Organizing Principles for Science Education Partnerships: Case Studies of Students' Learning About 'Rats in Space' and 'Deformed Frogs'

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We describe how science education partnerships composed of educational researchers, technologists, classroom teachers, natural scientists, and pedagogy experts can create effective instructional innovations using Internet technologies. We show that our Scaffolded Knowledge Integration framework gives partnerships a head start on effective designs. We illustrate this process with the Deformed Frogs partnership and the Rats in Space partnership. We conclude with suggestions for future partnerships.

☐ How do we design quality science instruction incorporating the most effective technologies? Natural scientists, pedagogy experts, technology experts, and classroom teachers often tout inquiry, collaboration, hands-on experiments, and other features as essential (or useless) for effective instruction. Recently many have identified the Internet as either a boon for classroom learning possibly replacing the library, or the bane of modern technology generally misleading students. Norms or criteria for success are also widely varied. Some favor results from standardized tests. Some advocate performance assessments, portfolios, projects, personally constructed tests, case studies, engagement levels, or other outcome measures. This lack of consensus spurs debate, but offers no obvious path toward agreed-upon solutions.

We argue that Internet science education partnerships offer a mechanism for individuals holding these diverse views to resolve their differences in the context of the design, implementation, and testing of innovative instructional materials. Global networking technologies such as the Internet offer a unique opportunity for scientists already developing Web resources to join science education partnerships and collaborate on the creation of on-line curriculum materials. We show that this process, guided by our knowledge integration framework, can lead to a shared vision for instruction, enable negotiation of shared criteria for success, and result in powerful uses of technology.

SCIENCE EDUCATION PARTNERSHIPS

We define a *partnership* as a group of individuals committed to designing instruction, artifacts (e.g., curriculum materials or software), or science learning environments in a context of collaboration and mutual respect. Successful partnerships involve long-term collaborations between experts in all the relevant disciplines, including classroom teaching, natural science, technology, curriculum, assessment, and pedagogy. *Design* involves looking at the warrants for various ideas, constructing novel approaches, and testing these innovations in classrooms, selecting criteria for success. Partnerships engage in an iterative process of principled refinement of innovations they design.

We describe our pedagogical framework and report on two partnerships featuring our Knowledge Integration Environment (KIE) (Bell, Davis, & Linn, 1995) software. Both partnerships included science teachers from local schools, and on-line materials created with leading researchers. In the Deformed Frogs partnership, scientists studying deformed frogs and middle-school science teachers participated. In the Rats in Space partnership, high-school biology teachers and scientists researching human bone loss in microgravity (using rats as scientific models for humans) participated. In both partnerships our knowledge integration framework, developed over the past 15 years, guided the design process (See Linn & Hsi, in press).

KNOWLEDGE INTEGRATION

We refer to the process of making diverse ideas explicit, negotiating among them, and building new understanding as *knowledge integration* (Linn, 1992, 1995; Linn & Eylon, 1996). Knowledge integration involves seeking alternative perspectives, distinguishing among these ideas, gathering empirical, experimental, or observational data, discussing alternatives, and designing new approaches. To succeed, groups or individuals engage in testing their ideas, establishing shared criteria, and progressively refining their views. In partnerships, individuals come in with a diverse set of ideas, add new ideas to the mix, create a design, gather evidence, restructure, reorganize, or reconceptualize the task, and repeat some or all of the steps.

In the partnerships described here, we supported members as they jointly integrated their ideas to create and test science units. The KIE group contributed software in the form of a Web-based learning environment as well as a pedagogical framework. The science teachers contributed classroom activity structures and targeted instructional goals for their students. The natural scientists contributed an understanding of science content and knowledge of current controversies. The design process required considering alternatives, negotiating criteria to make decisions and delivering instruction to students.

The projects described here build on a series of partnerships among chemists, physicists, classroom teachers, pedagogy experts, and technology experts that created instruction in thermodynamics, light, and sound. The resulting Computer as Learning Partner (CLP) curriculum makes effective use of technology and sets students on a path toward lifelong learning. In this work, we established the Scaffolded Knowledge Integration framework (SKI) that gives designers of new units a head start in their design efforts (Linn, 1995; Linn, Bell & Hsi, in press; Linn & Hsi, in press; Slotta & Linn, in press). The two science education partnerships described here used this pedagogical framework in their collaborative work. We analyze how the partnerships integrate ideas and how the SKI framework contributes to their success.

Partnership Processes

How can we support science education partnerships so groups of scientists, teachers and educational researchers can integrate their diverse ideas and design effective instruction? We need to create an environment of mutual respect. We want the diverse participants to build on each other's ideas, entertain new ideas, gather information to distinguish among ideas, and develop a shared vision for success A common focus in our partnerships is the incorporation of technology components as learning partners to support student inquiry and learning (Linn, 1992). We would like to support partnership participants as they try solutions, use feedback to refine their approach, and establish joint criteria for effectiveness. We distinguish reforms decreed by standards committees, text book adaptation committees or curriculum authors from innovations designed by science education partnerships who make decisions collectively (Linn & Hsi, in press).

We see similarities between the design activities of science education partnerships, of software teams, and of students learning complex science material. For example, just as it is important to make visible students' ideas about science, it is important to make visible designers' ideas about science instruction. These parallels motivated us to use the SKI framework to support our science education partnerships. This framework helps us design curriculum for students learning about science, so we thought it would also help us support a partnership learning about the design of effective instruction.

By using the framework to design partnership activities, we also model the framework for participants. Using activities designed with the framework gives participants first-hand experience with framework ideas. We also hoped that these partnership experiences would help us refine the framework; essentially new partnerships offer a test of the framework that we can use to improve our pedagogy.

THE SKI FRAMEWORK

The SKI framework offers tenets to guide a partnership engaged in instructional design. A partnership of individuals holds a mix of diverse and usually contradictory ideas. Individuals involved in multidisciplinary partnerships may not share the same criteria for the selection of ideas. For example, when working with natural scientists, pedagogy experts frequently discover that the standards for experimentation differ across fields, that methodologies accepted in one domain are ridiculed in another, and that instructional practices such as lectures or whole class demonstrations are well established in some fields and viewed as peripheral or even useless in other fields. In this paper we report on ways to support partnerships as they negotiate common criteria for curriculum design.

Curriculum designers may believe in active learning, passive learning, authentic inquiry activities, direct instruction, building on students' knowledge, or eradicating students' intuitions. Designers may design for motivated students or assume that students are "cognitive economists," unlikely to make connections among ideas. Designers may believe that students are inherently inquisitive and likely to explore ideas or that students need motivational activities to succeed in science. Furthermore, in spite of apparent inconsistencies and even contradictions among these ideas, a single individual could hold them all! When designing instruction, individuals select from among a rich and potentially incongruent set of images of learning. They use some ideas, scrutinize some, and ignore others. In addition, individuals might restructure, reorganize, or promote some ideas, pay less attention to others and decide that some ideas are relevant to software design while others apply to lecture design. The SKI framework can help individuals and partnerships select among these diverse ideas, and develop a coherent approach to the design of effective science curriculum.

Select Accessible Goals

The first tenet of our framework says to select accessible goals so learners can connect new ideas to those they already have. Our work on thermal concepts illustrates this idea. Students, when asked to explain insulation and conduction, often describe some objects like Styrofoam® or thermoses as barriers that keep things hot or cold, permanently! Students often describe metals as actually imparting cold because "they feel cold" (at room temperature). And, some students describe materials like wool as capable of "making things warm" because "sweaters warm you up." To help students sort out these observations, we could offer students models at several levels of analysis. The accessible heat flow model could help students connect their observations to scientifically normative ideas such as thermal equilibrium. The microscopic and mathematical molecular kinetic theory that research scientists find elegant and parsimonious could help students make precise predictions, but it is incomprehensible to many students. Choosing a model that students cannot understand convinces many that science courses are irrelevant. These models may also reinforce unhelpful ideas (Eylon & Linn, 1988; Linn, Bell & Hsi, in press; Linn & Muilenberg, 1996). Molecular-kinetic theory, with its emphasis on molecular movement, reinforced for some students the idea that both heat and cold molecules could move. In our research, the heat flow model proved to align better with the problems that concerned students: wilderness survival, for example.

To encourage knowledge integration we also need to respond to conflicting beliefs held by students. For example, how do we help students interpret observations that metals feel cold and therefore can impart "cold energy"? If we ask students to explain how metals feel in a car on a hot day, we sometimes stimulate them to compare how metals feel at room temperature to how metals feel in warmer situations. This idea motivates some students to reorganize their ideas about materials, distinguishing conductors from insulators. We note that this idea motivates other students to distinguish heating from cooling. In both cases, introducing a hot automobile trunk (or hot oven) is *pivotal* because it motivates a reorganization of ideas. Pivotal ideas lead students to reason, although not always in the normative direction.

When applied to partnerships, this approach means adding accessible and potentially pivotal ideas to the mix. Each partner comes to the collaboration with ideas about the learning of science. The KIE members of the groups worked to generate alternatives and examples to see which ideas would prove accessible to the other partnership participants.

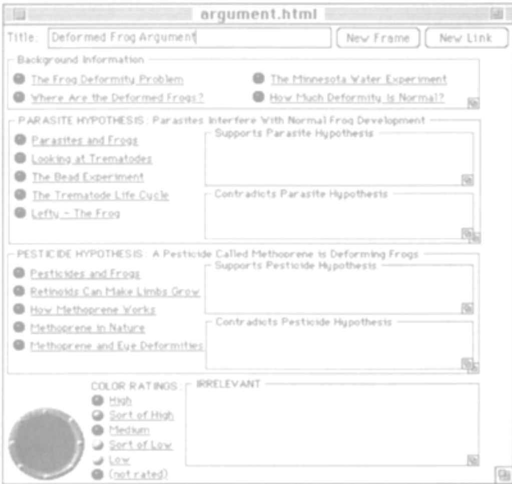
For example, the Deformed Frogs partnership described below began with the creation of a shorter and simpler unit on twins: how do you know if people are twins? The group could identify several alternative levels for the materials. Scientists favored the presentation of relatively complex genetic arguments that teachers were unsure the students would understand. To help resolve this dilemma, the KIE team suggested developing and administering a pretest to see what level of understanding students currently held. Results showed that very few students had any level of genetic explanation for twinning, and in one class more than half of the students thought that people who dress alike are twins. This quiz introduced new ideas about student thinking, ideas which proved to be pivotal for the partnership because they helped the group recognize how students think about the subject matter and led to an improved, shared understanding of what it means for seventh-graders to think like scientists.

Make Thinking Visible

A second tenet of SKI involves making thinking visible so others can understand how people solve problems. Too often, science instruction fails to describe the authentic thinking process people use to solve problems. For example, lecturers in chemistry, physics, mathematics, computer science and other disciplines often mislead students by describing the steps in a problem solution or research program without mentioning the dead-end paths they pursued and incorrect alternatives they considered. Students may conclude that their own floundering is wrong rather than learning ways to verify their conjectures and assess alternatives. Computer technologies can also help make thinking visible by displaying the mechanisms such as heat flow behind verbal descriptions. In CLP, a heat flow animation helped students develop explanations for complex problems (Lewis, 1991).

The KIE group has created a tool called SenseMaker (see Figure 1) to make visible the process of organizing warrants to support an argument (Bell, 1997). Using this tool, individuals identify evidence in the form of Web pages and use frames as well as notes to explain how this evidence contributes to an argument. SenseMaker is often used to make the competing hypotheses associated with a scientific investigation visible to the students so they are encouraged to explore different perspectives. We found that the Deformed Frogs partnership participants could also use SenseMaker to help understand the debate and how best to present it to students.

Figure 1 ☐ Initial SenseMaker argument map presented to students for



For example, scientists could illustrate how they look at the evidence for the environmental and genetic hypotheses. They formulated a representation of the debate in SenseMaker to illustrate their perspective to the team. This formulation also made the complexity of the argument immediately visible, helping the team to select the most promising level of analysis for classroom instruction. In this case a tool designed to support student argumentation (see Bell, 1998; Linn, Bell, & Hsi, in press) also served the partnership in making thinking about curriculum design visible.

Provide Social Supports for Learning

The third SKI tenet involves ensuring that the social context of learning supports the process of building on ideas contributed by others. In classrooms, collaborative learning has this goal, but does not always succeed (Hsi & Hoadley, 1997; Linn & Burbules, 1993). Similarly, design partnerships initiated with the goal of collaboration may lack sufficient mutual respect for all ideas to be considered openly. For example, perceived status differences among participants can lead to problems. Historical accounts of science curriculum design report that scientists sometimes neglect evidence from classroom trials of their approaches (e.g. Novak, 1968; Welch, 1979). Teachers also sometimes neglect feedback on classroom materials from expert scientists. In the cases that follow, we deliberately tried to build an environment of mutual respect to enable partnership participants to respond to the concerns of others. We implemented a diverse set of opportunities for interaction to encourage participants to listen and learn from each other, including regular meetings, visits to labs and classrooms, and electronic discussions, as well as presentations to new groups including peers and colleagues.

The groups learned from each other, for example, when developing a view of scientific inquiry. The KIE group, the teachers, and the scientists each held ideas that others found inaccessible. The KIE group argued that there were many obstacles to thinking like a scientist, including lack of content knowledge, difficulty applying reasoning skills, and lack of confidence. The scientists thought that difficulty often stemmed from lack of understanding of diverse scientific methods, complaining that precollege texts are too simplistic. The teachers often asserted that students lacked relevant experiences and basic reasoning skills such as weighing competing alternatives, so they floundered. This discussion introduced ideas that helped the partnership gain a better understanding of scientific reasoning by listening and learning from each other. Each participant contributed pivotal ideas for some other participants. We describe how this played out in the discussion of the Deformed Frog case later in this paper.

Promote Autonomy

In both our classroom and partnership activities, we hope to create lifelong learners who regularly evaluate new ideas and reconsider their views of science. Science instruction can never hope to address all the topics students will need to understand in their lives, so we endeavor to set students on a path of lifelong learning (Linn & Muilenberg, 1996). Similarly, members of science education partnerships will ideally continue to reflect on their pedagogical philosophy and test it in subsequent instructional settings.

In our classroom studies we find that reflection opportunities, where individuals inspect the links and connections among their ideas, promote autonomy (Davis, 1998). In addition, when students carry out sustained work in projects they often gain autonomous learning skills (Linn & Clark, 1997).

Our science education partnerships promote autonomy in several planned and spontaneous ways. We asked each partnership member to take responsibility for one part of the design. This enabled each person to use the collaboration's emerging pedagogical philosophy in specific ways. For example, the scientists in our Deformed Frogs partnership took on the task of creating the first draft of the deformed-frog evidence. Often they ended up contacting other researchers to clarify information or find out about recent advances. In these discussions, the scientists were motivated to reflect on their goals and explain the KIE projects, as well as to decide what they expected middle-school students to learn.

The classroom teachers took on the project of creating new activity structures for their classrooms. They considered how best to implement discussions of scientific topics, the final in-class debate, and other KIE activities in their classrooms. The teachers researched these new activity structures by watching videos of other KIE teachers, talking to peers and to members of the KIE team, discussing science learning with scientists, participating in demonstrations of lessons, and talking to a veteran KIE teacher, Mr. Kirkpatrick. One teacher remarked, after successfully implementing new class practices:

> [The students] all felt like they could contribute to this frog problem by 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 scientists were listening to them . . .

Ultimately, we hope that our partnerships will enable teachers to incorporate new ideas about pedagogy into subsequent teaching and curriculum design. And, we hope to refine the SKI framework based on these experiences.

THE KIE DEFORMED FROGS PARTNERSHIP

The KIE Deformed Frogs Partnership involved a year-long intensive collaboration between veteran middle-school science teachers, educational researchers, technology experts from the KIE Research Group, and biology experts, two graduate students from the Integrative Biology department at the University of California, Berkeley. This paper reports on our first year of collaboration in this ongoing partnership. The partnership was part of an educational outreach initiative on the Berkeley campus called the Interactive University. The goal was to unite university personnel with K–12 students and teachers, to bring university expertise into urban schools, and to foster connections between university representatives and those urban students who are typically underrepresented in higher education. The Interactive University and the school district provided resources that allowed one day of release time per teacher per month for extended design sessions, as well as technical support and computer resources. These modest financial supports were crucial to the success of the partnership.

The Deformed Frogs Partnership School Context

Franklin Middle School (pseudonyms are used for the names of the schools and the participants) is an inner-city school in Northern California with a highly diverse student body. Two thirds of its 860 students qualify for free or assisted lunch programs and one fourth are designated ESL (English as a second language). Four teachers from Franklin participated in the partnership, each of whom had different classroom contexts and student populations: 7th-grade honors biology (two classes, $n = 66$), "regular" 7th-grade biology (two classes, $n = 62$), a Russian bilingual class with grades 6, 7, and 8 in one classroom ($n = 25$), and a small class of students designated GLD (gifted, learning disabled), with four of these students participating on KIE projects as members of the other classes). Additionally, a 6th-grade science teacher participated in the design process, as did the school's technology resource teacher.

The KIE Deformed Frogs partnership sought to develop a set of instructional materials that would engage this very broad range of students, teach sophisticated science concepts, and convey an active scientific process of inquiry to students. By inquiry, we mean an understanding of the authentic work of science, giving students a realistic view of the broad range of scientific methodologies and a sense of the activities of the scientists (National Research Council, 1996). For other aspects of their science teaching, the teachers reported using a more traditional textbook-focused curriculum.

Goals of Deformed Frogs Partnership Participants

The teachers came to the partnership wishing to improve the coordination of science teaching in their school. They also sought new teaching tools and projects that would challenge and motivate their students. The project's natural scientists became involved because of a general interest in practicing educational outreach and exposing students to the nature of science. They contributed their knowledge of a current science controversy about the possible causes of deformed frogs, and explored how this controversy could contribute to science instruction. The KIE group contributed the SKI instructional framework and sought to refine it to meet the specific demands of the classroom contexts represented at Franklin.

Another important goal for the partnership was the integration of technology and science instruction through the new curriculum units we would develop together. The curriculum developed by the partnership made use of the KIE learning environment. KIE provides instructional supports for the learning of scientific knowledge, procedural scaffolding for important activity structures involved with scientific inquiry, and tools that promote important individual and group cognition (for details see Bell, Davis & Linn, 1995; Linn, Bell & Hsi, in press). The KIE view of technology-enabled science instruction, using computer technologies as a learning partner, was quite different from the separate "basic computer skills" classes that were the norm at Franklin. The teachers shared the goal of using KIE to help students become more intelligent consumers of Internet science resources, critiquing and integrating information instead of the increasingly dangerous approach of believing everything they see on the Web.

Deformed Frogs Partnership Activities

The year-long partnership activities included:

- Initial team building and goal setting. The diverse members of the team discussed objectives and articulated their personal goals.
- Design, development, and implementation of the KIE Twins project, a brief activity intended to introduce students and teachers to the KIE instructional environment. This effort helped establish a collaborative design process, and fostered respect for the diverse skills and contributions of the various members of the team.
- Design and development of the KIE Deformed Frogs! project, taking into account lessons learned from the design of the Twins project.
- Implementation of the Deformed Frogs! project in the classroom, first with the seventh-grade science classes and then with the Russian bilingual class.
- Group reflection on the partnership activities. Reflection resulted in redesign of the KIE activities and also informed the everyday practice of the teachers, researchers, and scientists on the team.

The diversity of the team brought tremendous power to the design process. It also challenged us to integrate the diverse objectives and visions for student learning initially espoused by the various members of the team. We used the SKI framework to shape not only the curriculum that was designed for the classroom, but also the process of partnership collaboration to promote knowledge integration among the individuals on the design team. The team adopted new visions of learning and pooled their diverse expertise to bring new topics and tools to the classroom. The SKI framework guided the partnership in this process.

The Deformed Frogs! Project

The Deformed Frogs! project explores the apparent increase in physical deformities among frog populations which has been observed in many parts of North America since 1992. Seventh-grade students in Minnesota used the Internet in the summer of 1995 to bring media attention to the phenomenon when they published their field observations of frogs with a wide variety of unusual deformities. Since that time, the topic has received quite a bit of attention: Scientists still do not agree on a cause, and many are concerned that the deformed-frog problem may be an indication of a growing environmental danger that may eventually affect humans and other animals. The deformed-frog controversy represents a complex, multidisciplinary problem involving environmental, genetic, and biochemical arguments. The topic also fits well with the overall seventh-grade curriculum focus at Franklin on genetics and simple organisms. Because it is an unsolved mystery, the topic legitimately engages students in scientific inquiry and debate around "science in the making" and according to students, deformed frogs are "really cool."

In the KIE Deformed Frogs! project, 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. A Web-based version of the Deformed Frogs project is available at: http://www.wise.berkeley.edu/WISE/about/frogs. Students first look at background information that includes pictures of deformed frogs and an interactive Internet map of locations where deformed frog specimens have been found. They investigate evidence related to one of two leading scientific hypotheses (see Figure 2 for a sample of KIE evidence). Hypothesized causes investigated and debated by students include a type of parasite that scientists believe can physically interfere with the natural development of frog limbs, and a pesticide that may, after exposure to sunlight, interfere with the hormonal signals that control limb development. We have subsequently focused the latter hypothesis more generally on the influence of environmental chemicals since a direct connection to pesticides has yet to be established by scientists. Since pesticides are widely distributed and have produced deformities in lab studies, scientists are still investigating their possible involvement in the controversy.

Deformed Frogs! activities spanned approximately three weeks, including both classroom and lab activities. In addition, activities related to the project were integrated throughout the year, including hands-on frog dissections and a tank of developing tadpoles in the classroom.

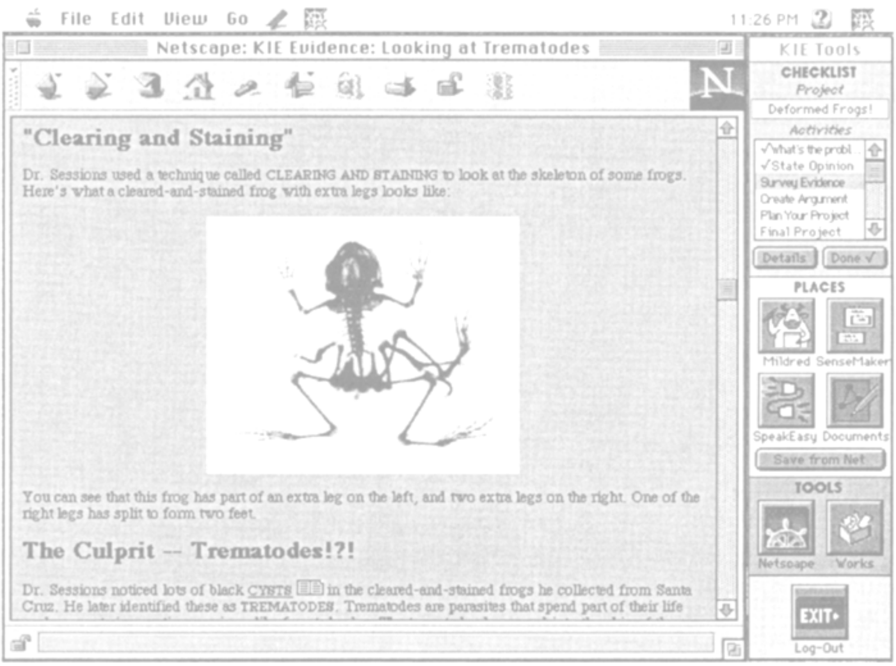
This topic provided both motivation and challenge to the members of the partnership. It was important to make this extremely complex and still-evolving scientific controversy accessible for all students with whom we would be working at Franklin—honors and regular seventh-grade science students, bilingual students, and the small GLD class, without sacrificing the core scientific ideas involved in the topic. In addition, the topic provided a forum for discussions of the perspectives about science—be it the real activities of scientists or the particular topics introduced in school science—that were initially held by the various members of the team.

How did the partnership carry out this work? We describe the partnership process that enabled this project to succeed according to the four components of SKI, and identify several supports for a diverse team involved in knowledge integration and curriculum design.

Identifying New Goals for Learning in the Deformed Frogs Partnership

The SKI framework advocates selection of accessible instructional models for the science we wish students to learn. For students, the goal is to present the models in ways that are authentic but personally relevant, engaging their varied repertoires of current ideas and encouraging them to expand, refine, and distinguish ideas in support of a more integrated understanding (Linn, 1995). For partnerships, it is similarly important to present accessible models for instruction. To meet this goal, we need first to analyze the ideas initially held by members. Then we need to select new models to add to the mix to motivate knowledge integration. Eventually, the partnership needs to develop shared understandings of what is to happen in the classroom, building on the diverse goals and

Figure 2 ☐ Evidence from the Deformed Frogs! debate project and the KIE tool palette



perspectives of everyone on the team to generate integrated and age-appropriate expectations for instruction. In addition, the group may need to review its norms and criteria for successful learning in order to reach answers.

Goals for Students: Connecting Controversies to Classroom Instruction

To develop shared goals for instruction on the Deformed Frogs! project, we began by eliciting the objectives of each team member, making sure to illuminate visions for student learning and technology use as well as personal professional objectives for project participants. From these discussions, an understanding began to emerge of desired models of instruction and the ways in which those models were different from what was currently in place in the classroom, in turn shaping the steps required for design and implementation of the curriculum.

During the design phase, the team sought a vision for several dimensions of instruction. In each case, the vision required negotiation among a varied set of models held initially by members of the team:

- *Scientific knowledge:* At what level should complex and evolving scientific content be presented to students? Scientists were concerned that the instructional materials we developed should be an authentic reflection of the state of the scientific controversy (e.g., the pesticide hypothesis rests primarily on the chemical similarity between a sunlight-treated form of a particular pesticide and hormones that control limb development) while teachers had broader and more student-focused goals (e.g., showing students lacking previous chemistry instruction that "sunlight can cause substances to change"). We were able to introduce the construct of pragmatic conceptual models that help bridge between intuitive ideas about the subject matter and models used by research scientists. Pragmatic models occur at a functional level of analysis and ultimately enable connections to the microscopic model (Linn & Muilenburg, 1996). For example, hormones that impact limb development were introduced not at a chemical level but by stressing outward hormone functionality, with effects such as adolescent growth spurts that would be extremely familiar to seventh-grade students.

- *Scientific language:* What vocabulary and syntactical constructs will support communication, be age-appropriate for all students, connect to related personal experiences, and support the bilingual students as they simultaneously develop the required language skills? Content was initially formulated in complex and authentic scientific language, fondly coined "Duncan-speak" by the teachers (after Duncan, one of the scientists in the partnership). Rather than simplifying language to a level comparable to everyday speech, we established a goal of maintaining elements of scientific language but increasing the regularity of terminology and sentence structure so that terms and syntax could be learned. Linked glossary pages for terminology central to the controversy were embedded into the evidence Web-pages to provide additional linguistic support for students. The team's definition and documentation of guidelines to describe the language used in evidence helped the participants to agree on wording that was challenging yet age-appropriate and supportive of language learners (Shear, 1998).
- *Scientific inquiry:* What levels of scientific investigation and debate did we expect from students in the science classroom? Students and teachers alike were accustomed to a model of science instruction where textbooks asked students to learn instructed facts. By contrast, KIE's instructional framework promotes a process whereby students actively critique and make sense of Web-based evidence, and are called upon to construct their own explanations and arguments for scientific positions. The model of scientific inquiry and debate presented in the classroom leveraged the scientists' experience with authentic research and scientific discourse, the KIE team's experience with inquiry-focused instruction, and the teachers' understanding of classroom techniques and student backgrounds and skills.
- *Culture of computing:* How can technology be used to support learning? Part of the richness (and importance) of partnership research is that it raises authenticity issues such as how to use computer labs in an urban school. When attempting to establish new practices in a learning community, it is important to be aware of related, existing practices held by the community since the new and old practices may be in conflict with each other (Brown, 1992). Attempts at supporting important, new practices in learning communities are aided by systemic designs that move beyond the development of technological tools, but also include supports for new activity structures and evaluative criteria for the new practices (Pea, 1993; Salomon, 1990). Our KIE curriculum and software contrasted with the existing use of computers at Franklin. The computer lab had typically been used for typing and multimedia classes. The students, at first, could not envision using the computer lab to learn science. Also, the KIE learning environment bore little resemblance to the game-focused or graphics-intensive software they had previously used. The partnership's shared goals for the integration of technology into science instruction, combined with explicit classroom discussions about authentic uses of technology for what one teacher called "brain training," encouraged students to use KIE (and the computers) to engage in science critiquing.

Project results indicate that the team was successful in implementing its visions in each area. Outcomes were assessed primarily through analysis of pre- and posttests of science understanding, language, and scientific beliefs; student debate performance; and notes taken in KIE. Posttests included both elaborated multiple-choice and essay questions. 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 work. Selected results are presented here; for more detailed analysis of project outcomes, see Shear (1998).

For example, on the science posttest, students explained the mechanisms behind the hypothesized causes of frog deformities. Student explanations of the causal mechanisms for the two hypotheses were coded based on the level of conceptual model employed using the key shown in Table 1. Results from the Russian bilingual class for the parasite hypothesis are pictured in Figure 3.

Figure 3 shows that more than 50% of the students articulated understanding of the mechanism of the parasite hypothesis to some degree, and nearly 25% were able to describe the complete instructed model, which indicated that trematode parasites embed themselves into the tissue of a tadpole where limbs will grow and block normal leg growth during metamorphosis. For example, one student wrote:

> Trematode goes into the limb buds of the tadpole. When tadpole goes through metamorphosis it deform frogs limbs. It could split leg into two or stop it from growing.

Another student's answer related the mechanism to a piece of evidence from KIE, depicting a scientist's experiment that used a surgically-implanted plastic bead to simulate the effect of a trematode cyst:

> Trematodes, live most of their lives in a tadpole. And it looks just like bead. It just blocks the way for leg to grow, so it splits, or grows in the wrong place. Just like in bead experiment.

Although it did not make sense to pretest this mechanism question, it is extremely unlikely that any of these students were familiar with the relationship of parasites to frog limb development before the project began. These results suggest that complex scientific content was successfully learned through the instructional models developed by the partnership. This result is particularly significant for the bilingual class, as these classes often postpone grade-level science until the requisite language skills are established. The bilingual students were able to build science and language skills simultaneously using these materials (see Shear, 1998 for more details).

One of the most striking project results 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 task completion. In the two regular seventh-grade science classes, the teacher estimated that about 65% of the students typically turned in assignments. For the Deformed Frogs! project, all students but one turned in KIE assignments. The teachers considered this basic class participation an important accomplishment for some students. Not only is assignment completion the first step toward learning, but KIE notes provide tangible evidence of intellectual activity. Said one teacher:

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

What was the quality of the KIE work? Did students exhibit cognitive engagement and real learning? For many students with a history of low performance, the results are strikingly positive. For example, one seventh-grade student was observed in non-KIE activities to be completely disengaged from classroom work, refus-

Table 1 ☐ Coding Key of Student Model Response

Code	*Definition*	*Example*
1	No response	
2	Unclear or random response	My answer is based on the pestice theory and I support it all the way.
3	Descriptive response	I think that this frog became deformed because it has some chemicals in the lake.
4	Other causal model	Trematodes jump on a frog and limbud to life in there and eat their vitamins.
5	Partial instructed model	When the frog is still tadpole the trematode go in its limbbuds, and then it makes a lot of legs.
6	Full instructed model	Trematode get into tadpoles limb bud and when the legs grow the trematode blocks the way.

Figure 3 □ Percentage of posttest responses to question about mechanisms for the parasite hypothesis

ing to participate in classroom activities or to complete written assignments or tests. By contrast, on the Deformed Frogs! project this student was observed to be focused and working most of the time in the computer lab, and delivered a debate presentation that represented a clear and thoughtful analysis of the available evidence. Another student *appeared* distracted through most of the computer work, and delivered a showy presentation that demonstrated little learning, but received the highest class grade on the posttest. These cases not only demonstrate the power of new models for learning; they also demonstrate the requirement for new models of assessment that allow students nontraditional means of showing their teachers, their peers, and themselves that they are capable of learning science.

Goals for the Partnership: Current Controversy in Science

The topic of deformed frogs contributed to the success of the partnership. This topic fit with both the curricular needs of the teachers and the expertise of the scientists. Our scientists were able to contact other scientists involved in the controversy to inform the design of the materials and to define current aspects of the controversy.

The KIE materials allowed a range of levels of engagement for students with different interests and abilities. The KIE evidence Web pages began with the pragmatic conceptual model, but many pages also contained links to further information resources on the Web (usually requiring knowledge of related subject matter). Select students were observed moving between the two levels based on their personal interests and abilities.

In addition, the topic had the benefit of timeliness: new information about the deformed-frog problem continued to come out as we developed and implemented the project in the classroom. Students saw articles on the topic in the daily newspaper as they researched it on the Internet at school. This science-in-the-making dimension lent authenticity to the debate activity and to the study of science in general.

Making Thinking Visible in the Deformed Frogs Partnership

To make partnership thinking visible, we establish both current practices and new models as targets of observation, discussion, and ongoing reflection. Project team meetings, particularly in early phases of the project, were opportunities to make the expertise and approaches of each team member visible in a group setting. Teachers brought current textbooks, samples of student work, and stories from their classrooms; the KIE team brought curriculum approaches, assessment samples, and stories from other classrooms; the scientists contributed expertise in the deformed-frog controversy and of the nature of science. This process established a team environment rich in reflection and mutual respect. It brought varied expertise to the surface so that it could be leveraged. In addition, some amount of conflict is inevitable between diverse perspectives or between theory and practice in a particular setting. Making thinking visible early helped to bring out potential issues so that they could be addressed during design activities.

Examples and case studies often provided a productive focus for these discussions. For example, during one of our monthly meetings before KIE was used at Franklin, the entire group watched a video produced by the Annenberg Foundation about the CLP classroom (Annenberg/CPB, 1995). As noted earlier, the pedagogical framework for KIE grew out of CLP, and many of the instructional approaches and goals for using technology in the classroom are the same.

The video featured segments of instruction by the CLP teacher, and offered suggestions for incorporating technology into science teaching and how to support student thinking in the classroom. In response to this example, the teachers had an opportunity to discuss how difficult it is to get students to think critically, and to link good ideas they saw in the video to their own instructional environments (e.g., how can we conduct similar discussions when we're in a computer lab rather than the self-contained classroom shown in the video?). This process helped to make new ideas accessible and relevant to current classroom practice, and supported teachers as they expanded and linked their repertoire of instructional models.

The CLP teacher shown in the video was also able to visit the classroom and computer lab at Franklin while the Deformed Frogs! project was running. In several classes, he modeled how to introduce one of the KIE software components to students and also discussed with the teachers the various issues involved with using technology to teach science. Through these direct means, the CLP teacher was making expert thinking visible for teachers who had not used technology as part of their science teaching before.

New Classroom Activity Structures

Prior to KIE, the Franklin teachers used a variety of activity structures, including lectures, laboratories, and field trips. They were accustomed to making changes to their teaching. Still, when KIE researchers suggested framing the Deformed Frogs! project as a classroom debate, they initially hesitated to agree. They had never seen a debate activity in a science class and were unsure of how students would respond. The debate format represented a very new model for productive student peer-to-peer discourse, a goal that had been difficult to achieve in some Franklin classrooms in the past because of disruptions and lack of student focus.

The KIE group, however, has researched classroom debates for several years and made visible the student learning potentials associated with such a project (Bell, 1996; Linn, Bell & Hsi, in press). The KIE group distinguishes a classroom debate from a scientific debate where theories (and sometimes careers) are being judged. A classroom debate can be a learning experience for all students in the class. It is a means to allow a group of individuals to explore competing theories (or hypotheses), compare interpretations of evidence, refine personal arguments, and use the collective expertise represented in the group to make progress on the debate topic.

The decision about using debate to structure the frog project was left open for several weeks as other aspects of the project were designed. One way that the KIE group could make debate visible was through a video of representative student debates from the classroom of the CLP teacher. The teacher of the honors science class was the first to watch the video. She liked the demonstration of debates as student presentations with facilitated peer-to-peer discourse, and agreed to frame the project as a debate for her students. Members of the KIE team agreed to model tactics for facilitation of the discussions, provide worksheets to structure student participation, and help ask questions during debate presentations. KIE classroom debates are primarily student-driven explorations of the topic with typically 90% of the turns of talk being student-generated (Bell, 1996). Teacher questions still play an instrumental role by prompting students to consider new points of view, to reason about thought experiments put to them, to carefully support scientific claims with actual evidence, and to interact productively.

Once the honors teacher agreed to try the debate format, others followed suit, structuring the debate in slightly different ways that they considered appropriate to their goals for their students. For example, two teachers added a panel of outside experts (in one case, scientists and KIE team members; in another case, other teachers at the school including the principal) to add importance to the debate activity.

Based on the success of this activity, teachers reported later that they planned to incorporate similar activity structures and supports into their regular teaching repertoires. The debate structure became a *pivotal* instructional idea for leveraging off of students' prior investigations with Internet resources or labs. In order for the debate activity structure to be successfully integrated into instruction, the group relied on several mechanisms for making thinking visible throughout the partnership, with ongoing participation of the KIE team in the classroom to model associated approaches.

New Roles for Scientists

The scientists made their thinking visible and accessible to the partnership. They came to the collaboration with a commitment to educational outreach. They had access to a detailed, up-to-date understanding of the deformed-frog controversy. The scientists ensured that the group maintained intellectual integrity on the topic. They also made their expert thinking visible to the group during partnership design meetings, and made their reasoning about science visible to the students when they visited the classroom. Both teachers and students worked enthusiastically with the scientists.

For example, at our first meeting the teachers and scientists became very engaged in a discussion about science itself. The group discussed a range of different science methods, including the simple Hypothesize-Experiment-Conclude models depicted in the students' textbooks. The group eventually decided that, as a discipline, science employs many scientific methods, including careful observation, case studies, and comparisons of alternatives. This conversation had such a profound effect on the teachers that they changed how they introduced the scientific method to the students, so that they could more appropriately portray the plurality of approaches found throughout science.

Social Supports in the Deformed Frogs Partnership

Science-education partnerships offer an opportunity to improve knowledge integration through social support from members of the team. On this project, monthly all-day meetings and frequent less formal get-togethers during the school day provided structural support for collaboration. The goals of the partnership, including the newness of science teaching with technology, provided the required motivation. We sought to establish an environment of sharing and collaboration.

For example, this project provided the teachers, to a greater degree than they had ever experienced, with the opportunity and motivation to compare notes about strategies they had tried and to work through issues as they came up in the classroom. Teachers touted this collaborative environment as one of the most significant benefits of the project:

> I really liked the team-building 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.

Another example of capitalizing on social support occurred when the researchers modeled techniques for introducing students to the software, leading classes in the computer lab, and facilitating discussions with students. The partnership gradually turned responsibility over to the teachers as they became more comfortable with teaching with KIE. The teachers modeled for researchers ways to handle particular classroom situations. The teacher whose CLP class had been watched on video participated as a "guest facilitator" for several classes at Franklin and shared classroom stories and challenges with the teachers.

Learning from Each Other About Assessment

As is typical of the CLP and KIE projects, the partnership jointly addressed the issue of assessment of student learning from this new curriculum unit. The group designed assessments aligned with the new goals associated with the deformed-frogs project (Figure 4). KIE assessments diagnose knowledge integration using

Figure 4 ☐ Conceptual assessment item from the Deformed Frogs! project

The frog shown below, and many others like it, were found in a lake in Canada.

Picture copyright © 1998 MPCA.

a) What do you think caused the deformity? (choose one)

___ Methoprene physically interfered with its leg development.
___ There could be a smaller frog growing inside of the bigger frog.
___ Trematode cysts interfered with its leg development.
___ The lake probably has a chemical in it that behaves like a retinoid.
___ It is probably a natural mutation of the frog.

b) Explain the main reason for your answer.

short essays. They assess knowledge beyond that tapped by multiple-choice questions. They are also more complex to grade. We made the design and execution of methods for grading tests a deliberate target of collaboration on this project, setting aside one of our monthly meetings for a "grading party." We discussed and designed scoring rubrics and spent the day grading tests together. The group discussed the merit of particular student responses. Knowledge integration was a new concept for teachers as well as students, and this collaborative grading process provided the social supports required to gain insight into student thinking and better assess the knowledge integration that was achieved. It was a mechanism for sharing and refining increasingly targeted, shared criteria for student learning from the curriculum projects.

Selection of shared criteria for grading student work wasn't always easy. For example, the KIE team's traditional approach has been to give students some credit for partially-articulated ideas on posttests to indicate the process of knowledge integration at work. By contrast, the bilingual teacher gave poorly articulated answers significantly less credit. For her students, ability to express their academic ideas with clarity was a primary requirement for future school success. As a result, this goal was consistently reflected in her approach to grading student work. These discussions forced partnership participants to make assumptions and objectives explicit, consider diverse models and priorities, and integrate theory and practice.

Promoting Autonomous Learning in the Deformed Frogs Partnership

We seek to promote autonomous learning where everyone becomes a reflective, lifelong science practitioner. Autonomous learners ask themselves questions about the fit of new ideas with their existing repertoires both in and out of class. The teachers on this project found our meetings and project activities to be good tools for reflective practice, linking new techniques to existing ideas. They report the successful application of theory to practice, beyond just the times when they teach with KIE. Some report significant changes in approach, such as exploring alternative assessment strategies. Most adopted more specific tactics such as using the concept of *evidence* to support conjectures in mathematics or tips for structuring class discussions to encourage students' peer-to-peer dialog in more explicit ways. Said one teacher:

> 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.

Goals for Professional Development

According to a study commissioned in 1995 by the Office of Technology Assessment, 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). 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 teachers with their own work rarely occurs in professional development programs. Using the SKI framework to consider teacher support needs can help ensure that the focus remains on true professional development and long-term growth for teachers rather than simply "teacher training."

On this project, ongoing professional development for *all participants* was a goal that went beyond incorporating new ideas into practice. We hoped to empower teachers to play leadership roles with newer KIE teachers and to present their work at conferences. The scientists on the project have new perspectives on education as a career and have widened their circle of scientific contacts. They have also shared their science education work with other science practitioners through their professional meetings. KIE group members learned about various student populations, developed an understanding of partnerships, and made refinements to the SKI framework. These professional gains go beyond activities on the project per se, and demonstrate the potential of partnerships like this one to support lifelong learning for all participants.

THE KIE RATS IN SPACE! PARTNERSHIP

The KIE City High School Partnership illustrated another perspective on KIE partnerships. Curriculum partnerships vary depending on the learning contexts, teacher experience, scientist interests, and group goals. Finding potential ideas to add to partnership negotiations and eliciting contributions to group goals requires careful listening by partnership coordinators. Teachers bring varied experiences with technology and models for effective uses of technology. Likewise, scientist partners range from those who have worked in precollege settings (but still desire to contribute) to those who are active in educational outreach. Still other factors will influence a partnership's complexion, including the age and ability level of students for whom the curriculum is being designed, the technology capabilities of the school, the number of teachers and students involved, and the curriculum topic itself. Our second partnership involves a technology-rich setting, a scientist previously engaged in educational outreach, and a teacher familiar with the use of computers in her curriculum. We show that our knowledge integration model can support a diversity of partnerships to create effective curriculum innovations.

Rats in Space Partnership Participants

This partnership involved collaborations between a biology teacher at a local urban high school, a biologist working with NASA Ames Research Center in educational outreach initiatives, and members of the KIE Project. In this case, the partnership was inspired by the biologist herself, who was employed by NASA Ames Research Center to develop educational applications of its Life Sciences Data Archive (LSDA).[1] This archive is publicly available in a Web-based format, and contains all the experimental data from every NASA mission, including all Apollo and Shuttle missions. NASA hopes to make this underutilized resource available to school science programs to increase both interests and understanding of science.

The NASA biologist approached members of the KIE Project after seeing a demonstration of the software and pedagogy at a local conference, and offered to create a curriculum activity. Our response was to create a curriculum partnership, according to the knowledge integration model defined in this paper. Because this involves finding at least one enthusiastic teacher, we contacted a biology teacher who had participated in an earlier KIE summer workshop. This teacher used computers in her curric-

1 The URL for the NASA Life Sciences Data Archive is: http://lsda.jsc.nasa.gov/.

ulum, teaching honors anatomy and AP biology at nearby City High School. She volunteered to collaborate in authoring a curriculum unit for use in her own classroom. The teacher was a leader in her science department, a schoolwide technology trainer, and a proponent of technology who encouraged both students and colleagues to become technologically literate. She was already involved in designing a series of Web-based projects for use in her honors anatomy course. These included an on-line cat dissection page as well as a series of student projects published on the Web. Similarly, the NASA scientist was an ideal partner, as she was already highly involved in educational outreach activities, and had thought about design curriculum for the available content. This partnership, like the Deformed Frogs partnership, required negotiation of criteria and sharing of perspectives.

The benefit of working with these two partners was clear from the outset. The high-school teacher was quick to grasp the KIE technology, having already completed a KIE summer teachers' workshop the year before. In addition, she was already adept at guiding her students through Internet-based activities, which was extremely helpful when it came to implementing KIE in her classroom. Similarly, the NASA scientist entered the partnership with a great awareness of pedagogical issues relating to using NASA science content in schools. She had received training in the development of educational outreach materials from NASA, and was working with a team of professionals whose purpose was to develop such applications for the LSDA. She was excited by an educational technology like KIE, which offers scaffolding to students as they explore difficult materials such as those of the LSDA.

One challenge resulted from the high-school teacher's familiarity with technology-based instruction, and her existing ideas and approaches relating to Internet-based curriculum. While these ideas did not run precisely counter to the KIE pedagogical view, it was sometimes a challenge to build on her ideas about the curriculum design. This exchange of perspectives became an essential and ongoing activity challenge for this partnership, and an important test of the knowledge integration model.

A second challenge was related to the nature of the LSDA, which is a collection of data, images, and experiment abstracts from all NASA missions. The problem is that many of these sources are written by medical or scientific authors, and are beyond the reach of school students. Entering the curriculum design with a constrained set of materials made for some real challenges in the kinds of activities we could choose, and the level of conceptual difficulty that we were required to scaffold. When we entered the partnership, we all believed that the LSDA would offer a wealth of relevant resources for a KIE project. Yet when we began probing the content, the materials we found there were highly esoteric from the perspective of high-school learners, and often very sophisticated. Finding ways to preserve the pedagogical tenets of our SKI framework, yet still meet the goals of the science partner, became another significant challenge to the partnership.

This partnership provides an example of collaborations between teachers, scientists, and researchers who enter the process with well-developed goals and ideas about pedagogy. The KIE researcher who participated in this partnership was challenged to connect the firmly held goals of the scientist and teacher partners. This involved negotiating shared criteria between all partners in order to arrive at a curriculum activity that was consistent with the pedagogy of SKI. This partnership provided an interesting contrast to that of the KIE Deformed Frogs partnerships, where teachers and scientists entered the partnership with little experience in Internet-based pedagogy, and were dedicated explicitly to expanding their styles of practice. While the Rats in Space partners were not closed-minded about pedagogy or content, neither were they expressly committed to expanding their views. Thus, our SKI partnership model was challenged to help teacher, scientist, and educational researcher build on their existing ideas and negotiate shared criteria for success.

Rats in Space Classroom Research Context

City High School is a diverse urban school in northern California with nearly 3,000 students. For a pleasant change of pace, technology was actually not a large problem in this collaboration. By hook or by crook, the high-school teacher had managed to outfit her own classroom with 13 fairly modern Macintosh computers. This meant that our KIE software could readily be installed. In addition, another science teacher in the department was in charge of administering the network technology, and was highly accessible throughout our project. The classroom was completely wired for fast Internet connectivity. Thus, our partnership had the luxury of workable technology and local staff to support it.

Because of the timing of our partnership, it was decided to pilot the curriculum in the honors anatomy class. This was a very diverse class of talented students who had elected to take a difficult course. Many of the students were seniors who were also enrolled in AP biology, while some were juniors taking an advanced senior elective. A total of 21 female and 13 male students participated, working in small groups of approximately 3 students to a computer.

The Rats in Space! Curriculum Project

The KIE-City High School partnership created a curriculum activity where students critiqued NASA mission research that used rats in studies of bone loss. Rats are used widely in medical and biological research as living models for humans or other larger animals. Rats are mammals so there is some basis for comparison of rat and human physiology. But to what extent are such comparisons valid?

For decades, rats have been used as laboratory animals in NASA mission flight research. They are small and light weight, vital qualities for space missions. Additionally, their characteristics can be readily controlled through breeding, to the extent that experimental and control animals in any research could even be genetically identical. Finally, and perhaps unfortunately, these animals can be subject to treatments that would be horrific if performed on humans, but which allow for experimental control or facility.

However, to what extent do experiments with these animals apply to humans? This is a fair question with no quantifiable answer.

NASA researchers argue that rats make fine models for humans, and performed experiments to justify this assertion. Because these research reports were the original source materials from the NASA LSDA, the challenge was to support students to understand and interpret such complicated science content.

The Rats in Space! Project, designed by this partnership and pictured in Figure 5, is a *critique project*—where six NASA experiments are critiqued by students in terms of their use of rats as a model of humans. These experiments are all concerned with bone degeneration, and make use of rats as their subjects. Students begin the project with an activity where they review an existing curriculum module about models, and then hold a discussion in SpeakEasy (an on-line discussion tool in the KIE software suite) about validity of models in scientific research. They then review three evidence items concerning bone growth and remodeling (drawn from the LSDA), and critique each one in terms of its modeling assumptions. A third activity allows them to critique experiments relating to the effects of loading and unloading on bones. Finally, they close the project with a SenseMaker activity where they evaluate the validity of using rats as models for humans in microgravity research.

The activity preserved and accommodated the commitments of each partnership participant. All partners were ultimately enthusiastic and are continuing to collaborate. In addition, classroom results were stunning, as students came up with critiques that NASA scientists found stimulating. For example, in articulating her argument about using rats as models for humans, one student expressed the following insights:

> The two main experiments that helped us conclude that rats make good models both focused on bone calcium regulators. Calcium regulators are hormones that, when released, either increase osteoclast activity or osteoblast activity . . . . The results of the two experiments were almost identical: PTH levels remained unchanged, so bone resorption did not increase, but Calcitonin levels were less than they should have been, so their was a decrease in bone production. In both the human and rat subjects, the bone mass decreased. Because of these similarities, my group decided that rats did make good models for humans, as their reactions to microgravity in terms of bones were the same.

Figure 5 ☐ In the Rats in Space! project, shown in our new Web-based format, students explored evidence from NASA bone-loss research

Promoting this type of student reasoning about complex science materials and concepts is difficult even for veteran teachers. The classroom teacher in this case study was so impressed by student achievements that she offered the following testimony in a postsemester interview:

> My kids are great students no matter what they do, but it was really amazing how well the "Rats in Space" project helped them stay focused and stay productive even though they were working in groups. It was really helpful for them to take their group's evidence notes home to help them create their arguments . . . . The KIE software, and the design of this activity, was remarkable in how well it scaffolded the students in dealing with this difficult concept and truly difficult NASA materials.

We are currently working in this partnership to create additional activities for use in the teacher's classroom, as well as other classrooms around the country. We look forward to building on the success of the Rats in Space partnership. The scientist is already creating student-accessible materials to support their use of new LSDA items, and the teacher is excited to expand on her new understanding about the software and pedagogy of KIE.

DISCUSSION

These two KIE science education partnerships illustrate the challenges and rewards of partnership in science curriculum design. The partnership developed innovations that improved science learning and set in motion a process of classroom testing and instructional refinement.

Rather than disputing the potential of the Internet, these partnerships sought creative ways to use Internet resources in the service of knowledge integration. This paper highlights the way that partnerships, dedicated to negotiating in a context of mutual respect, can resolve controversies and create powerful instruction that takes advantage of technology. In the process of creating both Deformed Frogs! And Rats in Space! all partnership participants reflected on their beliefs about technology, considered alternative perspectives, and developed a richer, more nuanced, and more coherent perspective. Critics of technology discovered that even flawed claims could provide students with opportunities to exercise their scientific analysis skills. Advocates of technology discovered that even well-designed materials can primarily frustrate users, requiring substantial redesign. The partnerships found effective uses for technology but also gained respect for the process of design.

We saw in these partnerships two primary advantages for our SKI framework. First, the framework gave the partnerships a head start on the design of KIE. For the KIE software, the framework ensured that designs made the process of conducting a project visible, orchestrated effective social interactions among learners, and encouraged reflection. Most importantly, the framework motivated each partnership to make sure the instructional materials connected to what students already know. Thus the framework made it easier for the partnership to create materials that supported students in their knowledge integration.

Second, the SKI framework helped partnerships design and monitor their own knowledge integration. The success of these two partnerships owes a great deal to the technologies used to promote partnership activities. Access to electronic mail and Internet resources ensured that all partners could be included in every decision. This openness often quickly resolved difficulties and dissipated fears that instruction might be decreed rather than designed. The SenseMaker arguments constructed by participating scientists made the details and intricacies of the Deformed Frogs debate visible to the other participants and also provided a concrete mechanism for discussing the classroom goals. Design decisions about scientific inquiry, such as which pieces of evidence should be included in the "must see" category, enabled pedagogical discussions, while also revealing alternative views of the nature of science. Partnership meetings were lively and seriously connected to pedagogy precisely because the group needed to negotiate a detailed view of scientific inquiry in action. The Internet resources, being authentic and flawed like most reports of science in the making, placed considerable responsibility on the designers to ensure that learners gained a balanced view. As noted, this effort also led the team to gain a better understanding of the diverse views of science held by students—especially those from school systems in other countries.

Technology cannot be viewed separately in these partnerships or in the SKI framework. Technology cannot even be easily disentangled from such activities as negotiating a shared view of instructing. We cannot distinguish the role of the Internet, electronic mail, the telephone, public transportation, the automobile, and face-to-face discussion. We all argue that the number of alternatives and the frequency of iteration seems hastened by technology but this is also the tenor of the times.

Technology and Science-Education Partnerships

Technology-related innovations bring both opportunity and challenge to partnership participants. Our partnerships used computer tools to bring content and pedagogy to the classroom that would have been difficult or impossible otherwise. We also encountered a number of partnering issues that were either unique to the use of computers in the classroom, or made more visible because of it. These issues are important to consider for any technology-related curriculum effort.

First, partnership members' comfort level and approach, both for project development and in teaching with technology, vary tremendously and often reflect their familiarity with computers. We worked with one teacher who was a first-time computer user, and others who had used computers only scantily in their work and personal lives. Other participants were confident computer users, often with already-ingrained ideas of computers as typewriters or toys rather than learning partners. An important part of the project was supporting teachers as they became comfortable with their self-image as computer users, listening to their ideas about how computers could be used in the classroom, and providing the degree of support and modeling necessary as teachers introduced the new learning environment to their students.

Second, technology comes with a myriad of practical issues for the classroom or computer lab. At City High these challenges were relatively minimal, as the school was well-equipped and accustomed to managing technology issues. At Franklin, however, use of the Internet for instruction was a new endeavor, as was thorough integration of technology and science education. We spent a great deal of effort to ensure the access to working computers and a speedy network during the school day that was fundamental to the success of the project. Science-education partnerships should recognize that adding computers to the mix takes a lot of time, as well as a systemic approach to planning that is often lacking in school technology labs that have seen less complete integration with the curriculum.

Finally, we found that a partnership approach to the implementation of technology-based science curriculum was an opportunity to build new channels of communication within the school that did not necessarily exist previously. We found that teachers wished that issues of technology planning were irrelevant to their role; one told us that she "didn't have time to waste" on issues such as how students would print their work. Similarly, technology resource staff sometimes failed to see issues of teaching and learning as relevant to their job, remaining unconcerned when new scientific software threatened construction. Establishing a science education partnership helped both sides to recognize that computers and learning may be fundamentally intertwined, and to establish communication channels that are necessary if efforts such as these are to succeed.

Advantages of the KIE Software

Developing educational innovations for science classrooms that use technology requires attention to issues of student learning, assessment, technological design, central concepts and processes in science, and a practical understanding of specific classrooms and learning cultures. Partnerships provide a viable mechanism for marshaling the requisite expertise associated with these design efforts to develop successful innovations.

The KIE approach provides a pedagogically sound instructional framework to foster autonomous learning and knowledge integration in students, and to connect teachers, scientists and educational researchers in authoring partnerships. KIE provides students with a wide range of activities and supports as they work with evidence from the Web, including cognitive and procedural guidance, and social supports to encourage discourse and sharing of ideas. Science-education partnerships can quickly take advantage of these resources.

Scientists often wish to connect their work to education: the Web already includes countless educational sites constructed by scientists during their personal time. KIE enables partnerships to take advantage of these sites while also promoting knowledge integration. Teachers provide a wealth of resources and energy for curriculum development, yet need tools and partners to make this process effective. KIE provides a framework to implement these ideas as well as a mechanism for trial and refinement. Finally, educational researchers have well-defined models of curriculum development, but may not connect these to scientific content and the realities of the classroom. KIE provides a focus for this connection.

The process of developing a KIE project offers a favorable focus for partnerships. Scientists who would author their own educational sites are provided with design guidelines. Teachers who would develop curriculum relating to current science issues are connected to scientific expertise, as well as supportive technologies and sound instructional approaches. Researchers like the KIE Project team gain valuable insight into the realities of teachers and scientists. In addition to adding projects like Deformed Frogs! and Rats in Space! to the KIE project library, these partnerships help us understand how better to support relationships between teachers, scientists, and developers of educational technology.

Organizing Principles for Science-Education Partnerships

To ensure successful partnerships we recommend, first, to start small. In the Deformed Frogs partnership the team designed a small unit about twins that helped foster collaboration. In the Rats in Space partnership, the teacher had designed a preliminary activity in the KIE summer workshop. These initial activities were very helpful in preparing participants for the collaborative effort to follow.

Second, we recommend that partnership participants experience each other's challenges first-hand. In both partnerships, all team members taught in the project classrooms, tested their scientific ideas against those of others, and jointly designed assessment devices. As a result, partners understood and respected each others' needs and concerns.

Third, we recommend that partnerships create a context where partners can articulate mistakes, problems, and obstacles, and explore possible solutions. These partnerships succeeded because participants continuously described their failures as well as successes. They also succeeded because all members of the partnership helped resolve the problems that arose. These efforts ensured that the groups developed rich, shared criteria for success rather than accepting superficial testimonials.

Fourth, we recommend planning partnership activities with appropriate supports for collaboration. Each participant must have both incentives and supports for participation. Incentives may be monetary, as in paid time for participation, or they may be explicit steps in personal or professional development, as in the opportunity to present at a conference or play a lead teacher role within the district. One critical support is time to meet, often a challenge in teachers' busy schedules and accomplished in the Deformed Frogs partnership with scheduled release time. Other important supports include human resources to perform project coordination and technology maintenance, and more mundane requirements such as a room in which to meet where no classes are held during the school day. Without consideration of these issues, partnerships may collapse under the weight of practical challenges.

Finally, we recommend that partnerships plan on multiple cycles of trial and refinement. One reason is because productive researcher-practitioner partnerships focused on professional development benefit from being long-term collaborations (Wineburg & Grossman, 1998). Also, most complex systems—including the curricular innovations described here—require testing and tuning to succeed. KIE science education partnerships involve a vast array of new elements that both singly and jointly can fail in creative ways. In our partnerships the software, computer labs, debates, science topics, and expectations for success are new to most participants. Deciding how to integrate each of these elements raises questions that often can be resolved only in classroom trials. Pretests, pilot tests in the computer lab, and trials in other classes can help, but even the best planning still raises problems. For example, in one school where we worked, we tested the KIE software under every imaginable condition. Nevertheless, on the first instructional day, everything went wrong because the district had installed new screening software for Web browsing without warning. To develop effective and robust curriculum, there is no substitute for cyclical classroom trial, reflection, and refinement. This is especially true given the systemic quality of the range of items to be designed and orchestrated in these innovations, from assessment items to complex software tools. In some settings, we arranged multiple trials by staggering implementation wherever possible so that subsequent classes benefited from the experiences of their peers.

Reflecting on SKI

These studies illustrate the value of the SKI framework and also suggest ways to elaborate and refine it. First, devising goals for science that build on what students know is time consuming and difficult. Building a database of solutions would speed up the process for others: a good design framework gives partnerships a head start on design.

Second, making thinking visible succeeds when participants find ways to communicate. As the Deformed Frogs partnership illustrated, iterative design of the SenseMaker argument map and joint definition of the criteria for success on a class assessment helped members of the partnership develop shared criteria for successful curriculum activities.

Third, social supports offer a rich opportunity for science education partnerships. We are now experimenting with an on-line design forum (*http://islandia.berkeley.edu/workshop*) leading up to a workshop to provide more diverse and extended opportunities for participant interaction. Other groups are also devising promising tools (e.g., the Center for Innovative Learning Technologies [CILT], http://www.cilt.org) to support professional development through virtual communities.

Fourth, promoting autonomy has many components. The partnerships described here particularly benefited from opportunities to report on their experiences to colleagues, peers, and professional organizations. Making this a more central element of professional development seems promising and is already established in countries like Japan (e.g. Lewis, 1995).

These partnerships refined the SKI framework in several ways. First, the groups devised new partnership practices and activities such as jointly reviewing a video tape from another classroom. We realized the value of using video and audio to enrich professional development of pedagogy. Second, we realized the need to create rich examples to illustrate pedagogy. We sympathized with the difficulty participants have of finding ways to put their views into words without sounding as if they live by slogans. To distinguish one's view of inquiry from popular renditions can take hours. However, the SKI framework provided a useful structure within which participants could reflect on and express their personal philosophy.

Reflects on Knowledge Integration

By advocating SKI both for science education partnerships and as a metaphor for science learning, we raise issues about the nature of knowledge integration. Many argue that knowledge integration in science differs from knowledge integration in history or English. We are saying instead that the process of knowledge integration in science and in science curriculum design follows the same process. How can we advocate such a view? We argue that the process of design characterizes advances in science, in computer science, and in curricular innovation. In all cases, participants combine information from different sources and of varying levels of validity. These are combined to form a coherent argument. Philosophers have explored these issues extensively (e.g. Keller, 1983; Brickhouse, 1994; Lakatos & Musgrave, 1970). They remain captivating as we seek ways to support partnerships in the process of designing classroom innovations using technology. □

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REFERENCES

Annenberg/CPB. (1995). Science images: Computer as Learning Partner (Doug Kirkpatrick) [video]. S. Burlington, VT: NCREL.

Bell, P. (1996). *Debate as an instructional form in science education.* Unpublished Master's Thesis, University of California, Berkeley, Berkeley, CA.

Bell, P. (1997). Using argument representations to make thinking visible. In R. Hall, N. Miyake, & N. Enyedy (Eds.), *Proceedings of CSCL '97: The Second International Conference on Computer Support for Collaborative Learning* (pp. 10–19). Toronto, Canada: University of Toronto Press.

Bell, P. (1998). *Designing for students' conceptual change in science using argumentation and classroom debate.* Unpublished Doctoral Dissertation, University of California at Berkeley, Berkeley, CA.

Bell, P., Davis, E.A., & Linn, M.C. (1995). The knowledge integration environment: Theory and design.

In *Proceedings of the Computer Supported Collaborative Learning Conference (CSCL '95: Bloomington, IN)* (pp. 14–21). Mahwah, NJ: Lawrence Erlbaum Associates.

Brickhouse, N.W. (1994). Children's Observations, Ideas, and the Development of Classroom Theories about Light. *Journal of Research in Science Teaching, 31*(6), 639–656.

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

Davis, E.A. (1998). *Scaffolding students' reflection for science learning.* Doctoral dissertation, University of California at Berkeley, Berkeley, CA.

Eylon, B.S., & Linn, M.C. (1988). Learning and instruction: An examination of four research perspectives in science education. *Review of Educational Research, 58*(3), 251–301.

Hsi, S., & Hoadley, C.M. (1997). Productive discussion in science: Gender equity through electronic discourse. *Journal of Science Education and Technology, 6*(1), 23–36.

Keller, E.F. (1983). *A feeling for the organism: The life and work of Barbara McClintock.* San Francisco, CA: W.H. Freeman.

Lakatos, I., & Musgrave, A. (Ed.). (1970). *Criticism and the growth of knowledge.* New York: Cambridge University Press.

Lewis, E.L. (1995). *Educating hearts and minds: Reflections on Japanese preschool and elementary education.* New York: Cambridge University Press.

Linn, M.C. (1992). The computer as learning partner: Can computer tools teach science? In K. Sheingold, L.G. Roberts, & S.M. Malcom (Eds.), *This year in school science 1991: Technology for teaching and learning* (pp. 31–69). Washington, DC: American Association for the Advancement of Science.

Linn, M.C. (1995). Designing computer learning environments for engineering and computer science: The scaffolded knowledge integration framework. *Journal of Science Education and Technology, 4*(2), 103–126.

Linn, M., Bell, P., & Hsi, S. (in press). Using the Internet to enhance student understanding of science: The Knowledge Integration Environment. *Interactive Learning Environments.*

Linn, M.C., & Burbules, N.C. (1993). Construction of knowledge and group learning. In K. Tobin (Ed.), *The practice of constructivism in science education* (pp. 91–119). Washington, DC: American Association for the Advancement of Science (AAAS).

Linn, M.C., & Clark, H.C. (1997). When are science projects learning opportunities? *Research Matters.* http://science.coe.uwf.edu\narst\research\projects.htm

Linn, M.C., & Eylon, B.-S. (1996). Lifelong science learning: A longitudinal case study. In *Proceedings of Cognitive Science Society, 1996* (pp. 597–602). Mahwah, NJ: Lawrence Erlbaum Associates.

Linn, M.C., & Muilenburg, L. (1996). Creating lifelong science learners: What models form a firm foundation? *Educational Researcher, 25*(5), 18–24.

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

National Research Council. (1996). *National science education standards.* Washington, DC: National Research Council.

Novak, J.D. (1968). A case study of curriculum change—Science since PSSC. *School Science and Mathematics,* 374–384.

Office of Technology Assessment (1995). *Teachers and technology: Making the connection.* OTA-HER-616. Washington, D.C.: U.S. Government Printing Office.

Pea, R.D. (1993). Practices of distributed intelligence and designs for education. In G. Salomon (Ed.), *Distributed cognitions: Psychological and educational considerations* (pp. 47–87). Cambridge: Cambridge University Press.

Salomon, G. (1990). Studying the flute and orchestra: Controlled experimentation vs. whole classroom research on computers. *International Journal of Educational Research, 14,* 37–47.

Shear, L. (1998). *When science learners are language learners: Designing linguistically aware instruction to teach science "the knew way."* (Unpublished Master's Thesis). Berkeley, CA: University of California at Berkeley.

Slotta, J.D., & Linn, M.C. (in press). The knowledge integration environment: Helping students use the Internet effectively. In M.J. Jacobson & R. Kozma (Eds.), *Learning the sciences of the 21st century.* Hilldale, NJ: Lawrence Erlbaum & Associates.

Welch, W.W. (1979). Twenty years of science curriculum development: A look back. In D.C. Berliner (Ed.), *Review of research in education* (pp. 282–308). Washington, DC: American Educational Research Association.

Wineburg, S., & Grossman, P. (1998). Creating a community of learners among high school teachers. *Phi Delta Kappan (79),* 350–353.