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ABSTRACT

The past decade has seen great strides in the design of new learning technologies that support learning aligned with standards-based constructivist and inquiry teaching practices. Though there is considerable evidence that these technologies can help students learn when used appropriately, they are rarely employed beyond the small-scale settings in which they were designed and nurtured. Therefore, they have had only limited impact on K-12 education. This paper argues that a major reason current learning technologies are not being used broadly in schools is that there are incompatibilities between the demands of the innovations being introduced by the research community and the extant culture, capability, and management structures of schools. There are many plausible reasons; this paper suggests that a primary one is the nature of current research on learning technologies. The paper proposes that research on technology for learning should give expanded attention to a broad range of factors in school settings in order to better understand what is needed to bridge the demands of innovations and the realities of school culture, capabilities, and policy and management structures. As a starting point, the authors present potential areas for research in terms of the key challenges faced by teachers in trying to use inquiry-oriented technology, by educational leaders in enabling the use of inquiry-oriented technologies in schools, and by researchers attempting research in systemic school contexts. These challenges are derived from the authors' own experiences in the use of technology as a part of a large-scale urban systemic school reform project. (Contains 80 references.) (Author)

Creating Scalable and Systemic Technology Innovations for Urban Education

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Abstract

The past decade has seen great strides in the design of new learning technologies that support learning aligned with standards-based constructivist and inquiry teaching practices. Though there is considerable evidence that these technologies can help students learn when used appropriately, they are rarely employed beyond the small-scale settings in which they were designed and nurtured. Therefore, they have had only limited impact on K-12 education. This paper argues that a major reason current learning technologies are not being used broadly in schools is that there are incompatibilities between the demands of the innovations being introduced by the research community and the extant culture, capability, and management structures of schools. There are many plausible reasons; we suggest that a primary one is the nature of current research on learning technologies. We propose that research on technology for learning should give expanded attention to a broad range of factors in school settings in order to better understand what is needed to bridge the demands of innovations and the realities of school culture, capabilities, and policy and management structures. As a starting point, we present potential areas for research in terms of the key challenges faced by teachers in trying to use inquiry-oriented technology, by educational leaders in enabling the use of inquiry-oriented technologies in schools, and by researchers attempting research in systemic school contexts. These challenges are derived from our own experiences in the use of technology as part of a large-scale urban systemic school reform project.

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Creating Scalable and Systemic Technology Innovations for Urban Education

Technology is becoming an increasingly common component of K-12 education in the United States. The student to computer ratio has been dropping at an accelerating rate (Becker, 1999), and the number of schools and classrooms with Internet connectivity has been rising just as rapidly (Rowland, 1999). For educational researchers interested in using technology to support teaching and learning, that's the good news. The bad news is that computers in schools are not being used to promote thoughtfulness, inquiry, or other learning behaviors called for both by new curriculum standards and cognitive conceptions of learning. It is essential that researchers who work with technology ensure that school uses of technology both promote the greatest amount of student learning and contribute to the broader systemic reform agenda, as opposed to uses of technology that either preserve the troubled status quo or are merely technology use for its own sake. If the public perception of technology is that its expense does not equate to improved performance, support for *any* kind of technology use will wither, and so will research and development of technology for learning as a viable enterprise. This paper is about the challenges associated with using technology to promote inquiry and thoughtfulness on a large scale as a part of systemic reform. We argue that the field as a whole needs to concern itself with these issues, or the promise offered by recent studies of technology and learning will fail to have a meaningful impact on schooling.

In her 2000 AERA Presidential Address, Shepard (2000) describes the transition in education from a behaviorally motivated curriculum of "social efficiency" to a reformed vision of curriculum rooted in Vygotskian social constructivism that assumes that all students can learn. Earlier, Graham (1993) described the changes in American education as a movement from social sorting to a vision of equal access for all and finally to the current (and still highly contested) notion that all students can achieve at a high level. Research in technology for learning has these shifts in educational priorities, and the past decade has seen the development of "tools for thinking" that enable learning activities that would not be possible (or would be prohibitively difficult) without them (Bransford, Brown, & Cocking, 1999). This includes tools that promote expression, collaboration, and critical discourse among students both within and across classrooms (Scardamalia & Bereiter, 1991). They are tools that enable students to visualize complex phenomena and work with large datasets that represent cutting-edge scientific practice (Edelson, Gordin, & Pea, 1999). They include tools for modeling cause and effect relationships to help students build their understanding of complex natural systems (Jackson, Stratford, Krajcik, & Soloway, 1994). And tools that scaffold complex investigation process for students (Linn, 1996; Quintana, Fretz, Krajcik, & Soloway, 2000). These tools specifically address the kinds of learning called for both by modern content-area standards documents (e.g., National Council of Teachers of Mathematics, 1989; National Research Council, 1996) and summarized in the recent National Academy of Sciences report on cognitive concepts of how people learn (Bransford et al., 1999).

These cognitively-based tools, however, are not widely used in schools today. The most prevalent uses of technology in schools are those that are rooted in behavioral theories of learning (such as integrated learning systems or drill and practice tools), or those that are designed without regard for any particular pedagogy (such as PowerPoint, HyperStudio, or word processors) and that on their own, absent from deliberate curriculum design or reform efforts, are rarely used to support inquiry or constructivist teaching.

Why is it that uses of technology which have been shown to help students achieve at high levels and meet new educational standards (Roschelle, Pea, Hoadley, Gordin, & Means, 2000) are not proliferating in our schools? One major reason is the culture of schools, which has been described by many as resistant to change and highly effective at suppressing or subverting innovations that break with established norms and practices (e.g., Cuban, 1986; Sarason, 1982; Tyack & Cuban, 1995). Another reason concerns the research approaches that have been used to date. By necessity, these cognitively-based technologies are developed in "hothouse" environments where students and teachers receive generous attention from both university faculty and graduate students (or their corporate equivalents, for industry-sponsored development projects). The resource environments for these development sites is unusually rich, to make sure that innovations don't fail to work for reasons that can be avoided, such as inadequate numbers of computers or malfunctioning software or limited teacher knowledge. Advances in the scientific understand of learning with technology predominately occur in either laboratory settings (e.g., Koedinger & Anderson, 1990), or as part of design experiments (Brown, 1992). This form of research has been and will continue to be essential to developing both new technologies and refined understanding of the learning process. But it is insufficient for ensuring that the lessons learned about how to foster increased student learning find a foothold in everyday practice in classrooms that do not enjoy the same focused attention and support. The result is that the most valuable uses of technology are not achieving meaningful *scale*, and more importantly, are not becoming a part of the everyday or *systemic* practices of schools or school reform (President's Committee of Advisors on Science and Technology, 1997). As a field, we lack knowledge of the pathways or channels between small-scale research and development in technology and learning and the means of bringing it to broad-based systemic use in schools. Shepard (2000) recognized this when she advised AERA members to develop research approaches that are embedded in the "dilemmas of practice" (p. 13). 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 paper is about *what it will take* to move the new and inquiry-oriented technologies being developed by the research community beyond hothouse research and development environments and into large scale and systemic use in schools. In other words, what it will take to address Shepard's "dilemmas of practice." To begin, we argue that work in systemic reform is fundamentally different than simply "scaling up." We also present a model for examining how technology "fits" into various school contexts. Next, we examine the range of challenges that high-end technology presents for teachers and educational leadership that inhibit the successful systemic and wide-spread use of innovations. Finally, we turn to a consideration of challenges and new directions needed for those who conduct research on the use of technology in education. The challenges and the model presented in this paper are based on work by our research group in collaboration with the Detroit Public Schools in the context of the Center for Learning Technologies in Urban Schools, a long-term effort to introduce standards-based and inquiry-focused curricula with embedded learning technologies to middle schools in Detroit.

Scale vs. Systemic Reform: Distinctions that Make a Difference

The popular media is full of stories of innovative technology uses in classrooms across the country, but these are isolated (and often short-lived) pockets of innovation. Using current conceptions of "large scale," researchers are understandably pleased if their innovation is used by hundreds of teachers, reaching (potentially) tens of thousands of students. But there are approximately three *million* teachers in the United States, so it is possible to reach hundreds of teachers yet still not make a dent in the larger educational system. Furthermore, teachers who participate in these types of innovative projects are typically volunteers. These teachers operate with the permission of their administrators and schools, but not necessarily with their support. In considering the differences between this type of scaling and *systemic* reform, we rely on the commonly used definition from Smith and O'Day (1991), which speaks to a focused coordination of elements of the larger educational system beyond a single classroom or school. Such coordination includes state-wide policy, curriculum, and professional development efforts. Reflecting on systemic reform work in Union City, New Jersey, Honey, McMillan-Culp, and Carrigg stated the challenge in the following terms:

> In order to be effective, innovative and robust technological resources must be used to support systematic changes in educational environments that take into account simultaneous changes in administrative procedures, curriculum, time and space constraints, school-community relationships, and a range of other logistical and social factors. (Honey, McMillan-Culp, & Carrigg, 1999)

Technological innovations that are constructed with systemic reform as a focus must actively seek out the participation and understanding of personnel across and at all levels of the school district. If an innovation becomes rooted in schools in a systemic and sustainable fashion, it can potentially influence the learning of much greater numbers of students over the long haul than even the largest short-lived innovations. It is possible to work "at scale" and not have achieved systemic use of one's innovation, but to work systemically, it is important to have some understand of how an innovation will function at scale, or at least at the scale of an entire school district. In the case of large urban districts, this frequently means working with a larger number of teachers than most "large scale" technology projects that have a widely distributed base of participants.

To be sure, there are challenges in working with a large-scale technology innovation project that is not intended to be systemic (Gomez, Fishman, & Pea, 1998). However, the solutions for such problems tend to be idiosyncratic with respect to individuals' needs in different locations, and not designed to be systematic or necessarily sustainable (though the latter is often a goal of large-scale projects). Such solutions might be sufficient for commercial technology developers, where selling large numbers of units is more desirable than systemic adoption in any particular local setting. Developing innovations for a systemic reform context, on the other hand, requires attention to systematic issues such as policy change, wide spread professional development planning, reliable and affordable materials production and distribution. These differences present an entirely new level of challenge for research and development of technology for learning.

If a reform is to be considered "systemic," it is important that the results of the reform be innovations that are both *scaleable* and *sustainable*. That is to say, the innovation or reform must be useable (and used) by a broad range of actors at the targeted levels of the school system, and it must be useable over the long term, without the kinds of targeted (and expensive) support that normally accompany the early, "experimental," rollout or introductory phases of an innovation.

A Framework for Considering Technology in Systemic School Contexts

Our own work as part of the Center for Learning Technologies in Urban Schools[2] provides a window into the challenges of working with technological innovations in a systemic reform context. The basic frame for this effort is the development and systemic integration of inquiry-based science materials with embedded technology in the Detroit Public Schools (Blumenfeld, Fishman, Krajcik, Marx, & Soloway, 2000). In this ongoing research, we are engaged in a collaborative effort with the school district to develop and deploy challenging, standards-based and technology-integrated inquiry science curricula for use by teachers and students in middle schools throughout the district. This work involves extensive curriculum development efforts (Singer, Marx, Krajcik, & Clay-Chambers, 2000), development and integration of technologies to support both student and teacher learning (Fishman et al., 2001; Marx, Blumenfeld, Krajcik, & Soloway, 1998; Soloway, Krajcik, Blumenfeld, & Marx, 1996; Soloway et al., 2000), broad-based professional development efforts (Fishman, Best, Foster, & Marx, 2000), and work with school and district administrators (Fishman & Gomez, 2000; Murray, Fishman, Gomez, Williams, & Marx, 2001). Other papers document our accomplishments and challenges regarding student learning (Krajcik, Marx, Blumenfeld, Soloway, & Fishman, 2000).

Although we feel that we have had many successes in our collaboration with Detroit, there have been many bumps and detours in the work. Our research group has been involved in more traditional (i.e., not systemic) forms of educational technology development for more than a decade, working primarily with volunteer populations of teachers involved in design experiment types of projects (e.g., Blumenfeld, Krajcik, Marx, & Soloway, 1994; Krajcik, Blumenfeld, Marx, & Soloway, 1994; Marx et al., 1994). To help us understand the challenges we were facing in the unfamiliar territory of systemic reform, we developed a framework depicting three critical dimensions of the school environment that must be considered when working in reform (Blumenfeld et al., 2000). These three dimensions are district culture, capability, and policy and management, and may be conceptualized as axes that form a three-dimensional space (see Figure 1). Together, these three axes describe the capacity for using an innovation that exists within the particular context being explored.

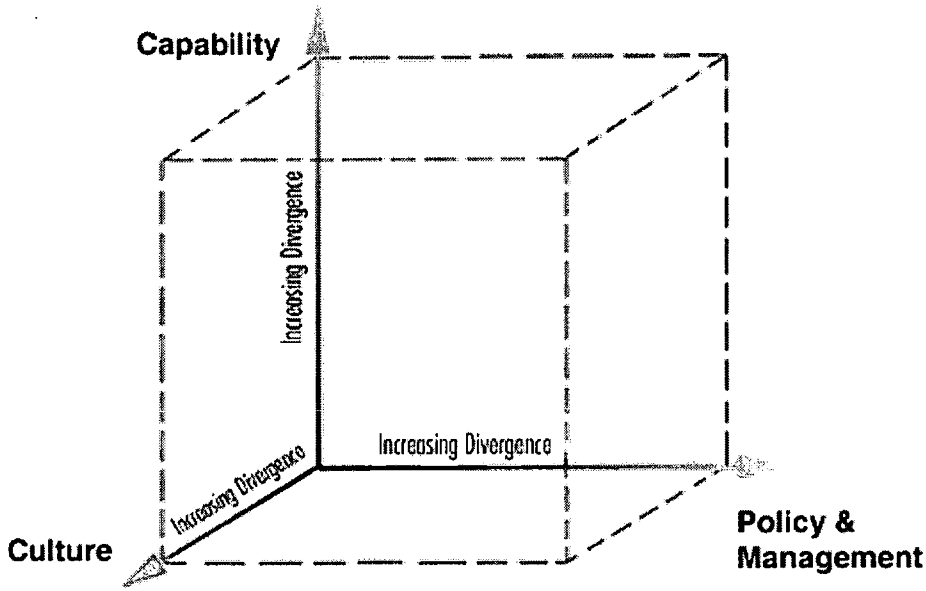

Figure 1. Diagnostic tool to identify challenges to innovations in systemic reform.

The three axes of Figure 1 represent dimensions that define "gaps" between existing conditions in schools and the requirements of technological (or any other) innovations. From the perspective of the users of the innovation, the space in the cube defines the "capability gap," "culture gap," and "policy and management gap" inherent in the innovation. We posit that the closer an innovation is to the origin of these axes, the less challenging it is to the users' existing capabilities, organizational culture, or policy and management structures, and the more likely it is to be adopted and sustained. The placement of an innovation and its components on an axis defines the space within which collaboration among partners needs to take place in order for the innovation to succeed. The greater the gap in any dimension, the more pressing it will be either for the innovation's developer to modify the innovation, or for the school district to modify its practices, culture, or capabilities, perhaps through professional development or some other means.

It is important to recognize that the required changes are not the sole province of the school system. Rather, change must be a two-way street, with the innovation's developer(s) making modifications where needed as part of ongoing collaboration with the adopting district(s). Note that the scale of the axes is completely relative; one cannot assign an absolute rating on any dimension without reference to a specific context. That is, each time an innovation is brought to a new setting, its "location" within the three dimensions must be considered anew. Furthermore, there are external pressures on both the system and the innovation, so today's conditions might be different tomorrow. Thus, the relationship between the system and the innovation on these axes must be continually reevaluated. We have presented this framework to facilitate our discussion of the challenges in the systemic use of technology for both teachers and educational leaders.

Challenges for Teachers

Teachers are the key to the successful implementation of any educational innovation (Hawley & Rosenholtz, 1984). Yet when it comes to new forms of learning technologies, researchers and developers have not yet given serious attention to the kinds of support that teachers require in order to grasp and ultimately apply these innovations in their teaching. Many of the challenges facing teachers are related to a mismatch between technology and school culture. Researchers need to carefully consider how their innovations stress the cultural norms of the school operates for teachers, especially the norms for teaching and learning practices. Other challenges come from the ways that technology pushes the limits of teachers' capabilities.

Lack of Curricular Materials

One reason why technological innovations fail to take hold in schools is because teachers do not have proper guidance in how to make use of them. A common approach taken by the educational technology community is to under-specify ideas or models for curricula that utilize their technological innovations, believing perhaps that such important integration tasks are best left up to the teaching professionals who will make use of the new tools. But this approach caters only to the minority of teachers who are willing or able to invest effort in such development. The vast majority of teachers are prepared to develop lesson plans, but not entire curricula. They acknowledge that constructing such materials will be very challenging, and several research groups are attempting to meet this challenge in an effort to embed guidance on both inquiry-oriented teaching and embedded technology use in new curriculum materials (e.g., Singer et al., 2000).

We believe that a major impediment to the successful use of new technologies, particularly those that call for a change or reform in the way teachers teach and students learn, is a lack of curricular materials that serve as a practical guide to enactment for teachers. In their examination of why different types of instructional innovations succeed or fail, Tyack and Cuban (1995) employ the metaphor of a "grammar of schooling" that provides structure for everyday activity and serves as a framework for the interpretation of new materials or ideas. In our framework, this "grammar" is the culture of the school system. For instance, self contained software programs like tutorials fit easily into classroom routines that focus on drill and practice; software that entail data collection, multi-modal representation, cycles of public critique, and revision and collaboration within and outside the school are more difficult to instantiate (Hodas, 1993). In addition to stressing the cultural norms of schooling, a lack of curricular materials also presents a challenge to the capabilities of teachers, who will look to such materials as a guide for practice.

Our experiences with Detroit illustrate the need for good curricular materials that integrate technology. Our collaboration began as a joint effort to explore the possibilities for integrating technology in science within the city. It was rapidly established by the school district participants that a key to this effort would be the development of curriculum that provided a context and guidance for the use of technology in teaching. A number of research-based tools that have enjoyed widespread adoption are also embedded in curriculum materials that address standards and provide adequate guidance to teachers on how to use the materials in their curriculum. These include a number of projects developed by the Cognition and Technology Group at Vanderbilt, including the Jasper Woodbury series in mathematics (Bransford, Sherwood, Hasselbring, Kinzer, & Williams, 1990), and the Little Planet literacy series (Sharp et al., 1995). The Middle School Mathematics Through Applications project (Goldman & Moschkovich, 1998) has also found success in promoting the systemic use of their tools for modeling and science as part of complete curriculum units for teachers. Our curricula were designed with explicit links to district standards and frameworks to reassure teachers that using these materials would not detract from their progress in raising test scores in required areas.

Ball and Cohen (1996) recognized the disjunction between innovation and school culture when they crafted their argument about embedding reform practices into curriculum materials. They refer to curriculum materials that embed guidance on reform-oriented teaching "educative." Their argument is that teachers turn to curriculum for guidance about what to teach and how to teach it. Thus, curriculum teaches *teachers* how and when technology can and should be used with students. Since curriculum is, from teachers' perspective, a dependable component of school culture, it is a valuable tool for introducing technology into classroom practice.

Technologies Often Call for Challenging Pedagogical Approaches

Another area of difficulty is that the "high-end" uses of technology that show the most promise for school reform and learning, those that foster thoughtfulness and inquiry, are also linked to pedagogical practices such as constructivism (Von Glasersfeld, 1989) or project-based learning (Blumenfeld et al., 1991) that stress the capabilities of teachers (Cohen & Barnes, 1993). These approaches are widely recognized as challenging for teachers to learn to use in the classroom, involving new approaches to classroom management, the organization of knowledge, and assessment, to name just a few areas of difficulty. In pointing out this challenge, we do not mean to suggest that new technologies should back away from these pedagogical approaches. Rather, we want to make explicit an area where many teachers may be inclined to shy away from a proposed innovation. This is another case where innovations may violate the culture that teachers are familiar with, in this case by asking them to make changes in their pedagogy to accommodate technology without providing sufficient supports or changes in the surrounding context for teaching to enable such a shift. Such a change also poses a definite challenge to capabilities.

Teachers' discomfort with open-ended student exploration led them to either lead students through the use of Model-It modeling software (Jackson et al., 1994) in a step-by-step fashion, resulting in student models that were all exactly the same, instead of a variety of models representing the results of students' pursuing answers to their own questions. This "start-up" issue resolved itself for most teachers in the second and third year they used the curriculum materials. They could see the goal state in the curriculum materials, and with professional development eventually took the necessary steps to include the new approaches in their teaching. The main point we wish to make is that, absent connection to a coherent program of curriculum and professional development, it is likely that new technologies will be rejected or abandoned by teachers who are not able to see their eventual value. In addition, the cognitive benefits to students may be rendered moot as teachers convert inquiry to recitation.

Teachers Need More Than Just "Technology Training"

Nearly every report about technology in education calls for expanding teacher training with technology (e.g., CEO Forum on Education and Technology, 1999; Education Week, 1998; U.S.

Congress Office of Technology Assessment, 1995). That teachers need to know *how* to use technology before they can successful use it in the classroom is not in dispute. However, just knowing how to use technology is not the same as knowing how to use technology to improve student learning. What teachers need to help students learn with technology is specific pedagogical content knowledge (PCK; Shulman, 1987), strategies to help teach content using particular methodologies and tools (Margerum-Leys & Marx, 2000). At present, the archetypal form of teacher development for technology is the after school workshop, where teachers are taught how to use word processors or presentation tools or web browsers. Because the people leading these workshops are not involved or familiar with the curriculum teachers are using, no attempt is made to show teachers how to use the new technologies within the curriculum. The result is predictable—teachers generally don't use the technology as part of regular curricular activities (Becker, 1999).

We again turn to our work with Model-It to provide an example of the importance of providing PCK support to teachers as part of teaching them how to use technology. Though we had several workshop sessions where we gave teachers tutorials on the many different functions within Model-It (a "technology training" approach), our observation of teacher use of Model-It with students showed little evidence of any knowledge building other than a familiarity with the aspects of the software. Follow-up with teachers revealed that they were still unsure of how to successfully utilize the tool in their classroom. This information was used to design a subsequent workshop on Model-It that focused on concepts embedded within it, such as graphical representations of relationships, and pedagogical principles involved in getting students to use these tools. We also introduced evidence from pre-post tests on the water curriculum unit around which this collection of workshops was focused (which demonstrated that students are particularly challenged by line graph representations of data, which are used in this software tool) to focus on student work. In this manner, teachers not only gained familiarity and comfort in the use of this software, but they also examined student challenges in working with this tool. Sample models were created to demonstrate student challenges with graphing, as well as other research based challenges (Krajcik, Blumenfeld, Marx, & Soloway, 2000) in using Model-It. Teachers were asked to review the models and, within small groups, develop assessment strategies to evaluate student learning. They then focused on developing strategies for using this tool with their students, including the introduction of the tool, focus on content modeled in the software, and management strategies for working with groups of students using this tool. Subsequent evaluations and artifacts created from this professional development activity showed more understanding of the use of this tool as well as greater perceptions of understanding of the pedagogy by the teachers. In-class support personnel notes from the field revealed that teachers who participated in this workshop were indeed better able to help their students use Model-It, and their students showed improvement on post-test items related to graphing.

There are Too Many Forms of Technology for Teachers to Learn

The piecemeal nature of technology is a challenge to teachers' technological capabilities and is another impediment to its implementation and widespread use. For the most part, the technologies that are most used in schools today are general purpose tools, such as word processors and web browsers (Becker, 2000). Such tools are the products of industry, developed primarily with the lucrative business market in mind. Software tools developed by the educational technology research community, on the other hand, are usually developed with a specific purpose in mind. Some examples are tools designed to help students learn about weather (Fishman & D'Amico, 1994; Songer, 1996), tools to help students visualize two-dimensional data (Edelson et al., 1999), tools to support learning about genetics (Horwitz et al., 1998), or tools to help students learn to read (Pinkard, 1999). The challenge for teachers is that each of these tools has a unique interface, requiring teachers (and students) to learn new commands, skills, and metaphors for each new area in the curriculum that uses technology. The learning curve is tremendous, particularly for a tool that students might use only once, and for only a relatively brief period of time, in their academic career. Principles of software usability design (e.g., Nielsen, 1993; Norman, 1988) and more student-focused learner centered design (Soloway, Guzdial, & Hay, 1994) dictate that such hurdles act as a strong disincentive to the adoption of technology.

Another hurdle is cost. Though research-based technologies are frequently given away for schools to use (such tools are usually not linked to curriculum, however, limiting their potential for adoption), tools that are licensed and distributed by commercial publishers can be expensive. One example that we have seen is a river simulation tool (of excellent quality) that cost thirty dollars per machine. If a school were to purchase a classroom set of fifteen, that would be an investment of $450 for a tool that is only designed to be used a single time for two to three days. In our work, we have found greater success by developing more generic tools, such as Model-It for general causal modeling and Artemis to support web searching and student inquiry (Wallace, Kupperman, Krajcik, & Soloway, 2000) that are used in many different curriculum units across several years of schooling. It is far easier to use a technology to achieve an educational goal if the already know how to use the technology. Otherwise, students have to learn *both* the technology and the content (Soloway et al., 1994).

We realize that there is an inherent conflict between developing interface standards for educational software and continued innovation in the field of educational technology. However, it is important for those who develop technology to realize the true cost of new designs or unique interface metaphors in terms of teachers' learning to use them in teaching and fitting them into an already full curriculum.

<u>Expanding Classroom Boundaries</u>

Technology creates another challenge for teachers when it makes connections for students to new communities not normally encountered, stressing both the boundaries of teacher capability and school culture. The Internet is an excellent medium for fostering mentoring and collaborations with people beyond the classroom, which can be very exciting for students (e.g., Pea, 1993; Riel & Levin, 1990). While connecting students to domain experts and involving family and community in education is almost universally agreed upon as a benefit of new communications technologies, such connections do pose issues for teacher planning and the monitoring of student behavior. Researchers must identify these issues and develop appropriate scaffolds to help teachers make these connections fruitful for students.

One issue is that both students and those outside of the classroom must be properly prepared if the communication is to be successful. Cycles of activity and work in classrooms are different than those in the larger world of work, with school days ending earlier than the business day and various breaks, vacations, and class schedules placing stringent limitations on the time actually available for communication (Levin, Waugh, Chung, & Miyake, 1992). Response expectations, the amount of time one expects to wait before hearing a response in a given medium, also must be managed. We have observed students send a message to a mentor at the beginning of a class period, only to be disappointed when a response doesn't arrive in the next forty-five minutes (Fishman, 2000). Or, when the message does arrive, the language is at too high a level for the students to understand (O'Neill, Wagner, & Gomez, 1996). Teachers must be helped to understand these problems in order to prevent them.

Another difficulty is that the Internet creates a new and potentially baffling realm in which teachers must monitor student behavior. Pea (1985) has written about computers as cognitive amplifiers, but they are also behavioral amplifiers (Fulk, Schmitz, & Schwarz, 1992; Lea, O'Shea, Fung, & Spears, 1992). Students who act out in face-to-face situations will also act out on-line, but it can be much harder for teachers to monitor and prevent, though they are still responsible. Preventing students from gaining access to objectionable material is another potential trouble spot. Schools can create acceptable use policies (Fishman & Pea, 1994) to assist teachers in these tasks, but it will remain a difficult area and a potential disincentive to the use of Internet-based technologies for many teachers.

Summary

If technology is to have an impact on student learning, it ultimately must be implemented by teachers. We have presented key issues that arise when teachers working in systemic reform attempt to use the kinds of innovations that researchers have developed. The research community can help address teachers' needs in terms of both capability and cultural expectations by embedding technology into standards-based curriculum materials, providing appropriate professional development, working to reduce the complexity that exists across multiple forms of technology, and helping teachers address new demands placed upon the culture of the classroom by technologies such as the Internet.

Challenges for Educational Leadership

Perhaps because success for innovations is so closely linked to what teachers do within classrooms, much of educational research has chosen to focus on teaching practices and student learning at the classroom level. But we have come to appreciate the key role that school leaders at all levels of the system play in the eventual success of classroom-level innovations. When researchers conduct a small-scale experiment or design experiment, permission is often sought from building and/or district administrators for the activity. Such permission is, however, more likely an exemption from "business as usual" than it is an invitation to jointly examine the practices that surround support for teaching with technology. For reform-oriented teaching with technology to be successful, it appears that changes are required in schools' management and policy structures. In our collaboration with Detroit (Blumenfeld et al., 2000), we have identified a range of critical challenges for the successful classroom use of inquiry-oriented technology that reside at the level of policy, management, and administration.

Planning for Technology

Federal programs such as the "e-rate" (Carvin, 2000) make it possible for schools to receive discounts on telecommunications costs, but one of the primary requirements for participation in this program is that school districts have a technology plan that is approved by their state department of education. This has resulted in a bloom in the number of schools that have technology plans. Sadly, few of these plans will create a technology environment prepared to support the kinds of teaching and learning called for by the research community, because few if any of these plans have a focus on teaching and learning using technology. Instead, most technology plans read more like shopping lists for hardware and software, and many are developed by consultants external to the school or by computer or computer-literate teachers working in relative isolation within schools (Fishman & Pinkard, in press). Unless planning for technology *begins* with questions about how teachers want to teach with technology, the technology itself can become a barrier to innovative teaching and learning practices, by limiting the ways in which technology might be used to support teaching.

For instance, the most common configuration for technology in schools is in a computer lab. This is both how the computer industry markets their products to schools, and how principals prefer things, since it is so much easier to show a shiny computer lab off to the public than smaller bits of technology dispersed throughout a school building (Hodas, 1993). But consolidating computers in a lab creates scheduling difficulties for teachers, who must rotate their students into the space almost as if computers were an elective, like art or music. This makes it virtually impossible to conceptualize technology as a tool to be used throughout the curriculum, as is called for in most research-based educational technology development. In our work with Detroit, we helped several schools re-think their technology planning to align their new purchases with the pedagogical goals embedded in the larger reform program. The result was that several schools decided to purchase a "mobile lab" of laptop computers that could reside in a teacher's classroom for as long as they were required to facilitate the use of the new curriculum, and then moved to another location as needed.

<u>Acquisition and Distribution</u>

A necessary step prior to the use of technology in schools is the acquisition of technology. We have observed that the purchasing and distribution of technology is often an overlooked or under specified area of school management. Even in districts where curriculum management and decision making is centralized; technology acquisition is primarily decentralized. That is, principals can make individual decisions about technology purchases so long as the machines are within district guidelines. The result of these policies in Detroit is that machine capabilities are not uniform, vary within and across school buildings and many existing machines cannot run or be upgraded to run current educational software. Also because principals work directly with a wide range of vendors, many have been sold sub-standard hardware. Simple incompatibility between new forms of educational software and the capabilities of the installed base of computers can be a serious impediment to the use of the new class of inquiry-oriented technologies being developed by the research community.

The problem of how to allocate scarce computer resources "fairly" presents a touchy political problem to administrators. When computers are distributed among classrooms, many principals' first instinct is to divide the machines equally among teachers. This may be a politically wise move, but it is pedagogically ungrounded. Since most schools do not purchase five or six computers for every classroom initially, the result is one or two computers in each room, which creates a student to computer ratio unsuitable for the kinds of computer use called for in many technology-oriented innovations. In our experience, in schools where teachers had some computers (usually between three and five) available to them within their science classrooms, science-related computer activities could proceed without access to the central computer lab, though teachers had to find ways to resolve challenges of having so few computers for their entire class. The alternative, going to the computer lab, could be equally unsatisfactory, as this sometimes entailed turning the class over to the "computer teacher," resulting in the science teacher not becoming comfortable with the technology, and the integration of the technology with the overall learning objectives in the curriculum being diminished.

Maintenance and Support

The "personal computer" as a concept is an oxymoron in the context of schools. How can a computer be "personal" when it is used by between ten and fifty people each day? This is not merely a semantic point. The chief issue is that modern operating systems in personal computers (such as Windows or the Macintosh OS) consist of many interrelated components and controls, each of which contains its own settings. In some cases, improper adjustment of those settings causes the entire computer to become inoperable, particularly when access to networks is desired. Entropy thus rules the day, as the many different users of each computer tweak and fiddle with them. Even if the behavior of each individual user is benign, the computer quickly becomes unstable and requires maintenance. This is a challenge both to policy and management and to the capabilities of school staff.

In our experience, urban schools are ill-equipped to provide this maintenance in a timely way. One school in which we work, facing a growing student population without a concomitant increase in the number of teaching FTEs, resorted to eliminating the position of school librarian in order to provide another subject-area teacher. This situation was not uncommon in schools in which we have worked, and principals report to us that in such conditions it is highly unlikely that they will be able to allocate funds to hire a trained computer technician. And if they do decide to hire a technician, they have difficulty finding someone with the appropriate level of experience at an affordable salary. Labor rules in school districts are often tricky when it comes to personnel who are not certified to teach, and hiring a non-teaching staff member at a higher salary than teaching staff can be contentious. The result is that teachers cannot get the help they need when they need it, which becomes a strong disincentive to the inclusion of technology in their regular teaching practices. Our experiences are reflected in the results of a national survey of technology use in schools (Ronnkvist, Dexter, & Anderson, 2000), which found that more than two-thirds of teachers nationally who reported needing help with technology couldn't get that help when they needed it. Furthermore, the survey results indicated that support was less available in low-SES districts than in high-SES districts, and that nearly half of the technology coordinators also had classroom teaching duties.

One approach taken by districts is to centralize support into a "help desk." The help desk as a solution has its roots in industry, which has a different cost support structure than is typically found in school districts. These phone-in systems are not convenient for teachers who do not have phones in their classrooms, and they are not designed to handle "emergencies," such as a teacher who has a lesson that requires Internet access but finds that the network isn't working. The help desk typically is designed to record problems, assign a "job ticket," and dispatch the appropriate resources to fix the problem when they are available. Many teachers and building administrators with whom we work have reported that rather than wait for repairs using this cumbersome method, they have, on their own, turned to outside contractors to repair problems. Unfortunately, these outside contractors frequently make repairs that are not compatible with the standards for computers in the school district, or they take advantage of the schools in other ways, such as using sub-standard parts. Everyone seems to recognize that this is an important problem to solve, but the cost of solving the problem (in terms of personnel) is so high that no solution is forthcoming. This disconnect is, at least in part, rooted in technology management and leadership practices that are optimized for older, less interconnected and immediate technologies.

New Technologies Span Traditional Boundaries in Organizational Structure

Just as inquiry-oriented and communication technologies pose problems for teachers who must learn to communicate in new ways with new audiences, they post similar problems within educational organizations, forcing communication where none was thought to be necessary before. At root, this is a problem presented by the organizational structure of the institution. In many large school districts, responsibility for technology management is assigned to centralized offices that by various names, but can be referred to generically as "management and information services" (MIS) departments. As most school districts used computers and networks for the management of their business functions long before the classroom use of computers became popular (Hodas, 1993), these MIS departments were logical candidates for overseeing the purchasing and use of classroom computers as well, since they already had experience with the required technologies. These organizations had not previously had to cope with the highly interactive and interconnected curriculum and education applications made possible by the Internet in the classroom. Perhaps most critically, the people who work for MIS departments are not accustomed to supporting classroom learning, and are not good candidates for coordinating or problem-solving with classroom teachers. This new role for MIS is giving rise to new problems and a new need for organizational coordination.

We believe that the Internet is both one of the most promising and at the same time the most challenging technologies to be employed in classrooms, and it especially makes the incompatibilities between different parts of school organization apparent. This is because the Internet connection to the classroom is dependent upon the cooperation and coordination of multiple levels of the school system. A teacher can plan a lesson using stand-alone software and, assuming that the computers are working and available, be reasonably confident that all will go as planned. The Internet, on the other hand, may not be functioning when it is needed, and there is no way for the classroom teacher to predict ahead of time (even minutes ahead of time) whether or not the Internet will be available as planned.

Our experiences to date indicate that in K-12 settings, especially urban settings, the Internet is "down" more than it is "up," making such planning a bit of a gamble for teachers. But the problem is even more complex than it seems. When the Internet is "down" in the classroom, the problem could be in: (a) the configuration of the individual machine or its software, (b) the wiring or hubs in the room, (c) the wiring, hubs, or routers in the school building, (d) the wiring between the school building and the network office (usually located in the central school administration building), (e) the wiring, routers, software, or hardware in the network office, or (f) the connection to the Internet provider "upstream" from the school district. Alternatively (g), there could be no physical problem *anywhere* in the complex system, but the individual Internet web site or sites the teacher or student was trying to reach may be momentarily unavailable. If a teacher is to feel confident enough to use the Internet in everyday teaching, there needs to be a tremendous amount of coordination among different levels of the school system in order to provide a reasonable level of reliability and re-assurance. After all, given all of the different places at which Internet connectivity *could* fail, who can or should a teacher call when there is a problem?

Summary

If teachers are the key to technology's use by students, then administrators are the holders of the keys. Administrators can go far beyond merely offering their support or acquiescence to technology research and development. Researchers need to work with administrators to help them understand how their policies and plans for technology will interact with the changes embedded in the reform effort, how to acquire, distribute, and maintain technology to support the reform effort, and how to provide support for teachers and other staff who will enact the reforms. Ultimately the integration of technology across learning and teaching activities in a school system may force a thoughtful re-organization of roles and responsibilities throughout the system. Those who develop technology for use in classrooms can aid this process by actively engaging administrators in a discussion of what is necessary to plan for, manage, and use technology well in the context of a particular innovation or reform.

Challenges for Researchers of Technologies for Learning

Each of the challenges described above for teachers and school leaders is also potentially an area for focus by the academic community. There are, however, several critical areas for exploration and linkage to related research traditions that have not yet been adequately discussed. These are areas that challenge the ways in which think about their work, and its relationship to K-12 schools.

Re-thinking the Nature of Innovations

Earlier in this paper we introduced a model for considering the "fit" of innovations to local contexts (see Figure 1). In early stages of our collaboration with Detroit, we explored the dominant models for describing the scaling-up of innovations, known as "diffusion" models (Rogers, 1983; Rogers, McManus, Peters, & Kim, 1985). These models often view innovations as relatively static, moving through a population or transferring from one setting to another more or less intact. This spirit is captured in the very name of the "technology transfer" offices that many universities now have. Our experience has been that current inquiry-oriented teaching approaches require a great deal of local re-invention in order to succeed, a process that can cause an "innovation" to look very different across different locations. A challenge for researchers and designers is to identify those areas in which an innovation will need to be flexible in order to match the needs of local settings. An example of this in our own work with Detroit was the design of an Internet search tool called *Artemis* (Wallace et al., 1998). Our original design used an Internet protocol that would have required extensive changes to the district's security system (the firewall). After extended work with the district to implement these changes, we both came to the realization that it was too difficult, and the *Artemis* functionality was re-implemented using a simpler protocol. A cost of this change was that some of the more advanced functionality was lost. This is a two-way street. Innovations must be modifiable, but schools must also consider changes they might need to make to take advantage of the innovation. This is the nature of reform as argued by Tyack and Cuban (1995). The research community must develop heuristics that can help guide adaptation of technology innovations in local contexts. Furthermore, researchers have to better define the core principles of their innovations, so that changes that occur in adaptation are not fatal to the innovation itself.

Collaborative Partnerships

Addressing gaps of culture, capability, and policy and management between innovations and schools requires close collaboration among researchers and school personnel. Our experience shows that all parties must own and be committed to the innovation. This goes further than simple endorsement by the central office. It involves creating a common vision and plans to achieve it. Essentially, it means that once innovators have initially specified and developed the innovation, they need to work with school personnel to specify and develop plans for enactment that take account of divergences between the conditions of the school system and needs 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.

Such plans are likely to entail changes to the initial specifications and development. Schools will "push" on innovations to conform to business as usual in their setting. At the same time, the researchers/designers are likely to push on the system to preserve the fidelity 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 makes on access to computers. This dynamic is congruent with the caution of Stokes, Sato, McLaughlin, & Talbert (1997) that the challenge of getting a reform to scale is more than adding numbers of classrooms. It is the challenge of translating an externally conceived and supported program into one that will be internalized so that it is conceptualized, governed and practiced in the schools. In this way, ownership shifts and underlying norms and practices change to sustain the core principles of the innovation.

In addition to collaboration between researchers and schools, there also may need to be collaborations between researchers and other researchers, and researchers and commercial technology developers. The layers of challenge inherent in systemic reform work that we have laid out in this paper are daunting, and the broad variety of expertise and effort needed to address these challenges will undoubtedly be too difficult for researchers working by themselves (a traditional mode of academic work) to take on. For that reason, researchers who employ technology for learning must work to establish linkages to other researchers working on school reform issues in order to build larger organizations that *do* have the capacity to address the varied needs of reform.

One difficulty of such efforts is that academic institutions are not set up to easily facilitate such collaborations, or to reward it. The field has to work to change these limiting factors in order to achieve success. Another activity that the research community is not particularly well suited to is the long-term support of innovations. In our own work, we talk about "tenacity" as a key element of our collaboration with schools. The fact that we work as partners with schools and teachers for periods of years is viewed as positive by teachers and administrators; they know that we'll be there when they need us. 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 commercial entities who can take stable innovations and support and service their ongoing use in school systems.

Distributed Leadership

Our experiences in Detroit made clear the linkage between the policies and actions of school leadership and the classroom implementation of innovation. This is not news to researchers in educational administration, where Rowan (1995) has employed contingency theory (c.f. Perrow, 1967, as cited in Rowan 1995a) to argue that "routine" organizational tasks are best managed with mechanistic forms of management, whereas "non-routine" tasks are best managed using organic approaches. In instructional terms, behavioral approaches to teaching and learning are "routine" in schools, and the hierarchical and highly-structured organizational forms that are common in schools support such instruction competently. Reform-oriented and cognitive approaches (e.g., Bransford et al., 1999) to teaching and learning, on the other hand, are ill-matched to current administrative structures, which we believe to be a key explanation for why so many reform-oriented technology innovations have trouble finding a home in schools. Elmore (2000) makes a similar argument, claiming that school leaders are frequently products of the environments they manage, and thus ill-suited to meet the new challenges posed by standards-based reform. Technology compounds this problem by introducing issues that to date have not been a part of administrative or instructional practice in schools.

In light of these challenges to current forms of school administration, Spillane and colleagues (Spillane, Halverson, & Diamond, 1999) ask researchers to consider a distributed framework for investigating school leadership. In such an approach, they present a working (re)definition of leadership premised on the assumptions that: leadership is best understood through the tasks of informal and formal leaders; leadership is stretched over the practices of many actors within organizations, and leadership is distributed through materials and artifacts of organizations (Spillane et al., 1999, p. 5). Their approach depicts leadership as a function of how organizations function as a whole, more than as traits held within individual actors. This is consistent with Rowan's (1995) view of "organic" administration.

The essential point is that school leadership, as it concerns technology, is currently under profound re-negotiation. Most schools leaders today are in the early part of the learning curve. Educational researchers need to get smarter about how to encourage and support this new learning. We also need to encourage school leaders to be more reflective about how to use all the things they currently know, in productive ways, to meet these new challenges (Murray et al., 2001). To accomplish these ends, it is essential for researchers who employ technology to engage with researchers in educational administration to better understand the role that school leaders play in the successful adaptation and use of technological innovations.

New Models for Research

At the start of this paper we alleged that reform-oriented learning technologies would not thrive in real-world school environments in part because they are created and evaluated in "hothouse" environments. We want to be clear on the following point: there has been much excellent research involving technology, and a great deal has been learned about individual and group learning supported by technology. Research on learning technologies has made great strides in the areas of design and evaluation of improved learning environments on a small scale. However, the currently dominant research paradigm is not providing information about how to link our new understandings to real-world challenges presented by school district culture, capability, and policy and management. In other words—work on school reform is not well informed by research to date on technology and learning. We repeat—this is not the result of flaws in the research as it was conducted. Rather, it is a consequence of the intent and the paradigms under which that research was conducted.

This situation arises because most prior and current research in technology for learning is focused on the design of technology and on questions about *whether* or *how* technology influences learning (discussed above in relation to our first assumption). A shift in this focus that is beginning to emerge asks questions about how to *enable* the use of technology in regular classrooms. Furthermore, the change in focus is also a change in magnitude. Much previous literature focused on the use of technology *in one classroom*, or on how teachers *as individuals* in many classrooms might best foster the use of computers with their students (e.g., scale without a systemic focus). This new direction represents a change in the very nature of research in education, from laboratory-style psychological research to design experiments, and more recently to testbeds and research on systemic reform (Gomez et al., 1998). Some major structural differences between these forms of educational research are summarized in Figure 2.[3]

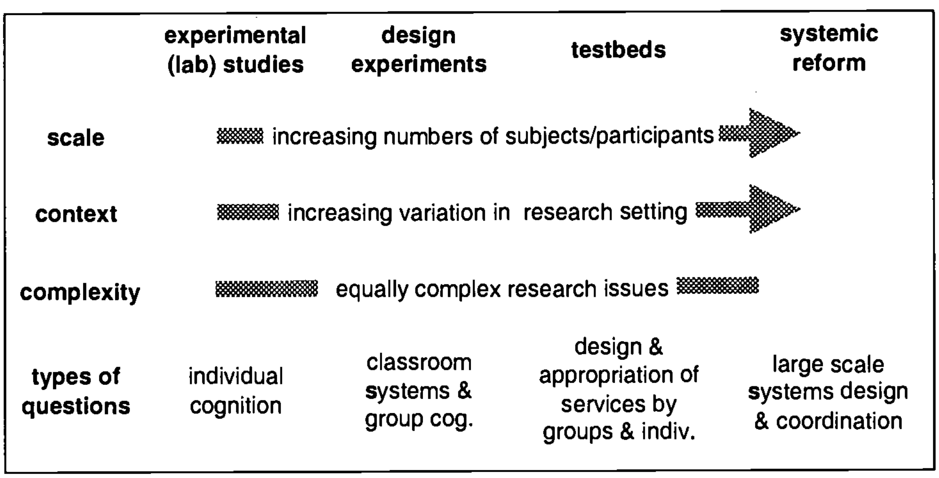

Figure 2. Attributes of four research paradigms for educational technology (adapted from Gomez et al., 1998).

With Figure 2, we do not intend to imply that the testbed or systemic reform paradigms are somehow more important or evolved than experimental studies or design experiments. All of the research paradigms have yielded and continue to yield important information about the relationship between technology and teaching and learning. Furthermore, each of the paradigms involves complexity in its own way. It is no mean feat to design an experiment that actually tests what the researchers intend to evaluate, especially in a classroom setting.

If educational researchers are to seriously address the culture, capability, and policy and management challenges to working with technology in systemic reform environments that we have outlined so far in this paper, then they must form an understanding of what it means, methodologically, to conduct research in systemic reform environments. If researchers choose not to move their work in this direction, then it is critical to at least grapple with what is required to make connections between their work and larger reform efforts, so that others may continue to expand the reach of promising technologies and classroom practices with technology.

Conclusion

In this paper we have presented a challenge for researchers on learning with technology to consider. Why is it that so few of the inquiry-oriented learning technologies have found a place in the everyday practice of teaching and learning in K-12 schools? As we argued, there are a confluence of factors, some relevant to teachers, others relevant to administrators, and all relevant to the research community in terms of issues that must be addressed in order to take our work to the next level in terms of impact on practice.

We understand that not all researchers who work with technology will find work in systemic reform appealing, or even appropriate. There is and always should be a place 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. These efforts need to be continued, nurtured, and funded as always. But there is a long-term risk to only or primarily doing this kind of research. The risk is that the only kinds of technologies that will find a home in schools are those that support the dominant didactic paradigms for teaching and learning. These kinds of technologies are not intended to help schools reach the goals set forth in recent educational standards documents, and continued failure to show meaningful progress in this direction will in part be blamed on the failure of these technologies. If this happens, public support for research in technology will evaporate, as the public does not currently distinguish between the commercial technologies that proliferate in schools today and the inquirty-oriented learning tools that continually emerge from the research community. We owe it to ourselves as a community of researchers interested in improving school performance to make sure that this does not come to pass.

End Notes

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2 Information about LeTUS can be found at http://www.letus.org/.

3 Our thinking about the dimensions of research on technology in education is also informed by the "LTC Framework" developed by the Cognition and Technology Group at Vanderbilt (1996).

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