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ABSTRACT

Technology-enabled learning environments are beginning to come of age. Tools and frameworks are now available that have been shown to improve learning and are being deployed more widely in varied school settings. Teachers are now faced with the formidable challenge of integrating these promising new environments with the everyday context in which they teach. This paper describes the implementation of a curriculum framework and Internet-based software toolset called the Knowledge Integration Environment (KIE) in two urban schools serving diverse student populations. The framework of Scaffolded Knowledge Integration (SKI) is used to assess the interplay between the context of teaching and the adoption of new tools for learning. In this study, students engaged in KIE projects on the subjects of Life on Mars and Deformed Frogs, two current scientific controversies. Results indicate that striking improvements in cognitive engagement and learning were achieved by the group of students who had been labeled "failures" in more traditional classroom environments, and that more advanced students were able to integrate their knowledge in new ways. This paper also offers suggestions for evaluating the contextual issues that shape the implementation of new learning environments, and presents SKI as a framework to support teacher professional development as they adopt new tools and techniques into the real world of the classroom. (Contains 44 references.) (Author/PVD)

Debating Life on Mars:

The Knowledge Integration Environment (KIE) in Varied School Settings

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Debating Life on Mars: The Knowledge Integration Environment (KIE) in Varied School Settings

Abstract

Technology-enabled learning environments are beginning to come of age; tools and frameworks are now available that have been shown to improve learning, and are being deployed more widely in varied school settings. Teachers are now faced with the formidable challenge of integrating these promising new environments with the everyday context in which they teach. This paper describes the implementation of a curriculum framework and Internet-based software toolset called the Knowledge Integration Environment (KIE) in two urban schools serving diverse student populations, and uses the framework of Scaffolded Knowledge Integration (SKI) to assess the interplay between the context of teaching and the adoption of new tools for learning. In this study, students engaged in KIE projects on the topics of Life on Mars and Deformed Frogs, two current scientific controversies. Results indicate that striking improvements in cognitive engagement and learning were achieved by a group of students who have been labeled "failures" in more traditional classroom environments, and that more advanced students were able to integrate their knowledge in new ways. This paper also offers suggestions for evaluating the contextual issues that shape the implementation of new learning environments, and presents SKI as a framework to support teacher professional development as they adopt new tools and techniques into the real world of the classroom.

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"I teach at a Chapter 1 high school. The students in my life sciences classes are about 90% minority, primarily Hispanic and black. The students are self-identified as non-college-bound; many are not planning to graduate from high school. Unfortunately, many of these students have failed this required course once, some twice before. They need to be empowered, motivated, and challenged."

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"I teach a self-contained bilingual class for Russian-speaking children who are designated LEP (limited-English proficient) or NEP (non-English proficient). Grades 6, 7, and 8 share the same classroom. This group is unusual because the math and science curriculum of their native country is a few years above our middle school curriculum, but most students have little or no experience with inquiry, critical thinking, or computers. They are used to learning the 'facts' and anticipating the 'correct answer'."

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"My class is about a dozen students who are both gifted and learning-handicapped. It is intended to provide access to the core curriculum of regular middle school or the same curriculum as other gifted classrooms. I see my role as a mentor to help them successfully negotiate middle school."

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-- personal statements from three teachers participating in the KIE Summer Workshop, August 1997

The teachers quoted above all teach science, at the middle- or high-school level. Yet the challenges they face in the classroom, and the goals they have for their students, are markedly different. These issues are likely to shape their views of the classroom, of teaching, and of the tools and strategies that can make a difference for their students. In turn, they can heavily impact the success and character of educational innovations as they roll out beyond the pilot classroom.

When we began to work with teachers at each of the two schools examined in this study, they described the difficulty of bringing new teaching tactics into their everyday practices. One teacher, for example, was part of a school-wide effort to de-track high school science and replace traditional techniques with engaging new team-based methods that position students as scientific investigators. Although they had carefully researched the available options and invested heavily in professional development, when this teacher brought the new methods to her class, with widely ranging ability and motivation levels and up to 25% of the students absent on any given day, she found them to be unworkable: in her own classroom environment, promoting true heterogeneous collaboration turned out to be more difficult in practice than it appeared to be in theory. The ideas are good, she concluded, but they just won't work in "my classroom" with "my kids."

This paper explores the interplay between the context of teaching and the adoption of innovative tools for learning, particularly in urban schools where challenging contextual issues tend to be more evident. Rather than giving up on the goals, as was the outcome above, or imposing idealized strategies, as policymakers and reformers are frequently accused of doing (e.g. Cuban, 1993; Little & McLaughlin, 1993), I suggest instead that we take a careful look at the everyday environments of schooling and determine ways to help teachers to integrate new and promising ideas with the real world context of their work and the repertoires of strategies they have found to be effective in the past. Specifically, this study addresses the following questions:

- ❑ What are the dimensions of the "real world" of urban schools, and how do these issues support or challenge the learning that can be achieved using new tools?
- ❑ How can we support teachers in integrating desired new learning strategies with what they already know to work in "my classroom" with "my kids?"

The focus of the study is an Internet-based instructional environment for science education called the Knowledge Integration Environment, or KIE, which was developed by a team of researchers at Berkeley under the direction of Dr. Marcia Linn. KIE focuses on the cognitive goal of knowledge integration: connecting information learned in science class to other student experiences, both in class and in the real world, to acquire learning strategies and relevant scientific understanding. Extensive research in an eighth-grade classroom has shown KIE to be effective at facilitating science learning, high-order thinking, and teamwork skills (Linn, Bell, & Hsi (in press)).

For the present study, we implemented KIE in two very different school settings. In the first, we worked at a large and diverse high school that I will call Walker High[1] to implement a six-day KIE project in which tenth-grade students investigate and debate the issue of life on Mars. The second school, Franklin, is an urban middle school in which we collaborated with several biology teachers and two Berkeley scientists to build and run two KIE projects; the project of focus here is an extended student inquiry into the cause of rising numbers of frog deformities in North America, an important current scientific controversy. Together, these implementations represent two schools, five teachers, and a diverse population of middle- and high-school students with varying science abilities, language abilities, and backgrounds: an initial sample that hints at the variety of classroom environments that are settings for innovation.

The theoretical framework on which KIE is based is called *scaffolded knowledge integration*, or SKI (Linn, 1995). By using accessible models for scientific concepts, making thinking about scientific ideas and processes visible, providing social supports for learning, and encouraging students to become autonomous lifelong learners, SKI establishes an environment in which students are engaged as scientific investigators and critics in a way that connects new scientific ideas to their active views about the world and provides a foundation for ongoing investigation.

This paper will use the SKI framework twice, with two different - but parallel - intents. The first is to investigate student learning: for each element of the framework we will look at the interplay between contextual factors we encountered, design and instructional strategies we used, and the learning achieved on these projects. In turn, this will provide some insight into strategies for making new tools successful in everyday classroom contexts.

While innovative new tools may offer tremendous promise, the decidedly non-trivial task of adopting them to improve student learning in everyday classrooms falls on the shoulders of the teacher. Therefore, many of the issues discussed in this paper will be reflected in comments from the teacher's perspective, and the discussion will conclude by revisiting the SKI framework once again: this time applying the principles of effective knowledge integration to teachers, who, like students, are faced with the challenge of integrating new ideas and models with their existing repertoires.

To begin, the next section looks to the literature for a discussion of what others have found to be the promises and challenges of technology-enabled learning in urban settings. The paper will then describe the KIE learning environment and the particular projects and school settings in which it was used in this study; offer learning results and an analysis of contextual issues and design strategies that led to those results; and conclude by suggesting implications for teacher professional development.

[1] In this paper, names of the schools and their inhabitants have been changed.

Technology-supported Learning in Urban Education

> The computer motivates. It is non-judgmental. It will inform a student of success or failure without saying by work or deed that the student is good or bad. The computer individualizes learning, permitting mastery at one's own pace. In most instances, the learner has far more autonomy than in many other teacher directed settings. The computer gives prompt feedback. And good software makes the computer, at least potentially, remarkably imaginative. Such generic qualities allow the learner more often to be in charge. This is a quality missing in the lives of many students, especially those who are at-risk...
>
> *- Hornbeck, 1990, p. 5*

Technology has many qualities that suggest the potential for success in urban schools, and theoretical descriptions of its promise abound (e.g. Kozma & Croninger, 1992). This discussion focuses on what it takes to achieve successful learning in practice. The common call, consistent with other threads of urban education reform, is to use technology in ways that support project-based learning, with heterogeneous student teams using computers as tools to support challenging and authentic tasks for all students (Means & Olson, 1995; Sheingold, 1991; Collins, 1991). A number of technology environments (e.g. CoVis (Gomez & Gordin, 1996); CSILE (Scardamalia, Bereiter, & Lamon, 1994); Kids as Global Scientists (Songer, 1996); Jasper (The Cognition and Technology Group at Vanderbilt, 1990); and others) have been developed and proven to meet such needs, and their developers are at various stages of confronting the issues involved in achieving real cognitive gains on a broader basis.

At a macro level, the challenges of establishing productive technology-supported learning environments in urban schools or those serving primarily minority children are extensive. Studies have shown, for example, that in comparison to their suburban or middle-class counterparts, such schools typically have fewer available computers in instructional rooms (Owens & Waxman, 1995; Sheingold, Martin, & Endreweit, 1987; Heaviside et al, 1997); have older technology (DeVillar & Faltis, 1991) and physical building infrastructures that fail to support it (Zlatos, 1995); and are more likely to see computers as a tool for drill-and-practice on basic skills than for more innovative learning (Owens & Waxman, 1995; Simmons, 1987; DeVillar & Faltis, 1991), consistent with the textbook-and-memorization style of pedagogy that many claim dominates instruction in urban schools (e.g. Haberman, 1991). Even within a particular school, computers can be distributed in ways that exacerbate equity issues rather than resolving them, as evidenced by the differential computing environments reported by Schofield (1995) in one high school: a separate "gifted computer room", typically inhabited by "bright, white boys" (p. 134), with significantly better resources than the equivalent room for public access.

Against such a bleak backdrop, the opportunities are even more significant. What can we learn from those who have implemented new learning environments successfully about the types of success that are possible, and the strategies that are helpful in achieving them? While overall frameworks to describe the implementation of technology in varied school environments are still emerging, a number of themes can be drawn from the available literature to help us understand the promise and the challenges.

The promise of technology in urban schools

Innovative environments for authentic project-based learning, supported by technology, have been capable of having strong positive impacts on schooling in underprivileged environments (see Means & Olson, 1995, for detailed case studies of nine schools; see also Carver, 1992; O'Neill & Gomez, 1994; Means, 1997; Reil, 1992; Newman et al, 1993; Rowe, 1993; Lamon et al, 1994). A number of benefits are consistently cited:

Student cognitive performance. Technology-supported learning environments have been shown to result in significant improvements to student learning, including mastery of more complex tasks, increased autonomy over student learning, and integration of a broader repertoire of ideas (Means & Olson, 1995; Sheppo et al, 1995; Newman et al, 1993; Lamon et al, 1994). Improved reading and writing skills are often cited as well, as word processing applications transfer some of the mechanical challenges of writing to the computer so that students can focus on cognitive issues (Hornbeck, 1990).

Student engagement. A common problem in disadvantaged schooling environments is student disengagement with classroom activities, making learning impossible (Maeroff, 1991). Significantly increased motivation to learn is reported nearly unanimously in these studies: say Means and Olson of the nine schools they studied, "case study teachers were nearly universal in citing the positive effects of technology in student motivation" (Means & Olson, 1995, p. S-2; see also Collins, 1991; Schofield, 1995; Newman et al, 1993; Rowe, 1993; Carver, 1992). This motivation often took the form a new engagement in school activities and attention to quality of work; extra time spent outside of class, and improved attendance rates; and evident pride in accomplishments. Reil (1992) notes that AT&T's Learning Network, which links classrooms around the world, provided new motivation to her students, some of whom lived in Juvenile Hall: she reports that they had incentive to pay attention to the quality of their submissions to the learning circle, including writing skills and grammar, "so as not to appear 'dummies' to the other schools in the circle" (p. 483). Other reasons for motivation stem from the fact that schoolwork using technology seems directly relevant to later careers (Schofield, 1995), and the pride and empowerment of expertise in something that parents or even teachers may not know how to use (Means & Olson, 1995; Schofield, 1995; Emihovich, 1992; Rowe, 1993).

Classroom environment. Many of these projects report a marked shift from competitive student interactions to cooperative ones characterized by collaborative activity, mutual respect, and equity (Collins, 1991; Emihovich, 1992, Means & Olson, 1995; Newman et al, 1993; Lamon et al, 1994; Songer, 1996). The CSILE project, for example, provides a networked database environment for collaborative student inquiry. Students receive explicit instruction on writing notes that are "helpful, thoughtful" rather than put-downs or simply platitudes. Working with CSILE helps students to build productive collaboration skills, and offers opportunities for heartfelt personal communication between students who would not normally cross social paths due to age differences or social status (Means, 1997). A sixth-grade teacher in a turbulent inner-city neighborhood also noticed significant improvements in classroom community when her students began to work with computers, and contends that such basic interpersonal skills are of paramount importance:

> [The children] need to be taught, step-by-step, how to go about what we adults often describe to them as 'getting along'. Indeed, given the hazards of the world my students enter after they walk out of school each afternoon, a convincing argument can be made that such skills will serve them at least as well as the traditional academic skills we spend so much time and effort on.
>
> *- Rowe, 1993, p. 110*

Other community-related improvements cited include increased student freedom, compared to traditional classrooms where students are required to stay in their seats and not talk to each other (Schofield, 1995), and increased opportunities for students with social or academic difficulties to win respect (Schofield, 1995; Rowe, 1993). Cummins and Sayers (1995) report that these community-related benefits can reach to cultural and global awareness and critical literacy; to that end, their book provides an extensive guide to resources and projects that support networked learning across classrooms.

New teacher roles within the classroom. In the school studied by Schofield (1995), when asked in an interview to discuss any shifts in teacher behavior from the classroom to the computer lab, one student said: "He doesn't teach us any more. He just helps us" (p. 30). Technology-enabled learning environments tend to support a shift in teacher roles from lecturer to facilitator of small group work, from authority to mentor, and from recipient of curriculum materials to designer (Means & Olson, 1995, Sheingold et al, 1987, Collins, 1991). In a survey of 600 teachers who have been successful integrating technology into their classrooms, Sheingold and Hadley (1990) found that teachers also frequently report having higher expectations of their students, being more open to individualized accomplishments, and being more likely to think of issues as having more than one answer.

New opportunities for teachers outside the classroom. The roles described above provide significant opportunity for teacher professional growth. Because teachers within a school or farther afield are in a common position of being learners of technology-related teaching issues, they often take advantage of opportunities for collaborative professional development (Means & Olson, 1995; Lamon et al, 1994). In addition, the professionalism of teachers is supported by increased participation in the process of curriculum development, and opportunities for exposure to professional resources and tasks that go beyond the school community, whether collaborating with outside supporters on projects, writing grants, or presenting project results.

Common challenges

As suggested by the above benefits, these learning environments are far more than technology tools: their goal is to support overall classroom and curricular approaches that promote improved student learning and community. The student and teacher role changes defined above do not happen automatically, nor are they easy. As such, the successful adoption of technology supported learning environments meets challenges on a number of levels. Commonly-cited challenges include:

Reliable technology, and sufficient access to it. Dedicated computers that are recent enough to run most new software environments are a luxury rarely seen in urban school environments. Most of the projects surveyed here were challenged by the need to share computer resources or insufficient support to keep them running (O'Neill & Gomez, 1994; Means & Olson, 1995; Sheingold & Hadley, 1990). On the Discover Rochester project, Carver (1992) reports that the need for rotating access to computers caused significant class management difficulties, and the logistics of sharing sometimes required the time-consuming process of moving computers on carts from classroom to classroom between periods. The requirement for projects is flexible curriculum design and scheduling; for schools and districts, it is creative funding strategies (e.g. Grandgenett, 1995) and difficult budget tradeoffs (Gains, Johnson, & King, 1996).

Teacher professional development. The teacher's classroom practices hold much of the key to the success of learning environments, and many report that professional development opportunities commonly available are insufficient to help teachers navigate the change. Initial resistance may result from unfamiliarity with technology, reluctance to disrupt the classroom environment and lose control, or simply fear of computers: said one teacher about the new computers that were delivered during a recent school-wide technology initiation, "I'll be honest with you. Everybody was afraid of them" (Schofield, 1995, p. 116). Even teachers who are more enthusiastically adopting new technology practices are further challenged by lack of dedicated free time to learn and experiment; lack of computer resources and applications for their own use; and training opportunities that focus on how to push the buttons rather than how to integrate it into the classroom and build curricula: available training programs tend to view teachers as consumers rather than builders and shapers of curriculum (Sheingold et al, 1987; Sheingold, 1991; Office of Technology Assessment, 1995; Means, 1997). Full teacher adoption is a long-term process (Carver, 1992; Means & Olson, 1995; Office of Technology Assessment, 1995), and one that is rarely supported by current short-term views of teacher professional development.

Issues of time and space. Project-based learning supported by technology challenges many elements of school functional organization and layout. For example, once time is set aside for logging in and out, it is very difficult to accomplish real project work in a typical 50-minute school period, nor are such short blocks of time supportive of teachers learning to use and develop curriculum with new tools (Sheingold, 1991; Means & Olson, 1995). Computers are often distributed too thinly to classrooms to be usable for serious work, but the alternative - housing them in labs far down the hall - tends to isolate technology from authentic applications and from teachers (Means & Olson, 1995).

Lack of overall vision. Many schools are adopting technology one teacher at a time, leaving policy-related challenges unaddressed: insufficient funding; absence of long-range curriculum/application planning; limited support for effective teacher professional development; schedule and space constraints. Without a systematic approach to innovation (Means, Olson, & Singh, 1995; Sheingold, 1991; Gains, Johnson, & King, 1996), successful implementations at the classroom level remain difficult.

The overall message is clear: the opportunities offered by technology-supported learning environments are significant, both to extend learning opportunities to all students and to support new professional development opportunities for teachers. However, achieving these learning objectives is not a simple thing, and can be challenged by a wide assortment of issues whose character and impacts often vary greatly across school contexts.

Based on our experiences implementing KIE in two urban school environments, this paper will use the framework of Scaffolded Knowledge Integration (Linn, 1995) to put issues like those listed above into a context that links the requirements for successful learning and the challenges and strategies that impact its success in particular classroom environments. KIE and the particular classrooms and projects with which we worked in this study are described below.

The Knowledge Integration Environment

The Knowledge Integration Environment, or KIE, provides a suite of Internet-based software tools and a project-based curriculum framework that helps students to understand and link ideas in a complex scientific domain[2] (Bell, Davis, & Linn, 1995; Linn, Bell, & Hsi, in press). Both the Internet and traditional classroom learning provide vast amounts of information, but often in the form of discrete facts with few incentives or supports to connect them into more coherent understandings. KIE's project-based framework offers extended projects on personally relevant topics, while software tools and related classroom activities encourage students to synthesize Web-based evidence and real-world observations into an integrated understanding of scientific phenomena.

The Internet is increasingly both an authentic source for scientific research and an important tool in students' personal lives; however, its unregulated growth makes it a source that is at best confusing, and at worst dangerous. In KIE, students engage with Internet information as *scientific evidence,* which they learn to investigate, critique, and link to scientific hypotheses and claims. For example, on the Deformed Frogs! project, students critique and analyze current scientific evidence related to two leading hypotheses for causes of frog deformities (Figure 1), which they will ultimately use for an in-class debate to decide the cause.

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[2] http://www.kie.berkeley.edu/kie.html

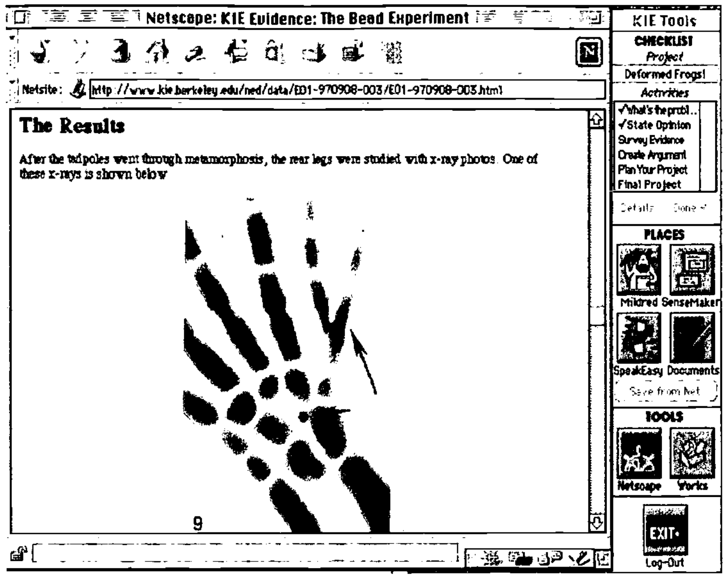

Figure 1: Students use KIE to investigate scientific evidence on the Web

The goal of knowledge integration is supported by the *Scaffolded Knowledge Integration framework*, or *SKI*, which is an instructional framework to guide the design of classroom science instruction (Linn, 1995). SKI includes the following four components: a) *Identifying new goals* for science learning, ensuring the selection and presentation of accessible models for scientific phenomena; b) *Making thinking visible* by encouraging students to articulate their views, providing multiple representations, and explicitly supporting the process of scientific thinking; c) *Providing social supports* in an open and supportive classroom environment in which students collaborate in pairs as they elaborate and organize their ideas; and d) *Encouraging lifelong learning* by supporting student autonomy and connecting the ideas of classroom science with the world outside the classroom. In KIE, these components are supported by technology-based tools and related classroom activities and practices.

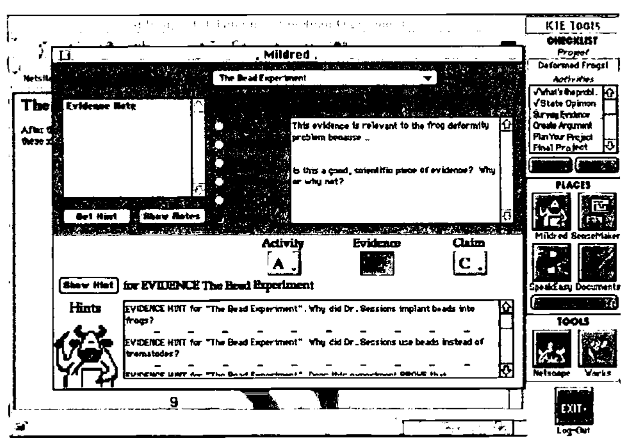

Figure 2: Mildred the Cow guides students as they critique evidence

For example, Mildred the Cow (Figure 2) is KIE's bovine guide who supports student autonomy with hints, prompts, and suggested discussion topics as pairs work together to evaluate and critique evidence.

In the research described here, students at each of two schools conducted one of two KIE projects: Life on Mars? and Deformed Frogs! These specific projects are discussed below, in the context of the school environments in which they were implemented.

The Projects: Background and Methods

Life on Mars at Walker High

Walker High School is a very large and vibrant community in northern California, serving a population of 4100 urban and suburban students that are highly diverse in ethnicity, socioeconomic status, and achievement. According to Cheryl, the classroom teacher with whom I worked, Walker was once the worst-ranked school in the county on all academic measures. In the early 1980's a number of turnaround programs were implemented, including a strong focus on student activities, innovative pedagogies, and technology. Average Walker achievement levels on standardized tests are now reported to reach the 50th percentile nationwide, indicating that some of the recent programs have contributed to improvements in student learning.

The school-wide commitment to technology is reflected in a well-funded program: each classroom has a TV/VCR and six personal computers, as well as shared access to LCD projection panels, computer rooms, and media labs. All students now have e-mail, and the school is considering adopting a policy that adds technology use to teachers' annual performance evaluations.

Walker is also pursuing a focus on interactive pedagogies and authentic learning experiences. Cheryl is one of several teachers of a two-year integrated science curriculum called IE (Investigating Earth). Now in its third year, IE was designed to engage students as teams of scientists, exploring real-world issues of earth science and biology. This program is offered to all students: the first two years of science are now completely de-tracked. As a result, the classroom in which this research took place has a very broad diversity of students, not only in terms of ethnicity and socioeconomic status but also academic ability. Achievement levels varied from students who used to be in the honors program and tended to be extremely high achievers to just over 25% of the students who were maintaining a D or F average and consistently failed to turn in any written work or engage productively in schoolwork. Despite the innovative curriculum, the teacher was finding it very difficult to engage all students in learning activities. She was also struggling with the challenges of managing and evaluating student-driven work; these issues and others were causing her to back off on some of the innovative methods. "The climate to be innovative is definitely there," she said, but "realities are different than theories."

Cheryl had used KIE on two projects in the past, and reported in an interview that she was attracted to the fact that it capitalized on the engaging qualities of the Internet, useful for motivating this diverse group of students, but in a way that encouraged them to think and to make connections rather than just surfing. The Life on Mars topic fit well as a capstone to earlier student investigations of early life on Earth. We designed it collaboratively to encourage connections to these earlier elements of the curriculum as well as to provide materials that would be engaging and challenging for students of all levels, using a structure of focused primary evidence with links to more complex targets of exploration for more advanced students.

Life on Mars?

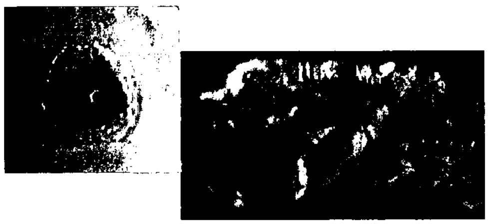

Figure 3: Mars physical landscape

In this seven-day debate project, students investigate current scientific evidence related to the possibility of life on Mars, and use this evidence to support a hypothesis of whether or not life ever could have existed on the planet. Evidence investigated includes descriptions and photographs of the physical environment on Mars (Figure 3) as well as pictures and scientists' conflicting analyses of a recent and widely-publicized discovery of what some claim are Martian fossils on a meteor (Figure 4). Because this project was conducted at Walker in the spring of 1997, the Pathfinder expedition had not yet taken place; a strength of the Internet format for investigation of current scientific controversies is that current evidence such as reports from Pathfinder can easily be incorporated as they become available.

Figure 4: Alleged Martian fossils

As they look at KIE evidence, students are supported by Mildred the cow guide, who encourages them to follow the steps of careful evaluation and critique of evidence and linking its contents to the issue of life on Mars, and to relevant knowledge from earlier classroom activities about life on Earth. For example, for a piece of evidence about the atmosphere on Mars, students are asked the following questions to prompt discussion:

> What was the early atmosphere on earth like?
>
> How did plate tectonics affect earth's atmosphere? If it was lacking, as on Mars, how would the atmosphere be impacted?

Student investigation of evidence on KIE is also supported by integrated classroom activities. For example, they are introduced to the topic by a half-hour video documentary that had recently aired on television about man's search for life in outer space, and later the students prepare and conduct a formal classroom debate in which teams present their argument and rebut critiques from the opposing side. Total instructional time for the project is seven days, four of which were in the computer lab (the maximum number of days for which we were allowed to sign up for this schoolwide resource) and three in the classroom.

Data collection

The research sample included two second-year IE classes, with a total of 55 students. The project did not include pre- and post-tests in the traditional sense; data included notes taken in the KIE software, videotapes of final debates, audiotapes of some class discussions, and extensive field notes, as well as several informal interviews with the teacher. Due to a large number of student absences the day of the debate, final presentations for some classes had to be rescheduled and were not captured on videotape. The planned teacher post-project interview met the same fate, and was ultimately conducted less formally over the phone due to administrative requirements that had to be attended to at the originally scheduled time. The challenges that the setting held for the goal of tidy research also held significant ramifications for student learning, as will be explored in the Results section that follows.

Deformed Frogs at Franklin Middle School

Franklin is an inner-city middle school in northern California, serving approximately 860 students in grades 6-8. The student body is highly diverse, with no clear ethnic majority, reflecting the surrounding neighborhood's rich mixture of recent immigrants (primarily from Asian countries and Russia) and long-term city residents. Two-thirds of students qualify for free or assisted lunch programs, and 25% of students are designated ESL.

The project at Franklin was a year-long collaboration with teachers, the KIE research team, and two Berkeley scientists, supported both by Berkeley's Interactive University project[3] and by significant extra funds, resources, and knowledge gained from KIE's NSF grant. The project provided one day of teacher release time per teacher per month so that we could work together, and a level of human and computer resources that allowed a new server to be installed to support the project, among other required technical upgrades.

The technology focus of the project was a computer lab setting, which was used primarily for computer skills and media arts classes but where subject matter teachers could also bring their classes. Each teacher also had a single computer in the classroom, which were connected to the Internet for the first time during this project; these allowed some discussions of Internet evidence in the classroom, but did not provide enough of a critical mass of computers to support regular KIE activities.

On this project we worked with four teachers, all of whom had very different classroom contexts and student needs: 7th-grade honors biology (two classes, n=66), "regular" 7th-grade biology (two classes, n=62), a Russian bilingual class that served 6th, 7th, and 8th grades together in one classroom (n=25), and a small class of students designated GLD (Gifted, Learning Disabled, with four students participating on KIE projects along with the other classes). A fifth teacher, whose 6th-grade students did not use KIE this year, also participated in the project design process, as did the manager of the technology lab.

[3] http://iu.berkeley.edu/iu

While data was collected for all classes indicated above, this paper will focus primarily on the four 7th-grade biology classes. The complex issues surrounding the use of KIE with the bilingual class are addressed elsewhere (Shear, in preparation).

The collaboration resulted in the design and implementation of two KIE projects: a brief introductory unit on the topic of twins, and a more in-depth inquiry into the problem of deformed frogs. The latter project provides the focus of most of the data discussed here. The project was designed through a collaborative process that included contributions from scientists, teachers, and KIE developers, with the goal of providing appropriate materials and supports for all students.

Deformed Frogs!

In the summer of 1995, 7th-grade schoolchildren on a field trip in Minnesota discovered a large number of frogs with significant developmental deformities: extra legs, missing legs, missing or misshapen eyes, and a number of other odd deformities (Figure 5). Since then it has become a topic of heated discussion and investigation by scientists, who still do not agree on a cause, and in the press, based on concerns from environmentalists that the deformed frog problem may be an indication of a growing environmental danger that may affect humans and other animals. The topic and the controversy make it a very engaging and authentic topic for student scientific inquiry.

Figure 5: A many-legged frog

In the Deformed Frogs! project in KIE, students take on the role of scientists who evaluate the available evidence on the Internet and conduct an in-class debate about the causes of the problem. Students look at background information that includes pictures of deformed frogs and an interactive Internet map of locations in which they have been found, and then investigate evidence related to one of two leading scientific hypotheses:

> *The Parasite Hypothesis:* A small parasite called a TREMATODE burrows into a tadpole near where the legs will develop. This parasite gets in the way and causes legs to develop incorrectly.
>
> *The Pesticide Hypothesis:* A chemical called METHOPRENE is used by many farmers as a pesticide. After it has been in the sun, this pesticide changes into another chemical that may cause frog deformities.

These complex scientific hypotheses are made accessible through illustrations, class discussions, and other mechanisms for visualization (see *Making Thinking Visible* later in this paper). This project was also designed specifically to be accessible to students in all classes; for example, supports included "glossary pages" that illustrated complex meanings of words, particularly for the benefit of the bilingual students. Deformed Frog! activities typically spanned 2½ weeks, including both classroom and lab activities. In addition, activities related to a "frog theme" were scattered throughout the year, including hands-on frog dissections and a tank of tadpoles in the classroom.

Data collection

Data collected throughout this collaboration was intended to document the Deformed Frogs! project in particular as well as the year-long collaboration more generally. Data for the Frogs project include written pre- and post-tests of subject matter, student pre- and post-project interviews, notes taken in the KIE software, videotaped records of student debate performance, and audiotapes that sample classroom activity and interactions over the course of the project. Longer-term data collected over the course of the year-long collaboration include written student beliefs tests taken in November and April, post-project interviews with all project participants (some of which are still in the process of being conducted), and extensive artifacts and notes from the collaborative design process.

Results: Student Learning

The results that follow will show that, in both of these school environments, KIE was successful in some expected and some unexpected ways, although its full implementation faced a number of contextual challenges. This analysis will examine some of the particular contextual issues in the schools and classrooms sampled that can make learning difficult, and the ways in which these challenges were met - successfully or unsuccessfully - on these projects. Because the intent is to describe a range of issues that can be important to learning in urban school environments, I will not present separate case studies for the two projects; rather, the results offered will include cumulative learnings from the full sample of classrooms.

Because in each school we were working with diverse student abilities, even on a very successful project performance would be expected to vary widely. As anticipated, some students learned more than others. This analysis will focus on particular cases to illustrate the type of learning that occurred, and the unexpected range of students who were able to achieve success with KIE.

Varying degrees of knowledge integration

As described earlier, both the Life on Mars? and Deformed Frogs! projects were developed to support a fairly basic level of understanding for some, with opportunities to explore further and to make connections at greater depth for those who were able to do so. The following debate excerpt from the Life on Mars project, for example, illustrates this range:

> *Student A:* The second argument against life on Mars is that Mars has very harsh conditions. Mars is very cold and dry. Huge dust storms and strong winds regularly occur on Mars. Under these harsh conditions it is very unlikely that life could ever have existed. Furthermore, the water on Mars right now is frozen and liquid water only existed for a very short time [...]

years ago. If water existed for a very short time it is unlikely that life could have ever existed. Lastly, there is very little oxygen on Mars atmosphere, about [...] percent, again making life on Mars difficult.

Student B: I'm responding to their comment on their... introduction that there were harsh conditions on Mars so living things can't form. But if you think about it, we had harsh conditions on earth like black smokers and you see bacteria and living things forming from them, and so that living things can form from harsh conditions. And they say that water wasn't there for a long enough time for living things to form, but if you think about it they found evidence that water *was* on Mars because there's creases in the surface area, you can see that there was an imprint left from the ocean and lakes... in Mars' surface, so the water had to have been there for a while so that... evidence could have been made on the surface area...

Student A's argument shows that she understands the evidence presented at a factual level: she correctly cites descriptions of the Martian landscape and atmosphere as warrants for her claim. She is also able to draw some connections between those physical conditions and current requirements of normal life on earth. However, the connections she draws between Martian physical characteristics and the possibility of life's early evolution are less successful. Her argument implies, for example, that oxygen was required for all forms of early life (lines 7-8). In KIE the students were encouraged to integrate new information on Mars with their knowledge from classroom studies earlier in the year about early life on Earth, including forms of anaerobic bacteria. In this case, the student learned the instructed facts about Mars, but has not successfully integrated them with prior knowledge.

Student B's response, however, is not only well organized and targeted to specific elements of her opponent's argument, but uses evidence accurately and draws connections to related scientific concepts. In particular, as they thought about the evidence students were prompted to consider the role of black smokers for early life on Earth (lines 11-12) and the length of time it takes for water to shape the landscape (lines 13-18), but these concepts were not presented directly. This link between evidence from KIE and evidence from prior instruction represents the knowledge integration that was the ultimate goal of the unit.

Finally, the following exchange, again from a Life on Mars debate, illustrates the level of engagement in class activities that might be expected for some low-performing students:

Student C: Scientists thought that the sky was dark blue but there was evidence the sky was pink it was a reflection of Mars' red dust...

[Whisper from a member of the audience]: We can't hear you!

[Loudly, from a teammate]: Don't interrupt!

[Audience member]: Sorry.

Student C: ...in the atmosphere. Yes we do think that the Viking Lander results ruled out the possibility of life on Mars. They found red dust particles and it's still debated whether it's microorganisms or life on Mars.

9 *Teacher:* Now wait, you guys are arguing Yes, there's life on Mars.
10 *Student C:* Yeah.

In this case the student focused on an irrelevant issue, red dust, and confused evidence supporting the two sides of the debate. Interruptions in the presentation, most notably from a teammate (line 4), are consistent with this lack of focus and consistency.

As expected, a similar range of performance was exhibited on the Deformed Frogs! project. The following for example, is one student's answer to a post-test question that asked students to apply their knowledge to determine the most probable cause of a particular frog deformity and to support their answer with a reason. The picture (Figure 6) showed a frog with limb deformities similar to those that have been shown to be linked to the presence of parasite cysts, although students may also have good reasons for believing it was caused by pesticides. This student checked an answer that suggested parasites, and supported her response as follows:

Figure 6: What caused these extra legs?

1 The main reason for my answer is because cysts interfere with the growth
2 of limbs, causing extra ones to go near the area with limbs. Also because
3 it has been proven by the bead experiment that cysts do cause these types
4 of deformities.

The student provides a mechanism for the interference of parasite cysts, and cites evidence ("the bead experiment", in which a scientists used an implanted bead to simulate the effect of parasite cysts on limb development) to support her hypothesis.

By contrast, the following response to the same question indicates that some students were engaged in the debate without actually learning the science behind it:

1 My answer is based on the pestice (sic) theory and I support it all
2 the way

This student offers no warrant whatsoever for the hypothesis he selected. It is unclear whether he did not remember (or try to remember) any supporting evidence, or whether he was simply unaccustomed to the requirement of providing scientific justification for an answer to a multiple-choice question.

In these diverse environments, then, a broad range of learning was experienced. A more interesting question than "did the students learn?" might be, "which students were successful?" In particular, several of our teachers were struggling to reach a population of students that never did any visible classwork, never gave any indication of paying attention in class, and were consistently issued failing grades as a result. Was this pattern consistent in the KIE projects?

New patterns of success

One of the most striking unanticipated results, evident in both schools, was that the KIE projects afforded new opportunities for success for many of those students who were typically unsuccessful in traditional classroom activities. The first indication was simply task completion. At Walker, before the project began the teacher identified a group of low-achieving students (maintaining D or F averages) that she claimed never handed in any assignments. Of the 16 such students in the sample, 63% turned in notes they had taken in KIE. At Franklin, results are similar: in the two "regular" science classes observed, the teacher estimates that about 65% of her students typically turn in assignments. For the Deformed Frogs! project, all students but one turned in notes taken in KIE (Figure 7). Whether or not these students performed well on the post-test, each teacher considered basic class participation an important step up for some of these students: not only is it the first step toward learning, but completed notes provide tangible evidence of academic activity. Said one teacher,

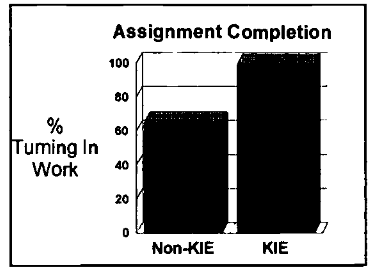

Figure 7: Dramatic improvements in completion rates

> This project... gave me another way to measure non-productive students: [particularly those who are] the first to raise their hands in class discussion, but never turn in work.

The next question, of course, is the quality of the work performed: did the students simply play on the computer and turn in the result, or did they exhibit cognitive engagement and real learning? In each of the two schools, for particular students with a history of low performance, the results are strikingly positive. The following examples are drawn from the project at Franklin; similar cases were evident at Walker.

For example, Janice is a 7th-grade student who was observed in non-KIE activities to be completely disengaged from classroom work, often sitting by herself with her head down on her desk. According to her teacher, she typically turned in tests without reading them, writing "I DON'T KNOW!!!" in response to each question. In an interview she indicated that she wants to be a hair dresser when she grows up, and therefore science is irrelevant to her life. By contrast, on the Deformed Frogs! project this student was observed to be focused and working most of the time, even asking on occasion for help with the correct spelling of a word she was typing, and otherwise asking not to be interrupted so that she could focus on the evidence, which was difficult for her to read. Although she continued to protest that frogs are "boring," and that her partner would be making the presentation because she herself was not interested, when the debate day came Janice stepped up to the microphone and delivered the following presentation, read from a prepared script. She prefaced this speech with, "Don't laugh at me!", acknowledging that this was a social risk for her but that she was willing to try.

Our hypothesis was the parasites, and we thought the trematodes. We think that the parasites are causing these problems because in... 1790 they found some deformed frogs and in 1790 they didn't create methoprene yet, so trematodes may have caused the deformation. We also think that the trematodes were the ones because they were on the abnormal leg of the deformed frogs and not on the frog's normal leg. Then they might have caused the other leg to deform. The parasite may not have caused the problem because there are many deformed frogs in many states so if a state that don't - that doesn't have methoprene has deformed frogs and only one that could cause it are trematodes. Pesticide that falls on frogs could not have harmed because scientists say that the pesticide methoprene doesn't harm animals. And about the Minnesota Water Experiment, whoever that thinks is a good evidence for the pesticide may be wrong because in the experiment they took some samples from tap water. Maybe the trematodes are in the water so it could deform frogs.

In this presentation, Janice cites five pieces of evidence, each clearly linked to her hypothesis:

- *Deformed frogs were found as early as 1790 (lines 2-4),* before pesticides were used. This evidence was presented in the Nightline video that students watched as an introduction to the project, indicating that she is able to integrate multiple sources of data.
- *Trematodes were seen on the abnormal legs of deformed frogs (lines 4-7),* a reference to KIE evidence that showed pictures of parasite cysts found inside frogs with leg deformities.
- *Deformed frogs have been found in many states (lines 7-10),* not all of which use the pesticide methoprene. This statement refers to KIE evidence in which students investigated a map of deformed frog sightings.
- *Scientists say that methoprene doesn't harm animals (lines 10-12).* This is an accurate statement of a piece of KIE evidence that refers to initial safety tests of methoprene. Although she does not reference later evidence that shows that scientists now have reason to believe that it can harm animals in a natural environment, it is significant that she is drawing evidence from both sides of the debate.
- *The Minnesota Water Experiment could have involved trematodes (lines 12-15).* The Minnesota Water Experiment evidence described a test in which scientists grew frog eggs in water from "normal" pond water and water from ponds where deformed frogs had been found. The frogs growing in the latter condition had a high incidence of deformity, indicating that the cause was something in the water. They later tested tap water of residents near the same ponds, with similar results. Many of the students used this evidence to support the pesticide hypothesis, since it was easier to visualize pesticide as an unseen agent than parasites, which are small living creatures that would surely be visible. Janice was one of the few students to critique this claim, suggesting that these parasites, which are microscopic, could have been at work as well.

Not only did Janice use KIE evidence effectively as warrants to support an organized set of claims, she drew her evidence from multiple sources, and included evidence that was presented in KIE to support her own hypothesis as well as a critique of evidence from the other side. Her argument indicates that she had engaged in the analysis of a great deal of evidence, and was able to link these separate ideas to construct a coherent overall model of the frog deformity problem.

The following is her teacher's summary of her performance:

> I have this student who the first day said, "I hate frogs. Why do we study about frogs - what difference does it make anyway? I will NEVER get up in front of the class and talk about frogs." She... absolutely knocked me off my feet - I wanted to cry. This student was able to express herself, she was able to present... her side of the argument and use evidence to back it up.

The emotion in this statement indicates how unusual this student's performance was, as well as how important her success was to her teacher. Unfortunately, although she did complete an informal written opinion survey, Janice's post-test indicated that she had returned to her prior habits of disengagement, including such answers as "I don't know" and "I'd like to know too" to questions that required applied knowledge similar to what she had successfully exhibited during the debate. A discussion with the teacher and an interview with researchers both indicated that she does not consider traditional academic formats such as a written exam to be appropriate forms of communication that are "worth her time". While overall academic success would require that Janice begin to take such schoolish tasks seriously, this project did enable her to prove to classmates, to teachers, and to herself that she is capable of learning and performing, particularly when she feels comfortable with the social context in which learning is situated and when she is allowed to express *her* opinion, rather than being expected to memorize the *right answers*.

Other students succeeded in different ways. One Franklin student, for example, appeared distracted through most of the computer work and delivered a showy presentation that demonstrated little learning, but received the highest grade in his class on the post-test. Post-tests included both multiple choice and essay questions, and responses were graded by the team of teachers and researchers on a scale that indicated depth of understanding and appropriate use of evidence; therefore, a high grade is a good indication of cognitive success. His teacher considers this to be a turning point for this student who had previously been labeled a "failure":

> So I have one student that does nothing, and got the highest grade in the class [on the Frogs post-test]... He's now begun to think ahead, and to excel and turn some work in, because he says, well, I can do this and a lot of people thought I could.

Interestingly, patterns of success changed for some high-achieving students as well. The honors science teacher at Franklin, for example, described a "star student" who excels in traditional school situations: she learns quickly, is academically motivated, and takes success for granted, appearing somewhat aloof from most class activities. According to the teacher, this student did not take work in the computer lab seriously; after all, this type of activity is not "real science". The student got a low B on the post-test: an unusually low score for her. Summarized the teacher,

> If I give her a routine math problem she'll get it right away. This required her to *apply* it.

The KIE projects, then, represented a new type of learning environment, with new opportunities for engagement and for assessment. Some students who were traditionally unsuccessful learned that they could succeed; others who were traditionally successful with a cognitive minimalist approach to school requirements learned that other approaches might be more productive.

To understand what happened, it is important to look closer at the implementation that occurred: how did the learning goals of these projects differ from the curricula that were already in place, and what contextual factors that were at play to influence the learning achieved? Answers to these questions can help to isolate the challenges that teachers face as they move to new learning environments like KIE, and some strategies that seem to work - or not work - to meet those challenges.

The following analysis will use the tenets of *Scaffolded Knowledge Integration* to assess the interplay between the intended learning framework and the classroom context within which it was implemented. This framework of *Identifying New Goals, Making Thinking Visible, Providing Social Supports,* and *Encouraging Lifelong Learning* identifies a range of strategies important to support successful learning in the classroom. What special implications did these components take on in the environments we studied, and how successfully was each achieved?

Identifying New Goals for Classroom Science	*Making Thinking Visible*	*Providing Social Supports*	*Encouraging Lifelong Learning*

In the schools we studied, several areas emerged as distinctly new goals for classroom science. These have implications both for skills that students are likely to bring to the table and for new classroom practices that must be implemented to support these goals.

Goal 1. Science learning as active thematic investigation, with thinking as a minimalist requirement for participation

> I really wanted my kids to work with scientists, and begin to think more like a scientist would think... And I also wanted them to use knowledge that they gained in my classroom, as well as knowledge that they had before they came into this classroom, to be able to come up with their own hypothesis and ideas. A lot of times science is just, I tell it to you, you tell it to me back, we take a test, we

may do an experiment. But I really wanted them to work like a scientist would do, to create much more interest and much more of a thinking process.

- a 7th-grade science teacher

At Franklin Middle School, teachers described their existing science curriculum as a linear series of topics with little thematic integration. Their current textbooks include brief lab experiments and worksheets, which typically ask students to focus on isolated topics. For example, when students learned about genetics and genetic diversity they were asked to list as many kinds of birds as they could, or to count the colored kernels on an ear of corn. There was no precedent within the curriculum, said the teachers, for students to be engaged as scientists or to integrate their ideas on complex scientific issues.

Although the honors curriculum provides more challenging opportunities for students, their teacher still contends that important thinking skills were missing:

> A lot of [my honors students] would do quite well going on Jeopardy... because they know all these little bits of information, and you can give them tests and they'll score in the 90's... [But they rarely] ask questions why. "It's just a fact, I just know it," you know.

The textbook-focused model for science instruction that was used prior to KIE, then, focused on the learning of discrete ideas rather than their integration. By contrast, KIE asks students to investigate a series of ideas that relate to a particular thematic topic, and requires that students organize these ideas and assess their relationship to a central concept or important hypotheses. The requisite skill of deciding whether a piece of evidence supports or contradicts a particular hypothesis, for example, turned out to be new and very challenging to many of the students.

At Walker High School, by contrast, the curriculum within which KIE was used was new, and deliberately structured to encourage students to take on the role of scientists Investigating Earth. When we began to work together, however, the teacher lamented that getting all students to take responsibility for learning in such a curriculum was proving to be more challenging than anticipated. Much of their work, for example, was evaluated on the basis of artifacts produced by the group rather than the learning that individuals achieved, and the work itself did not necessarily force all students to engage to a detailed level in the content. Again, the fact that KIE activities asked students to understand and critique scientific evidence as a basic requisite for participation was new and difficult for some.

Implications and strategies that this issue suggests will be discussed later in the framework, under the topic of *Making Thinking Visible.*

Goal 2. Classroom discourse as constructive debate, with an emphasis on student peer-to-peer dialog

In the non-KIE classes I observed in both schools, instruction generally included a mix of teacher-directed discourse and student-directed group work. The teachers used group work to varying degrees in their instructional repertoires, and experienced varying degrees of success in promoting real academic discussion among the students when they worked together in teams. For example, in the class I observed in which students were counting colored corn kernels to assess genetic patterns, student talk was more commonly either off-topic or arguing over who was counting what than discussions of the science. The teachers often did not have effective tools to focus groupwork and student discourse in the intended cognitive directions. KIE was envisioned as such a tool; as they work in KIE, students are asked to write joint notes that require consensus between team members, and are given suggested productive discussion topics as "hints" by Mildred, KIE's cognitive guide.

The culminating project debate also represents an important opportunity to change the classroom dynamic from a teacher-centered model to one in which students offer theories and probe the ideas of others. The debate model establishes the primacy of student ideas, rather than the more schoolish goal of finding the "correct answer" held by the teacher. Again, this proved to be a new model that was adopted by both students and teachers with varying degrees of success. Results and implications of these issues will be discussed under the topic of *Providing Social Supports.*

Goal 3. The computer lab as a setting for authentic subject matter inquiry

> Is it OK if they do the thinking in the classroom, and type the answers in the lab?
> *- one school's technology coordinator, who was trying hard to balance our lab time requirements with the demands of other teachers*

When the computers are contained in the science classroom, it is relatively easy to position views toward technology to match other components of the classroom culture. When they are instead in a separate computer lab, technology can take on a culture all its own. The above quote illustrates the potential clash of models between authentic use for purposes of scientific inquiry, and the more typically "lab" view of computers as tools that host particular types of software, word processing for example, that are learned for their own sake, independent of any authentic context for their use.

In the lab environment we experienced at Franklin, children spent time each day learning keyboarding skills[4], and then were frequently allowed to play games on the computer ("to learn mousing skills") during class or during their free time, apparently contributing to a view of the technology lab as a playground rather than an academic arena. This resulted in a number of challenges when we tried to focus the students on serious science activity in the computer lab; for example, when one person in a pair was typing in KIE, the other would frequently begin playing a game on the adjacent computer rather than engaging in joint cognitive work.

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[4] Writes Hornbeck in a 1990 analysis, "Happily... fewer school people are putting whole schools of students through eight weeks of familiarity with the keyboard. It is increasingly recognized that the computer will be used by most people as the telephone, television, and automobile is - to accomplish other objectives without being able to either build or fix one" (Hornbeck, 1990, p. 6). It is now 1998, and we found the strategy of isolated keyboard training alive and well, although the search for better solutions has begun.

Strategies for dealing with this challenge ranged from the logistical (for example, turning off computers not currently in use to reduce the temptation for launching games) to explicitly stated objectives. We discussed with the students reasons for doing scientific research in the computer lab rather than the classroom, and one teacher introduced students to the work they would be doing in KIE as follows:

> You're used to using a computer for fun. This is different - this is brain training.

It was also instrumental for us to include the school's technology management team in much of our work to create a shared understanding of the objectives of using computers. We were lucky to have strong support for those objectives from the technical staff; while this view of technology was new to them in practice, shifting to a model of integrated science and technology learning was one of their primary objectives for participating in the project. As a result, they were extremely supportive of KIE, critical in particular when numerous teachers were in competition for scarce available machine time in the lab.

Identifying New Goals	**Making Thinking Visible**	*Providing Social Supports*	*Encouraging Lifelong Learning*

The intent of *making thinking visible* is to find ways to make the content of science, as well as the process and skills of scientific thinking, explicit and accessible for students. The first is a common curriculum development task, and will be discussed here in terms of the visualization components of the projects and their importance and impact in the classroom environments we studied. The second component, making scientific thinking visible, is less often explicit but equally important to the success of curricula with the goal of engaging students as scientists.

In fact, we think of these two components - scientific ideas and the scaffolds that help students to integrate them - as inseparable. However, in the environments we studied, the second component was a newer practice to both students and teachers, and took on different implications for implementation. Therefore, they are discussed separately below.

Making scientific ideas visible

In any classroom environment, strategies for visualizing scientific ideas are an important component for introducing new conceptual models to students for consideration. We found such strategies to be even more important when working with students who tend to disengage when asked to focus on academic content. Keeping students on task was important not only for their own learning, but also to avoid a disruptive classroom environment that may interfere with the learning of others.

Because these projects, particularly Deformed Frogs!, included complex and somewhat abstract scientific ideas, we were challenged to avoid creating evidence that primarily described the content in text form. Deciphering such abstract text is a typical demand of school science (Cummins, 1989), but one that is particularly difficult for students who are less academically focused. In both projects, we worked hard to illustrate scientific ideas as much as possible to provide a visual context for the scientific text and to engage students in the task of reading it.

Figure 8: Lefty the Frog

In particular, pictures of deformed frogs proved to be very compelling to the students. As one of the teachers said in a design meeting, "You want them to say 'Oh, gross!' and then you know they're paying attention." Indeed, many of the pictures (for example, Lefty the Frog in Figure 8) generated this reaction from students, and even students who overtly dismissed the topic of frogs as "boring" examined this evidence carefully. This particular "gross" picture carries an important scientific message: because this frog has legs growing from the chest, scientists believe it cannot be explained by the parasite hypothesis, which contends that parasite cysts block or disrupt leg growth when and where it normally occurs.

The more challenging ideas were also supported by other visualization mechanisms. For example, full class discussions were illustrated where possible with a can of household bug spray containing the pesticide they were investigating; an online video clip of salamander limb regeneration; or a demonstration of a biological mechanism that included students as "cells" in a tadpole body. On a larger curriculum level, these city students - some of whom reported that they had never seen a tadpole - were also helped to visualize the process of frog development with a tank of tadpoles in the classroom from the beginning of the year, a hands-on frog dissection activity earlier in the semester, a computer-based exploration of frog anatomy, and a field trip to a local pond.

At both schools, we found that active or multimedia illustrations (online or using videodisk) during class discussion significantly raised the attention level of class participants. "Loud thinking exercises", in which an issue is raised for group discussion to bring new and relevant perspectives to a topic being studied, are a common technique in KIE classrooms to promote the integration of new learning with relevant ideas (see Kucan and Beck, 1997, for a broader discussion of thinking aloud strategies). In these environments, focused class discussions were often difficult to lead because students would often take the opportunity for disruptive behavior or simply fail to pay attention. At Walker, for example, in both observed classes a planned discussion to set the stage for a debate using real evidence ("Someone stole your backpack. What evidence might you use to prove who did it?"), while engaging much of the class in a useful discussion, was derailed by several participants whose disruptive behavior forced the teacher to switch to discipline management rather than discussion management. By contrast, a wrap-up discussion of the atmosphere and conditions on Mars that was supported by videodisk illustrations of the Martian landscape is shown on review of the audiotape to include productive participation from some of the same disruptive students.

Similarly, the deformed frog demonstration that cast students as tadpole body cells drew the attention of the class and was cited frequently in debates and post-tests, an indication of its effectiveness as a visualization mechanism. An important caveat is that in one class in particular, this demonstration was repeatedly cited as a source for an *incorrect* model of the mechanism: many of the students had confused two different parts of the demo and integrated this interpretation into their understanding of the evidence. Clearly, these engaging and effective techniques must be supported with explicit debrief and reinforcement of ideas to be sure that the learning result is as intended.

In this classroom environment, then, visualization techniques served not only to make visible the subject matter being discussed, but they also served to allow the discussion to proceed productively at all. Research also indicates that students generate a richer set of ideas based on multimedia evidence than on textual representations of similar content (Bell, 1996). Of course, multimedia techniques must be used with explicit supports to ensure that they result in the promised cognitive value rather than simply entertainment value for "media generation" students.

Full-class discussions that served to make students' thinking about these ideas visible also represented a new type of integration between the classroom and the computer lab. We experienced a tension between the need to use scarce lab time efficiently - often resulting in suggestions to have discussions in the classroom instead, or the need to intersperse full periods of related classroom work when the lab was not available - with the goal of establishing the computer lab as a "thinking zone" in its own right, with integration of ideas and pair collaboration both active parts of the work facilitated by computers. Explicit class discussions that presented the lab as a place of authentic scientific research helped to make visible students' and teachers' thinking *about* computers, as well as supporting the goal of thinking *with* computers.

Making scientific thinking visible

The above section focused on ways to make visible student thinking about the *content* of science. A second important and tightly interrelated challenge was to make visible the *process* of science: challenging students to understand the steps they must take in conducting scientific inquiry and evaluating hypotheses.

One of the elements that teachers found attractive about KIE was its design emphasis on scaffolding students through the process of scientific inquiry. Students are guided through a checklist of activities, for example, that make steps like surveying evidence and planning for a debate explicit, and Mildred is prepared with questions and prompts that scaffold productive directions for student discussions of evidence and planning. When they use KIE, students are required not just to browse the information on the Internet, but to analyze it in specific ways that lead to the ability to link it to a larger context. Teachers summarized the importance of these elements as follows:

> Right now I think [using computers for cognitive work] is still kind of novel... If you don't set just strict, strict guidelines right now they tend to think of it as ok, this is not really the learning, I don't have to be serious about it with the computer... [With KIE,] they weren't just reading something off. They got some information, they had to stop and think about it, then do something further with it... They got away from that, ok, it's just a place to go for information, like you would from a book.
>
> What I think was good was to set up their arguments... there was a form there that they had to follow. Because what I find sometimes in this age group, they love to argue but they really don't know what are good steps - they just argue.

While the above quotes illustrate that KIE's process supports were useful, available technology proved to be a challenge to their complete implementation. In both schools, computer memory limitations and conflicts with the lab's security software were such that only some components of KIE could be run, so worksheets were developed as workarounds for tasks that are normally computer-enabled. At Walker, Mildred asked her questions on a written sheet of paper rather than the computer. In the teacher's view, this may in fact have been a positive adaptation for her class, allowing students something familiar and "tangible that they can hold in their hand" to scaffold their work along with the newer computer-based elements.

At Franklin, memory constraints prohibited students from using the SenseMaker tool (which helps students to rate and categorize evidence as they create their arguments) while other tools were running. A worksheet version of SenseMaker proved less useful; the students appeared to view it as a separate cognitive challenge rather than an integrated support for understanding the evidence, and few chose to use it on a regular basis. Although KIE is designed to scaffold the complexity of the task of scientific analysis, these problems and others - screen sizes smaller than the software had been designed to support, slow network speeds, frequent machine crashes - all challenged the software's ability to play this role successfully. This experience points out the need to develop software with limited technical requirements for effectiveness in underfunded school computing environments.

In addition, the requisite thinking skills that require scaffolding vary according to student skills and prior experience with schooling. Over the course of these projects we identified a number of particular skills which were new to many of the students, and which required explicit instruction and support. For example, the notes students write in Mildred require that they decide how each piece of evidence is relevant to the debate or to the specific hypothesis under consideration. For some students, understanding what to write was a difficult challenge. With one class, we found it useful to break down the task into a series of steps that included summarizing the key points of the evidence, then deciding how the information is relevant (although this latter piece remained challenging for some, particularly without use of the SenseMaker tool). In future project designs, teachers suggested that Mildred be used to ask questions that step students through the thought process more explicitly if students are new to the task of linking their ideas.

A partial list of requisite skills that proved to be particularly challenging for many students is given in Table 1. These are all skills that are frequently taken for granted in instruction, but that we found to be important to students' ability to step up to the challenge of conducting scientific inquiry and which may be missing for students who have experienced traditional forms of instruction in the past. In KIE, many of these skills are made visible through examples or discussions, questions asked by Mildred, tools such as SenseMaker, or (as in the case of critiquing evidence) even focused KIE projects, with the recognition that these are ways of thinking that must be introduced and reinforced consistently over time. The teachers with whom we worked indicated that an expanded and explicit repertoire of such tools would be useful for teachers whose curricula did not include these skills.

Table 1: Skills for scientific thinking

New skill	Traditional requirement
Relating information to a larger context	Learning particular chunks of information
Critiquing evidence; questioning the interpretation, value, and source of information on the Internet	Memorizing textbook information at face value
Constructing arguments by supporting scientific hypotheses with evidence	Citing the "right answer"
Viewing pictures critically for relevant information	Perusing pictures for entertainment or interest
"Taking notes" as tool for analysis and learning	"Taking notes" as tool for content summary and recall
Applying ideas to related situations, in analysis and assessment	Learning ideas as isolated topics; assessment as factual recall

An additional thinking skill that we found important to make visible was language use. The bilingual teacher with whom we worked made this a particular emphasis of her teaching, building vocabulary lessons into her science instruction and constantly facilitating connections between scientific and everyday uses of words. Interestingly, teachers whose students were all fluent English speakers - teachers who indicated that they had traditionally perceived themselves as teaching science, not language - decided that such supports were important for their students as well to give them the tools they needed to engage in scientific thinking.

For example, a challenging requirement in KIE was the task of deciding whether something "supports" or "contradicts" a hypothesis. This decision was modeled explicitly during the Deformed Frogs! project in multiple class discussions - for example, offering evidence that supports or contradicts an invented "scientific" claim such as "School uniforms promote better student performance" or "Aliens are deforming the frogs." Nevertheless, a number of students seemed to be having particular difficulty making this decision about each piece of evidence. Late in the project, student questions made it clear that they did not know the meaning of the word "contradict"; although the scientific concept had been illustrated, the requisite vocabulary had not been mastered. After the project, several teachers indicated that they would focus more in the future on making scientific language issues visible in their instruction, as indicated by this assertion from the honors biology teacher:

> What I'd like do next time around is to make sure that I do focus on the vocabulary... A couple of weeks ago I went to a conference on gifted education, and they were saying - and it is so true, when you look back - that a lot of times in some of these projects we give it out to the gifted students, but we don't give them the vocabulary of what they need for it... so I could see if we had a way to really build in the vocabulary of everything they use... when they do go give their arguments, they [would be at a] higher level.

On the Deformed Frogs! Project, we were fortunate to collaborate with two "real scientists": graduate students in biology at Berkeley who were instrumental in quite literally making visible to the students both what it is to be a scientist, and how to think like one. Contrary to most student conceptions, one of our scientists was a woman, whose teaching experience allowed her to relate student ideas to scientific ones very effectively; the other, Duncan, was a very tall man who generally wore hiking boots and won almost cult-like fame among the kids for his rumored extended camping and biking excursions. The teacher called the children's enthusiasm "the Duncan phenomenon", personal connections which commanded a great deal more attention to discussions he led of the process that scientists go through to evaluate hypotheses, and the importance of scientific evidence.

Identifying New Goals	*Making Thinking Visible*	**Providing Social Supports**	*Encouraging Lifelong Learning*

Learning relies on a productive classroom environment, one which is safe for students to express their ideas and in which scientific inquiry is sanctioned. In urban schools, such environments are sometimes harder to come by, even in classrooms led by talented and caring teachers. Social supports stressed in the KIE curriculum include student teaming; frequent solicitation of student ideas, including structured opportunities for idea-sharing such as class debates; and modified teacher roles as coach and supporter rather than lecturer and judge. In the classrooms we studied, how successful were these approaches?

Supports for collaboration

As discussed earlier, most of the students with whom we worked were accustomed to working in teams, but their interactions with teammates were not always productive or on-task. We found teaming to be particularly challenged by several factors:

- *High levels of absenteeism.* Absenteeism is a frequent problem in urban school environments (Maeroff, 1991). In one class at Walker, I counted 25% of students missing the first day. The teacher reported an average absentee rate of 10-15%, with additional students gone on days when there were special events. There were five of these special events in the nine days I observed: two ethnic festivals, and several music and sporting events. Walker's investment in student activities is laudable, but proved to be very disruptive to classroom continuity, particularly since many other students missed class regularly to care for younger siblings or to work.[5] As a result, teamwork had little consistency: students often had to work alone because a partner was absent, and as debates began one team complained, "But our other team member isn't here, and she has all the notes!"

- *Unproductive or individualistic attitudes.* Students did not always feel a sense of responsibility for group accomplishment. Sometimes this was reflected in failure to share the work; as one student at Franklin who was monopolizing the keyboard said of the partner sitting next to him, "But he wasn't here yesterday, he'll just screw it up. It's easier if I just do it." Other students simply refused to work together, choosing instead to log on separately or looking for excuses to trade partners.
- *Widely ranging abilities and motivations.* Successful teaming of high- and low-achievers requires strong incentives and norms for participation and for partnership support. Without it, such teaming was rarely successful. For example, in one situation in which two low-achieving boys were teamed with two high-achieving girls, the girls immediately began working while the boys began talking about their plans for the weekend. When the girls were asked whether their teammates were helping, they responded, "Well, they gave us their notes." Low expectations of the boys' contributions on both sides resulted in little incentive for mutual support.

Given these challenges, the KIE software and instructional strategies seemed to offer some support for productive collaboration. We established goals that required teamwork, such as a final presentation that would be conducted jointly, and offered consistent encouragement for students to talk together and share responsibilities. Some techniques were logistical, such as deliberate seating of pairs in the computer lab to minimize disruptions, and in one case conducting debates in teams of four rather than two to improve team continuity in the face of absences. The computer itself, and the requirement to type collaborative notes based on discussion, also seemed to serve as productive external focus for collaboration. Franklin's technology lab manager noted that small-group chatter as KIE teams discussed evidence and notes was a welcome addition to the lab environment, and one teacher commented:

> Working with someone else on the computer helps them to get work done. With regular assignments in pairs, working together is very much a distraction.

[5] When the teacher complained to her administration about the frequency with which students were taken out of her class, she reports that she was told simply to give them make-up assignments. Unfortunately, such an approach is at odds with project-based and team-based learning, as it assumes that learning can be accomplished by a series of discrete individual assignments. Lamented the teacher, "But that's exactly how they keep telling us *not* to teach!"

Nevertheless, the success of teaming was significantly impacted by the teamwork skills that students brought to the project. In many cases, real collaborative teamwork was lacking throughout the unit. As with other issues of classroom culture, lasting change is likely to take time to enact, an issue to which I will return in a later section.

Promoting student dialog

KIE offers an opportunity to shift from a culture of teacher-led class discussions to one of student/student dialog in which student ideas are respected. One teacher suggested that she expected the dynamic in the computer lab to be more focused on student interactions with the computer than with each other, but she was pleasantly surprised:

> I pictured it to be... not as much of a conversation going on between the kids... I pictured it more as just another place for information for them to get... [but] when you went around the room, you heard them talking to each other - "well, let's go look for that, I don't think that one looks like this..."

On both projects, the class debate was a particularly fruitful opportunity for student/student dialog on scientific topics. The interaction was scaffolded, with worksheets for student questions that they would ask of other teams and appropriate questions modeled by the adult participants. In particular, the structure around the process appeared to help the dialog to be productive and increased levels of student interaction. One teacher indicated that without such tools, class presentations in the past had been much less conducive of student questioning. She compared the final debate to more typical class discussions:

> Usually I ask questions, they answer, I tell others to be quiet. Now students are asking questions of each other.

In different classrooms, debates were structured in different ways according to the goals and practices of the teacher. These alternative formats included teams of four presenting to a panel of student judges; students presenting to the class as a whole; and students presenting to a panel of teachers, including the school principal. In each of these formats, debates proved to be a particularly motivational forum, with most students of all abilities preparing notes or scripts, and the attention of the class held much more firmly than lectures or class discussions were generally observed to do. Teachers credited the elements of performance and competition, and the important fact that students were being encouraged to present their own ideas:

> [In the classroom debate, students are] competing to convince somebody that they're right, not competing for the right answer or a grade like they usually do.

Changing roles for teachers

Facilitating the type of social support and dialog described above means a very different set of roles for teachers from the traditional ones of lecturer, class discussion leader, or disciplinarian. KIE teachers in the past have found this to be a profound but positive change: because the software is providing the content and procedural guidance, students become more autonomous with respect to the process of learning, and the teacher is freed to focus on more cognitive discussions with individuals and pairs of students. To support an open classroom environment, it is also important for the teacher to solicit and encourage student ideas rather than be the keeper of the "right answer".

Not surprisingly, different teachers adopted the new roles to different degrees. The issues involved in teacher role modification and adoption of innovation are extremely complex (see for example Sheingold & Hadley, 1990; Means & Olson, 1995). Here, I will limit myself to several brief comments:

- Some teachers, particularly those who were already most inclined to support and encourage student ideas, found wonderful opportunities to facilitate student thinking as pairs worked in KIE. For example, one teacher reported that in discussing with a pair of students a piece of evidence presenting an interactive map of deformed frog spottings, she was able to elevate the students' focus from solely map content to help them think about how the Internet made this map a valuable collaborative tool for scientists across North America.
- While behavior issues tended to be lessened when children were working on the computers, those issues did not go away, and remained consuming for teachers in the more difficult classes. Although some teachers indicated that KIE was affording them more opportunity to interact closely with their students, one teacher responded:

  > My students required that I be a controller instead of an interacter.
- When we were running these projects, there was always a minimum of one graduate student working with students in addition to the teacher; at times there was also a technical support person on call. The above statement indicates that without these extra bodies, the cumulative task of managing behavior and facilitating cognitive discussions can be overwhelming for new KIE teachers, even with the support of technology tools - and particularly if technical difficulties are added to the mix.
- Several of the teachers were inconsistent with the degree to which they adopted new roles. One worked with individual pairs but primarily on logistical issues of how many notes they had written or how to use the software; another responded to individual questions (primarily on the same topics), but when students seemed on task she took the opportunity to log on and catch up on e-mail. Modeling interactions with students was generally helpful, but building these new skills would require an extended process of modeling, reflecting, and experimenting.

Issues that surround teacher adoption of new tools will be revisited in the Discussion section below.

Kids don't want to think - they resist it mightily.
- a 6th-grade science teacher

Providing the appropriate supports for students to engage successfully in scientific inquiry is one thing; ensuring that they choose to engage is another, particularly for students who are typically less academically motivated. KIE's goal is to give students the tools they need to become lifelong science learners, continuing to refine their scientific ideas and applying them in their life outside the science classroom, which in turn requires that the students take on the responsibility for their own science learning.

One tactic that proved to be quite successful in all classes was to select curriculum topics that represented current and interesting scientific controversies, both so that students would experience science as a living and dynamic enterprise, and also to increase the likelihood that they would think about what they had learned in school when they saw a report on television about the Pathfinder mission to Mars or read in the paper about possible implications of deformed frogs. In fact, shortly after the Frogs project was completed at Franklin, an article ran on the front page of the local major newspaper about a new scientific report suggesting that deformities were linked to Vitamin A in the water, a finding that supported one of the hypotheses the students had explored. The honors teacher had this to say about her class's reaction:

> It was funny, after we had finished up in the computer lab and we had actually taken the final tests, it came out in the newspaper about (it's up there over the door) Vitamin A... and I had about 10 students who brought in the article, and I know that before this is something they would have just passed over. Even though they're looking sometimes for science articles. It's still very much on their mind. Are they were still saying, "See, I told you it was this." "But no, that doesn't mean it's solved..." So they're accepting that science - there's not *the* answer, or *the final* answer, and I think that's important for science.

An ongoing interest was also reported by a teacher of "regular" kids - students who were typically less likely to bring school-learned topics outside the classroom:

> Out in the schoolyard I could hear them through the windows and they were challenging each other, "Pesticide!" "Parasite!" Back and forth. And you know what, my students don't talk very much about school and academics outside the classroom. It was really exciting to me to hear them integrating this subject... into (their talk outside school).

Not all the students brought their work outside the classroom, or even focused on it inside the classroom - some of them were typically off-task in the computer lab, or deliberately refused to apply themselves to questions perceived as too difficult. However, as reported earlier, for some students who were labeled "failures" in traditional academic venues the projects provided an opportunity for cognitive success and academic recognition, indicating a possible pathway to lifelong learning for a group of students that school science traditionally fails to serve.

Long-term results are not yet in; indeed, with only a two-week intervention, lasting improvements are difficult to achieve. According to one teacher at Franklin, many students quickly returned to their old habits when the class went back to the more traditional textbook model for subsequent units: "They're fitting their academic persona, that's who they are."

However, these cases are important for two reasons. The first is that students demonstrated to themselves that they are capable of success - not from playing on computers or contributing artwork to a group project, but cognitive success that is reflected in deserved grades. For some, experiences like this one may lead to the possibility of engaging in a future learning process that was previously inaccessible.

The second result of significance is that student thinking was made visible, not only to the students, but also to teachers who had never before seen evidence of their students' academic participation. Teachers at both schools noted the importance of alternative forms of assessment that allow students to receive credit for less traditional exhibitions of learning. At Walker, students in the Life on Mars? project were not given a written post-test; debate results were taken as the basis of their final grade for the unit, and the teacher was pleased that she was able to justify higher grades as a whole than for most traditional work. At Franklin, the teachers with whom we worked and their partner teachers (teachers who see the same students for language arts and social studies) have begun a dialog about how to provide equitable assessment opportunities for all students:

> The biggest thing that I learned is that there needs to be alternative forms of assessment. The written paper kind of test and the traditional methods of teaching all children is really handicapping for some kids... What it's doing is forcing me to evaluate day to day, as I teach a lesson and as I require a piece of paper at the end of the day to prove what they've done, that I've got to come up with another way to have kids who really will not perform very well at that level be able to also get credit for what they've done in a day's worth of work.

There are a number of possible explanatory factors for the results we saw, and it is difficult to isolate their effects (Brown, 1992). Projects selected were significant, engaging, and challenging. To some students, work on the computer is an interesting novelty, consistent with the findings of many other projects touting the strong motivational capabilities of computers (Means and Olson, 1995; Collins, 1991; Schofield, 1995; Newman et al, 1993; Rowe, 1993; Carver, 1992). The software and learning environment were designed to scaffold success, and perhaps were unique enough to break students out of their cycle of non-performance. A public presentation forum, with an element of competition in some cases, appeared to be extremely motivational. And with attention from graduate students, scientists, and video cameras, students were made to feel special. As one Franklin teacher put it,

> The debate, again - for them to be able to do so much research and then to... have a forum that they could express their opinion and their viewpoint, and that mattered - there was an importance to it. I think that was a great benefit. They really felt like they could contribute to this frog problem by the time they were done, that their ideas and their thoughts were contributing to maybe a solution or further steps to finding a solution to this dilemma... To seventh graders... in their development they feel very insignificant, and I think they were made to feel a little bit more important...

The challenge remains to make students feel "a little bit more important" on an everyday basis, as part of the regular curriculum and without special resources. Based on these observations, however, innovative project-based learning environments like the one supported by KIE appear to hold some promise.

Discussion

This paper has indicated that, despite the challenges of urban school environments, tools such as KIE can be successful, both in new models for learning offered to all students and in new opportunities for success offered to typically low-achievers. It has also indicated that for teachers implementing these new tools, the challenges of integrating these tools into their classroom environment and teaching repertoires are significant. I now return to the questions with which this paper began: what are some of the dimensions of the teacher's "real world" context, and how can we support them as they integrate new approaches?

Dimensions of classroom context

Based on the above analysis, there are a broad range of contextual issues which influence the ease with which learning environments are adopted, and which can reshape them in ways that either promote or disrupt their effectiveness in supporting learning. With an understanding of these issues and their impacts, we can begin to develop a set of supports for teachers that suggest alternative strategies that may be useful in particular classroom environments. Some of these supports may be additional lesson suggestions (for example, illustrating the basic skills required to evaluate scientific hypotheses, if the students have not yet encountered such a demand). Some supports may be more in the form of logistical tips (for example, possible ways to configure student seating in a computer lab environment to minimize distractions). The intent is to allow the teacher the flexibility to integrate innovative environments such as KIE with the demands of his or her own classroom context in a way that maintains the ultimate goal of learning.

Figure 9 illustrates the dimensions that we found to be the most important influences on these projects. In the center are the immediate settings of "my classroom" and the teacher's own beliefs, goals, and repertoire of strategies, all of which were both the setting for and objects of innovation, surrounded by a set of external influences within which they operate. The questions that follow suggest some important avenues of analysis to navigate design issues and understand results on particular projects.

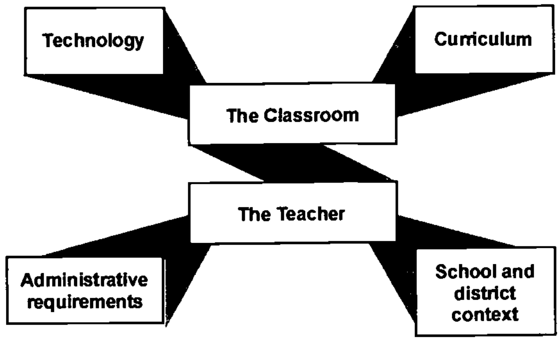

Figure 9: Dimensions of context for innovation

- *The Classroom:* What are the current norms of behavior, respect, and teamwork? To what degree are student ideas solicited and sanctioned? What patterns of classroom discourse are common? Who are the students, and what range of cultures, languages, abilities, and motivation levels do they bring? How strong are their adaptive behaviors toward schooling, both cognitive and social? How much continuity can we count on, particularly in terms of absenteeism and student turnover? These issues and many others strongly impact project design and teaching strategies. To the teacher, the classroom is also a place of more immediate logistical requirements: desks to be arranged, papers to hand out, students to be seated in ways that minimize distractions.

- *The Teacher:* Teaching strategies selected by the teacher are also strongly influenced by his or her own beliefs, goals, and skills. What are his/her dominant images of teaching and learning? What current repertoire of teaching and assessment strategies does s/he bring? How much free time is available to work on innovation design and adoption? Where is s/he in terms of career or professional development opportunities? What is his/her experience with, and views of, technology? Of scientists and science?

- *Technology:* Issues here include the strategic, the technical, and the logistical. What is the dominant culture of computing: are computers learning partners or games? Is technology use guided by a strategic plan? What computer configurations are available, in the classroom or the lab? How much computer time is available, and how much downtime is expected? What are the capacities and limitations of hardware, software, and networks? How easy or difficult is it to install and configure new software in the shared lab? What budget and support resources are available?

- *Existing curriculum:* How rigidly dictated is the school's curriculum, in terms of topics or approaches? Will the project be a capstone, a foundation, or simply an instructional unit? How much instructional time can be devoted to this project? These issues can significantly impact the freedom within which teachers can design and adopt innovations, or the channels that must be followed to gain additional freedom.

- *Day-to-day administrative requirements:* We often don't take these into account in research, but they represent a significant parameter in the teacher's world. How long are scheduled periods, and does the schedule rotate from day to day? Is there any schedule flexibility? How often can we expect assemblies and other schedule interruptions? What grading requirements are imposed?
- *School and district supports:* What supports or pressures are imposed by administration, locally and at district levels? What are leadership's goals for pedagogy and for technology use? Is there a culture of collaboration among teachers, or school-wide support for innovation? Are there processes to establish release time, extra pay, or other incentives and supports for teachers to participate?

In one way or another, each of these elements impacted the design or effectiveness of the KIE projects we implemented. For example, computer downtime, lengths of class periods, and schedule interruptions all forced us to plan creative and flexible lesson plans. The current repertoire of teaching strategies used by the teacher and the scientific thinking skillsets of the students indicated what skills needed to be taught and modeled explicitly. Teacher and administrative views of grading requirements made us look at the deliverables students were producing in new ways, and sometimes caused tension between supporting creative student ideas and grading for the "right" ones.

When teachers implement innovation in their classroom, they are faced with the task of balancing each of these interrelated issues as they adopt new tools and techniques in support of learning. The following section suggests a framework for helping to support teachers as they navigate these challenges.

Support for teacher knowledge integration

The work at Walker was an initial exploration into the contexts of schooling and the adoption of environments like KIE by teachers. We worked with the teacher in partnership, but did not yet have the opportunity to provide significant structured supports.

At Franklin, by contrast, we had the luxury of a year-long partnership with teachers and scientists, supported by monthly meetings and numerous gatherings over lunch, during which we could build more solid professional relationships. This structure allowed us to explore the process of teacher knowledge integration in action, and to experiment with supportive activities.

The partnership as a whole was a comprehensive and complex project which will be analyzed in more detail in a separate paper. This section contains some observations of the process as it related to teachers, using Scaffolded Knowledge Integration to frame the types of supports that seemed to be valuable in this process.

New goals for science teaching:

- ❑ A primary focus of our initial meetings was explicit discussion of goals brought to the table by all participants, and agreement on a joint vision of what we wanted to see happen in the classroom. This step was critical to ensure that KIE was not perceived as being imposed by others or "thrown over the wall." It was also cyclic, as some goals were emergent as we saw how KIE was interacting with the students and with the teachers' traditional practices.
- ❑ As described earlier, deliberate goals included both student learning about science content and scientific thinking, and the adoption of particular teaching practices that could support learning and more productive classroom cultures.
- ❑ As noted earlier, we found it very important to include school technology management staff in these discussions, as a new goal of the project was to integrate science and technology instruction, both in vision and in practice.

Making thinking visible:

- ❑ In both formal monthly meetings and informal lunchtime ones, we deliberately made visible the supports and approaches that each side contributed. The KIE team brought methods, worksheets, and post-test samples and templates; teachers brought current textbooks, samples of student work, and a wealth of expertise and stories about strategies they use in the classroom. Many of the environmental challenges we faced surfaced in these discussions, rather than waiting to surprise us later. In this way we were able to put together a joint design for the real classroom situations and constraints that teachers were facing.
- ❑ Another source of input was a video of Doug Kirkpatrick, a very experienced KIE teacher, as he used KIE in his classroom. This gave the teachers an opportunity to share ideas about what would work and would need to be adapted for use in their own environment (for example, how will we ensure full student attention during class discussions in a computer lab, as opposed to Doug's self-contained classroom environment?).
- ❑ While instruction was occurring, graduate students were always on hand to model KIE teaching techniques in general as well as specific discussions that are useful, for example, for introducing new ideas of "critiquing evidence", or techniques that encourage productive peer-to-peer dialogue in debates.
- ❑ We also made visible many parts of the curriculum development process beyond the subject matter and teaching strategies. For example, how do researchers make student thinking visible? We discussed and tried our techniques of student beliefs surveys, which we analyzed as a group and decided together how to use in instruction.
- ❑ As part of our research, we videotaped and tape recorded parts of the sessions with students, including teacher interactions, making visible what actually occurred in the classroom and lab. We jointly viewed student final presentations and discussed related teacher practices. Due to limited available

time, however, we were not able to discuss samples of recorded teacher interactions with students as much as would otherwise be desirable.

Providing social supports:

- A critical element to teachers was that our formal monthly meetings, and informal ones during lunch or free periods, established an environment of sharing and collaboration between the teachers that had never before existed. The varied talents and areas of focus among the teachers allowed them to compare notes about strategies they had tried: for example, when the quality of student notes was an issue, one teacher suggested that she had asked her students to devise a set of rubrics that they would commit to. Teachers touted this collaborative environment as one of the most significant benefits of the project:

  > I really liked the teambuilding attitude that happened with the science teachers at [this school]. In the four years that I've been here I hadn't experienced that, so that was great. There's a lot of give and take now between those of use who are part of this project.
  >
  > I think [the process of collaboration] went excellent, I was really really pleased. I thought we had support, and I know that once-a-month meeting that we had with all of us together was really good. And then just the weekly, or sometimes it seemed like daily, meetings with just the teachers here was just really good, because someone would have tried something in the classroom and it didn't work, and someone else would have tried a different approach and go back and you can change it.

- This environment of teacher collaboration was extended outside of Franklin as well: Doug Kirkpatrick was able to visit the classroom, to spend time with the teachers and to broaden his own understanding of how KIE works in varied environments.
- To support the teaching itself, there was always at least one graduate student in the classroom or lab. We began by doing most of the teaching, while teachers were still learning the environment, and gradually faded the scaffolds, encouraging the teachers to take on the role of running the class while students were using KIE.
- In this case, social supports also meant simple elbow grease to coordinate the project, develop evidence and post-tests, and support technical difficulties. It is very important to note that the required investment for bringing innovations like this successfully to urban classrooms is not a small one.

Encouraging lifelong learning

- This project encouraged teachers to be reflective about their teaching, and about the practices they could bring back to their classrooms even when they were not using KIE. These issues ranged from significant changes in approach, like exploring alternative assessment strategies, to more specific tactics like using the concept of "evidence" to support conjectures in mathematics, or tips for structuring class discussions to encourage student peer-to-peer dialog in more explicit ways.

- Lifelong learning is also an issue for teachers from a larger career standpoint. We found it important to explore the professional development opportunities that may be of interest for teachers as a result of this experience, including a lead teacher role in future collaborations or opportunities to present project results to peers.

As a result of this process of knowledge integration, teachers reported that they felt they successfully brought new ideas to their work, while maintaining and even reinforcing their substantial existing teaching skills:

> The other thing was the teamwork, the team effort that the Berkeley people gave me was really a benefit to me. It helped me change things that I needed changing, and it helped reinforce some things that were good about my teaching. So there were both, the give and take there that I really enjoyed.

According to a study commissioned in 1995 by OTA, policy discussions of professional development related to technology usually focus on "short-term, one-shot" training on computer literacy or on the use of a particular application (Office of Technology Assessment, 1995, p. 1) without considering the need to develop curriculum that supports student learning using these applications, the implications for the teacher's role in the classroom, or how technology can help the teacher with his or her own work. Using the SKI framework to consider teacher support needs can help ensure that the focus remains on true teacher professional development and long-term growth rather than simply "teacher training."

An important component of ongoing professional development is professional collaboration among teachers. Little (1990) indicates that "teacher collaboration" is often imposed by institutionally-sponsored initiatives as a goal in itself, without providing teachers with a felt incentive to engage in collaborative activity. Our work with these teachers suggests that the challenging and compelling goal of adopting KIE, including its tools and classroom practices, encouraged a natural process of collaboration which was initially supported by the funded project but which teachers plan to continue on their own. We feel that this ongoing process of collaborative planning and reflection is key not only to continuous improvement to the KIE curriculum as implemented at this school, but also to promote professional growth for the teachers themselves.

Another important note is that, as with children, knowledge integration for teachers takes time. In a 1989 survey of 600 teachers selected based on successful classroom use of technology, Sheingold and Hadley (1990) found that teacher practices surrounding classroom computer technologies typically continue to evolve for the first five or six years, beginning with computer uses that tend to reinforce current classroom practices and growing toward more enriching applications that can represent more substantial gains in student learning. Our observations support this perspective of teacher knowledge integration as a gradual evolution, beginning with logistical and practical considerations (How should students be seated? How will I issue grades?) and, once those are ironed out, moving toward a focus on student ideas and scaffolding their learning. Again, a long-term strategy is required, going far beyond a brief training session or even a summer workshop.

A challenge for the future is developing ways to support this ongoing process of contextualized learning without the luxury of dedicated resources at each site. The KIE project is beginning to experiment with electronic supports for teacher knowledge integration; project structures that team teachers from within a school or from multiple sites, with guidance from experienced KIE teachers; and repertoires of alternative classroom strategies from which teachers can choose or which they can use as starting points to develop their own strategies. A critical factor is support at a school and district policy level to provide release time and other mechanisms that allow time for teachers to focus on collaborative project work. As with any serious change effort, substantial gain will require a substantial ongoing investment.

Conclusions

This paper has described the process and achievements of implementing project-based technology-supported learning environments in multiple classroom settings in two urban schools. Results suggest the promise of significantly improved student achievement. For those who were traditionally unsuccessful in school science, the type of learning environment that KIE represents afforded a new engagement and accomplishment in the endeavor of learning. For those who were traditionally more successful, KIE extended that success by offering ways to connect isolated pieces of knowledge into a more coherent repertoire of models.

These results would not have been achieved without a concerted effort - on behalf of the teachers, the school's technology team, and outside supporters - to facilitate the integration of new tools with the existing classroom context. As it was, a degree of fidelity of the innovation was necessarily sacrificed at both schools. Some of these modifications were due to real contextual constraints; for example, some software tools could not be implemented due to technical limitations. Other factors, such as teacher comfort level with new practices and tools, may evolve through an extended process of professional development that will benefit both students and teachers.

On these projects, we were on site collaborating with the teachers in looking hard at issues of classroom context and developing strategies that met both practical requirements and learning objectives. In broader rollouts, teachers will need to be more autonomous in reflecting on their own unique situation and selecting workable solutions. The results presented here suggest that the potential for substantial gain is very real, and that frameworks such as SKI can help to support the difficult process of blending theory with everyday practice to result in learning.

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