of the goals and research approach was a proximal cause of a project being forced out of its school setting (Confrey, Bell, & Carrejo, 2001). The Schools for Thought project in Nashville encountered a similar issue with respect to the local school board (Goldman & Cottom, 2001), where local politics created unforeseen challenges to a project that was otherwise successful. The lack of stability among top school administrators, particularly in urban districts, presents a challenge to any attempt to create educational innovations that by their very nature are intended to be implemented over an extended period of time. In situations where leadership shifts, an external research partner might in fact be a source of continuity, helping to ensure that activities at the level of classrooms, schools, and middle levels of district management find an audience with new top leadership, in order to promote continued effort for promising innovations. This was our experience in Detroit, where the LeTUS partnership helped to provide a consistent goal for curricular reform that has, so far, lasted through three changes in district leadership. In part, this was because the partnership was seen as a source of continued external visibility and funding for the districts' ongoing efforts at reform.

In our experience with Detroit, we found that our extended collaboration was important for establishing trust with schools, for bringing multiple viewpoints to inform strategy, for opening doors to solve problems such as making the Internet available to specific classrooms, and for creating specialized professional development programs to serve teachers involved in our cognitively oriented technology innovation. Tenacity is a key element of our successful collaboration with Detroit. That we work as partners with schools for periods of years is viewed positively by teachers and administrators; they know that we will be there when they need us. To be successful, these partnerships must outlast the typical duration of current funding cycles or the notoriously short tenure of urban school administrators. But as academics, there will come a point where we will move on to other sets of issues, perhaps in another location. For this reason, researchers and schools need to work in collaboration with entities that can take stable innovations and support their ongoing use in school systems. A key to our partnership was the presence of a champion within the district, who helped to legitimize our innovation within the district. Are the presence of such individuals a matter of happenstance? Or can research uncover strategies for identifying and working with champions? How can innovations be made sustainable when champions leave the district or are replaced?

In addition to collaboration between researchers and schools, there also needs to be collaborations among researchers, and between researchers and commercial enterprises. The layers of challenge inherent in systemic research on innovations that we describe are daunting; the broad variety of expertise and effort needed to address these challenges will undoubtedly be overwhelming for researchers working by themselves. For that reason, researchers who employ technology for learning would benefit from establishing linkages to other researchers working in school reform to build larger organizations that *do* have the capacity to address the varied needs of reform. Our own research group combines expertise in computer science, educational technology, psychology, science education and language and literacy. Other research groups have reached out across projects to form innovative collaborations, such as Schools For Thought, which combines three different cognitively oriented technology innovations into a district-wide reform effort (Williams et al., 1998). How can these kinds of multiorganizational collaborations be fostered?

Can multiple cognitively oriented technology innovations exist in a shared school context? At the moment, this is problematic due to the piecemeal nature of much technology design. The technologies that are most used in schools are general-purpose tools that were developed for businesses, such as word processors and web browsers (Becker, 2000). Software tools developed by the research community, on the other hand, are usually developed for a specific purpose. Each tool has a unique interface, requiring teachers and students to learn new commands, skills, and metaphors. The learning curve is tremendous, particularly for a tool that students might use once, and only briefly. Principles of software usability (e.g., Nielsen, 1993) and learner centered design (Soloway, Guzdial, & Hay, 1994) predict that such hurdles are strong disincentives to the adoption of technology. In our work, we have found greater success by developing tools that are used in many curriculum units across grades. How can the field develop shared frameworks for the design of common technology interfaces? This is a serious challenge that can only be resolved through collaboration.

The issues of collaboration and the manner in which we conceptualize cognitively oriented technology innovations are potentially significant barriers to the usability of those innovations. If we are to make progress on closing usability gaps, it is essential that we reexamine the assumptions inherent in our own research organizations that may impede our ability to help schools make effective use of our innovations.

CONCLUSION

Why have so few cognitively oriented learning technologies found a place in the everyday practice of teaching and learning in K–12 schools? We argue that a primary reason is that research to date has not focused on issues of how such innovations function at the level of school systems. This results, in part, from the fact that much design-based research focuses on a designed product or resultant theory and not the system variables that impact the scaling potential of the work beyond the sites where the research was carried out. We have argued for extending or conception of design-based research to include research on system-level issues that impact the scalability, sustainability, and ultimately the usability of innovations. We also described a framework for examining the problem space for such research that explores usability in terms of "gaps" between the culture, capability, and policy/management structures that exist within schools and the demands of cognitively oriented technology innovations. Our experiences working in the context of systemic reform reveal that solutions to these problems do not result from focusing on any one of these dimensions to the exclusion of others. To the contrary, it is necessary to conceptualize research that addresses multiple dimensions in a way that reflects the real-world complexities of the settings in which cognitively oriented technology innovations are to be used. It clear to us that no technology innovation, no matter how compelling or well conceived, will become broadly used and sustained without attending to the issues surrounding the "dilemmas of practice." Previous research has uncovered many of these issues, but has not offered solutions. In part, this may be because each issue has multiple components that need to be addressed across areas of capability, culture, and policy/management. The ultimate goal of our proposed extensions to design-based research is to uncover the means by which cognitively oriented technology innovations can be made highly usable by schools. It is now possible to build upon research on cognitively oriented technologies at the classroom level in order to understand the constraints and contexts at the level of school systems. We have suggested the areas of teacher learning, assessment, technology planning, and organizational structure and leadership as areas that may be particularly valuable for further research related to creating usable cognitively oriented technology innovations. We hope that an expanded body of research in this area will allow schools and researchers seeking to create broadly scalable and sustainable cognitively oriented technology innovations to examine how others in similar contexts "reduced gaps" so that innovations might be employed successfully.

We understand that not all researchers who work with technology will find work in systemic reform contexts appealing or appropriate. However, it is essential that we continue to explore "cutting edge" technologies that may not be ready for widespread use in schools, as well as basic cognitive research on learning and understanding. But the field, as a whole, would benefit from engaging in systemic design-based research on technology innovations. If we do not undertake this challenge, the risk is that cognitively oriented technologies that demonstrate great promise for improving learning and are consistent with the goals of national standards are unlikely to achieve widespread use in schools, because we will not understand how to create conditions that make them usable in real school contexts. If we do not make progress in this area, we will have missed an opportunity to bring some of the most potentially valuable technological innovations from the research community to bear on the ongoing challenge of systemic school reform.

ACKNOWLEDGMENTS

This research was funded with support from the National Science Foundation under the following programs: REPP (REC-9720383, REC-9725927, REC-9876150) and USI (ESR-9453665). Additional funding was provided by the W. K. Kellogg Foundation, the Joyce Foundation, and the Spencer Foundation.

We are indebted to our collaborators in the Detroit Public Schools, to the students of Detroit, and to the staff of the Center for Highly Interactive Computing in Education (hi-ce). We also wish to thank Sasha Barab, Fred Carrigg, Elizabeth Davis, Margaret Honey, Ken Koedinger, Scott McDonald, Carla O'Connor, Paul Pintrich, Lesley Rex, Jody Underwood, Phil Vahey, and the anonymous reviewers for their feedback and assistance.

Many of the ideas contained in this article were presented by the first author in the Jan Hawkins Award session at AERA 2002 (Fishman, 2002). All opinions expressed in this work are the authors' and do not necessarily represent either the funding agencies or the University of Michigan.

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