The Knowledge Integration Environment: Theory and Design

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Abstract

The Knowledge Integration Environment (KIE) combines network resources and software with sound pedagogical principles to improve science learning. KIE networking tools allow students to use scientific evidence in activities that foster knowledge integration. In a pilot test in an eighth-grade physical science classroom, students worked collaboratively to answer scientific questions such as whether light travels forever or dies out. With the KIE, students use evidence from the Net and tools such as an electronic notebook and on-line discussion tools to make collaborative decisions. This paper describes the pedagogical framework, the components of the KIE software, and initial results from pilot research. We conclude by discussing promising next steps for networking in science education.

Keywords — science education, networking, Internet, K-12 educational technology, computer learning environments, scientific evidence, collaborative learning environments.

1. Introduction

The Knowledge Integration Environment (KIE) project draws on technical, cognitive, and social resources to create a productive electronic learning community. We seek to design a learning environment that helps K-12 students use the as-yet untamed (and growing) Internet to acquire skill in interpreting scientific material, gain an integrated understanding of complex scientific ideas, and develop a propensity toward integrating knowledge in general. As more and more schools connect to the information highway, the need for learning environments increases. Such environments take advantage of the corpus of "classroom materials" that are added to the network daily and allow students across the nation to work together to investigate scientific problems.

In this paper, we describe the goals and motivation for the KIE project, delineate the framework that guides this work, describe the preliminary design of the KIE, and summarize our pilot investigation. In conclusion, we describe future directions for creating electronic learning communities.

1.1. Motivation and Goals

The project is exploring how exciting and rapidly expanding new electronic tools, network resources, and human resources can jointly improve science learning and instruction. At present, Net[1] resources are underutilized and tools are inadequate, often limited to browsing without direction. The Net includes a broad array of scientific information that could be tapped to improve science education.

Educators and researchers agree that students need connected ideas, not isolated, inert knowledge. Yet students encounter topic after topic in science classes. National standards and state frameworks encourage integrated understanding, but list more topics than most students can integrate. When there is not enough time to get into a topic deeply, students become accustomed to looking at things superficially. Furthermore, incentives to integrate knowledge are few. Standardized tests generally assess isolated facts, and classroom tests often mimic standardized tests.

The material taught in science class is often too abstract for students to understand. Students need models that are appropriate for them, problems that are relevant to their lives, and guidance to help them develop an integrated understanding.

Teachers often understandably rely on tried-and-true methods, such as using lectures and textbooks, which can promote beliefs of "teacher or book as authority" and "science as a static field" instead of the active, understanding-focused learning and dynamic view of science that we would like students to see as they participate in science classes. To remedy this situation, the KIE software and curriculum helps students use the Net to work on large projects designed to help them integrate their ideas.

1.2. Using the Net for Learning

Research is needed to determine productive ways to take advantage of the Net connections to pre-college institutions. We need to develop good models for effective instructional uses of this resource. The Kids as Global Scientists project and the Collaborative Visualization project provide two examples of such models (Pea, 1993; Songer, 1993). In both cases, use is targeted primarily at questions involving the weather. We take a broader approach, seeking ways to help students draw on diverse information as they make sense of science.

How can we create an instructional environment that helps students develop the integrated understanding of science that they need? We discuss instructional, cognitive, and social issues.

In instruction, the Net has the potential for perpetuating or exacerbating the emphasis on breadth over depth in science. If students browse without a goal, their exploration may resemble channel surfing. Indeed, the Net can provide hours of entertainment. However, students need activities and resources that help them benefit from their investigations. The Net provides plenty of opportunities to look at or read material, but not as many opportunities to link and connect ideas. KIE provides activities for active, engaged learning.

From a cognitive perspective, students need scaffolding for navigating and searching on the Net, and they need guidance to determine what is worth paying attention to and what should best be ignored. KIE provides tools to make the Net more manageable, and begins a process of developing resources on the Net which are useful to students.

Making the Net a socially meaningful experience requires careful software and curriculum design. Working on the Net can be a very isolating activity. Interactions are not common among those providing information on the Web and those browsing that information. In fact, using the Net does not have to be collaborative at all. KIE promotes collaboration among students through its software design and curriculum structure as described later in this paper.

Furthermore, according to a recent study, about 90% of current Web users are male, and 87% describe their race as white (Pitkow & Recker, 1994). The Web must be made a more female- and minority-friendly place if it is to be of widespread benefit.

2. Scaffolded Knowledge Integration

To make the Net an effective and efficient tool for learning, KIE follows the Scaffolded Knowledge Integration Framework (Linn, 1995; Linn, Songer, & Eylon, in press). This framework synthesizes over 10 years of research on science knowledge integration. We describe the rationale, goals, and components of the framework.

The Scaffolded Knowledge Integration framework responds to research showing that science courses confuse students by contradicting "everyday" observations (Carey, 1985; diSessa, 1993; Resnick, 1983; Vosniadou & Brewer, 1992). Rather than changing their ideas, students respond to these contradictions by concluding, for example, that objects in motion come to rest at home but not at school, or that light dies out at home but not at school, or that heat and temperature are the same at home but different at school. To support knowledge integration, science courses must help students reconcile scientific models and intuitive observations, and guide students to distinguish technical and colloquial usage of science vocabulary. To help students gain a robust and predictive understanding of science, the Scaffolded Knowledge Integration framework emphasizes making connections between scientific concepts and relating these concepts to personally relevant situations and problems. The framework suggests guidelines for designers creating science learning environments such as KIE.

The Scaffolded Knowledge Integration framework helps students distinguish and connect their models of the scientific world. We view science learners as exploring and modifying a repertoire of models (Linn, diSessa, Pea, & Songer, 1994). Science is a dynamic process, nobody yet has found "absolute truth" in a single model or theory. Scientists enjoy testing, revising, and re-evaluating models of scientific events. To help students become lifelong learners and to prepare them for the vast array of models they might encounter when searching the Net, we can let them join in the fun of testing, revising, and re-evaluating models.

In science classrooms, we find a plethora of alternative scientific ideas: models that the teacher and textbooks provide and ideas which students bring when they enter the science classroom. We hope that instruction will encourage students to consider, besides their own ideas, others that are useful and close to currently accepted ideas. The Scaffolded Knowledge Integration framework guides designers to create activities and tools that develop the abilities of students to sort and distinguish among a multitude of ideas. The purpose of science instruction, then, becomes to find the best mix of models for the students, to ensure the presence of these models in the science classroom, and to engage students in analyzing and connecting these models.

The Scaffolded Knowledge Integration framework has four main components: (a) identifying new goals for learning, (b) making thinking visible, (c) encouraging lifelong learning, and (d) providing social supports (Linn, 1995). As mentioned above, the first component involves introducing a mix of models that build on student intuitions and encourage testing, revising, and reformulating scientific ideas. Providing studies energy: thermodynamics, light, and sound are the topics. For KIE activities, students work in groups that function as research teams. In the pilot study, they worked in pairs on the 16 available computers. Each randomly-assigned pair jointly conducted all aspects of the activity using a single computer. The KIE software has been designed to support groups of varying sizes to accommodate the differing availability of technology in schools.

We compared the KIE implementation of the "How Far does light go?" activity to the off-line version of the activity that students had used the previous semester. The KIE version (a) provided richer, multimedia evidence than the text-based evidence used in the off-line version, (b) supported students with on-line guidance, augmenting the assistance coming from the teacher, and (c) guided students as they completed each part of the activity with a checklist that indicated completed work and next steps.

3.3. Preliminary Results

Several benefits of KIE are apparent in initial analyses of the pilot study data. In addition, pilot test results suggest ways to improve the KIE software.

First, students worked productively with the software environment and within the activity structure provided. Student groups by-and-large made progress on their projects of their own accord and produced project work comparable to or better than in previous semesters according to holistic measures. In spite of the efforts necessary to learn the software, students could use it as intended.

Second, students worked with evidence differently with KIE than they had in previous semesters using the off-line version of the activity. In comparing their categorizations of identical pieces of text-based evidence, students connected more of the evidence to the debate than they had previously. This supports the conjecture that the KIE can be used to productively engage students in linking evidence to theories.

Some of the students were randomly assigned richer, multimedia versions of the evidence. For example, some students read text describing how telescopes can be used to see more stars in the night sky, while others viewed an image depicting the night sky with a blown-up insert of the corresponding image captured by the Hubble space telescope. Students treated the text and multimedia versions of the evidence differently. Thus, 75% of the students categorized the text version of the telescope evidence as supporting the "light dies out" position, while 65% found that the multimedia version supported the alternate "light goes forever" position. Students often connected multimedia evidence to different theories than the corresponding text evidence.

Third, trials of the guidance for KIE projects suggested revisions for the next version. Students used the procedural guidance to determine what to do next as they carried out their projects. Cognitive guidance, encouraging students to consider alternatives, reflect on their conjectures, or evaluate their progress was largely ignored. As a result we are designing more specific cognitive guidance and also altering the interface to make this guidance more prominent.

Overall, the pilot study demonstrated the feasibility of the KIE approach, suggested directions for further research on the role of multimedia evidence, and motivated improvements to the curriculum and the software.

3.4. KIE Dissemination Plans

We will provide the KIE software and curriculum to schools wishing to help us improve the materials. Dissemination to multiple schools allows students to collaborate with others electronically. Students can post information or data to the Net and participate in on-line discussions of activities. Teachers, too, can work with remote colleagues, exchanging curriculum materials, pedagogical knowledge, or technical advice. In addition, KIE could be used by learners at home and by individuals doing school projects.

4. KIE Software Design

The KIE software includes commercially available tools and project-developed materials. Commercial components include:

- *World-Wide-Web Browser*—which provides an appropriate graphical interface for evidence on the Net;
- *HTML Editor*—which allows students to create and edit multimedia documents for the Web; and
- *E-Mail Software*—which allows students to send and receive electronic mail with other individuals.

KIE also features the following project-developed software components (described subsequently):

- *KIE Tool Palette*—a constant interface component that affords navigation of the system components;
- *Netbook*—a Net-oriented notebook that allows student groups to organize, analyze, and author evidence;
- *Networked Evidence Databases (NED)*—collections of scientific evidence both from the Net and created by students, organized by science topic and activity;

models is not sufficient for knowledge integration. Students need to understand the process of thinking about alternative models and they need support so they can do this independently.

The second component of the framework, making thinking visible, emphasizes making alternative models accessible to students. Students need to understand several perspectives on scientific ideas in order to experience the fun of comparing and testing scientific ideas. Students also benefit when the actual processes of comparing scientific explanations, models, or theories are made visible. This might happen when two students debate about theories or when students read a debate between two natural scientists. Making thinking visible is not sufficient, however, since students also need to take responsibility for reaching their own conclusions in order to become lifelong learners.

Thus, the framework includes techniques for helping students reflect on their own ideas, and monitor their own performance. One approach is to engage students as investigators and critics of science.

The final component involves orchestrating productive social interactions in the classroom while guarding against situations which would support gender stereotypes or status effects (Linn & Burbules, 1993). Students can help each other compare ideas and link models when they respect each other.

By focusing on how models of scientific phenomena can be compared, by helping students distinguish among the models that they currently hold, and by emphasizing that scientists engage in this process of distinguishing and selecting models for scientific phenomena, the Scaffolded Knowledge Integration framework provides a firm foundation for students planning both scientific and non-scientific careers. Furthermore, as citizens make more and more use of the Net, they will need skills in distinguishing among models and selecting information relevant to their own ideas. KIE, by following the Scaffolded Knowledge Integration framework, will help students develop skills they will need throughout their lives, and also provide tools for the development of integrated understanding of complex scientific material.

3. KIE Curriculum and Pilot Study

We have developed KIE software and activities which have been tested with middle school students. This section describes the KIE activities and the pilot investigation. The next section gives details of the software design.

The KIE curriculum consists of activities that help students develop (a) the ability to critique evidence, (b) a propensity toward knowledge integration, and (c) an integrated understanding of science topics. To achieve integrated understanding, KIE activities emphasize depth rather than breadth. To ensure that students become independent learners, KIE activities scaffold and support students as they refine their scientific ideas. Since the Net lacks organization, KIE provides a structure for building collections of Net evidence and prompts students to systematically search for information relating to their projects.

In addition, KIE tools guide students to use the Net effectively rather than mindlessly browsing or superficially covering many topics. Students can use KIE tools for classroom activities and on personal investigations or projects. Looking at information on the Net is necessary but not sufficient to complete a KIE project. Students must analyze evidence, producing scientific explanations for real world phenomena. In doing so, they interact with a larger community of science learners. This community ranges from their schoolmates in other class periods of the same science course to natural scientists across the globe. The scaffolding helps students use specific evidence and also models the type of thinking appropriate for knowledge integration.

3.1. How Far Does Light Go?

As part of the KIE pilot study, students engaged in the "How Far Does Light Go?" project (described in Bell, 1995). The activity helps students integrate their knowledge by contrasting two theoretical positions about the propagation of light using evidence from both scientific and everyday sources. One position that students support is the scientifically normative view that "Light goes forever until it is absorbed" while the other is the more phenomenological perception that "Light dies out as you move further from a light source."

Students begin the activity by stating their personal position on how far light goes. Then they review evidence on the Web and determine whether each piece supports, contradicts, or is irrelevant to their position. Students next engage in a brainstorming activity to create pieces of evidence to bolster their argument by pulling from experiences in their own lives. Students can make the evidence they create available to all class members over the Net. The students then synthesize the evidence and formulate a scientific argument supporting one of the two theoretical positions. As they carry out these steps, the software scaffolds them by providing guidance and prompts. Student teams present their arguments in a classroom discussion and respond to questions from the other students and the teacher. Finally, students reflect upon issues that came up during the activity and once again state their position on how far light goes.

3.2. Methods

We tested the "How far does light go?" activity with 165 students in a classroom using the Computer as Learning Partner (CLP) curriculum. In this eighth-grade physical science class, students learn from laboratories rather than lectures or texts. The class studies energy: thermodynamics, light, and sound are the topics. For KIE activities, students work in groups that function as research teams. In the pilot study, they worked in pairs on the 16 available computers. Each randomly-assigned pair jointly conducted all aspects of the activity using a single computer. The KIE software has been designed to support groups of varying sizes to accommodate the differing availability of technology in schools.

We compared the KIE implementation of the "How Far does light go?" activity to the off-line version of the activity that students had used the previous semester. The KIE version (a) provided richer, multimedia evidence than the text-based evidence used in the off-line version, (b) supported students with on-line guidance, augmenting the assistance coming from the teacher, and (c) guided students as they completed each part of the activity with a checklist that indicated completed work and next steps.

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- *SpeakEasy*—a multimedia discussion tool which allows students to conduct structured conversations about their scientific ideas over the Net;

- *Student Knowledge Integration Planner and Profiler (SKIPP)*—a teacher tool that allows users to design and orchestrate Net-oriented activities for their students, as well as identify and customize activities for individual students based on their proficiencies and interests; and

- *Knowledge Integration Coach (KIC)*—an on-line guidance system which provides supporting prompts and feedback as students work on activities.

4.1. The KIE Tool Palette

At the start of class, each student in a group logs onto the KIE system. A palette is displayed that allows students to navigate between the different software components of the KIE system and to ask for guidance (see Figure 1). Additionally, the KIE Tool palette allows students to save a bookmark, the text, or a screenshot of something on the Web to their group notebook (discussed below). Students can alternatively save references to Web pages into different categorical groups. For example, in the "How Far Does Light Go?" project, students categorize a set of evidence from the Net as to whether it supports, contradicts, or is irrelevant to their stated theoretical position.

4.2. The Netbook

The Netbook allows students to collaboratively manage their projects and documents, as well as become authors on the Web (see Figure 1). A Netbook is opened for the team as they log onto the KIE system, providing access to their current and past work. This software uses a notebook metaphor to provide students with access to all of their projects (as tabs into the notebook), the sections within those projects (as folders within each project), and all of the documents that make up each of those sections. Students can create, open, or delete any of the Netbook elements.

The Netbook has been explicitly designed to simplify analyzing and authoring World-Wide-Web documents. It functions as a jumping off point to a Web browser, HTML editor, word processor, and other multimedia authoring tools. (Currently, KIE utilizes the Netscape Navigator™ software for web browsing and the ClarisWorks™ integrated application package for authoring Web documents using the Web-It™ module (Soloway, 1995).)

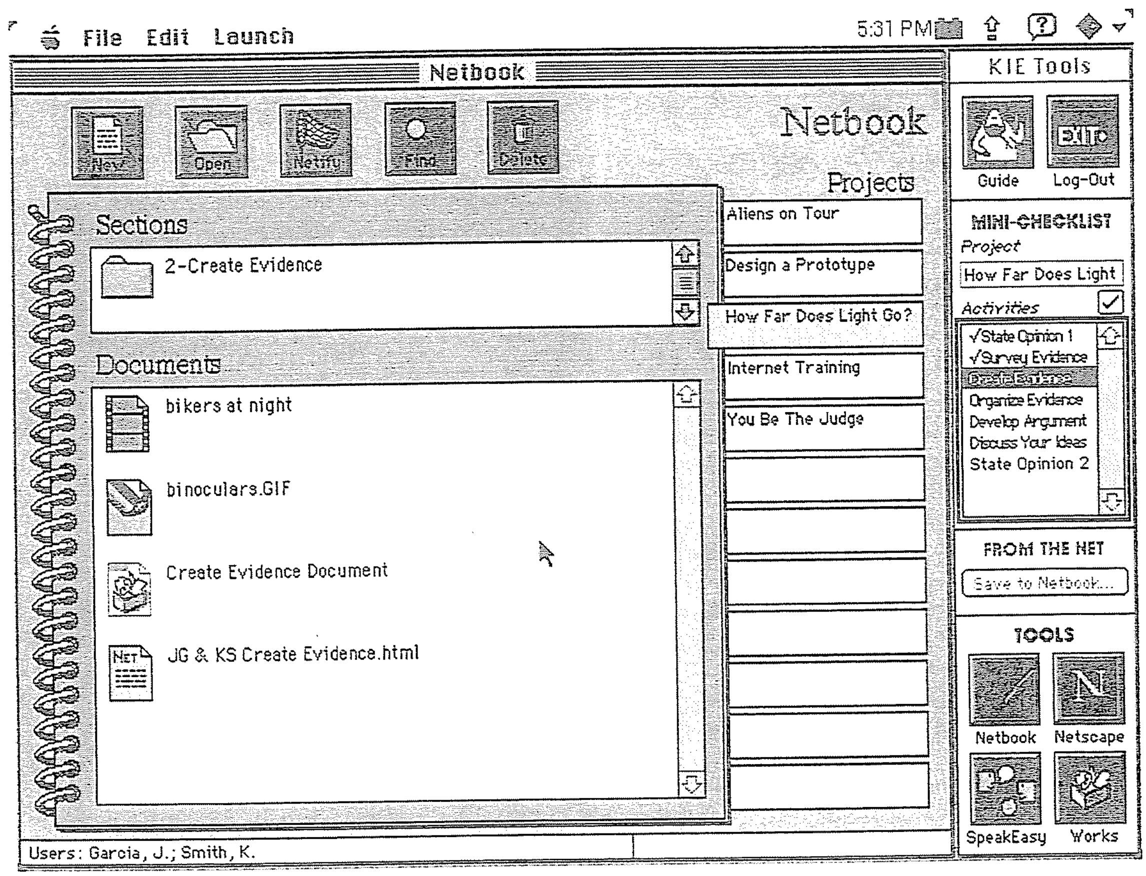

Figure 1. The Netbook and KIE Tool Palette.

4.3. The Networked Evidence Database (NED)

The World-Wide-Web allows individuals to organize existing information resources from around the globe into new representations. For example, an inspired student can take information relating to home insulation and turn it into an information resource on the Web structured by geographic area. As part of the KIE curriculum framework, we have designed and implemented a Web-based database structure composed of scientific evidence to be used by students in KIE activities.

The Networked Evidence Database (NED) is a collection of individual pieces of evidence, where each piece has been cataloged and described using a set of identifying characteristics (e.g., the type of evidence, the author's motivation and methodology in producing it, representative keywords, and a list of KIE activities for which it may be appropriate). Figure 2 shows a piece of "everyday" evidence that relates to the science topics of light reflection and absorption, light intensity over distance, and vision. It shows frames from a digitized movie of two bicyclists, one wearing black and one wearing white, riding up a street at night.

The NED is composed of evidence that has been created explicitly for use as part of KIE, as well as additional appropriate evidence that already exists on the Net. Submissions to the NED can come from the KIE Research Group, natural scientists, teachers, and the students themselves. As part of the KIE activities, students collaboratively engage in the creation of evidence to be published in the NED, drawing on the scientific methods and experience they may be engaged in as part of classroom laboratory or research activities. For example, a student team may author a piece of evidence summarizing a lab they performed in class or they may make a digital movie of a particular phenomena. Alternatively, evidence may come from newsgroup discussions taking place on the Net or from other information resources on the Web.

4.4. The SpeakEasy

The SpeakEasy is a tool for discussion and collaboration across the Net about multimedia materials contained in the NED. The SpeakEasy interface is based on a prior tool for collaborative learning in multimedia, the Multimedia Forum Kiosk (Hsi & Hoadley, 1994). Using the SpeakEasy, students record their opinion and participate in a discussion summarized in an argument map. The multimedia interface with images, texts, sound, and video has been tested and found helpful in stimulating productive discussion and reflection (Hoadley & Hsi, 1993).

Although not used in the pilot study, the SpeakEasy allows multimedia discussions over the Net. Teachers can request that a topic be set up, list the students permitted to interact or leave the conversation "open to the public", and attach multimedia materials to their topic. Students are then able to leave their

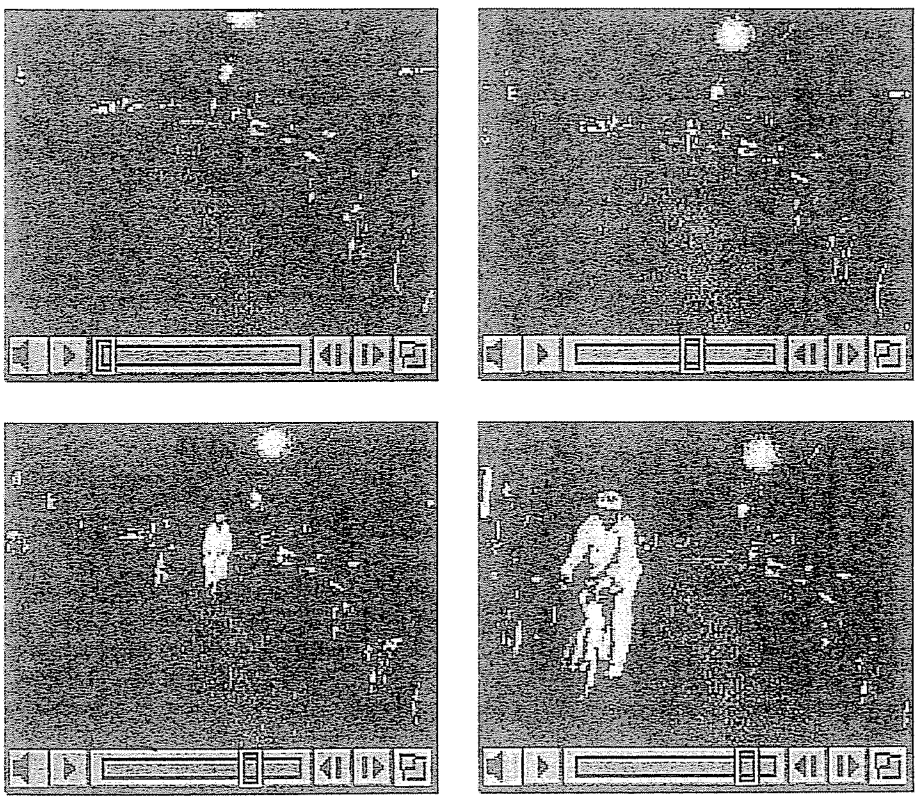

Figure 2. Frames from the "Bicyclists at Night" Evidence.

opinions and interact with other students by responding to their comments. The results are organized by individual viewpoint or by a diagrammatic representation of discourse. Students summarize the SpeakEasy discussions and add these to the NED. Discussions will be equally easy within a local site or between remote sites around the world.

4.5. Student Knowledge Integration Planner and Profiler (SKIPP)

The Student Knowledge Integration Profiler and Planner (SKIPP) will be comprised of two primary parts: an activity planner and a student profiler. The pilot study allowed us to refine the SKIPP data structure necessary to support having students work through various KIE activities.

The activity planner is used to manage a set of KIE projects, each of which has associated activities, which in turn have associated documents for student work, and guidance for students as they work on the project or activity, as well as lists of relevant and appropriate evidence. Furthermore, within the activity planner, teachers can design their own projects, or modify existing projects. KIE projects can be easily imported and exported from the SKIPP, allowing projects to be exchanged over the Net through a curriculum library.

The student profiler keeps track of the projects and activities each student has completed, as well as the evidence they have seen. The student profiler also provides an entry and storage location for student interests, preferences, epistemological beliefs, and knowledge about the scientific material. This information can then be used to allow projects and activities, as well as feedback, to be customized to particular student needs using the KIC.

4.6. The Knowledge Integration Coach (KIC)

One of the most important inputs to the SKIPP will be the guidance used by the Knowledge Integration Coach (KIC). The KIC provides guidance at three levels. Project-specific scaffolding guides students to think about what is the main idea they should keep in mind as they work on the various activities and look at the evidence for a particular project. Activity-specific hints help students as they work on a particular aspect of the project. For example, the student might be reminded of the goal of writing a critique of a piece of evidence, and what is appropriate to include in such a critique. Evidence-specific hints guide the student to critically evaluate evidence in the NED. All of these levels of scaffolding model appropriate modes of inquiry. They also provide stepping-off points for students to engage in meaningful discourse with their peers about particular activities or evidence. These hints are intended to help students develop an integrated understanding of the subject matter by encouraging them to produce personal explanations (e.g., Chi, Bassok, Lewis, Reimann, & Glaser, 1989).

5. Future Directions

The KIE project has several current goals. First, to make the KIE tools transparent and self-instructional we plan trial-and-refinement studies with a broad, representative range of users. Results from these studies guide revisions that make KIE flexible and easy to use for both students and teachers.

Second, to implement the Scaffolded Knowledge Integration framework KIE must provide effective guidance for students. We plan research on how best to guide students. Students can currently choose the amount of guidance that they want the KIC to provide. Instead, we might diagnose student guidance needs and personalize guidance depending on how students organize the materials they access. For example, we can use information in the SKIPP to personalize guidance from the KIC. We plan to research options for providing "meaningful" feedback and guidance.

Third, access to networked materials increases the importance of helping students assess the validity of evidence. When texts are the main source of scientific information students tend to accept statements uncritically. Results from our pilot studies indicate that students often extend this disposition to other materials they encounter in science classes. Since some networked materials are intended to persuade rather than inform and others are opinions rather than results from investigations, students need to develop skill in evaluating evidence. We plan to examine how students evaluate communications from peers, from newspapers, and from other sources to develop effective guidance for assessing networked materials.

Fourth, the KIE has the potential of fundamentally changing classroom activities and extending science learning into homes and other settings. We plan to study the new activities that these resources enable. We wonder which students will benefit the most from alternative environments for science learning. We will seek ways to use these technologies to motivate students who have lost interest in science.

The increasing availability of Net resources challenges educators to create a global community of science learners, to connect students to dynamic, ongoing science explorations, to communicate the nature of science as well as the concepts of science, and to sustain interest in science. The Scaffolded Knowledge Integration framework can help make the Net a partner in science learning. Ultimately, this framework and the KIE can help students develop a lifelong habit of science exploration sustained by Net resources.

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Additional information on the KIE project is available at "http://www.kie.berkeley.edu/KIE.html" on the World-Wide-Web.

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[1] Throughout this paper, we use the term "Net" to indicate global networking technologies, including the current Internet and the World-Wide-Web. When we explicitly reference the Internet or the World-Wide-Web, we use those more specific terms.