WISE Science: Inquiry and the Internet in Science Classrooms

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INTRODUCTION

This book captures the accomplishments and lessons learned within a large community of educational researchers as they designed, developed, and investigated a new technology-enhanced learning environment known as WISE: The Web-based Inquiry Science Environment. WISE was developed to capitalize on the exciting new features of the Internet in order to bring new kinds of learning and instruction into the science classroom. The project capitalizes on advances in the learning sciences that provide insight into how students learn and how instruction succeeds. The project began in 1996 at The University of California, Berkeley, and has grown over more than a decade with contributions from researchers, teachers and scientists from across North America, Europe, Israel, and Asia. Throughout this time period, we have improved WISE by incorporating the latest results from science education research, including from the findings from our own studies of curriculum and instruction carried out in numerous science classrooms where we have studied WISE in action and continuously refined its design.

WISE has enjoyed great success in both the research and practitioner communities, largely as a result of its capacity to bring so many expert voices together to develop powerful inquiry activities within a technology-enhanced learning environment. This endeavor has attracted a large community of participants from a variety of disciplinary backgrounds. For example, WISE has provided a technology platform as well as a curriculum framework for educational researchers from many different institutions. WISE has also partnered with science organizations like The American Physiology Society, the International Wolf Center, The Thousand Friends of Frogs, NASA, and the U.S. National Oceanic and Atmospheric Association (NOAA) to co-design inquiry projects that met the needs of those organizations while also capturing the WISE pedagogical principles. We partnered with computer scientists from the

University of California, Berkeley and other institutions to create a state-of-the-art technology environment for teachers, researchers and students.

WISE has provided a valuable infrastructure for educational researchers from across the United States and around the world, supporting their investigations of different aspects of science inquiry. For example, Janice Gobert was investigating the use of visualizations and models to help students develop a deeper understanding of earth science concepts.. Her approach had been successful in laboratory studies, but lacked the rich curricular context that would help them to be effective in a classroom setting. Gobert was able to embed her approach, including the visual simulations within a WISE inquiry project called "Plate Tectonics: What's on Your Plate?" Thus, WISE provided Gobert with a research platform in which she could develop materials, deliver them to classrooms and collect student assessments with great levels of control. The WISE technology benefited from Gobert's studies, which helped in the design of new functionality for peer exchange and collaboration. Such partnerships have resulted in a wealth of new research, including scholarly publications (e.g., Gobert, Slotta and Pallant, 2002; Gobert, 2005), presentations, (e.g., Gobert, 2004) and funded projects. In addition, the WISE technology environment and materials has been translated into many other languages, including Norwegian, Dutch, German, Hebrew, Japanese, Chinese, and Korean.

WISE has also proven its worth for students and teachers in classrooms around the world. This project can be judged a success based solely on the number of teachers who have adopted WISE in their science courses for all topics from grades 6-12 (ages 11-17). More than 100,000 students have now participated in a WISE inquiry project, and more than a thousand teachers. WISE is one of the very few products of educational research that has been able to cross over into the world of schools, teachers and students who were not affiliated in any way with the originating research group. This viability of WISE has offered new research opportunities relating to the scaling of innovations within schools and districts, and models of professional development for science teachers.

What makes WISE unique is its ease of implementation for teachers from such a wide range of school settings. Previous research projects – including some of our own discussed in this book – have produced exciting new technology environments, curriculum materials, and assessments. But these research-oriented materials were not typically intended for wide use by teachers, and would not have succeeded in the classroom without additional support. WISE is different because it was developed with the explicit goal of providing a technology-enhanced learning environment for a wide community of science teachers and educational researchers.

Our initial design of WISE was informed by a synthesis of the research literature, including more than two decades of our own prior research. Since then, WISE has been the focus of our ongoing research as well as that of our collaborators. From these efforts we have developed the knowledge integration framework (Linn, 1995; Linn & Hsi, 2000) and design principles (Linn, Davis, Bell, 2004) to guide future designs.

Currently, there are new funded projects underway. In addition, we have recently released a new open source version of the software that will enable researchers and other developers to adopt and adapt the WISE technology and curriculum materials for their own purposes

This book offers a comprehensive narrative about our experience in WISE, recounting the history of the ideas, the theoretical foundation of our designs, the challenges we have confronted, and the implications for science education. In chapter 1, we introduce the challenges and opportunities related to technology in education. Chapter 2 presents an overview of the WISE learning environment, including its various tools and features, the curriculum library, and of how it has been used by various teachers and research collaborators. Chapter 3 describes the theoretical framework, called Scaffolded Knowledge Integration, that has guided the design of all WISE technologies, curriculum and assessments. Chapter 4 outlines how we have developed curriculum patterns that build on the theoretical framework. Chapter 5 reviews some of the research that has demonstrated the effectiveness of WISE. Chapter 6 describes our partnership method of creating WISE curriculum and assessments, which has resulted in a fascinating range of inquiry projects and some ongoing research collaborations. Chapter 7 provides details about how teachers have succeeded with WISE, and Chapter 8 follows with a review of our efforts in teacher professional development. In Chapter 9, we begin looking forward to the legacy of WISE, in terms of the communities of sharing and exchange that it has fostered. We conclude the book by suggesting some important policy implications for science curriculum, educational technologies, and teacher professional development, as well as some specific ways that educators can get involved.

Throughout the book, we limit our use of academic citations mostly to cases where specific projects or researchers are being addressed. All citations are referenced to a wider bibliography, presented at the end of the book, that offer a comprehensive set of academic references that are relevant to this work. In addition, at the end of each chapter we provide an annotated set of recommended readings that help make specific connections to the research literature.

This narrative is directly relevant to some of the most important issues facing educators today: How can teachers help students achieve a deep understanding of science when they are confronted by standards and expectations that require a breadth-of coverage approach? How can we deliver on the promise of technology to enhanced learning, engage students, and enable new forms of assessment? How can teachers respond to the challenge of helping every student in their class? We hope that such a volume would be useful within graduate training programs, pre-service courses for teacher preparation, in-service programs for teacher professional development, school leadership, or any individual teacher, parent or developer that is concerned with these issues.

CHAPTER 1. TEACHING AND LEARNING SCIENCE IN THE 21ST CENTURY

The Internet is one of the defining characteristics of our transition into the new millennium. The World Wide Web emerged in the late 1990's, as if on cue to usher in the 21st century. Almost overnight, it seems that every aspect of our lives developed an online component: email, shopping (and reselling via Ebay), reading the news, finding directions, searching for apartments, sharing videos and photos, paying our bills, and trading stocks. Never has a new medium enjoyed such a swift uptake and made such an enormous impact in the world. Within a decade there were Internet cafes in every city around the world, and most sectors of society were embracing new forms of workflow, communication, and exchange.

Science itself has been profoundly transformed by the emergence of the Internet. At the most basic level, scientists now routinely exchange e-mails, drafts of manuscripts and analyses in progress, with vastly greater rates of turnaround than in any previous era. At an organizational level, scientists now coordinate workshops, conferences, and even online journals using Internet technologies. At an even deeper infrastructural level, there are now open access datasets where the latest genomic sequences or astronomical images are published by scientists for purposes of review and outright sharing with their peers – within hours of their initial collection. In addition, new internet-based functionality, such as graphical information systems (GIS) or agent-based simulations are profoundly altering the analytic processes within scientific communities ranging from geology to physics to social psychology.

Students must develop a fluency with information technologies, to succeed in almost any walk of life., Yet K-12 education has only just begun to show any signs of transformation in the age of the Internet, and most of those signs are at the administrative level rather than in the classroom. Internet technologies are indeed revolutionizing the collection and management of student information, offering powerful new mechanisms to track performance and attendance, coordinate special education programs and communicate with parents. In higher education, we are now witnessing a slow but steady growth in the use of learning management systems, where student activities and student-teacher exchanges are coordinated through online environments. Some instructors are even using these environments in new ways to change the structure of their courses, including collaborative projects, online discussions and peer review. Instructors are also developing online resources for their courses that can be re-used and improved with each new course offering.

In K-12 classrooms, however, Internet technology has yet to make any meaningful impact. Several prominent analyses of teachers' use of technology (e.g., Becker and Ravitz, 1999; Cuban, 2001; National Research Council, 2002) have revealed that there has been little to no transformation of U.S. classrooms by computers and information technology. These reports and surveys have documented teachers' preference for conservative, rather than revolutionary applications of technology, primarily related to skills acquisition using word processors or spreadsheets, or as a source for independent research projects.

Educators understand that the Internet presents many wonderful new opportunities for learning and teaching, and some teachers have indeed begun to experiment with new curriculum designs that engage students with online resources and activities. But the integration of technology into science classrooms has been a slow process, as teachers remain focused predominantly on lectures and textbooks, using the Internet primarily as a supplemental resource for Web searches or multimedia materials. In part, this reluctance to deeply integrate technologies is related to the issue of access and reliability: in order to truly integrate Internet technologies into the science curriculum, all students must have constant, reliable access to Web-enabled computers. Still, even with increasing levels of access to technologies (see Figure 1.1), teachers find it challenging to redesign their approach to instruction in order to integrate new materials, new functionality, or new patterns of exchange between students.

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Insert Figure 1.1 about here (Classrooms Connected to Internet)

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For several reasons, teachers have been reluctant to incorporate new methods that integrate technology, even when they have access to computers and the Internet. In addition to the technical challenges of access and reliability, there are substantial challenges relating to pedagogical design. While it is true that the Internet offers powerful new interactive materials, for example, it is not clear how to design science lessons that integrate those materials effectively so that all students learn. Online collaborations between students, which could provide a heightened level of interactivity and exchange within a classroom setting, are not a straightforward matter in terms of curriculum design. What should students collaborate about? How should teachers monitor or assess students' progress?

Thus, while teachers might try out some interactive learning materials or online adventures as supplemental or occasional resources, they are perhaps rightfully hesitant to undertake a major overhaul of their instruction. Given the current climate of standards-based instruction and high stakes accountability for teachers, such caution would be warranted. It is challenging to deeply integrate technology within an instructional design, coordinating the flow of people, activities, and materials so that all participants are rewarded with a rich learning experience.

K-12 teachers look to educational research to provide good examples of Internet environments and technology-enhanced learning – including evidence of student achievement. And indeed, WISE was developed in order to test and refine such a framework, as well as to provide a rich example for teachers and researchers of how technology can support new forms of learning and instruction. One of the most important goals of WISE is to provide a solid technology platform that will allow teachers to adopt new forms of inquiry-based instruction with confidence and support. Particularly in science education, such approaches offer promise, as instructors are challenged to communicate vexing topics such as natural selection, chemical bonding, DNA replication, or geophysical processes. Clearly, there is an opportunity for technology to play a meaningful, even central role in science instruction. But before this can happen, projects such as WISE must investigate new models and make successful approaches easy for teachers to adopt.

Researching the Integration of Inquiry and Technology in Science Classrooms

In order for teachers, principals, or school boards to change the nature of science curriculum, instruction, or assessments, they need substantial evidence from educational research. Teachers may wish to increase the emphasis on inquiry in their classes but lack confidence in the materials they find on the Web. Often these materials require a level of teacher support that is unrealistic or access to equipment that is unavailable. Teachers may find appealing materials such as dynamic, interactive visualizations on the Web, but they have no way of knowing how students will engage with these materials. Materials on the Internet are often complex, and not originally prepared for purposes of K-12 instruction. For example, many sophisticated scientific visualizations on the Web were produced by scientists for use by their peers or students. It is difficult to predict how precollege students will engage with such materials, or what they will learn. Particularly in science, it is essential to address the issues of accuracy, reliability, and age-appropriateness of instructional materials. Educational research is needed to investigate coherent approaches to the design of curriculum that takes into account how students learn. Teachers need materials that guide students through inquiry activities, and support their interactions with peers and instructors in the classroom.

In the past two decades, educational research has made some progress in defining productive roles for technology within the classroom. Much of this research has focused on defining pedagogical patterns where technology helps students and teachers interact with instructional materials in new ways, with greater levels of collaboration, peer review and reflection that lead students to a deep conceptual understanding of topics. In the following sections of this chapter, we synthesize the research literature into four important principles that have guided our development of WISE. Variations of these principles appear commonly in many research reviews (e.g., Roschelle et al., 2001; Quintana et al, 2004; Linn and Eylon, 2006), reflecting consensus amongst researchers. WISE was inspired as a way of capturing these basic themes and extending them to science classrooms in the form of a technology enhanced learning environment.

1. Support Autonomous Learning

It is widely held by educational research that learners construct their understanding of a topic through active reasoning that connects with their previous views or experiences. Science lectures are not likely to help students build such connections because they do not engage students in active reasoning about topics, but rather in passive efforts to understand a spoken message. Students tend to add these ideas to their set of views but not to distinguish them from other ideas. For example, students may learn about how electrical circuits work but still believe that electricity flows out of the wall and gets “used up” by a lamp.

Activities that promote autonomous learning help students make sense of new ideas and develop the ability to evaluate new information. For example, lab-based activities and small group work are much more likely to allow students the opportunities to make connections to their existing ideas, test their own hypotheses, and develop a personal understanding of topics. However, using labs or small groups is not sufficient in itself to ensure that students are reflecting and developing a deep understanding of science topics. Students can still just add new ideas instead of critiquing them and considering how they connect to their existing ideas. When teachers become a “guide on the side,” they can enhance learning by listening to students’ ideas, suggesting alternative explanations, and prompting students for deeper reflections. Thus, opportunities to learn autonomously allow students to engage deeply with the science topics and are more successful when teachers interact with students and encourage their reflections.

2. Encourage Collaboration and Peer Exchange

Learning in everyday life is rarely conducted in isolation from our peers. In nearly every place of work in every sector of society, our learning is conducted in close exchange with others. This is fortunate, because psychological theorists such as Vygotsky (1978) have argued that people learn best when they learn with peers who share comparable backgrounds and interests.

Classrooms are an ideal setting for such peer exchange and there is ample evidence from the research literature that students learn effectively in collaboration with peers. For example, when students construct a circuit and discuss how electrical circuits work, they can test ideas, develop criteria for distinguishing ideas, and critique the ideas of their peers. Often a hint from a peer can be sufficient to help a student compare the observation that the lamp is plugged into the wall to the finding that a wire from the battery to the bulb is not sufficient to power the bulb.

Collaborative learning is most successful when carefully designed. Some investigators have explored direct methods such as peer tutoring or peer learning circles. Richard Anderson and his colleagues have developed a method called Collaborative Reasoning where elementary students develop literacy skills by collaboratively reading and debating literature (Anderson et al., 2001). Marlene Scardamalia (e.g., 2002) and her colleagues have investigated the benefits of collaborative knowledge construction, developing a technology environment where students add written reflections, images and other media objects to a common database of ideas that helps them in subsequent learning activities. In our own prior research, we have explored the use of online discussions where students debate science topics with peers (Hoadley and Linn, 2000; Linn and Slotta, 2006. Taken together, this research demonstrates the value of collaboration and peer exchange, which should be included in the design of any technology-enhanced approach to learning.

3. Make Ideas Visible to Students and Teachers

The axiom, “a picture is worth a thousand words” is widely accepted because it captures the powerful experience that comes from looking at a visible representation of complex ideas. In science, this is particularly true. Who could imagine learning about chemical bonding and orbital shells without some of the rich visualizations employed by textbooks? Of course, with such power comes the capacity to do harm or to interfere with learning. A wealth of research has explored the misconceptions caused by scientific visualizations – particularly when complex or abstract representations are used with students who are encountering these ideas for the first time. Students may focus on the surface features, for example the red circles and the blue circles in a simulation of ideal gases, mistakenly believing that one of the gases is blue and the other one red! Researchers have found that simplified conceptual models, designed at an intermediate level of complexity, are more effective at helping students develop a conceptual understanding.

Simulations and interactive models are perhaps the most powerful form of scientific visualization, because they represent complex ideas and causal relationships in a temporal, "playable" format. For example, Figure 1.2 shows an interactive model of global warming designed by Bob Tinker and Keisha Varma and, implemented in the Netlogo system developed by Uri Wilensky (1999) and his colleagues. In this simulation, students observe a cross section of the atmosphere with the sun's rays entering through a cloud layer, and a dynamic temperature graph on the side that shows the average temperature of the earth. Students are asked to click buttons that say "Add CO2" or "Add Clouds", and observe the effects on global temperature as time moves forward. Of course, this is a highly simplified representation of the global system, but it provides students with an opportunity to make predictions and test their own ideas about the role of these variables, such as increasing the level of CO2 or the amount of cloud cover.

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Insert Figure 1.2 – Netlogo model – Interactive modeling for global warming

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In order for visualizations to make ideas visible to students they need to be embedded in an inquiry activity and strengthened with guidance from the teacher. For example, students using the Netlogo global climate simulation above without guidance, would probably just play around with the buttons and watch the temperature graph without developing any conjectures about the role of variables like CO_2 or clouds. Thus, for scientific visualizations to make thinking visible, we must carefully develop supporting materials that help to guide students' explorations and reflections. Even more important, the teacher must pay attention to what students are doing, and what they are saying about such visualizations, in order to be sure that they are gaining the intended benefits of the experience and not developing misconceptions.

Technology tools or environments can also help make students' emerging scientific ideas visible for themselves and others. For example, students could interact with technology enhanced visualizations like the global climate model above to test their ideas or compare with peers, and teachers could gain valuable insight into what students believe about the various processes being represented. Another way of making students' ideas visible is through concept maps, drawings, or graphs – all of which can provide the students with powerful ways of building their own understanding and give teachers a visual lens into what their students know.

Thus, technology can make scientific ideas visible to students, make student ideas visible to teachers, and support inquiry activities that stimulate constructivist learning in science. Educational researchers have made gains in investigating how such tools can make thinking visible and continue to develop more powerful approaches.

4. Promote the Personal Relevance of Science

Another principle that has emerged from educational research is to focus on the relevance of science to students in their everyday lives. To help every student develop a deep understanding of science that can be used in everyday situations, science instruction, must feature activities that offer relevant and meaningful connections to students' own ideas and experiences. Global climate, for example, can be used as an engaging and effective context in which to address chemical reactions and several other physical science because of its direct personal relevance to students' lives. If the curriculum emphasizes that chemistry and physics are at the heart of global warming, this will foster engagement and a sense of the relevance of school science. Topics like genetically modified foods, ecology, or the design of familiar things like houses, cars, or schools can all help students find relevance in science.

Researchers have recognized that students have much more to gain from science than simply an understanding of conceptual topics. Ideally, science class is where students will learn the valuable skills of critical thinking and argumentation that will be important throughout their lives. Citizens today must be able to decipher complex arguments about issues such as stem cell research, global warming, or home electricity usage, in order to participate in our democratic society. They need to understand the political debates on such issues so they can vote responsibly and help shape public policy.

The Internet, in particular, offers a valuable source of information for every conceivable topic, but searching for relevant information and distinguishing the validity of sources can be quite challenging. Science class can offer students the opportunity to learn how to search for valid evidence. Instruction can help students learn how to distinguish between persuasive messages and evidence-based assertions. These are valuable lifelong learning skills.

When it comes to science topics in class, on the playground, at home and throughout their lives, students need to engage in critical discussions with peers, evaluate arguments, and respond to feedback. Science class can become a place where students engage in such practices and see the relevance of the course to everyday life.

The Need for Depth of Coverage in Science Curriculum

Teachers receive mixed messages about assessment from various professional sources. During pre-service instruction they learn that continuous, formative assessment is essential to allow them to gauge student progress and respond to individual students appropriately. Such assessments provide some measure of student understanding during instruction, to which the teacher can respond in real time. They are not assessments that occur at the end of the curriculum to measure student achievement, but rather, they serve to reveal measures of students' progress at particular points within the curriculum. On-going or continuous assessments can provide valuable information that helps teachers make curricular decisions, such as whether students need further clarification about particularly topics, or whether they are successfully collaborating with peers.

During pre-service preparation, teachers learn that on-going assessments are vital to effective practice, but when they arrive in schools they encounter a heavy emphasis on coverage of content standards and high stakes, summative assessments. For various reasons, the prevailing atmosphere within many schools is one of concern over demonstrating successful performance on examinations that are directly linked to the content standards. In science, the national and local standards are a daunting set of topics that would be challenging for even the most veteran teacher to address with any depth. As a result, science teachers are often pressed to "make it through" their required standards in the limited time given to them within a school term. Teachers have trouble justifying any curriculum approach that demands more than the allocated fraction of time implied by the science standards. This can lead teachers to the belief that "there is no time for inquiry or project-based learning," because of the need to" cover all the standards and prepare for the test.

As a result, many students are left behind, feeling that science is a heavy load of facts and relationships that must be endured and mastered for a test. This inevitably leads to a competitive atmosphere, where students strive for a good grade and not for understanding and fulfillment. Only a fraction of students manage to endure this treatment and goes on to discover that science may be more than just a scholastic challenge. The others, many of our brightest and most sensitive students, are left with a negative impression and lowered self esteem by science courses, and proceed to put all of science behind them.

The four educational research themes discussed above do not emphasize the coverage of content standards at the expense of students' deep understanding. When teachers are forced to address a great many topics within a single course, they have very little time to devote to any innovative, inquiry-oriented approach. Yet research shows clearly that only by reflecting, applying ideas, and collaborating with peers can students develop a sense of the relevance of science and build a coherent understanding. Many researchers have criticized the traditional form of lecture-based instruction as being too superficial. This is captured by the famous "Bloom's taxonomy" of educational objectives, where the rote learning of knowledge is seen as the most primitive form of learning, subordinate to higher level objectives such as the application of ideas to new purposes, the analysis of ideas, and the synthesis of ideas (Bloom, 1956). Thus, a breadth-oriented approach might boost students' performance on exams, but it will result in disconnected learning of facts and procedures that students will be unable to apply to other problems, and will quickly forget.

A Role for Technology-enhanced Learning Environments

Traditional lecture and breadth-of-coverage methods are familiar to teachers and students alike, and are straightforward for teachers to practice. In contrast, it is much more challenging to adopt depth-of-coverage methods where students collaborate in pairs or small groups to perform inquiry activities. Teachers are justifiably wary about experimenting with such methods in their own classrooms. In order to support teachers as they adopt innovative approaches, many researchers have developed technology-based tools and, such as online scientific notebooks, graphing tools, simulations, concept maps and reflection notes. Such technologies can serve to capture student ideas in real time, making those ideas available to teachers for purposes of timely feedback and formative assessment.

Indeed, one of our basic motivations in developing WISE and its predecessors, described below, was to support students and teachers as they engaged in a depth-of-coverage approach to learning science topics. By supporting students as they conduct complex activities, technology-enhanced learning environments also serve to support teachers as they adopt such approaches. With well-designed technology environments helping to guide their students through complex inquiry activities, collect student work, and prompt students for reflections, teachers are free to focus on more meaningful interactions with students. Using such technology environments, teachers can gain confidence that students will remain on task as they circulate within the classroom, observing students' ideas on the computer monitors and interacting with students when they see good opportunities for relevant discussion.

Technology-enhanced learning environments are software systems that present curriculum materials to students, collect student work for purposes of assessment, and provide helpful user interfaces to guide students and teachers alike as they enact curriculum. The technology environment can deliver a wide range of curriculum, including functionality for the display of Web pages, for collaboration between students, and for various tools such as data tables, graphing and drawing, online discussions, and various simulations and modeling tools. Such technology tools can be woven together to support inquiry projects, scaffolding student activities, providing guidance in the form of helpful hints or prompts, and capturing all student work for purposes of assessment.

Many technology-enhanced learning environments have been created by researchers in recent years. For example, the Thinkertools environment, developed by Barbara White and John Frederickson, helped guide students in the use of scientific simulations to address their possible misconceptions of physics topics (White and Fredericksen, 2000). NetLogo, developed by Uri Wilensky and his colleagues, provides students a hands-on modeling and programming environment (Wilensky and Resnick, 1999). BGuILE, the Biology Guided Inquiry Environment, was developed by Brian Reiser, Bill Sandoval and their colleagues to investigate how students could work with realistic scientific datasets to address classic problems in biology (Reiser et al., 2001).

Before the age of the Internet, and before we ever conceived of WISE, our group conducted two decades of research in the domain of technology-enhanced inquiry learning. We developed two different technology environments to support our investigations of inquiry curriculum for middle school science in grades 6-8 (ages 11-13). First, the Computer as Learning Partner (CLP) project developed technology scaffolds to help students make predictions about heat and temperature phenomena, experiment with simulations, and compare their predictions against data they collected using probeware and graphed in real time. Next, the Knowledge Integration Environment (KIE – see Figure 1.3) expanded on the work of CLP by creating a more sophisticated technology environment, adding links to the Worldwide Web and improving our integration of tools such as reflection notes, data tables and online discussions. Begun in 1994, KIE was perhaps the first comprehensive research effort to incorporate Web materials into science inquiry projects (Bell, Davis and Linn, 1996).

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Insert Figure 1.3 Knowledge Integration Environment

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Research in the KIE project addressed several topics that would become foundational to our efforts in WISE. We investigated the most effective designs for student reflection prompts, the most engaging topics for online discussions, and the best way to introduce complicated Web pages. We also began to investigate the designs for different kinds of curriculum projects, such as debate projects, where students used Web pages and other evidence to make their own arguments about science controversies like “How Far Does Light Go?” Many of the findings of these two projects are reviewed in Chapter 3, as they provide the research basis for our development of WISE curriculum.

All the technology environments mentioned above were designed to support specific lines of educational research, with the aim of extending the field’s knowledge about learning and instruction. These systems were not intended for wide adoption by teachers, nor were they suited for that purpose. For example, the KIE environment was rather unwieldy, requiring a substantial effort to install software, with frequent technology bugs. Moreover, KIE curriculum projects consumed several weeks of class time, and generally required the presence of a research assistant in the classroom in order to help respond to student questions and solve technology problems. In most science classrooms, curriculum time is at a premium, and teachers could never spend several weeks on a single inquiry project. Nor could they afford the luxury of an assistant to help them administer the curriculum. KIE was not generally intended as a scalable system that would work well for any science teacher. Rather, it was a research system that was meant to help our group investigate questions about technology-enhanced learning. Thus, KIE was only implemented in a few classrooms, but it provided a foundation to our design of the WISE technology environment, which was designed to survive in the wilds of real science classrooms.

In WISE, we set out to design a new technology environment that would capture the core principles from research as outlined above, that would be easy-to-use for students and teachers, and that could be used widely in science classrooms. This raised a compelling conundrum: how can researchers develop materials that allow them to conduct their investigation while still being accessible to teachers? The answer requires a new technology environment that applies the research findings while responding to the complexity of classrooms and the diversity of teacher needs. In order to achieve these acrobatic goals, WISE would require a simple user interface, a reliable technology infrastructure (server, database, etc) and well-designed curriculum and assessments. The next chapter provides an overview of WISE, including several examples of curriculum and detailed descriptions of all the technology components.

Recommended Readings

We selected the following readings to as a good representation of the wealth of research that has addressed the role of technology in inquiry-oriented learning. Each of these books or papers provides a slightly different perspective.

Bransford, J. D., Brown, A.L., & Cocking, R. (1999). *How people learn: Brain, mind, experience, and school.* Washington, D.C.: National Academy Press.

This book presents a deep synthesis of research from across the learning sciences. It is a report sponsored by the U.S. National Research Council (NRC) that captures the results of a workshop, and draws on the expertise of a committee of renowned experts. At the time of printing, the book is available online in multiple formats at the following URL: www.nap.edu/html/howpeople1/

diSessa, A. (2000). *Changing minds: Computers, learning, and literacy*. Cambridge, MA: MIT Press.

This is a thought-provoking book by a respected scholar in the domains of cognitive psychology and education. Professor Andrea diSessa offers a penetrating discussion of the challenges of learning in the 21st century and the opportunities that technology can provide.

Edelson, D. C., Gordin, D. N., & Pea, R. D. (1999). Addressing the challenges of inquiry-based learning through technology and curriculum design. *Journal of the Learning Sciences, 8*(3/4), 391-450.

This paper, presented by two leading educational researchers, reviews the design and development of several technology-based curricula in the geosciences and identifies five significant challenges to inquiry-based learning.

Quintana, C., Reiser, B.J., Davis, E.A., Krajcik, J., Fretz, E., Duncan, R.G., Kyza, E., Edelson, D., & Soloway, E. (2004). A scaffolding design framework for software to support science inquiry. *Journal of the Learning Sciences, 13*(3), 337-386.

This article reviews the various successful approaches to technology-enhanced learning that have come from educational research and proposes a new framework that synthesizes the most effective design features.

Songer, N. B. (1996). Exploring learning opportunities in coordinated network-enhanced classrooms: A case of kids as global scientists. *The Journal of the Learning Sciences, 5*, 297-327.

This research paper reports on one of the earliest Internet-enabled science curricula: a 6-week weather unit where middle school students investigated various phenomena using Web resources, and even communicated online with peers.

CHAPTER 2. WISE: THE WEB-BASED INQUIRY SCIENCE ENVIRONMENT

WISE, the web-based inquiry science environment, was developed as a "next generation" system that would build upon the research principles described in the previous chapter and allow a continuation of our own research of technology-enhanced inquiry n the science classroom. In designing the WISE technology and curriculum, we set out to develop an accessible resource for science teachers that would function on any Internet connected computers and would not require a great deal of external support. In responding to this challenge, we began to research interesting new questions relating to patterns of interaction in the classroom. We explored new methodologies, worked with a greater audience of teachers and students, and developed a much wider range of curriculum materials. We also developed a state-of-the-art technology infrastructure that could support our development efforts as well as the scaled use by a large number of teachers and students.

The WISE software operates completely within a Web browser application like Firefox or Internet Explorer. Figure 2.1 shows a screen capture of the WISE learning environment running the inquiry project called "Deformed Frog Mystery." Teachers can choose from a small library of inquiry projects that were carefully designed by partnerships between science teachers, educational researchers, and science domain experts. WISE curriculum is designed according to a theoretical framework, known as Scaffolded Knowledge Integration, that we have developed over the course of two decades of research. This framework, described in detail in Chapter 3, supports the design of curriculum projects where students investigate problems, critique solutions and debate with their peers. These inquiry projects address key science standards, but they do so in a depth-of-coverage approach, requiring substantial classroom time for students to work autonomously within the WISE environment, developing a coherent understanding of the science topics.

Students navigate through the sequence of inquiry activities using the inquiry map on the left-hand side of the WISE window. Each time they click on a new step within the map, it results in some new inquiry tool or material appearing in the main portion of the WISE widow. For example, one step might call up a Web page that displays photos of deformed frogs from North American waterways, followed by a step that brings up a WISE reflection note to help students focus on the most relevant aspects of the Web page.

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Insert Figure 2.1 WISE: Deformed Frogs Mystery Inquiry Project

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Our previous generations of technology in the CLP and KIE projects (described earlier) had required support from researchers in order to maintain software and respond to problems. In WISE, we drew on the power of the Web as a delivery mechanism, with no software to install, since all content and functionality would be accessed within the Web browser. We also sought to develop more streamlined versions of the curriculum that captured our research principles but made more efficient use of class time so that teachers could run a WISE curriculum activity in roughly one week. This chapter will present an overview of the various components of WISE, including examples of several curriculum projects, and a discussion of the technology supports we implemented for teachers, students and curriculum authors.

The WISE Student Learning Environment

WISE set out to create a new software environment for students, teachers and curriculum authors, including new software tools for inquiry curriculum and assessments. When we began in 1996, the Web had just appeared on the scene, and we were excited about its capacity to distribute educational content. The Web also offered a natural resource for science learning materials, where students could access the latest data from governmental or non-profit science agencies, or search for pages that were relevant to their arguments. Finally, the Web offered new software functionality, enabling hypertext navigation, browser frames, and tools like online discussions or concept mapping. The notion of a “portal” had also recently emerged (e.g., MyYahoo), where each individual user has an account with specific security permissions, allowing users to customize what features appear in their portal and manage their own personal files. In creating our new Web-based learning environment, we sought to capitalize on all of these new technology directions.

In conducting WISE inquiry projects, middle and high school students work collaboratively and making use of "evidence" from the World Wide Web. For example, in the *Deformed Frogs Mystery* project, students compare two competing theories about why deformed frogs are appearing in American waterways, surveying evidence provided by practicing scientists and designing their own arguments about what is causing the deformities. In the *Sunlight, SunHEAT* project, students critique and compare energy efficient homes from the Web, conduct an experiment that converts light energy to heat energy, and participate in online discussions about passive solar architecture. Figure 2.2 shows the WISE *Sunlight, SunHEAT* Project, including a WISE note with a reflection prompt, and a cognitive hint (delivered by Amanda the Panda).

Insert Figure 2.2 WISE Sunlight, SunHEAT Project

A WISE project consists of steps that students complete in sequence by clicking one step at a time within the WISE inquiry map (presented in the left-hand frame of the browser window). When a step is clicked, it opens some materials or tools within the main part of the browser window. Steps could simply launch Web pages, or they could open the WISE Journal or Reflection Notebook, or any of the WISE inquiry tools, such as the Data Visualizer which presents tables and graphs, the Sensemaker, where students sort scientific evidence into arguments, or the Causal Map, where students arrange causal factors in an interactive concept map. Table 2.1 below lists all the available WISE inquiry tools, with short descriptions for each. These tools have been developed in response to the needs of different research projects over the past several years. For example, in the initial development of WISE, our research was focused on the critique of scientific evidence and arguments, and the use of online discussions as a forum for peer exchanges. Thus, the evidence display, critique, and online discussion tools were the first to be developed. In order to enable subsequent research studies, we developed tools for drawing, graphing, concept mapping, brainstorming, student portfolios, and more.

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Insert Table 2.1 about here: Description of WISE Step Types

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On a technical note, some of the WISE inquiry tools, such as online discussions, brainstorms, or reflection notes, are implemented using Web-based software like javascript and PHP. Other more interactive tools like the drawing tool or the Causal Map were created using the Java platform, and run as "applets" within the Web browser. The result is a seamless user experience where students click successively on the steps within a WISE project, launching a variety of different inquiry tools in a sequence that was designed by the curriculum author. The process of authoring is described in the next section.

The WISE Authoring Tool

An authoring tool was one of the first software systems developed within the WISE research program, primarily because we needed some way to actually create the curriculum that would run in the WISE student environment! We sought to design an authoring system that would allow any member of our research team or any collaborating teacher or scientist to participate in authoring. Over time, we found that the best approach was for a small team of researchers, teachers and science content experts to collaborate in the development of a WISE curriculum project. This is because each member of such an authoring team contributes a different form of expertise. The teachers bring a deep knowledge of their students and the broader curriculum in their course. The science specialist brings a deep knowledge of the disciplinary content that will be emphasized within the inquiry project. And the researcher, usually a member of the WISE group, brings knowledge of the pedagogical structures and theoretical foundation that leads to successful inquiry designs. This partnership model of authoring is discussed at length in Chapter 5 below.

Together, the members of a WISE authoring team use the WISE authoring tool to develop rich, interactive inquiry materials where students debate current science issues, critique evidence and arguments, and design solutions to personally relevant problems. These materials include embedded assessments, such as reflection notes or concept maps, which help students develop a deeper understanding of topics while helping teachers understand how their students are learning about these topics.

The WISE authoring tool is shown in Figure 2.3. It displays the WISE *Sunlight, SunHEAT* Project as it appears when authoring occurs. Notice that each activity in the project, like "Getting Started" and "Web Evidence" has a set of distinct "steps," just as it does in the WISE student software. Authors click on any existing step to open a menu that includes items like "change step name" or "author step content." Each step type has its own special authoring mode. For example, the authoring mode for Online Discussions allows authors to set the discussion topic, as well as various settings related to the discussion tool. The authoring mode for the Display Page steps simply asks for any HTML code to be pasted into the authoring window.

Insert Figure 2.3 WISE Authoring Tool – The Sunlight, SunHEAT Project

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The WISE authoring tool allows the development of a very broad range of curriculum, including any sequences of inquiry steps that could be envisioned by authors. Thus, we also require guidelines for how to develop that curriculum so that it successfully fosters learning, which is the essence of our research. Chapters 3 and 4 below will focus on the research foundations and the resulting design principles that help provide some guidance to help authors develop effective and engaging inquiry projects.

Many inquiry projects have now been created, as a growing community of educators has begun to use WISE, either as a platform for research or as a curriculum development and delivery environment. To support the diverse groups of authors who collaborate in designing, creating, critiquing and revising these materials, WISE includes a sophisticated user portal that provides viewing and editing permissions to any curriculum author, and allows that author to share those permissions with other WISE authors or teachers. In this way, WISE allows curriculum authors to host their own work on the WISE server, share that work with other authors, and manage versions of curriculum.

The WISE Student and Teacher Portals

Teachers can find a wide variety of WISE curriculum projects that have been carefully authored, tested and refined by our research group. When they first log into the WISE home page, they are asked to register for an account, which results in their addition to the WISE Teacher's Portal (see Figure 2.4 below). The Teacher's Portal is a powerful Web site that keeps track of all personal information related to a teacher's account, including his or her student accounts, grades, and any customizations of curriculum that they have created.

Insert Figure 2.4 WISE Teacher Portal

As shown in Figure 2.4, the Teacher portal includes several distinct sections or menus, which support teachers in different aspects of using WISE. In the Projects menu, teachers find links to the various WISE projects in the curriculum library, searchable by science topic or grade/age level. Each project includes a link to the student materials, a detailed lesson plan, embedded as well as pre and post assessments, connections to national (U.S.) science standards from the American Association for the Advancement of Science, and tools for setting up a custom grading scheme. When teachers select a project to run in their classroom, it becomes visible to students when they log in to their portal (described below).

The Management menu is where most of the important activities and interactions occur within the Teacher Portal. Teachers can create new passwords for students, assign them to working groups, and examine student work within a WISE project. Using the WISE Feedback tool, they can send comments to students concerning their progress or ideas within a project that is underway. In the WISE Assessment tool, they can view all student work, set up custom grading schemes, and assign grades and annotations to every student note, drawing, concept map, or other artifact created during the course of the project. Teachers can also set up custom assessments and even coordinate "share project runs" where their class joins another teacher's class during the WISE project's online discussions or peer exchanges.

In the Community menu, teachers may join special groups consisting of teachers, researchers and science content specialists. For example, the "WISE Wolf Community" is a special-purpose Web page designed to support all the teachers who are interested in the WISE *Wolves in Your Backyard* project. WISE online communities provide exclusive features for their members, including supplemental resources, online discussions amongst teachers, links to different versions of the curriculum, and organizational tools, such as calendars and whiteboards. Several distinct types of communities have been created, including the "topic community" (e.g., the Wolves community), "authoring communities," which support teams that are co-authoring a WISE curriculum project, "professional development communities," which support teachers who are participants within a common professional development program, and "school district communities" that support the teachers who are working within a common school board or district.

The goal of the WISE Student Portal (see Figure 2.5) is to make the student's experience using WISE as simple as possible. When students log into WISE, they find a selection of materials that were placed there by the teacher. For example, they may find a new project ready for them to begin, such as *Sunlight, SunHEAT*. They click on that project and it brings them into the WISE learning environment. They may also find comments left for them by their teacher from the previous day's efforts, or the results of assessments. Because of the careful control that is permitted by the WISE database, students never see any information from other teachers or students outside of their class. When they enter a WISE project from the Portal, students are always taken to the exact point where they last left that project (for example, "Activity 2, step 3" within the project). All of a student's work is stored in his or her private user account, which enables student to conduct project work from any Internet-connected computer, with no materials stored on any local computer. Thus, students can work on their WISE project between class sessions, either from their home or the school library, and they do not need to return to the same computer in the school computer lab. Only the teacher or other members of the student's working group can see any that student's work online.

Insert Figure 2.5 WISE Student Portal – Shows student work in various projects

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Over the past decade, WISE has matured into a sophisticated, reliable, easy-to-use technology platform for the design, development and delivery of interactive curriculum. More than a thousand teachers have implemented WISE projects in their science classrooms, and several school districts have established long term collaborations with our project. This success with teachers is primarily a result of the library of curriculum projects that target some of the most challenging science topics at all grade levels. Most teachers can find a project within the library that fits within their course, allowing them to add inquiry and technology to their own classroom.

The WISE Curriculum Library

The technology tools within WISE can help students learn from peers, make their ideas visible, and develop a deep understanding of personally relevant topics, but only if they are used within carefully designed curriculum that takes advantage of opportunities for learning, reflection, and exchange. For example, sending students to a particular Web site might be completely ineffective unless they are first encouraged to develop predictions before visiting the page, followed by carefully structured reflections that help them reconcile their predictions with what they observed. Similarly, online discussions can be fruitful opportunities for students to develop their own ideas, express them to peers, and receive feedback, but they could also be superficial and unproductive if not carefully designed.

Indeed, the WISE technology environment was developed by our research group primarily so that we could investigate such curriculum design issues. When we started, there was no guaranteed recipe, nor any theoretical formula for the design of a technology-enhanced inquiry project. Most WISE curriculum projects were originally developed as research materials that served as a basis for a variety of investigations. For example, one line of research was concerned with the use of student-generated visualizations as a means of helping make their ideas visible. To support this research, we created the WISE Draw tool, where students draw their own predictions of a temperature graph or map where they think an invasive species will appear within a geographical region. While a full discussion of such research is provided in later chapters, the sections below present three different forms of WISE curriculum project that have emerged as a result of our research activities.

WISE Critique Projects

In WISE critique projects, students learn to critically evaluate resources in terms of their scientific credibility or relevance. Many educators have expressed a concern about the source credibility of Web sites, which is a common argument against the use of Internet resources in science instruction. WISE critique projects respond to this challenge, recognizing that the science students of today will be the discerning citizens of tomorrow who will be making meaningful decisions throughout their lives based on scientific arguments and evidence from a variety of sources. Discussions about the energy efficiency of certain kinds of heating may be more suspect, for example, if they are found on a Web site managed by an energy corporation, than if they are found on a governmental science agency Web site. However, the Web has become an invaluable source of information in part because it represents a range of sources. Rather than trying to narrow the range of sources that students encounter, science instruction should help them learn to critique the full spectrum of sources in terms of motivation, credibility, and scientific content.

In WISE critique projects, students are engaged with a range of scientific evidence relating to a specific inquiry topic. The curriculum is carefully designed so that students first encounter a personally relevant science problem, and reflect on that problem. They are then presented with a set of “evidence items” – typically in the form of Web sites that were found by the curriculum authors for purposes of the project - that they must consider in relation to the science problem. For each evidence item, students are asked to rate it in terms of its relevant science content, its source credibility, and its usefulness to the current problem. The WISE learning environment guides students through these various steps in sequence, providing them with each evidence item to be critiqued, together with Web forms to collect their critiques and reflection notes to capture their detailed ideas. WISE critique projects typically culminate with an online discussion of the science problem where students are encouraged to comment on different aspects of the various evidence items.

In the *SunLight, SunHEAT* project, for example, students are presented with the scientific problem of passive solar energy, beginning with a hands-on lab where they investigate the effect of light on black and white surfaces. They are then presented with the notion that some houses are designed to capitalize on this scientific phenomenon, followed by a set of evidence items consisting of specific houses that were found on the Web. These are house designs that vary in the degree to which they capitalize on passive solar energy, and also vary in terms of who authored the Web page and what their motivation was for producing that page. For example, one evidence items called the Earthship (see Figure 2.6) documents an innovative house that relies on passive solar heating and cooling and makes use of recycled materials like old tires for exterior walls and soda cans for interior walls. This is a good example of the kind of interesting resource that the Web offers to science education, but that requires some guidance and instructional context in order to be used effectively.

Insert Figure 2.6 – WISE Sunlight, SunHEAT Evidence of Innovative House

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When encountering the Earthship evidence in WISE, students are asked questions such as: Who do you think wrote this Web page? How reliable is the scientific argument presented? Finally, they are prompted to ask two questions about the passive solar design of the home. The *Sunlight, SunHEAT* Project includes six different house designs that vary in terms of source credibility (some pages are actually advertisements that market specific house designs), as well as relevant science (some homes make little or no use of passive solar architecture). The project is structured so that students critique all six designs, then perform a culminating discussion in which they share their questions about the evidence and discuss the need for critical reflection about evidence (Slotta and Linn, 2000).

WISE Debate Projects

Another kind of WISE project is the scientific debate, where students learn to make use of evidence in constructing or evaluating scientific arguments. WISE researchers have investigated the best design for such curriculum: Should students be asked to take their own position in the debate before considering any evidence? What kinds of reflection prompts would be most helpful as they evaluate evidence? When should they debate with peers, and what should be the format of such debates? What should the teacher's role be, as students are engaged in the online activities? The researchers employed WISE to investigate successful structures and content for such debate projects, ultimately resulting in several effective projects such as the

WISE *Deformed Frogs Mystery,* where students evaluate and compare various arguments about why malformed frogs are appearing in North American waterways (Bell, 2004).

Another debate project is *What's in a House*, where students critique, compare and debate different features of houses that make them energy efficient, particularly for hot, desert climates. This project was developed as part of a sequence, building on the critiquing skills that students gained in *Sunlight, SunHEAT.* In the debate project, students consider evidence for a wide variety of windows, walls and roofing materials, critique that evidence in terms of its scientific content, and debate the most suitable components for house designs. Figure 2.7 shows *What's in a House,* with an evidence item related to tinted windows, which is one of the kinds of windows they critique in this project. Students critique many different architectural Web sites and then perform a comparison activity in which they are asked to debate all the different window strategies in terms of their desirability for the construction of houses located in desert climates. The students who originally participated in this research lived in a desert region of California, making this a very relevant and engaging task.

Insert Figure 2.7. "What's in a House?" Project – Shows evidence item

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WISE Design Projects

In design projects, a third form of WISE inquiry curriculum, students are guided by the WISE learning environment and the teacher to complete a sequence of activities in which they apply scientific ideas to the task of designing a solution to a personally relevant problem. Design oriented curriculum has been advocated by many educational researchers as a powerful, engaging form of inquiry (e.g., Kolodner et al, 2003). WISE researchers recognized that design curriculum would be well suited to technology enhanced learning environments, as the technology could scaffold a wide range of online and offline activities, collect student ideas, enable peer exchange, and encourage deep reflection about the science underlying students' designs].

For example, in extending the curriculum sequence of *Sunlight, SunHEAT* and *What's in a House*, we added a culminating design project where students apply their critique and comparison skills. If critique processes are seen as an important cognitive precursor to debate or comparison, then comparisons might likewise be interpreted as an important aspect of design. Designing a house for the desert will involve comparing different approaches to windows, such as tinting, gas-filled, glass block, reflective blinds, or awnings, which is exactly the kind of activity supported by *What's in a House*. In order to complete the sequence of WISE desert house projects and allow students to apply their critiquing and comparison skills, we created a final design project, known as *Houses in the Desert* (see Figure 2.8).

Insert Figure 2.8 WISE "Houses in the Desert" Project – Application of Critique and Comparison

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In WISE design projects, the technology-based learning environment supports students in a complex design project that consists of many sub-processes involving critique, comparison and reflection (Cuthbert and Slotta, 2004). Activities include journals and reflection notes, discussions with peers, drawing and sketching, searching the Web, completing science worksheets, and even performing offline experiments or observations. In the *Houses in the Desert* project, for example, students were asked to specialize in one aspect of house design – windows, walls, or roofs – then serve as expert consultants for peers who were not specialists in their area. They created an initial draft of their house design using the WISE Drawing tool, informing their choice of design features with reference to the science of heat and temperature (e.g., passive solar heating and cooling). Students worked in pairs, and consulted with peers who had specialized in other aspects of house design than their own. WISE provided students with design worksheets to help guide their decisions and encourage connections to the science. They submitted their initial designs for peer review, and then revised them based on feedback they received. All project activities were guided by the WISE inquiry map, including the provision of timely hints and prompts.

As a result of many research investigations conducted by members of our research group, the WISE curriculum library has gradually grown to more than fifty inquiry projects, suitable for middle school and high school science. These projects are available on the WISE web site free of charge, in an easily searchable form, with excellent support materials for teachers. Many of these projects incorporate the general sequence of critique, comparison, and design that was discussed above, although there are also other kinds of projects. For example, several projects have been written to engage students in modeling activities, where they investigate interactive models in order to test and refine their ideas about topics such as global warming or relative velocities. Other recent projects have explored an experimentation pattern, where students are asked to develop predictions of a model, then conduct experiments to test those predictions. Table 2.2 shows titles and short descriptions of a portion of the projects from the WISE curriculum library. The full library can be found on the WISE project Web site (http://wise.berkeley.edu)

Insert Table 2.2. WISE Curriculum Library, Project Samples

Maintaining the WISE Curriculum Library

All of the projects in the WISE library have been created in partnership with teachers and science experts from universities or governmental agencies. They have all been tested in several classroom trials and refined based on our analyses of where students might have been confused or overly challenged.

As a volunteer, collaborative effort, the projects in the WISE library are an ongoing work in progress. They are not a commercial product, and thus lack the highly polished and refined aspect that is present in most published texts. Indeed, there is no form of published or commercial product that is anything like WISE. These curriculum projects are highly advanced research materials that have been iteratively refined until they are suitable for use by the wider community of teachers. The WISE technology and curriculum resources are supported by our research team in a volunteer effort, which means to say that WISE receives no funding for the maintenance of our public Web site or materials. However, we greatly value this aspect of our work, and must maintain the project library for our own research purposes as well. Occasionally, a Web site that is linked from within a WISE project will disappear, which will only be discovered the next time a teacher or researcher tries to use the project. In these cases, or whenever a typo or technical bug is discovered, WISE researchers respond to the problem. Over time, we have maintained this library, expanded it, and watched it grow as new research projects develop materials.

We developed WISE in order to provide ourselves and the wider research community with a flexible platform for classroom-based research in topics related to inquiry and technology. However, we already had a sizeable head start, from a wealth of prior research that preceded WISE. Thus, while WISE was developed in order to promote research of inquiry and technology, it was designed according to a firm foundation of existing research. Furthermore, all the research that we've conducted using WISE over the past 10 years has focused on extending this foundation. The next two chapters of this book present the theoretical foundation that underlies all WISE curriculum, including detailed examples from our prior research in the CLP and KIE projects as well as some further illustrations from WISE.

Recommended Readings

Slotta, J.D (2004). The Web-based Inquiry Science Environment (WISE): Scaffolding Knowledge Integration in the Science Classroom. In M.C. Linn, P. Bell and E. Davis (Eds). Internet Environments for Science Education. 203-232 . LEA.

This chapter provides a detailed overview of WISE and reviews a research study where all the science teachers in a middle school adopted WISE projects over a period of several years. The chapter reviews the trajectory of the teachers and comments on interesting differences in their classroom practices.

Cuthbert, A. & Slotta, J.D. (2004). Fostering lifelong learning skills on the World Wide Web: Critiquing, questioning and searching for evidence. *The International Journal of Science Education,* 27(7) 821-844.

This research paper describes the WISE *Houses in the Desert* curriculum, in terms of its use of the underlying patterns of critique and comparison. It also introduces a new pattern of jigsaw specializations, where students choose one component of house design (windows, walls or roofs) and become a specialist in that area that will provide advice and expertise within their design groups.

CHAPTER 3. THE KNOWLEDGE INTEGRATION APPROACH: RESEARCH

How do students learn complex science? How do students make sense of everyday science experiences? How can we take advantage of these everyday activities to build student understanding? These questions have motivated our work for the last 20 years and led to the knowledge integration framework that has guided the design of the WISE learning environment as well as the curriculum materials created in WISE.

What Students Bring to Class: Evidence from the Computer as Learning Partner Project

What ideas do students have about science, and how do they go about responding to science instruction? We received a Wheels for the Mind grant from Apple Computer to investigate these questions in The Computer as Learning Partner project (CLP). This research, started in the 1980s, led to the development of the knowledge integration framework that forms the basis for all curriculum and assessments used in WISE.

In CLP, our research team collaborated with a middle school to introduce temperature probes in science classrooms and study how students used real-time data collection as part of their experimentation about heat and temperature. Initially we asked students about the difference between heat and temperature and about phenomena like the direction of heat flow, insulation, and thermal equilibrium. We were quite frustrated by the glib responses that students gave. For example, the students who considered themselves to be the “science types” would say things like “Heat is calories. Temperature is degrees.” But these answers did not connect to students' other ideas or even to the experiments that they conducted using the temperature-sensitive probes.

To get a better sense of students' ideas, we introduced questions that connected their classroom investigations with familiar problems. Thus, we asked students to predict what would happen if you were stirring a pot of noodles with a metal spoon or a wooden spoon. We asked them which would be the better spoon for stirring the noodles. The scientifically normative idea here is that heat flows at different rates depending on the material. In addition we hope that the students will learn about the nature of a subset of materials, appreciating that heat flows faster in metals like aluminum that in wood or Styrofoam.

When we asked students these questions, we found that they had many very interesting and rich ideas about heat flow based on their observations in their everyday lives. Students said things like "Metal spoons are bad—they get too hot," or "My mom uses a wooden spoon so she won't burn her hand." We extended this question, asking students "If you were going to roast marshmallows, would you rather have a wooden stick or a metal stick?" Students were very good at making predictions about which would be most desirable, arguing for a wooden stick. However students were less able to explain why one choice was better than another. Indeed, in spite of these relatively rich observations about spoons and sticks, many students argued that heat flowed at the same rate in all materials, completely disconnecting their observations of the world from their assertions about the science.

We further extended this approach to questions about insulation. We asked students to predict whether, for example, water would cool faster in a metal cup than in a Styrofoam cup. Here the normative scientific idea is that materials are insulators when heat flows slowly and are conductors when heat flows more rapidly. This is a relative distinction.

In response to these questions, students were relatively sure that the Styrofoam cup would be better at insulation than a metal cup based on their experience, but again, they lacked an argument based on rate of heat flow to explain the difference. Eileen Lewis, a graduate student at the time, asked students what was best to wrap a drink in to keep it cool in their lunch, and she gave them choices like aluminum foil, newspaper, or nothing. The vast majority of students preferred to wrap the drink in aluminum foil. They frequently argued that their mothers used this strategy for wrapping drinks to take to school in their lunch. After studying about these ideas, students were observed to change their behavior and not wrap their drinks as often.

Lewis extended this approach, asking a more intriguing question that caused some confusion for students. She asked whether it would be better to use a sweater or aluminum foil to keep a drink cold. Students frequently responded that a sweater would be a bad choice because sweaters warm you up. Thus, students argued that a sweater has the property of imparting heat rather than its actual capability of slowing the rate of heat flow, which works to both keep a drink cold for lunch and keep an individual warm on a cold night (Lewis and Linn, 1994).

Lewis then probed students' understanding, asking why they thought aluminum would be a good choice for keeping a drink cold. Many students responded that if you feel metals at home the metals feel colder than the wool. So they argued that metals have the property of making things cold. Lewis was intrigued to see that students were imputing agency to sweaters for keeping people warm and to aluminum foil and other metals for making things cold. Essentially, students ignored their own body temperature and their role in producing heat. Thus, rather than realizing that a sweater insulated them and therefore slowed the flow of heat, they assumed that the sweater actually could make them warm.

Although these ideas that students exhibit in such personally relevant tasks are not scientifically sound, the research team was interested in them because they reflected an effort on the part of students to really make sense of complex phenomena and try to explain why sweaters or aluminum foil might impact the temperature of an object. These observations further convinced the research team that students possess a lot of intriguing and potentially valuable ideas about science, but that there are some limits in their ability to interconnect these ideas or to apply them to new phenomena or problems.

Other members of the research team extended these investigations to new topics, exploring issues having to do with thermal equilibrium. Stop and think for a minute about how the students depicted above might describe the temperature of a wooden desk, a metal chair, and a rabbit—all in the same room. As the reader might have predicted, many students thought that a thermometer would show that metals have a lower temperature than wood if measured in the classroom, and that sweaters would have a higher temperature than other materials. These predictions were consistent with students' beliefs about the ability of materials to impart heat or cold and helped the research team understand the reasoning that students go through to make conjectures about scientific phenomena. Students were surprised to find, when they did the experiment, that the desk, chair, sweater, Styrofoam cup, and other objects would all have different temperatures consistent with the way they feel to the touch. They accurately predicted that the rabbit had a different temperature from the temperature of the room.

In this situation, students predict that the thermometer would measure temperature as what the object feels like when they touch it. Thus, students forget that their hand has a temperature that is usually different from that of the room—and consistent with the idea that they are producing heat to maintain their body temperature. When students sort out the difference between the temperature of their hand and the temperature of the objects, they realize that the apparent temperature differences that they were feeling are actually just differences in the rate at which heat is flowing between their hand and the object. In a typical room, a metal chair and wooden desk are cooler than their hand, so the heat energy flows from their hand into those objects. Here, students must use the idea that heat flows at different rates depending on the material, and understand that the heat flows faster from their hand into the metal chair than from their hand into the wooden desk.

Overall, CLP served to reveal the rich ideas that students brought to science class, particularly once we extended questions about heat and temperature beyond simple laboratory experiments and into everyday contexts. Many of these ideas were non-normative, meaning that they would not hold up to scientific scrutiny. Furthermore, many times students appeared to hold self-contradictory ideas. For example, students would combine the idea that heat flows only in one direction, based often on some prior science instruction about heat flowing from hot to cold objects, with their observations about heating and cooling. Thus, when we asked students whether heat flowed from warmer to colder or from colder to warmer objects, many concluded that if you placed an ice cube next to a warm drink, the "cold" would flow into the drink and the "heat" from the drink would flow into the ice cube, thus hypothesizing that two processes would be occurring simultaneously. These complex ideas helped the research team develop a deeper understanding of the nature of student ideas and led us to new ideas about instructional experiences that could help students improve their understanding of heat and temperature.

We realized that science education must capitalize on the views held by students, for two reasons. First, because the ideas represent intellectual contributions of the students, who have thought about the situation and come up with a conjecture that takes advantage of some of the evidence they have observed. Second, because by connecting science activities to everyday experiences we can make science more relevant for students and encourage them to consider scientific issues outside of science class. Far too often, students isolate their science learning in the classroom and see no reason to connect science ideas learned in class to their experiences outside of class. By incorporating everyday situations into the instruction materials, CLP was able to address this tendency and encourage students to think about heat and temperature within a broader and more personally relevant context.

Our observations about the diverse and sometimes conflicting ideas that students bring to class were somewhat new to the research literature. Many cognitive and educational researchers argued that students have a single conceptualization about a topic that, if non-normative, can be addressed or corrected by instruction. Instead, our work revealed that students often hold two or more differing and potentially self-contradictory ideas at the same time. It was difficult to reconcile this view of a cacophony of contradictory and incomplete notions with traditional theories of cognitive or conceptual development, such as that of Jean Piaget who said that students go through a series of stages in their development. However, other researchers were also beginning to argue that students do, in fact, possess a fragmented or incoherent set of conceptualizations that they use selectively. For example, Andrea diSessa (1993) had identified what he called phenomenological primitives as a set of ideas that students hold that emerge from their experience.

Our research group surveyed evidence from across the research literature as well as that of our own studies within CLP, and concluded that calling the ideas students developed in the course of trying to make sense of scientific phenomena “misconceptions” was unfair and misleading. These ideas, while certainly not consistent with scientific norms, were nevertheless grounded in students' observations and experience. Students had noted, for example, that metals feel colder than wood at room temperature, even though they had imputed an inaccurate mechanism to explaining that difference. Based on the CLP research, and our ongoing reflections about how student ideas emerge, we formulated the knowledge integration framework, which has guided all of our designs and development over the past two decades.

The Knowledge Integration Framework

The knowledge integration framework emerged to make sense of the ideas students bring to science class and to identify ways to make science learning more effective. Knowledge integration starts with the view that students bring a repertoire of rich, confusing, and intriguing ideas to science class. Of course, they need scientifically normative ideas but they also need specific versions of these ideas that can help them make sense of their observations. In order to understand why metal and wood feel differently at room temperature, even though the thermometer says that they are the same temperature, students need to understand two important scientific principles: first, that heat flows at different rates depending on the material; and second, that how hot or cold an object feels to the touch is actually related to the flow of heat into or out of the person's finger.

Metal objects feel cooler than plastic objects at room temperature because the heat energy flows more easily from our fingers or hands into the metal than it does into plastic. For the same reason, metal objects feel much hotter than wood objects when they have been left in a hot car or oven, because the heat energy flows more quickly into the person's hand from the metal than from the wood. If students lack these important ideas—or fail to see their relevance to the situation—then they will have difficulty reconciling their perception that a metal and wood object would feel different with their observation that they have the same temperature measurement.

In addition, students must improve at making inferences from their observations. Many times students have enough information to reach a valid conclusion but do not realize that the evidence they are utilizing lacks validity. For example, students knew that Styrofoam cups keep drinks at their temperature longer than metal cups, but they fail to consider that information when they choose what to wrap a drink in to keep it cool in their lunch. Similarly, students may often regurgitate isolated "facts" memorized from science instruction, or learn to solve specific kinds of problems, but fail to understand the concepts behind these facts and strategies. They might add new ideas from science class to their existing repertoire, but these would not be integrated with any previous knowledge. This could lead to a phenomenon we had observed frequently during CLP and other studies, where students believe that the ideas they learn in science class hold true in the classroom, but not on the playground or at home.

So students not only need new ideas from science instruction; they also need to improve their capabilities to make inferences from the evidence at their disposal, to develop criteria for what constitutes important evidence, and to draw conclusions based on multiple ideas or observations. The knowledge integration framework emerged to describe this process Students need to build from the ideas that they hold when the come to class. They need to link their ideas to new ideas. And they need evidence to sort out the alternative ideas they hold. This framework suggests instructional approaches that have the potential of increasing students' coherent understanding.

The knowledge integration framework was informed via comparison of two instructional programs that had both succeeded in helping students develop more coherent ideas but were, in fact, designed for very different topics. One of those instructional programs was the CLP project, discussed above. The second one was aimed at computer science instruction and designed to increase the effectiveness of undergraduate computer science courses at the University of California, Berkeley. We had formed a partnership with instructors of a new programming course to help students make sense of computational metaphors. Up until this point, efforts to teach list processing languages such as LISP and Scheme were thwarted by the difficulties that students had faced, and our efforts to improve students' ability to write computer programs in these languages constituted another important source of evidence for our definition of the framework.

By comparing studies of iterative refinement in the two curriculum programs – one in computer science and the other in middle school thermodynamics – we began to identify features of effective instruction. In both cases, researchers conducted iterative refinements of the curriculum, implementing the curriculum with one cohort of students, looking at student progress, diagnosing difficulties in student learning, redesigning the curriculum, and implementing it again with a new cohort. For the purposes of this book, we will confine our discussion to the CLP studies, although it is important to note that two lines of work contributed to the development of the framework (for discussion of the computer science work, see Linn, 1995; Davis et al., 1993; Davis, Linn, & Clancy, 1995).

In the case of the Computer as Learning Partner curriculum, eight different versions of the curriculum were tested over a ten-year period, resulting in an overall increase of 400% in student performance, as shown in Figure 3.1. In one important CLP assessment, students were asked a difficult question, “What is the difference between heat and temperature?” and were required to give two everyday examples to illustrate their ideas. The requirement to provide examples helped assure that students would not simply provide a memorized reply based on their studies.

The initial version of the CLP curriculum, which was essentially the typical middle school science textbook with a few supplemental activities, resulted in only about 12% of the students succeeding fully in this assessment. By the time we arrived at our eighth version of the curriculum, over 50% of the students were able to provide an accurate answer along with two examples, and the other half of the students were providing more sophisticated responses than anything we had observed in our first version of the curriculum. Students used evidence from their investigations and connected their reasoning to everyday experiences. Much more detail about the CLP curriculum is provided in the recommended readings at the end of this chapter.

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Insert Figure 3.1: Computer as Learning Partner Project Curriculum: improved efficacy over time

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In developing the knowledge integration framework, we identified common elements of effective instructional materials from the CLP project and the computer science course. These common elements became the tenets of knowledge integration. The remaining sections of this chapter describe the tenets of knowledge integration. We connect the tenets to a curricular example, and explain how these tenets have guided the design and development of WISE curriculum.

Make Learning Accessible

The first tenet of knowledge integration is to make science accessible. The tenet responds to our research of the repertoire of ideas brought to science class by students. This tenet calls for curriculum that makes science accessible to students by introducing a broad range of relevant and familiar contexts that serve to broaden students' perspectives on a science topic.

Embedding instructional materials in contexts that are personally familiar to students is one way to accomplish this goal. To help students understand thermal equilibrium, for example, the CLP curriculum asks them to make predictions about the temperature of objects on a hot day at the beach (around 100° F) and in a cold ski cabin before the heat is turned on (around 30° F). In order to contrast these two cases, students must extrapolate from their beliefs as indicated above. At first, students often make the same predictions for these extreme temperature situations as they made for the case of wood and metal in the classroom: that metal would feel colder than the wood. But when prompted to reflect, they often change their minds, saying that metal would feel really hot on a hot day, much hotter than wood, rather than colder. They also noted that metal might feel much, much colder than wood in a ski cabin, rather than just a little cooler, as they experienced in the classroom. These extreme hot and cold cases became powerful opportunities for instruction when the students learned that, just as they measured in the classroom, all the objects are still at equal temperature no matter how they feel to the touch.

How could this be so? There must be some explanation. The teacher is able to engage students with this challenging puzzle, which was personally familiar to students, enabling them to reason more deeply about the underlying science. By asking students to extrapolate their predictions to the new contexts of a much warmer surround and a much colder surround, the curriculum helped them make comparisons between their predictions for everyday temperatures and their predictions for more extreme temperatures.

In CLP, we continued developing thermodynamics problems such as designing a way to keep yourself warm in the wilderness or exploring ways to keep the drink in your lunch cold or the pizza warm. These problems were integrally connected to the science concepts, which is a key factor of making science accessible. Many textbooks, for example, attempt to make science accessible by including a captivating photograph of firefighters in protective clothing or a historical anecdote about phlogiston but neglect the important task of connecting these materials to the principles taught in the unit. By introducing numerous examples and connecting those examples to the science, designers can enable students to articulate a broad repertoire of ideas, ensuring that all of their ideas are integrated into the learning experience. This sets the stage for students to sort out their ideas, find the most promising ones, and connect ideas to form a coherent understanding of the science.

Consider the WISE Deformed Frogs project discussed in chapter 2, where the science is made accessible by presenting a dilemma that is reported in news accounts: the declining population of frogs and the increase in frog deformities. In general, students find frog malformations to be an extremely interesting topic. Linda Shear, who studied this project in early classroom trials, remarked that "if students say 'Yuck, gross,' you know that they will be paying attention to the curriculum." Because frog deformities were frequently in the news, it was possible to add to the accessibility of this topic by personalizing the scientists themselves. We involved several scientists in this curriculum who were actually working on problems related to amphibian decline and malformation. We introduced those students to the scientists virtually, through "Meet the scientist" pages within WISE, and even engaged students in asking the scientists questions at different points within the project (Linn, Shear, Bell and Slotta, 1999).

The make-science-accessible tenet of knowledge integration guides our development of the curriculum in several ways. First, it guides our designs of inquiry activities that connect science principles to relevant scientific problems. Second, it appears in prompts that ask students to explain personally relevant problems using science principles. For example, students might be asked to explain why a cake cools faster in a metal pan than a pottery pan, using the principles they've already learned about thermal equilibrium and insulation in conduction. Third, make-science-accessible appears in the curriculum in opportunities for students to understand scientific inquiry processes. Making these processes accessible to students can involve guiding them through the process of investigation, such as by asking them to make predictions, to conduct a simple experiment, and to interpret the results of that experiment based on their predictions.

Make Thinking Visible

The second tenet of knowledge integration is to make thinking visible wherever possible within the curriculum. Students must be enabled to make their ideas visible both to themselves and to their teachers. In addition, teachers and curriculum materials have the opportunity to make new ideas visible to students.

In traditional classrooms, students usually make their ideas visible only on homework and tests, with only occasional opportunities to do so during class. Technology-enhanced learning environments such as WISE use embedded assessments to provide teachers with access to student ideas with greater frequency, such as when they write reflection notes or participate in online discussions. By making student ideas visible more regularly and more comprehensibly, technology-enhanced instruction can increase teachers' awareness of the variety, diversity and complexity of student ideas. Adding more information about student ideas means that teachers have an opportunity to enhance and strengthen their instruction based on how their students are thinking in the moment.

There are many ways that curriculum activities can enable students to make their thinking visible. Students could be asked to make predictions about the outcome of an investigation, or to write reflections on their investigations, both of which would result in a visible representation of their ideas. The tenet of make-thinking-visible can be met through the use of online discussions, where students respond to or initiate threads. Students can also reveal their thinking when they work with a partner or small group, providing the teacher with insight into how the students are learning. By moving around the classroom listening to pairs of students discussing a complex scientific dilemma, teachers can observe how students think about scientific experiences in ways that are not readily tapped by whole class discussion—where only a handful of students typically participate.

Making thinking visible also helps students understand their own ideas. When students make their ideas visible to themselves, they have the opportunity to reflect on their thinking and to keep ideas in mind as they move through the curriculum. Thus, by making their ideas visible students gain insight into their own learning process, a factor we address below in the section on promoting autonomous learning.

In the CLP project, we worked with a veteran master teacher named Doug Kirkpatrick, known to the students as "Mr. K." Even though he had more than 20 years' experience in middle school science classrooms before he even joined our team, Mr. K quickly reported that his own instruction had been transformed by the improved access to students' ideas as they were learning within the CLP curriculum. He was surprised that students held such a variety of views, or that they could produce so many varied examples about insulation and conduction. He discovered that some students hypothesized that air was necessary for heating and cooling to occur. Others claimed that there needed to be holes in Styrofoam so that heating and cooling could occur by transporting air between objects. He learned that other students thought that it was only possible for heating and cooling to be influenced if objects were touching each other. These students neglected the role of air as a factor in healing and cooling.

Mr. K told our research team that he had not previously gotten such information from traditional classroom activities for two reasons. First, by the time a quiz came along, students had often forgotten or ignored their intuitive ideas, or may have been reluctant to speculate in the same fashion as that evoked by the CLP activities. Second, during class discussion in previous years, only a small fraction of the students had ever participated. Even when he had made efforts to call on other students in order to broaden the participation in the discussion, Mr. K found that many students were reluctant or even unwilling to voice their ideas. The increased opportunity to gather student insights into the learning process while they were still grappling with complex science material strengthened Mr. K's understanding of how his students were learning.

Another important way to make thinking visible is to use visualizations of scientific phenomena. In the CLP research, we investigated the question of how to make important scientific ideas more visible for students. The first area we investigated was concerned with data collection and graphing. We approached this challenging area by allowing students to use computer-based temperature probes to record information about scientific experiments and investigations they were conducting during the CLP curriculum. Using this approach of collecting "real time data," we were able to free students from the tedium of recording information, provide them with immediate graphs even as the data were being recorded, and emphasize the importance of observing and recording results carefully. Teachers also have the opportunity to make thinking visible by adding new ideas for students to consider. Traditionally, most new ideas have been added by textbook presentations or lectures. Today, it is also possible to use computer-delivered models, simulations, and interactive visualizations.

The CLP project connected the computer to various probes, heat sources, and other devices to make thinking visible. For example, students have difficulty understanding the relationship between the amount of heat, the volume of the water, and the change in temperature. CLP used immersion heaters, temperature probes, and graphs of the temperature over time to illustrate the impact of adding what was referred to as a "dollop of heat" to a cup of water. This experiment keeps the volume of the water constant and allows the student to add fixed amounts of heat. The combination of the immersion heater and the temperature probe allowed students to precisely calibrate the relationship between the amount of heat added and the temperature change of the system. Students could explore this phenomenon by varying the amount of the liquid to which they were adding heat while keeping the amount of heat added constant. In this way, students were able to conduct experiments and to study the relationship between the amount of heat added and the observed temperature of the system.

The use of temperature probes to gather data and computers to display data was controversial. Many teachers were sure that this "shortcut" would undermine understanding of temperature graphs. However, we found that the opposite was true. By using temperature probes students were able to understand graphing more deeply. They interpreted graphs of heating and cooling more effectively when they could watch the graph form as the temperature probe collected information than they could when composing the graph by hand.

This finding was somewhat counterintuitive, as some teachers feel that students benefit more from constructing a graph than from watching the graph develop automatically based on probeware and graphing software. However, our classroom observations in CLP showed that when students constructed a graph by hand, they often lost sight of the purpose of the experiment. Students were distracted by the graphing procedure since they typically had several jobs to perform, such as holding the thermometer, recording the data, or reading the output, rather than making sense of the experiment. In contrast, when they carefully observed the probe collecting data and watched the graph form automatically on the screen, they were able to notice important qualitative characteristics of the system. For example, in watching a liquid boil, students were able to see that the temperature curve suddenly leveled off once the liquid began boiling. They frequently wanted to conduct another experiment and vary one or another of the conditions. Thus, our experience in CLP showed that when students used the temperature-sensitive probes and real time data collection, the real time graphing helped make ideas visible. Through interacting with these resources, students were more able to interpret experimental investigations, and were more inclined to come up with their own investigations.

Another way in which CLP made thinking visible was by using a simulation called "Heat Bars" to help make visible the rate of heat flow in different materials. Using Heat Bars, students could select two materials, each in the form of a long rectangular bar, and observe a simulation of heat flowing through the two bars when they are both placed next to identical heat sources (see Figure 3.2). The heat bar simulation made the rate of heat flow visible, which many students found extremely helpful in reasoning about thermal phenomena. Research conducted by Eileen

Lewis showed that the heat bar simulation, more than any other classroom activity, helped students learn to distinguish the rate of heat flow in different materials and to connect their understanding to situations such as cooling curves for water (Lewis, Stern and Linn, 1993).

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Insert Figure 3.2 TITLE TK

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The WISE project drew on our CLP approaches to incorporate ways to make ideas visible, and added some new methods as well. One approach, called the WISE Principle Constructor (see Figure 3.3), challenged students to combine phrases to construct scientific principles. This provided an advantage for those students who found writing about science troublesome, as they could articulate their ideas effectively by selecting among choices in drop-down menus. In his PhD research, Doug Clark (2004) found that such a visual principle constructor provided a good source of information for assigning students to small group discussions in order to ensure that each group was made up of individuals who held diverse viewpoints.

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Insert Figure 3.3. WISE Principle Constructor – Making Students Ideas Visible

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Another way that students can make their thinking visible is by writing a report or keeping a journal. Betsy Davis (1998) explored this approach when she asked students to write a news article to explain Web-based advertisements concerning the nature of insulation and conduction. She found that students expressed very interesting ideas when asked to create a longer narrative and to warrant their assertions with evidence.

How does making thinking visible help students learn? Visualizations can be confusing and misleading. The visualizations in WISE and CLP succeeded for several reasons. First, these visualizations allowed students to analyze controlled experiments. In heat bars, students could compare metal and wood placed next to the same intensity heat source. Second, the visualizations helped students build connections to familiar situations. Third, they enabled students to create a narrative about the results. For example, CLP reflections helped students make their ideas visible about an experiment with immersion heaters, as they could articulate their own narrative, such as, “When you add five dollops of heat to one cup of water, it doesn't get as hot as if you add the same amount to a smaller cup of water.” Fourth, visualizations draw students’ attention to salient and essential information. In the case of heat bars visualization, students attention is drawn to the different rates of heat flow in different materials.

Learn from Others

A third tenet of knowledge integration concerns how students learn from each other. Well-designed interactions with peers can improve understanding of complex science. In classrooms, many activities enable students to interact with each other, but the circumstances under which these activities help students learn from each other is more limited. Often, class discussions follow a well-worn pattern where students who already know the answers to the teacher’s questions speak up while the other students are left out of the discussion and do not benefit. In this normal form of classroom discussions, there is very little exchange between students and their peers, and there is little opportunity for students who hold non-normative ideas to build connections to their ideas.

What can students learn from their peers? First, when students conduct investigations and discuss topics like the difference between heat and temperature, they can expand their repertoire of ideas by considering those ideas held by their peers. In the CLP project, students work in pairs and discuss evidence and observations such as their predictions about which container is likely to keep a hot drink warm for the longest time. Listening to these conversations in class, teachers are often pleased to see that students consider alternatives that they might not have considered if they were working by themselves. In such exchanges, students might disagree about their hypotheses, such as whether heat will flow faster in wood or metal. When required to write down their reason, one student might argue that “metals feel cold” as a reason that heat will flow more slowly in metal than in wood. Another student might bring in a different example and say, “Well, when you stir soup with a metal spoon, it gets hot faster, so the heat will flow through the spoon faster.” Such discussions can be valuable, because students are considering alternative explanations, adding evidence from their experience, and negotiating to reach consensus.

Learning amongst peers can also be effective when one student models effective ways of articulating ideas for other students. For example, discussions of rate of heat flow can help students develop effective ways to express their ideas. These opportunities to learn from others involve adding ideas that students had not considered, articulating ideas that students had not been able to verbalize, or clarifying ideas in explaining them to a peer.

Research in CLP and WISE explored a number of ways to orchestrate effective classroom and curricular activities that allow students to learn from one another. One effective approach is that of online discussions. Over the years, we have conducted many studies to identify factors that make such discussions effective. Initially, our online discussions were conducted in the back of the classroom on a stand-alone computer where students took turns entering their views and responding to the views of their peers. This was a relatively cumbersome way to participate in a class discussion, but it had the advantage that students thoughtfully responded to ideas contributed by others.

Sherry Hsi (1997) designed this early system, known as the *multimedia forum kiosk*, and then studied its impact on students' understanding of science topics. She found several factors that increased the effectiveness of learning under these circumstances. First, it was helpful to require students to first make an assertion about a situation before they read comments contributed by other students. Hsi began all discussions by posing a problem, such as whether a cake would cool faster if it was in a metal pan or a glass pan placed on a metal surface. Students began by making their own prediction and then reading the comments of others. Second, it was beneficial for students to describe the character of their contribution. Thus, students indicated whether they were elaborating on a comment, asking a question, contradicting an idea, or starting a new discussion. By considering how their idea fit into the overall classroom discourse, students were more reflective about the nature of their contribution, and more likely to benefit from interacting with their peers. Third, we improved online discussions with "seed comments" that introduce ideas that students might not have considered or that highlight ideas in ways that contribute to an effective discussion (Hsi and Hoadley, 1997).

Chris Hoadley (1999) studied the value of adding personalized- versus textbook-like ideas to the discussion. In the personalized format, a fictional individual periodically made contributions to the discussions, adding new ideas. In the textbook condition, new ideas were contributed by a neutral, authoritative guide. Hoadley found that by personalizing comments and associating a series of comments with the same character, discussions were more effective than when the ideas were introduced using textbook-like comments.

In addition to online discussions, there are many other ways that students could learn from each other in the curriculum. Many WISE projects include peer review activities where students are guided (by Web forms and reflection prompts) to critique the designs or arguments of their classmates. For example, in the WISE *Houses in the Desert* project described in the previous chapter, students critiqued each others' initial house designs, identifying aspects where the designs could be improved. Students benefit not only from the feedback that they receive from their peers in such activities, but from the process of identifying criteria and determining the gaps in someone else's design.

When students learn from each other they can expand their repertoire of ideas, negotiate criteria for distinguishing among their ideas, and learn new ways to articulate their views. This can happen when pairs work together to make predictions or write notes, in online class discussions of various types, and in critique activities. When students hold distinct ideas, peer interactions provide an opportunity to develop criteria they can apply in future situations. Ultimately, in order to sort out the ideas in their repertoire and build a more coherent understanding, students need criteria, and collaborative learning activities emphasize the formation and selection of such criteria

Promote Autonomy

The fourth tenet of the knowledge integration framework concerns activities that engage students in the lifelong process of integrating, distinguishing, and sorting out their ideas. Knowledge integration is an ongoing, continuous, and important aspect of scientific reasoning. Students benefit from multiple opportunities to reflect on their ideas and make them more coherent. Often, scientific activities in classrooms guide students to do specific tasks rather than helping them engage in the long-term process of integrating their ideas.

Activities such as comparing ideas, preparing an argument, or planning an experiment require autonomous reasoning. Promoting autonomy involves helping learners evaluate their repertoire of ideas, determine whether new ideas are valid, seek out new ideas when contradictions or uncertainties arise, and develop criteria for distinguishing among ideas. This includes sorting out ideas to develop a more coherent or convincing argument based on evidence.

Typical classroom instruction does not promote autonomous learning, leading students to prefer an economical approach where they respond to specific assignments. In our earlier work we described students as cognitive economists, always wanting to know when they have done enough. We found that students often asserted that two situations were unrelated in order to avoid the difficult task of establishing similarity or synthesis. Thus, one student argued that heating a casserole is completely different from heating water so the two situations do not need to follow the same principles. Another asserted that heating and cooling are completely different, so it was not necessary to incorporate information about heating in order to interpret cooling. Indeed, it can be challenging to motivate the intensive, self-directed kinds of learning and reflection that lead to knowledge integration, and certainly the typical atmosphere of the classroom does not promote such a mental frame. Encouraging students to recognize the benefit of autonomously integrating and evaluating ideas is an important goal of the knowledge integration framework.

There is substantial evidence concerning the benefits of autonomously monitoring and integrating ideas, which can be gathered from several research programs. For example, cognitive research on self explanations conduced by Micki Chi and her colleagues (Chi et al., 1989; Chi, 2005) shows that when students spontaneously explain something to themselves they learn more than students who do not engage in such "self-explanations." In the KIE project, Betsy Davis (1998; 2004) reports that learners who compose coherent letters integrating a variety of evidence are more successful in subsequent activities than those who finish all the assignments but neglect the overall argument. In sum, research suggests that when students are encouraged to explain their own thinking or make sense of complex information, they are more successful learners. Activities that promote autonomous learning and reasoning have the potential of helping students use techniques like self-explanation, and become more effective at monitoring their own understanding.

The cognitive mechanisms involved in autonomy or lifelong science learning involve a self-reflective process of comparing ideas, seeking evidence to determine which ones are most valid, looking for ways to make connections across seemingly disparate situations, and ultimately seeking a coherent understanding or account of the problem. Students often have difficulty making their ideas coherent, and may not pursue a coherent understanding when engaged in traditional forms of science instruction (e.g., lectures, homework's and exams). When students encounter too much information, as occurs in the typical science classroom today, they may legitimately be unable to find a way to engage in any kind of autonomous knowledge integration process. This tenet of autonomous lifelong learning aims to counteract that tendency, claiming that knowledge integration cannot happen unless students are engaged in sustained, autonomous reflection and reasoning. Clearly, this is a challenge for any science curriculum, and it is one of the tenets that we take most seriously in all of our designs. In order to enact a knowledge integration approach, teachers must be willing to allow some time, space and incentive for students to engage in their own self-driven learning processes.

In order to enhance the opportunities for students to become autonomous learners, the CLP project began investigating the best designs for reflection prompts. These are simple requests for reflections, such as “what do you think will happen?” or “What are some experiences you have had with this topic?” However, the design of such reflection prompts has great consequences for autonomous learning. When students are asked to explain their thinking at various points during the learning process, they have the opportunity to autonomously question or think through their ideas. They might be asked to compare two alternative views or to generate some evidence to support an assertion.

Reflection prompts have proven successful in a wide range of research studies, and there is considerable research to show that the kind of prompts that students encounter has a serious impact on their developing of coherent understanding of science topics. For example, Betsy Davis (1998; 2004) compared the use of generic prompts, which ask students quite generally to reflect on ideas and determine how valid they are, with specific prompts that ask students to compare certain situations. Somewhat surprisingly, Davis found that the generic prompts led to more autonomous, thoughtful reflections than specific prompts, because students often misinterpreted the specific prompts and because the generic prompts encouraged autonomous interpretations. Thus, students might be asked to compare two specific situations (using a specific prompt), but if those situations didn't make sense to the student, then they wouldn't have anything very useful to say. Whereas if the prompt asked them what they were thinking at the moment and what information they needed to make sense of the situation, then they could pick something they did not understand and explain their confusion.

Students gain opportunities to practice autonomous reasoning about science when prompted to reflect. But there are many other ways to encourage autonomous reasoning as well. WISE was designed to support autonomy, as students must work on their own interpretations, designs, arguments and critiques, and not simply listen to lectures or demonstrations from the teacher. WISE has incorporated many different tools and activities to promote autonomous learning, such as graphing, drawing, data collection, online discussions, note-taking, concept-mapping, and peer review. All of these activities, if well-designed, can foster a general attitude of autonomy, peer-exchange, and reflection. The WISE project supports students during such activities by providing scaffolding in the form of technology tools, cognitive guidance, and the inquiry map that helps them navigate through the project. Figure 3.4 shows the WISE *Deformed Frogs* project with the Sensemaker scaffold that guides them in designing an argument, as well a reflection note that pops up to encourage students in this process. By providing such guidance and scaffolding, WISE helps students to emulate the kind of autonomous or lifelong reasoning processes that are the hallmark of science.

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Insert Figure 3.4: WISE Deformed Frogs Mystery – Guidance and Scaffolding

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Engaging Students in Inquiry

The reader may remember from Chapter 1 that our ultimate goal is to promote an atmosphere of inquiry, autonomy and critical thinking in science class, engaging students and teachers in a more dynamic, collaborative form of learning. The knowledge integration framework is our effort to provide a theoretical foundation for such forms of learning and instruction. It guides our design of technology environments, curriculum materials and assessments, and guides interpretation of learning processes that occur when classrooms engage with our designs.

The guidance provided by our technology-enhanced learning environments helps students adopt a more autonomous form of learning that reflects the nature of scientific investigation. The scaffolding provided by such curriculum environments also helps to ensure that students complete the full activity, and never feel disoriented. The availability of such guidance helps teachers feel confident in allowing students to engage in complex activities that involve a wide spectrum of visualizations, collaborations and autonomous investigations. Such designs are challenging for teachers, because every student or small group requires individualized attention. WISE was designed to address this need. Because of the scaffolding and curriculum structure that it provides, teachers are freed to work with the students who are having difficulty while others in the class continue to conduct their investigations. The process of teaching with WISE is detailed fully in Chapter 7.

In summary, by providing scaffolding tools and inquiry maps, WISE can support students as they engage in complex inquiry activities that include the full range of an investigative sequence – making predictions, designing experiments, conducting experiments, drawing conclusions, writing reports, critiquing the reports of others, and identifying next steps . By guiding students through such inquiry processes, WISE provides them with valuable experiences in knowledge integration. With repeated experiences, they become adept at identifying the pitfalls and opportunities in scientific investigations, and gradually become more autonomous scientific reasoners.

Recommended Readings

Linn, M. C., & Hsi, S. (2000). *Computers, Teachers, Peers: Science Learning Partners*. Mahwah, NJ: Lawrence Erlbaum Associates.

This book offers a comprehensive description of the Computer as Learning Partner (CLP) research project, and a thorough review of the theoretical perspective of scaffolded knowledge integration. It offers rich anecdotes and illustrations from the classroom, with selected commentary from a teacher, "Mr. K."

Linn, M. C., Davis, E.A., & Bell, P. Eds. (2004*). Internet Environments for Science Education*. Mahwah, NJ, Lawrence Earlbaum Associates.

This edited volume includes chapters from several PhD students who completed their doctorates in our research group, working on the Knowledge Integration Environment (KIE) research project. The volume includes several overview and methodological chapters (Linn and colleagues), as well as specific chapters on argumentation (Philip Bell), experimentation (Doug Clark), prompting (Best Davis), collaboration (Chris Hoadley), and future directions with WISE (Jim Slotta) and other projects (Philip Bell, Marcia Linn).

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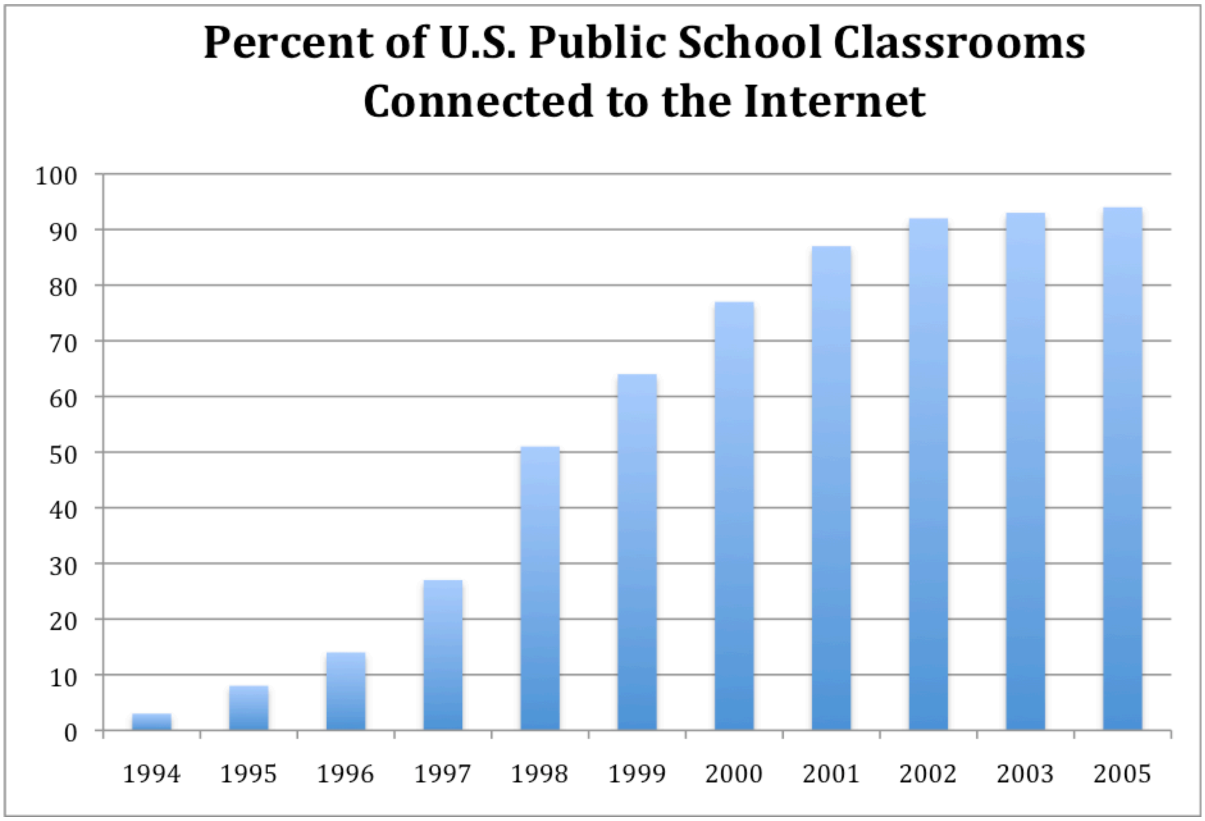

Figure 1.1 – Classrooms Connected to Internet. Percentage of U.S. public school classrooms connected to the Internet from 1994 - 2005. Figures obtained from the U.S. National Center for Educational Statistics (http://nces.ed.gov/)

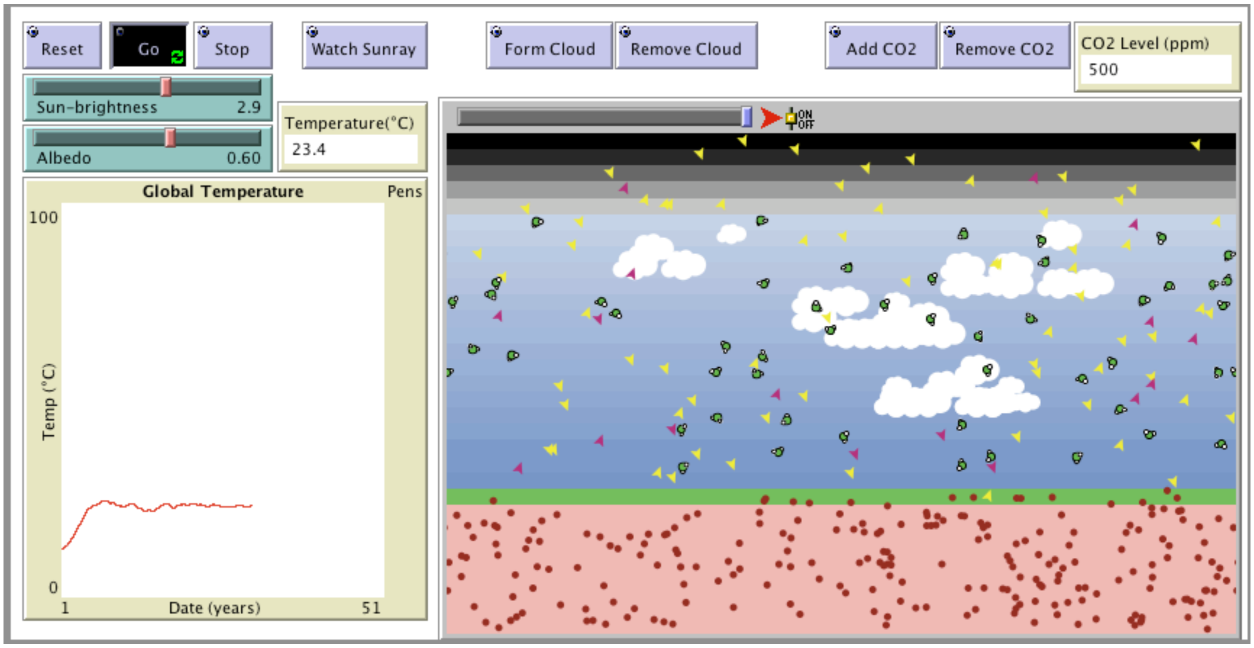

Figure 1.2 – Netlogo Model – Interactive Modeling for Global Warming. Simulations and interactive models offer a powerful form of scientific visualization. This figure shows a model of global warming, implemented in the Netlog system developed by Uri Wilensky (1999) and his colleagues. Students observe a cross section of the atmosphere with the sun's rays entering through a cloud layer, and interacting with atmospheric gases. A dynamic temperature graph shows the average temperature of the earth.

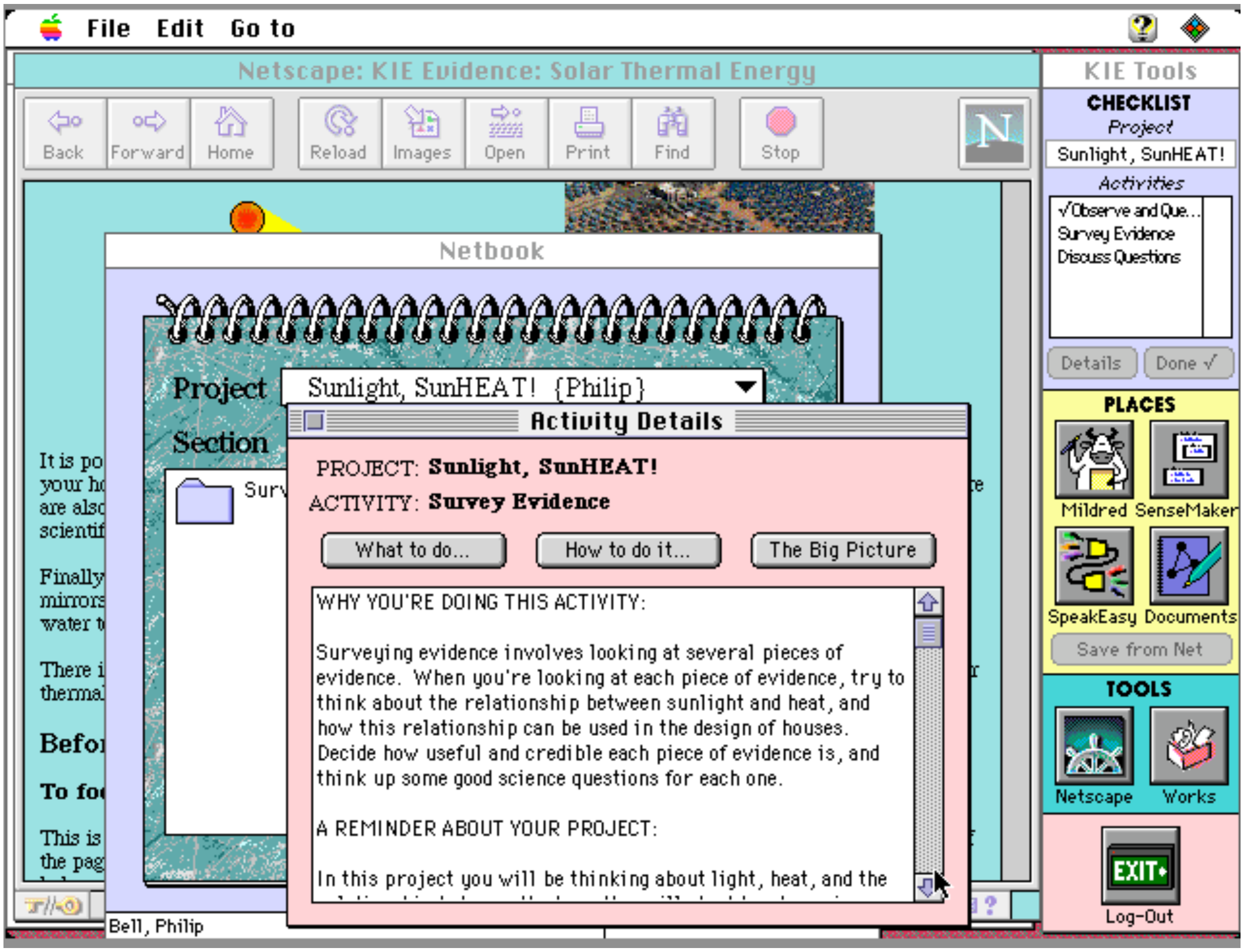

*Figure 1.3 **Knowledge Integration Environment.*** This Figure shows the Knowledge Integration Environment (KIE) which expanded on the work of CLP, adding links to the Worldwide Web and integrating tools such as reflection notes, data tables and online discussions.

Table 2.1 – WISE Step Types. WISE includes the capability for a variety of different kinds of curriculum and assessment activities, including Web pages (html), drawing, graphing, notes, journals, peer review, short answer and multiple choice assessments, etc. The Table shows the full list of available step types.

Brainstorm	Students are prompted to author a short response to a question, and then evaluate the comments of their classmates.
Branchpoint Selection	Students choose one of several options that you can author (for instance, sides of a debate or geographical location). Later steps in WISE can then be made into hinging steps, in which a different step is shown to students depending on their choice from this step. See Hinging Steps, below, for more information.
Challenge Questions	A small set of multiple choice questions that are presented at strategic points in the project. If students miss any of the questions, they are automatically re-directed to the relevant point in the project and encouraged to re-try.
Causal Mapper	Students can create a concept map in which various factors are connected with arrows showing their causal relationship.
Data Grid	A simple Web form in which students can enter numerical data into a table.
Discussion Forum	Threaded on-line discussion forum with many options, such as the "Gated" discussion, in which students are first asked to respond to an opening topic, and then these responses are all visible as the base comments of an open-ended discussion.
Display Page and Evidence Page	Each of these tools displays a page of HTML text, possibly with links to outside web pages. Students generally use the evidence page for providing key information relevant to the project's content, while display pages can be for more operational duties (introduction to the project, explanation of what the next step will entail, etc), but the user can use either for any purpose.
Form Analysis	Part of the WISE Forms engine allows students to view collected forms of data from their group, their class, or all classes that have already responded to the form.
Form Blank	Part of the WISE Forms engine creates an HTML form for students to fill out. This is used in conjunction with handheld computers to allow data collection in the field.
Form Review	Part of the WISE Forms engine prompts students to review their own responses to a WISE Form.
Hints	The purpose of the display of cognitive hints for any WISE step is to help students reflect on any particular step, typically in the form of strategic questions.
Notes	Students are presented with a question and starter prompt, with a particular goal towards reflecting upon evidence or other information they have been presented with. This notes section also allows for assessments in the form of multiple choice responses or brief open-ended responses.
Outside URL	The students are sent to an outside web page. In many cases, it's better to use an evidence page with a link instead, so that the experience on the outside page can be scaffolded and given context for the student
Problem Set	The students are presented with a set of questions, either for assessment purposes or surveys. Numerous question formats are available, where they can be arranged on multiple pages, with some advanced options (such as multiple versions, restricted times of availability, etc).
Self-Test	Students answer a progression of questions that will then let them know how they did and gives an explanation of why certain answers were right or wrong.
Sensemaker	A Java applet that prompts students to make sense (thus the name) out of assorted bits of data and evidence visually by sorting them based on what viewpoints or arguments they support.

Show-N-Tell	Prompt students to create a presentation out of their work so far in the project. Students can select their step work, add comments, and then share the presentation and comment on other presentations.
Show Alert	Pops up a simple alert box with a short instruction for the student. Often, a display page works better for this, but alerts do tend to grab the user's attention.
Show All Work	Displays a page that presents all the student's work. This page can also be accessed at any time via an icon in the upper left of the WISE display.
Student Assessment	Presents a set of questions to the student; after answering all the questions and submitting them, the students are then unable to go back and edit them. Users should also consider the Problem Set type (above), which provides similar functionality but more options.
Student Journal	Similar to Notes (above), but with a focus on encouraging students to add to the journal over the course of a project. A Journal icon is available in the student interface (in the upper left), allowing students to immediately bring up the journal and add to it.
WISE Data	Students can draw a graph from a given set of data points. Different kinds of graphs can be drawn, and students can modify them by changing parameters such as the ranges on the axes or the item plotted on each axis.
WISE Draw	A full-featured draw program that lets students create and manipulate shapes and drawings, including text boxes and labels.

Table 2.2. WISE Curriculum Projects. Short descriptions for some of the many WISE curriculum projects that have been developed for middle and high school science. A complete list including detailed descriptions, lesson plans and connections to science standards can be found on the WISE project Web page: http://wise.berkeley.edu.

Life science	Antibiotics: Will they work?	This project was created to help students understand antibiotic resistance- both the science behind it and how our use of antibiotics can affect resistance development.
	Creek Detectives	Students learn about watersheds, what is carried in them, and how to make careful observations. They examine the creek at different points along the water path and compare their observations from different seasons.
	How Do Earth and Space Plants Grow?	Students investigate different conditions for growing plants in space and on the earth. Then, they compare regular earth plants with NASA space plants, observing plant growth and development, and graphing their observations.
	Mitosis and Cell Processes	Students understand the stages of mitosis and associated cell structures within the context of cancer. They investigate three hypothetical plant-based medicines, each of which interferes with mitosis in a different way.
	Genetically Modified Foods	Students develop an understanding of genetically modified foods and debate what agricultural practices should be used in their area.
	HIV Prevention	Students investigate the transmission of HIV, and how they can protect themselves from HIV infection and AIDS.
	The Malaria Controversy	Students learn about the various cycles that characterize malaria, and debate three different strategies for controlling the spread of malaria worldwide.
	The DDT-Malaria Controversy	Students critique the scientific evidence related to the productive uses and harmful side-effects of DDT. Then they create an argument about the proposed global ban of DDT and present this argument during a classroom debate.
	The Deformed Frogs Mystery	Students investigate the nature and cause of frog deformities in North America, and debate competing hypotheses about the cause of those malformations.
	Wolves in Your Backyard	Students learn about the basic biology of wolves, including their social nature, and critique a wolf management plan from Minnesota or their own local region.
Physical Science	Life on Mars Debate	Students explore a contemporary scientific controversy related to the presence of life on Mars, debating evidence and creating their own argument
	Friends: Velocity Style	Through scenarios about friends and their adventures around town, students practice calculating velocity and interpreting multiple representations of velocity.
	How Far Does Light Go?	Can light travel forever, or does it eventually die out? Students explore 'evidence' of different aspects of light and create their own argument to support their position.
	Probing Your Surroundings	Students explore the temperature of objects around them, making predictions, gathering data and discussing principles to explain why objects feel hot or cold.
	Sunlight, SunHEAT!	Students learn about passive solar energy, developing criteria for critiquing information from Web. They evaluate the source credibility and validity of evidence.
	Houses in the Desert	Students design a house that would be energy efficient in a desert environment, drawing on critiquing and comparison skills from previous projects.
	Modeling Static Electricity	Students investigate incidents of refueling fires caused by static electricity and use different levels of models (charge, atomic, energy) to explain their observations.
	How Can We Recycle Old Tires?	Students investigate solutions to the problem of how to recycle scrap tires, connecting the chemical structures and chemical bonding exhibited by metals, ceramics, and polymers to methods of recycling those materials.
	Gas-powered Vehicles: A thing of the Past?	Using interactive simulations and models, students gain a conceptual understanding of energy released during chemical reactions and apply those concepts to critique hydrogen fuel cells as an alternative.
Earth Scien	Climate Change: Who's to Blame	Students investigate evidence for global warming and debate whether human activities or natural processes are the main cause for global climate change.
	Rainforest Interactions	Students consider species interactions, make a food web using the WISE causal mapper, play a simulation game offline, and predict relative numbers of organisms.

	Global Warming: Virtual Earth	Students learn about the greenhouse effect and global warming using an interactive model that represents heat flow on the Earth.
	The Next Shake	Can we predict earthquakes, or how much damage they will cause when they do occur? Students explore these questions using evidence from the Web.
	Rock Cycle: Igneous Rocks	Students learn about rock formation and the importance of models in science by creating models of the crystalization process and the formation of magma.
	Ocean Trawling: What a Drag!	Students collect evidence on the four main principles of evolution: variation, natural selection, change over many generations, and species change. They debate whether clown fish can evolve after bottom trawling destroys their habitat.

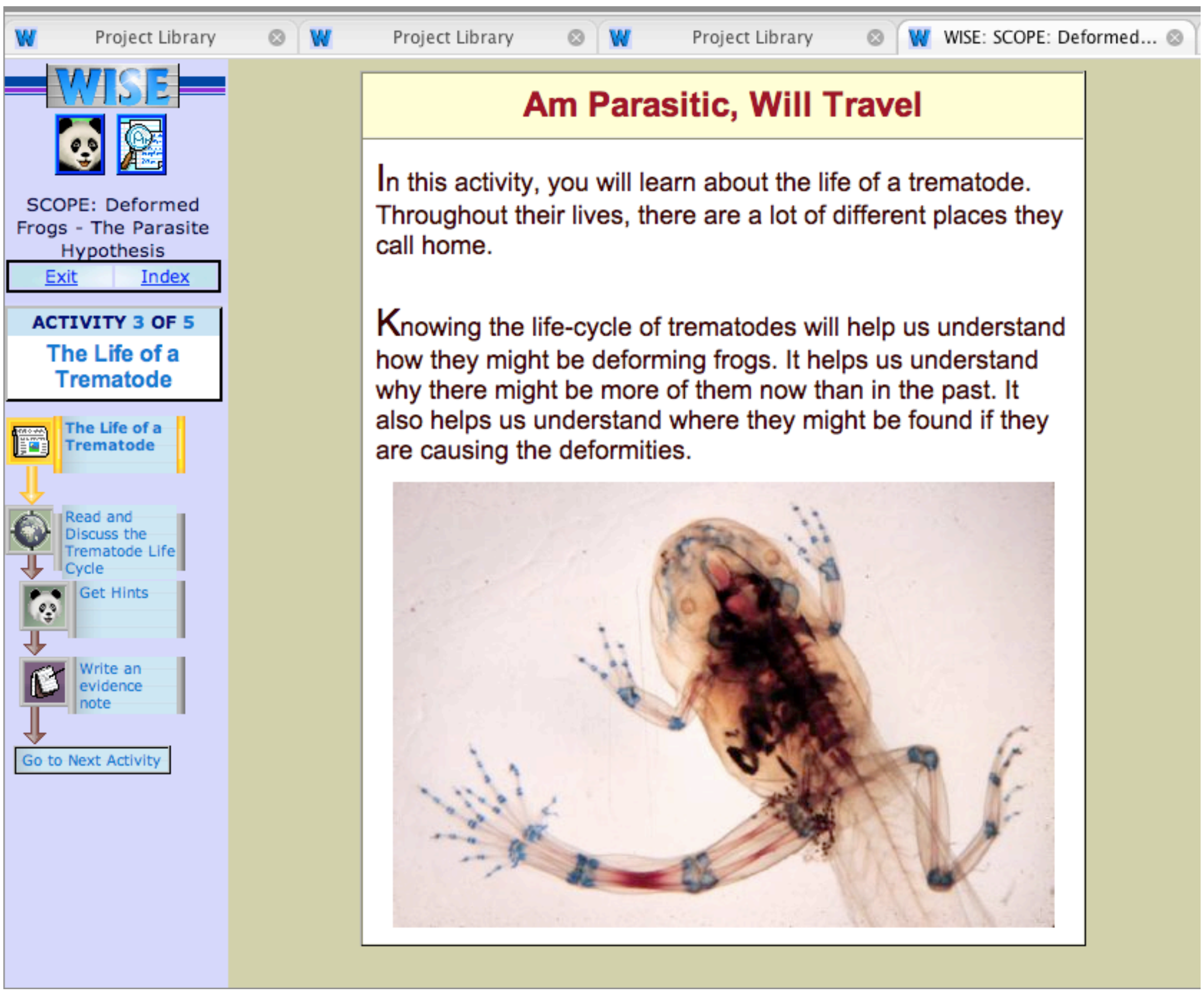

Figure 2.1 WISE Inquiry Project: The Deformed Frogs Mystery. This Figure shows a screen capture of a WISE inquiry project called *The Deformed Frog Mystery*. WISE offers a library of such inquiry projects, each of which is designed according to a theoretical framework known as Scaffolded Knowledge Integration.

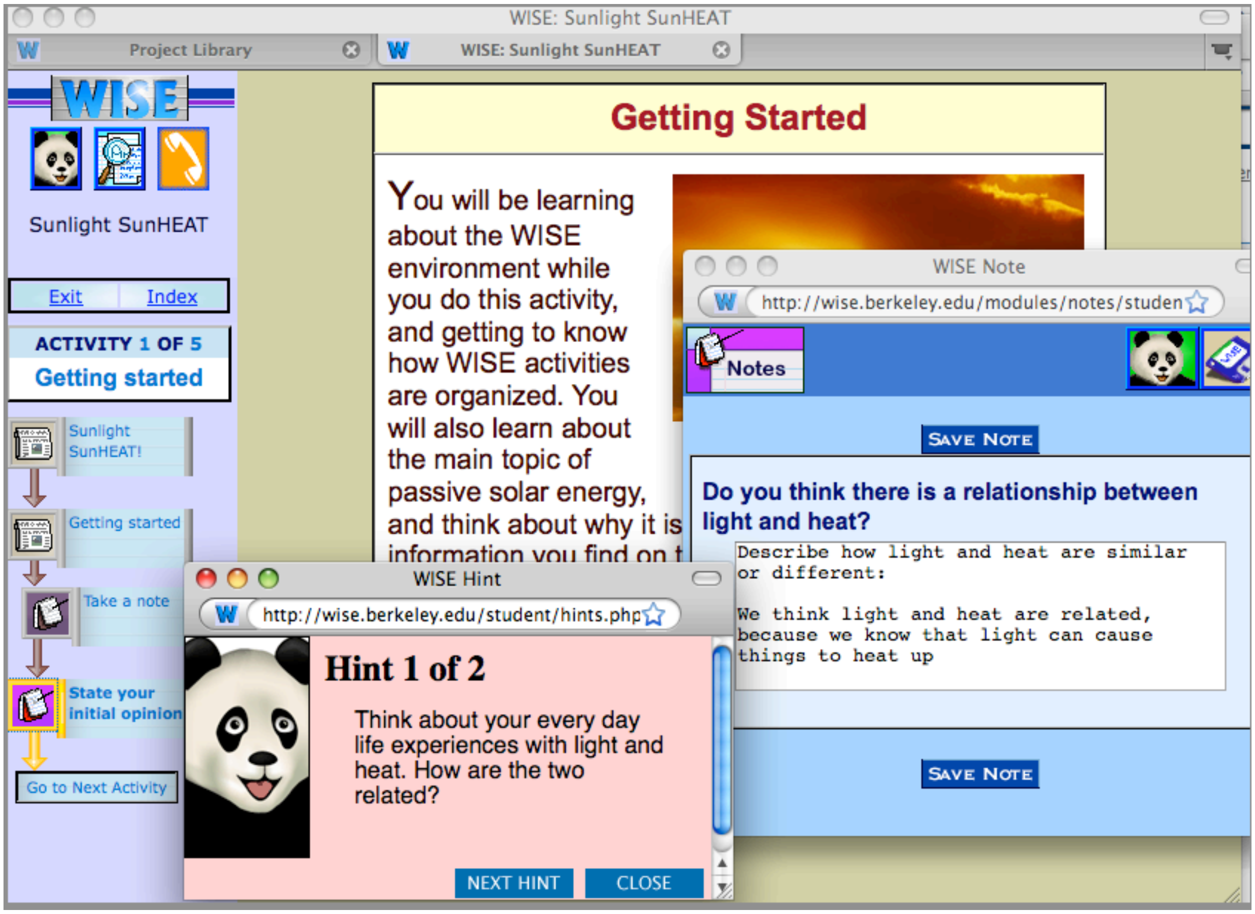

Figure 2.2 The WISE Sunlight, SunHEAT Project. In the *Sunlight, SunHEAT* project, students critique energy efficient homes that were found on the Web, and compare their features. This Figure shows the WISE reflection prompts and a cognitive hint, provided by Amanda the WISE Panda.

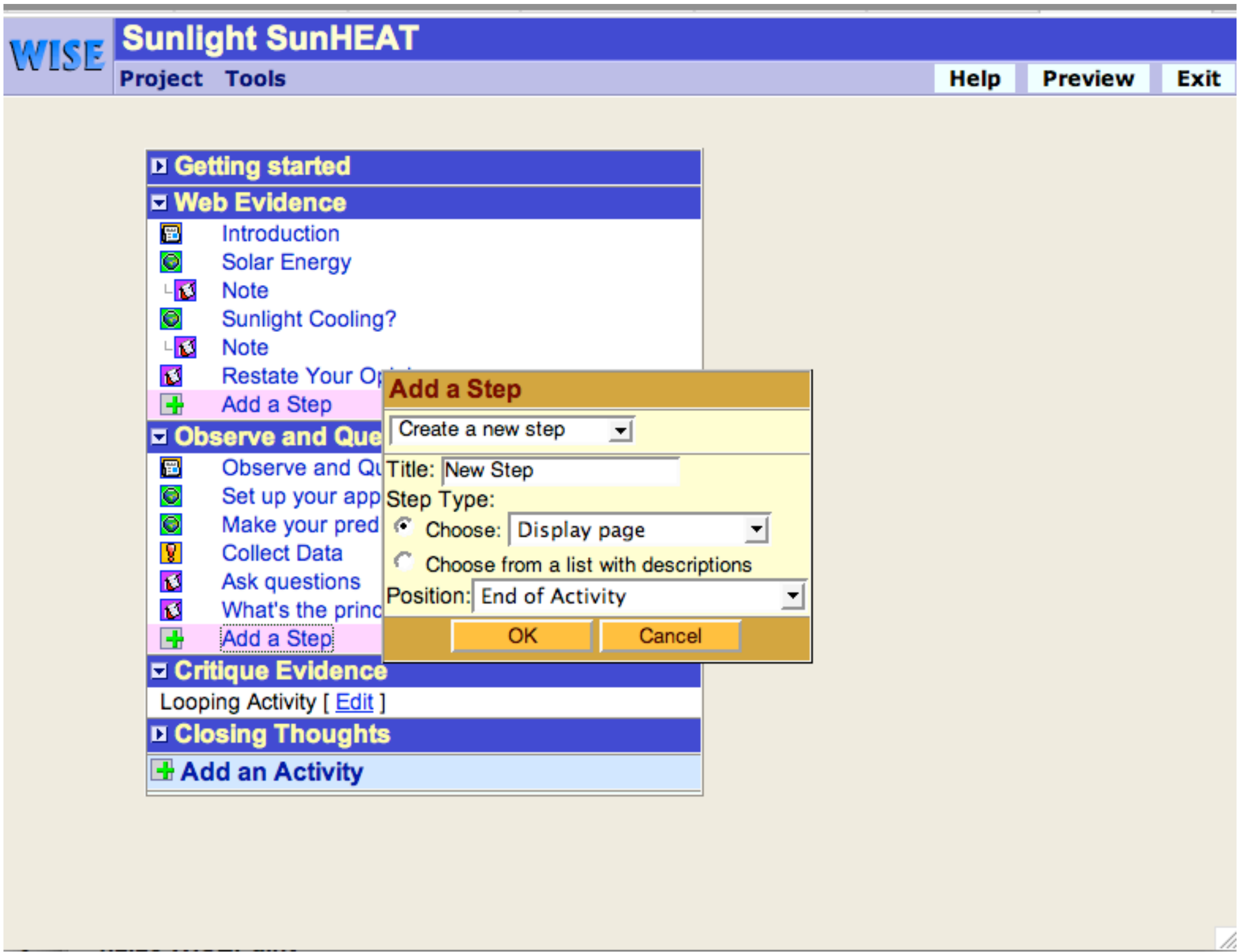

Figure 2.3 WISE Authoring Tool – The Sunlight, SunHEAT Project. WISE inquiry projects are created using the Authoring Tool. This Figure shows the *Sunlight, SunHEAT* project, which consists of several activities, like "Getting Started" and "Web Evidence." Selecting any existing step within an activity open a menu that includes items like "change step name" or "author step content." Selecting "Add a Step" (as shown in the Figure) opens a menu where the author chooses the type of step, names the new step, and so on.

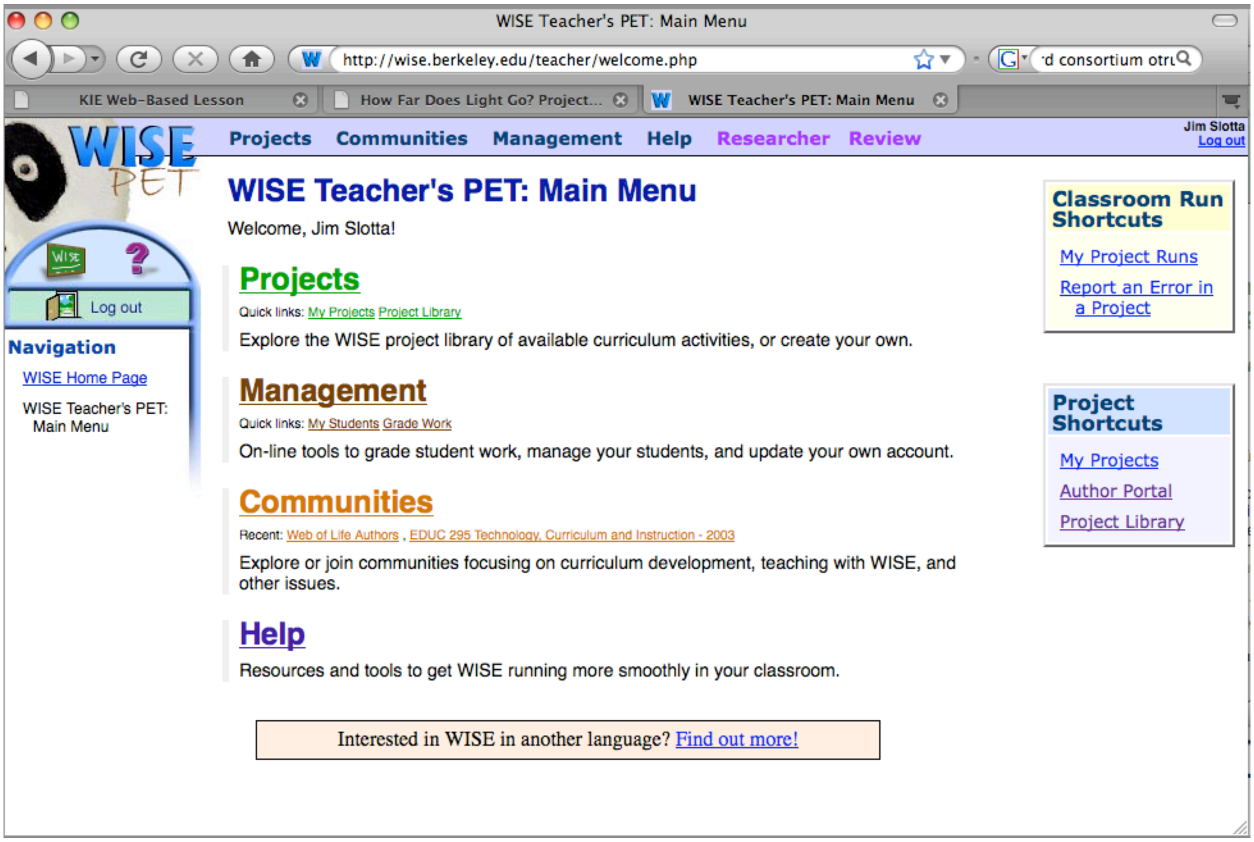

Figure 2.4 WISE Teacher Portal. The Teacher Portal offers three menus that support all WISE functions for teachers, curriculum authors, or researchers. The Projects menu provides access to WISE curriculum for authoring and enactment in classrooms. The Management menu supports access to student accounts, as well as tools for assessments and feedback. Finally, the Communities area supports teachers in curriculum or professional development partnerships.

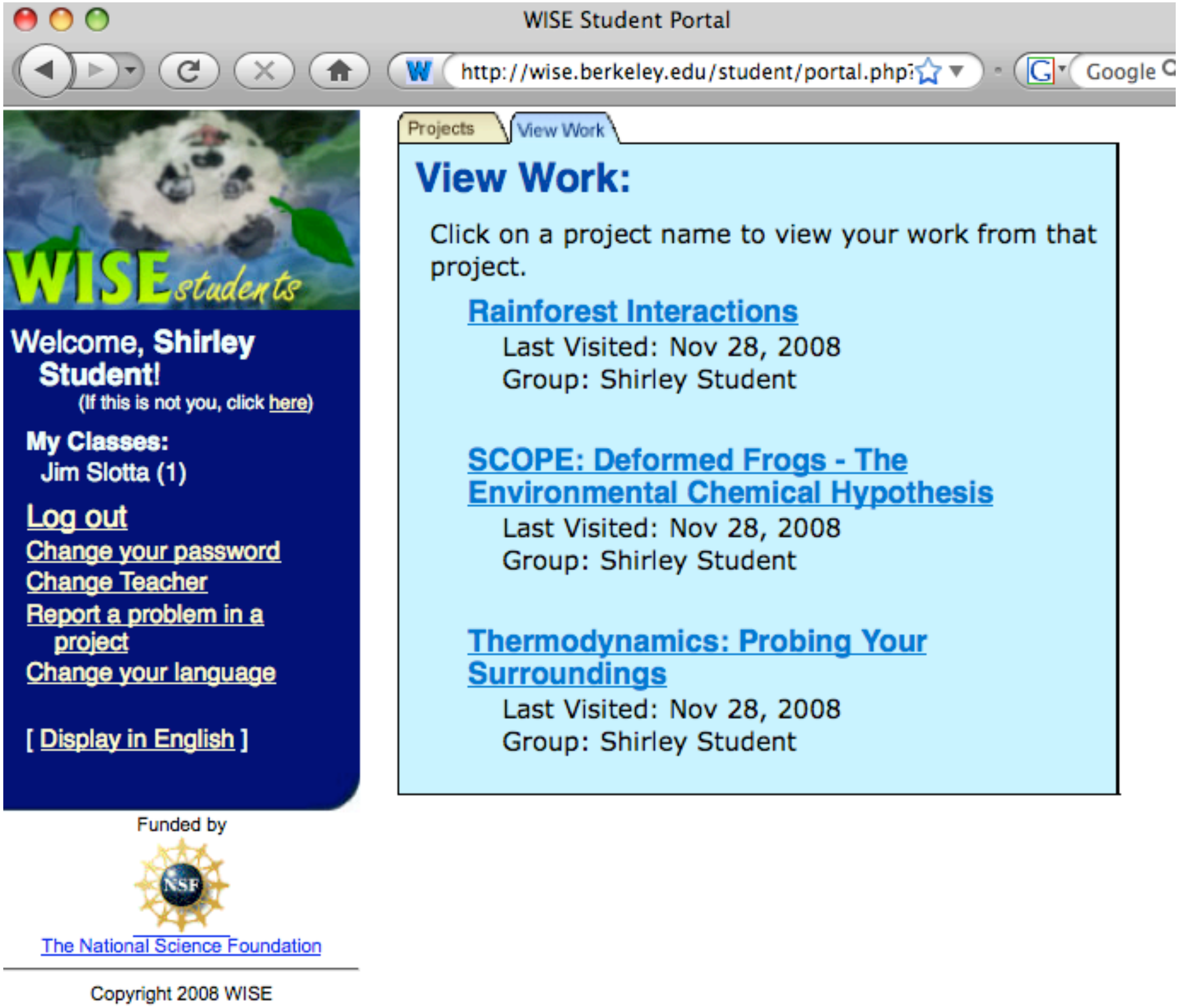

***Figure 2.5 WISE Student Portal*.** When students log into the WISE site, they are taken to the Student Portal, which supports all functions for students. Here, they find any curriculum projects that were set up for use by their teacher, as well as all prior work they have done in previous projects. The sample student shown here is looking at a list of three curriculum projects that she currently has underway.

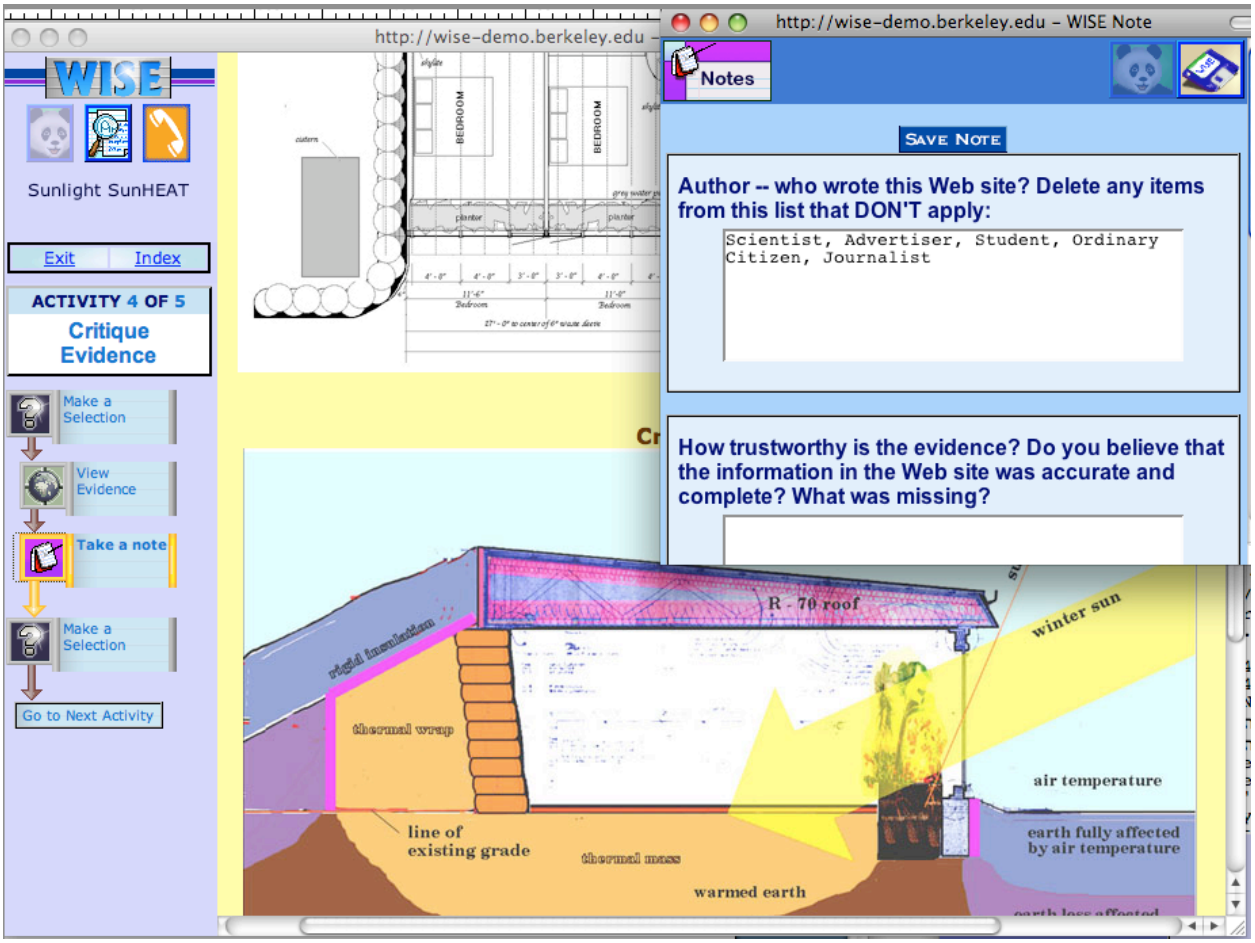

Figure 2.6 – WISE Sunlight, SunHEAT Evidence and Reflection Notes. This Figure shows a WISE Evidence page that presents students with a description of an innovative passive solar home that was published on a Web site, accompanied by a WISE Reflection Note. WISE Reflection Notes provide students with guidance and instructional context—in this case prompts them to consider two questions about the source credibility, as well as other questions about the passive solar design of the home.

Figure 2.7 – What's in a House Project. WISE provides students with support as they use many different kinds of Web pages. In the *What's in a House* Project, students consider different parts of a house: the roof, the walls, and the windows. Here, they are receiving some contextual information before following a link out to a commercial site that describes a special kind of window that becomes darker when illuminated by sunlight.

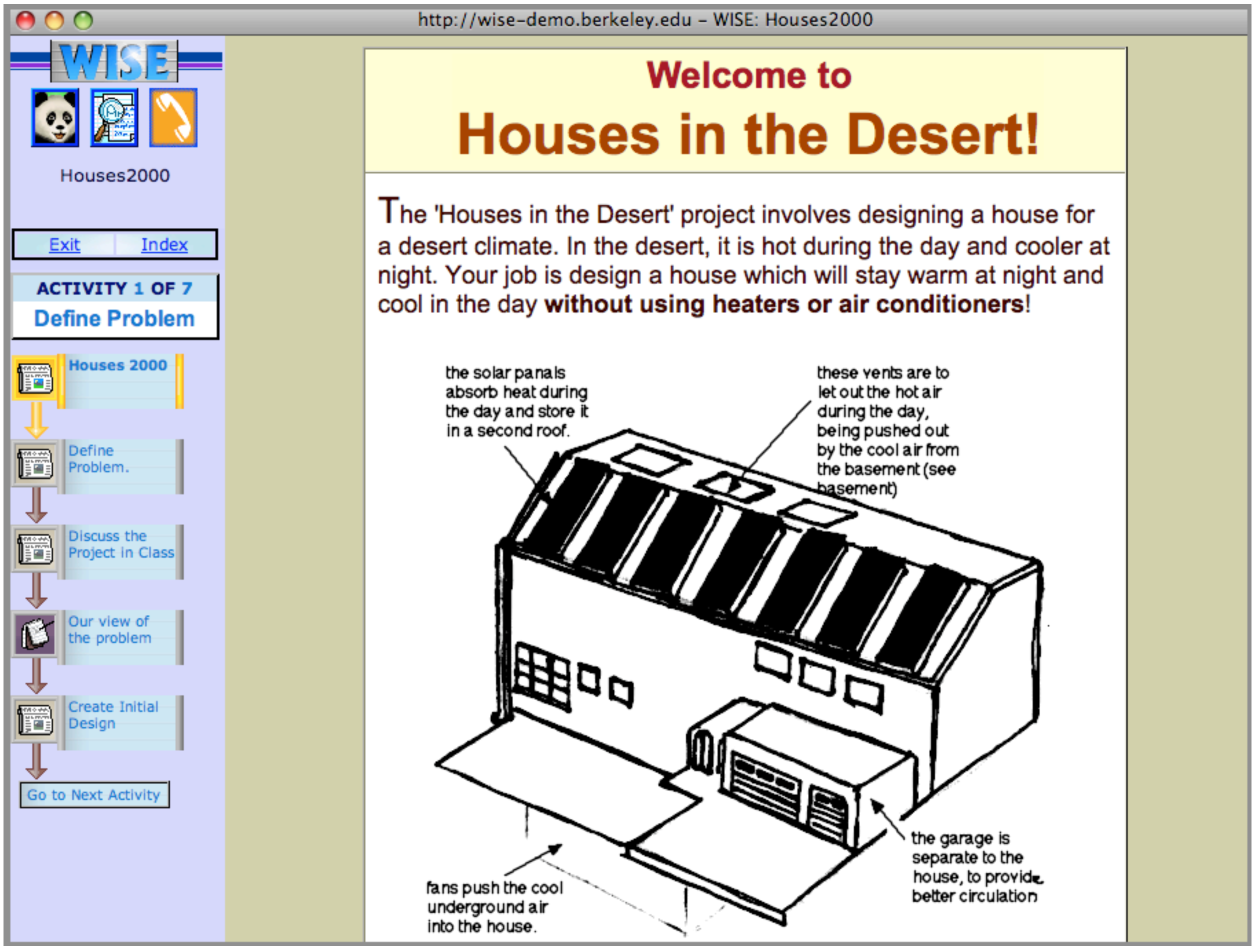

Figure 2.8 – WISE House in the Desert Project

In WISE *Houses in the Desert*, students apply what they learned in the previous two House projects and design a house that would be suitable for living in the desert. They apply the critique skills gained through *What's in a House* and the comparison skills they developed in *What's in a House*. Students offer critical feedback to peers on their house designs, and justify their decisions in a class presentation.

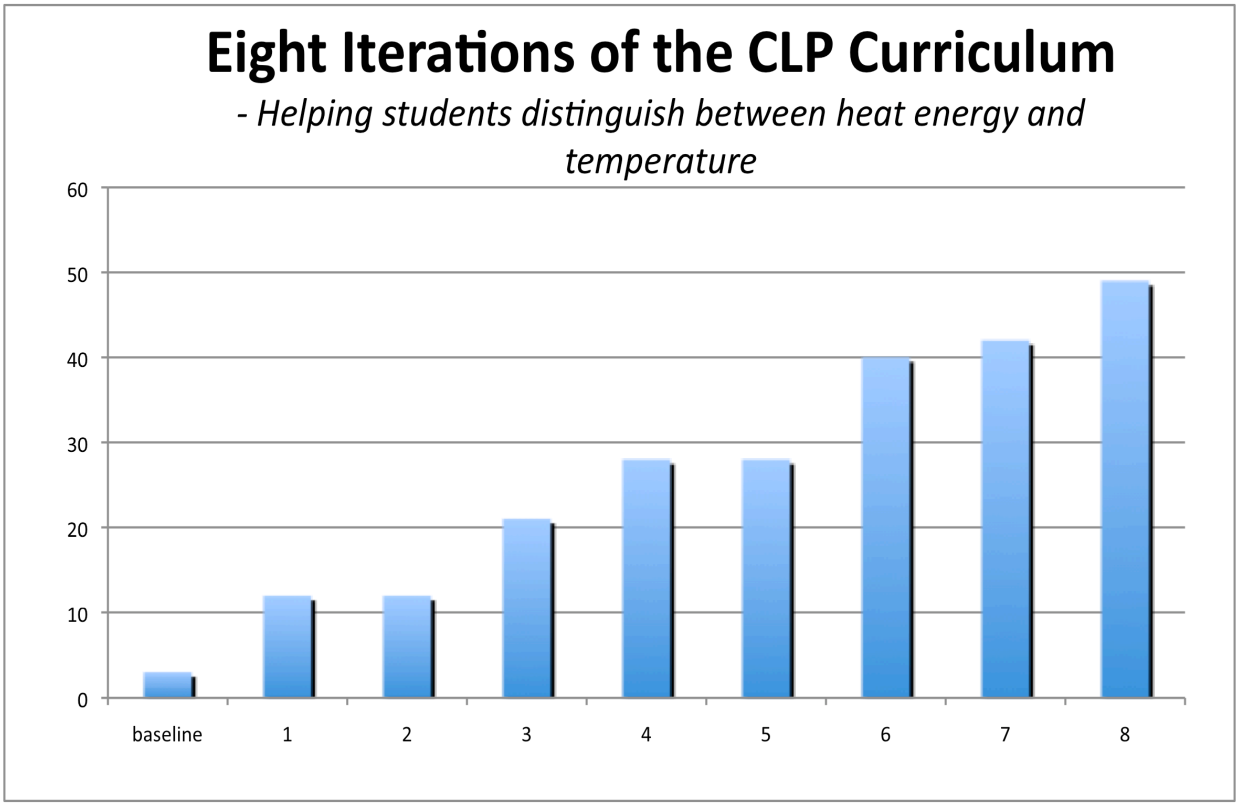

Figure 3.1 – Computer as Learning Partner Project Curriculum: improved efficacy over time. By gradually improving our CLP curriculum over a span of 8 semesters, we were able to improve students' capability to differentiate between the concepts of temperature and heat energy. This is a difficult distinction that escapes many university students. It is clearly difficult for students in these samples, as reflected in the very low baseline measure and relatively low scores overall.

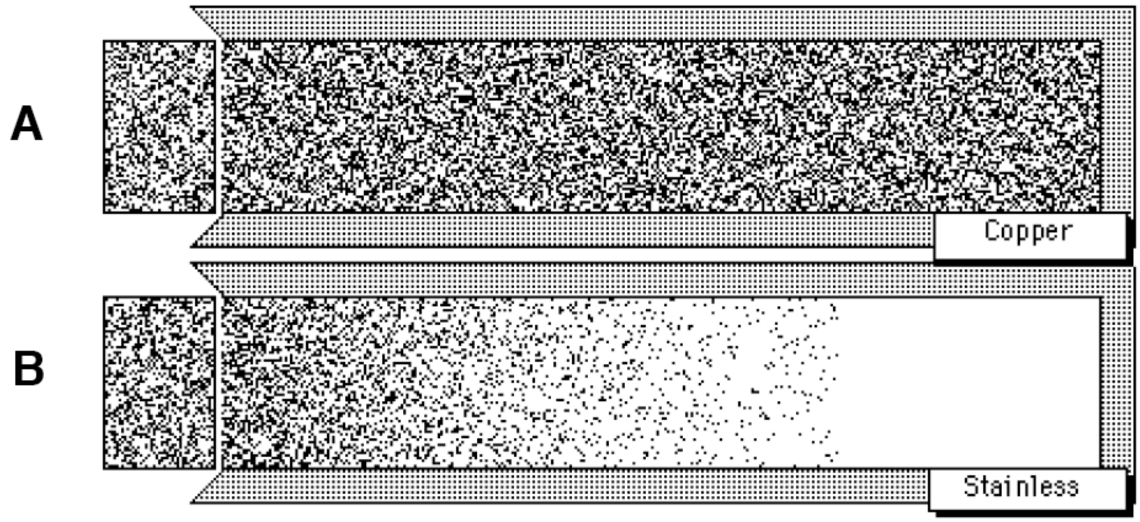

Figure 3.2 – Heat Bars Simulation from CLP project. This Figure shows a simulation used within the CLP project called "Heat Bars" where students compare the rate at which heat energy flows through two different materials – in this case copper and stainless steel. Initially, the two bars both appeared as solid white in color, and were touched at the end by identical heat sources (the shaded rectangles). Students observe as the heat energy progresses (in the form of shading) through the bars at differing rates.

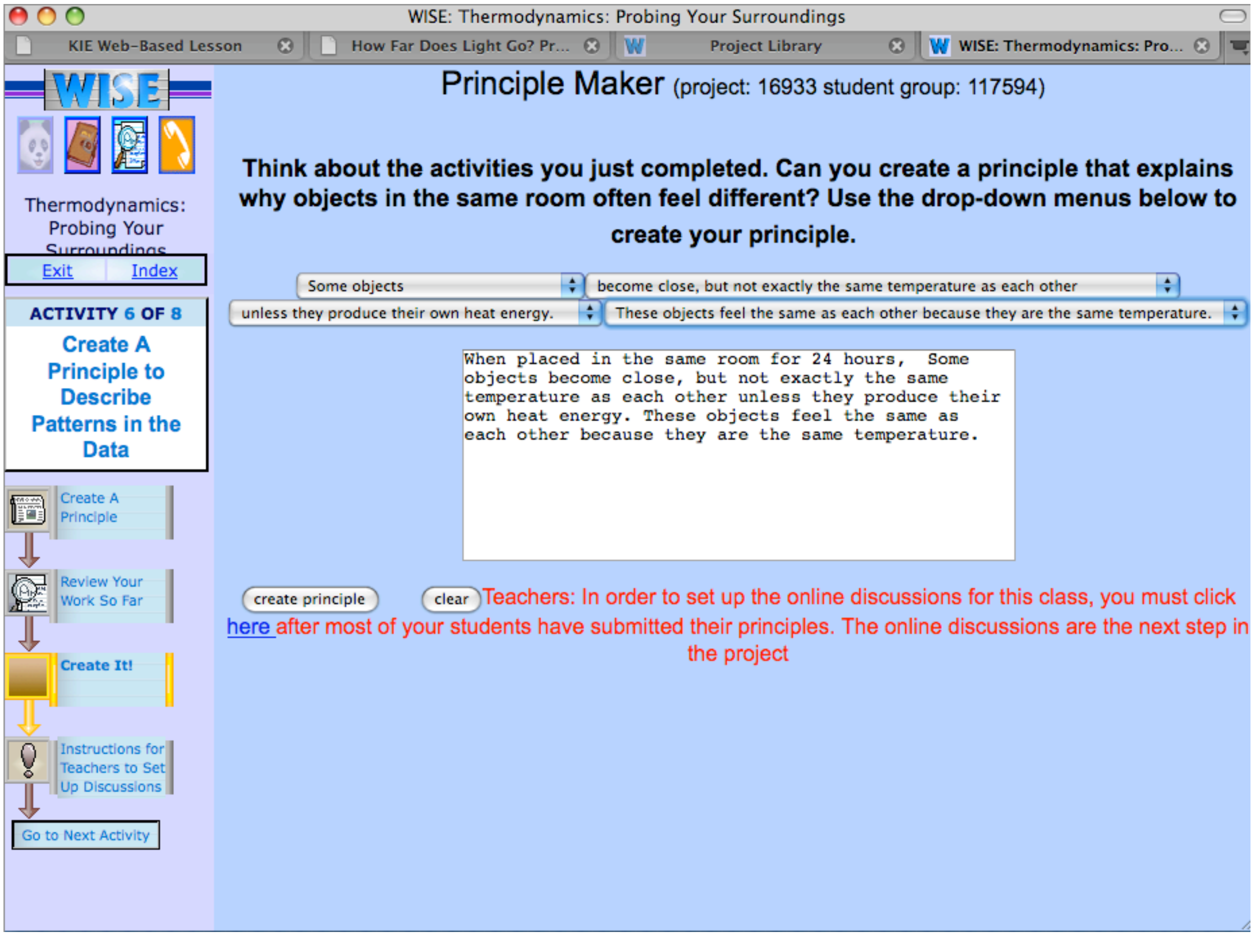

Figure 3.3 WISE Principle Constructor – Making Students Ideas Visible. In the WISE Principle Constructor, students create scientific principles from pull-down menus to reveal their ideas about specific science topics. In the case displayed here, the students reveal their belief that two objects will never become the same temperature, and provide some evidence of their reasoning. This tool has been helpful in research, and allows teachers to group students in online discussions according to their stated beliefs.

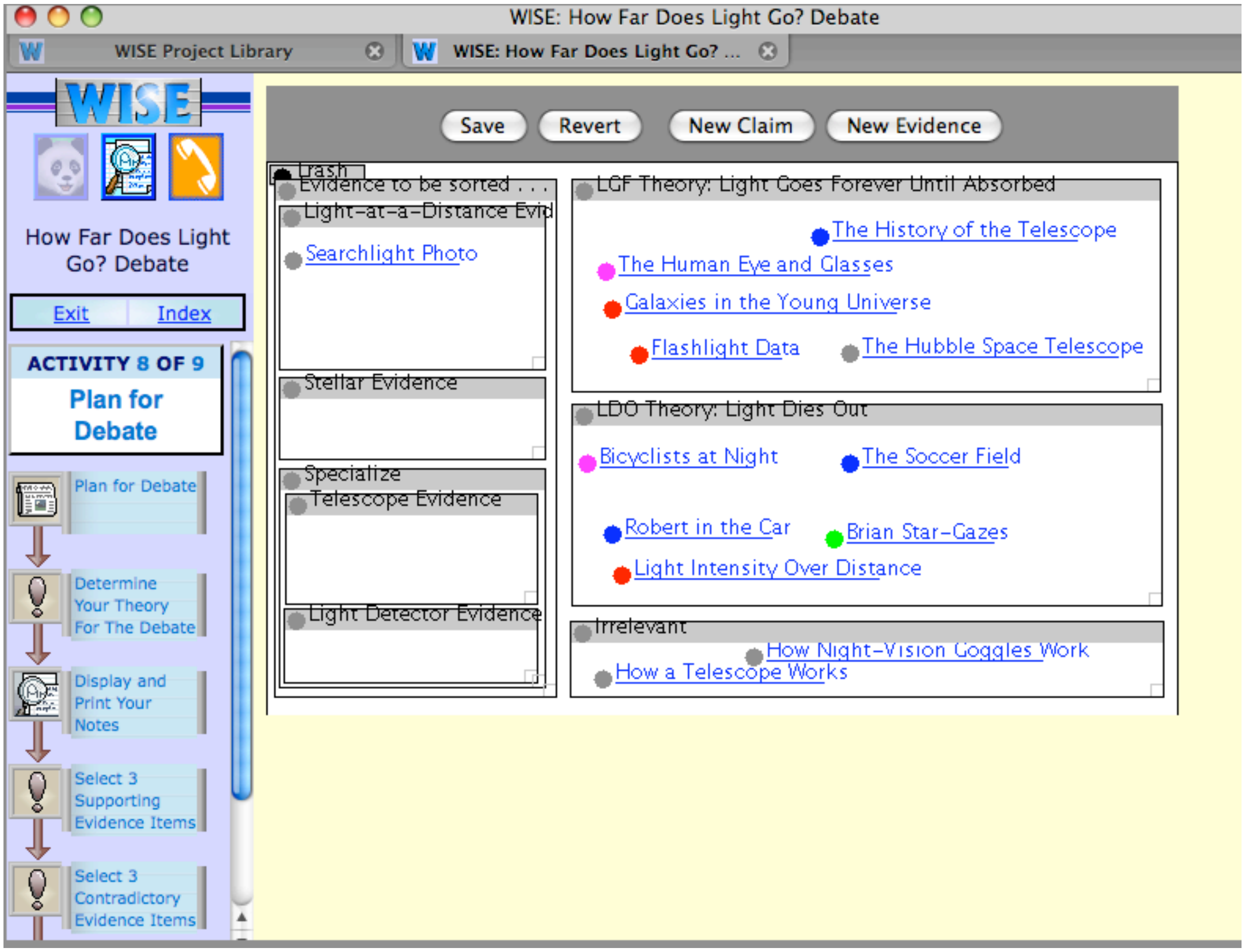

Figure 3.4 – WISE Sensemaker Tool – Scaffolding Student Argumentation. Using the Sensemaker Tool, students can sort their ideas, placing evidence from the Web into related categories, rating the strength of evidence and counterevidence with respect to different arguments. The Figure shows a view of Sensemaker as used in the *How Far Does Light Go?* project, where they debate whether light dies out or goes forever. Students use their Sensemaker file as a scaffold in subsequent classroom debates.