Internet Environments for Science Education

Edited by
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We dedicate this book to Matthew, Allison, Lucy, Zoë, and Sophie.
Fostering Productive Collaboration
Offline and Online: Learning From Each Other

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This volume describes a number of innovations in the field of Internet-based education from a research group that helped invent the general approach. Some readers may have come upon this volume hoping that it would contain simple prescriptions on how to use the Internet for learning as determined by simple either-or comparisons, the “hard research” that is so lauded by experimental traditionalists. However, as any teacher who has tried to implement a research-based innovation knows, there are no simple answers. Research is important, and the defining characteristic of research is an empirical stance, a willingness to “listen to the data” and to look for patterns that hold true across time and space. Our work as researchers certainly fits this bill. However, as is true with most educational research, the simple studies and simple answers (“Which is best, A or B?”) are notably backgrounded in the work. The tricky part of doing educational research is that the devil is in the details—interventions may take on widely varying forms depending on the teacher, the classroom context, and even the particular geographic location. In technology research in particular, many ask questions that belie the role of context. The question, “Is tool A better than tool B?” is foolish if one doesn’t ever examine what is done with tools A and B or why. In all of the work reported in this volume, these so-called horse race studies are backgrounded. They are used to answer important questions, but any experimental comparisons are highly embedded in a tapestry of efforts that blends
creative technology and curriculum generation, proactive implementation, and iteration. This cycle of activities makes sure that the comparisons examined make sense—that they are compelling—and that the interventions tested represent the best possible examples of their kind that could be provided.

One of the most valuable lenses with which to examine work in this volume is the idea of design-based research (Bell, Hoadley, & Linn, chap. 4, this volume; Design-Based Research Collective, 2003; Hoadley, 2002). This stance of design as integral to the work was especially important in the creation of collaborative tools and activities. Like many of the visualization and modeling activities in the Knowledge Integration Environment (KIE) that drew on years of experience in the Computer as Learning Partner (CLP) research and the CLP classroom, my work with collaborative technologies in KIE was grounded in years of prior work on creating collaborative tools and, equally important, collaborative contexts, or activities and cultural norms that supported collaboration leading to learning.

DESIGN AS A CONTEXT OF RESEARCH

When we as researchers discuss design, we imply certain ideas about the character of the activities we engage in. First and foremost, design is purposeful and creative. As researchers, our purpose was fundamental to our approach: We weren’t merely developing theories about learning but were also seeking ways to ensure that young students (in our case, 12- to 14-year-olds) were able to learn science. We were troubled by the deficits that seemed rampant, including disconnected knowledge that students might parrot but didn’t understand and certainly couldn’t apply to their own lives. This actually set us apart from pure technologists in that our major goal was not to find application of technology but to enhance learning.

A second defining feature of design is that design is open ended. This is usually thought of as what makes design challenging (as compared to, for instance, problem solving; Greeno & Simon, 1988; Simon, 1969). However, open-endedness proves to be an advantage in educational technology research because it means researchers’ designs are well suited to the types of open-ended questions the research addresses, such as “How can we best use technology to support reasoning in thermodynamics?” (in contrast to, “Are computers better than filmstrips?”).

Good design is iterative. The process of creating something to address a goal is repeated many times as the designed artifact or process is tested, observed, and refined. The iterative nature of design is often missing in research but is vital in testing researchers’ interventions. By repeatedly creating, implementing, enacting, and improving our interventions, we as researchers begin to understand intuitively and empirically what works and what doesn’t and also which features of the design are essential and which are irrelevant to our goals. In typical design, especially typical software design, this type of refinement is an informal way of doing research—user testing can encompass experimentation that would pass muster with the most stringent research methodologists, but usually it is far more informal. The sages researcher uses mixed methodologies combining informal and formal methods according to costs and benefits (Neilson, 1994). In our case, we used this refinement cycle as an opportunity to listen to the data and to conduct studies that were robust because they were meaningful and were grounded in the extensive contextual knowledge that came from participating in the design process that created the intervention in the first place. As with scientific research in general, we used studies to test hypotheses and to ground us as we constructed falsifiable models and theories from the data.

One of the tenets of the scaffolded knowledge integration framework (Linn, Davis, & Eylton, chap. 3, this volume) is the development of social supports for learning. This chapter provides a design narrative on how we as researchers studied what types of collaboration might support learning and how technology can enhance this collaboration.

Elsewhere, I (Hoadley, 2002) reported how design-based research can lead to better alignment between theories, experimental interventions, and outcome measures, a lesson learned while studying scientific discussion online and the “SpeakEasy” collaboration tool (Hoadley, Berman, et al., 1995; Hoadley, Hsi, et al., 1995). A design narrative of this explicitly collaborative tool is available in Hoadley (1999, 2002). However, by labeling tools either collaborative or noncollaborative, one oversimplifies things (Hoadley & Enyedy, 1999). Here, I provide a contrasting design narrative, one that shows how social supports for learning are important even when one is not designing groupware.

DESIGNING FOR COLLABORATION

This chapter is about some designs of technologies and activities that fostered collaborative aspects of learning. The discussion in chapter 4 (Bell et al., this volume) of design-based research and design narratives can and does apply to other aspects of the research reported in
this volume. Research on collaborative learning, however, presents some unique challenges that underscore the importance of a design-sensitive report of the work. In other work, Hsi, Hoadley, et al. (1995) discussed how collaboration research adds design complexity. Collaboration research is particularly sensitive to variations in context, and any intervention reverberates through the setting changing both the individuals and the social context. Time is required to see how the intervention settles into a steady state as both individuals' practices and the group practices adapt to the new tools.

Here, I give a design narrative for one particular innovation that began as a curricular unit to address specific learning needs. It provided a rich context for studying how technology could scaffold student learning and knowledge integration in science. Through this saga, I try to point out ways that the research team learned to provide social supports for learning and how technology, activity, and local culture interrelated in these studies.

**DESIGN NARRATIVE: THE HOUSES IN THE DESERT ACTIVITY**

In this design narrative, I describe how a student Internet project in a middle school physical science classroom was refined through four iterations. Although the curricular project was not initially thought of as a collaboration project, social concerns ended up being an important part of the learning experience and shaped the uses of technology in the project. The project, named "Houses in the Desert," or Houses for short, asked students to apply their knowledge of thermal equilibrium, heat energy, and light energy to the problem of designing a house in a desert environment. Like capstone design projects in engineering education, we hoped this final project in the classroom curriculum would help solidify student understanding of analytic concepts in energy and thermodynamics, and might serve as a performance assessment for student learning over the course of the semester.

This project is an example of the design genre of Internet project created in KIE. In some ways, the design of student design projects is the most difficult. As instructional, curricular, and technology designers, we had to be clear about the similarities and differences between our own design practices and student design practices. Even our choice of language was a challenge; "learning through design" was the phrase we selected that most accurately represented our goals. The students were learning to design, but this was subsidiary to the real goal of learning science content and scientific reasoning (as opposed to design skills). Design is also naturally a very open-ended activity, which left us many choices and few examples to follow in helping the students. Whereas some research has been done on teaching students design skills (in domains such as computer programming, architectural design, and engineering in which design is a part of professional practice), few have studied use of design activities specifically as a pedagogy for knowledge that is not inherently design based. Kafai (1995) and Carter Ching (2000) are the most notable exception to this rule, having studied how design activities may be used in elementary school mathematics. These efforts and those of our contemporaries like Kolodner (Kolodner, Crismond, et al., 1998) and Baumgartner (2000; Baumgartner & Reiser, 1998), inspired the research group to seek a role for design in the KIE environment.

As in prior chapters, the first project in the genre took considerable time and effort to polish. Unlike the theory comparison (Bell, chap. 6, this volume) and critique (Davis, chap. 5, this volume) genres, this genre did not have significant representation in the existing CLP curriculum. Indeed, the refinements of our design-based project were intimately intertwined with the design and redesign of the KIE software; software interfaces that made sense for claims didn't necessarily have as much relevance in a design context where decisions or constraints were more central. Likewise, as the collaborative technology of the SpeakEasy was a part of the project, our experiences with Houses in the Desert informed uses of the SpeakEasy tool in other contexts and some of the redesigns of this tool. However, in this narrative I focus more closely on how we structured the design activity than on changes to the overall KIE interface or to SpeakEasy. As is seen, although collaboration was not a central feature of this project in the beginning, through iterative refinement we came to understand how structuring collaboration was the most powerful way of scaffolding the students' science learning in the design.

**Goals for Design Curricula**

Design-based curricula appeared to offer some important benefits that initially attracted us to the genre. Through the use of design-based activities, we as designers hoped to help students apply and integrate their knowledge in the context of a real-world problem with relevance to the students. Design problems are by nature open-ended
and for this reason are an important class of problems suitable for problem-based learning (Boud & Feletti, 1991; Sherwood et al., 1998). Commonplace examples such as the “mousetrap car” activity found in physics classrooms worldwide point to design activities as motivating. Furthermore, by applying their knowledge to a real context, the designers hoped that students would be better able to apply their knowledge of thermodynamics and light energy, integrate their understanding through reconciling the various principles with a single designed artifact (the house plans), and bring in real-world experiences they had living in houses in a somewhat desert-like climate. (This research site was in a warm, inland valley in California, which had hot, dry weather.)

The context for which the activity was developed was Doug Kirkpatrick’s eighth-grade physical science classroom. As described earlier in this volume, Kirkpatrick was a member of the research and development team and had been working previously with the same research group at the University of California at Berkeley on the CLP project, a research and development effort that helped study student science learning and developed a semester-long curriculum on energy, especially heat and temperature.

The Houses project was developed with the help of other members of the KIE team. The initial creation of the project in 1994 was based on a much shorter CLP activity called “Aliens on Tour” in which students designed clothing to keep cold-blooded aliens comfortable at different temperatures; this project was originally created as a performance assessment by Nancy Songer in the late 1980s and later revised by Eileen Lewis and Elizabeth Davis. I led the creation of Houses with help from Sherry Hsi and Alex Cuthbert, and Cuthbert helped in subsequent runs. Kirkpatrick had enormous input throughout the design process. Considerable work has been done by Cuthbert refining the design project approach in multiple classrooms using the new Web-Based Inquiry Science Environment (WISE) platform since this initial phase of development in KIE, although it is not reported here (for more information, see Cuthbert, 2002; Cuthbert & Hoadley, 1998a, 1998b).

**Challenges for Learning Through Design**

Because our goal was to foster good learning experiences rather than good designs, the designers of Houses faced several challenges. The biggest challenge was that we wanted the activity to engage students in the scientific principles involved in the problem. In the case of Houses, students were not expected to learn architecture in this course or elsewhere, nor did we have time to teach the basics of architectural design. Many of the reasons that the problem we posed was engaging made it easy for students to focus on superficial aspects of the house design problem. Students were highly motivated to invent personal spaces and would have happily done so to the exclusion of the heat and temperature problems related to the design task (Kolodner, Crismont, et al., 1998).

Another challenge we as designers faced was how to constrain the task enough to prevent students from floundering. Our task was easily open ended enough to take the entire semester. We didn't want to lose the sense of an open-ended problem, but we also didn't want students wasting their time on unprincipled guessing as a design strategy (Baumgartner & Reiser, 1998; Williams & Bareiss, 1998).

A third challenge was to encourage students to refine their ideas. Certainly in a less project-based unit, students would practice their ideas through a number of exercises. Here, students could really only make a few major strategy choices about how their house would address the heat and temperature needs of its occupants. If they made these choices early on and if they made poor choices, they would have little opportunity to explore the scientific concepts or improve their design. Thus, avoiding design fixation (Jansson & Smith, 1991) was an important goal to help students in thinking through numerous examples (Linn & Songer, 1993; Linn, Songer, et al., 1996; Reiser, Ranney, et al., 1989).

Each of these goals was a design goal for the other Houses designers and me in creating the project, with justification from both the literature and theories of productive discussion. However, implementing these goals proved challenging and took several iterations. The focus of the design narrative that follows is how the KIE team came to achieve these goals in our setting by iteratively refining not only the technology tools but also the activities around them. For each iteration of the project, I characterize shortcomings of the design and how we remediated them in the next run. Again, the point of this chronicle is not merely to show that we put work into improving our intervention but rather to demonstrate the degree to which providing social supports for learning was a part of creating a successful project, even though it wasn’t initially perceived to be a project in which collaboration would be central. Also, by conveying some of the deliberate design choices and the justifications for them, I hope that this design narrative will enable others who wish to create projects for learning through design.
Iterative Refinement of the Design Activity

In this narrative, I focus on the first four iterations of the full project (there was a partial pilot test of the project before this story begins), one each semester in the same classroom. Research on the SpeakEasy discussion tool (Hoadley, Berman, et al., 1995) was also occurring in the classroom at the same time. SpeakEasy was one of the first two web-based discussion tools (predating the introduction of Netscape) and scaffolded students’ online discussion akin to the Computer Supported Intentional Learning Environments system developed earlier by Sear and Bereiter (Sear and Bereiter, et al., 1989). Although SpeakEasy was one of the four main software components of KIE (including the Mildred cognitive guide software, the SenseMaker argument and evidence organization tool, and the KIE Tools Palette for organizing and structuring student use of the other tools), SpeakEasy predates the KIE project and was in use as a stand-alone system for learning and for educational evaluation; it had been developed as a next-generation version of the Multimedia Forum Kiosk software (Hoadley & Hsi, 1992). More complete histories of this tool and the research on it are available elsewhere (Hoadley, 1999, 2002; Hoadley, Hsi, et al., 1995). SpeakEasy provided several novel features; it was designed to maximize social cues in discussion and used semantic labels to help scaffold participants’ contributions. SpeakEasy discussions were topical, with a question or proposition introduced by a topic author; in this classroom, students mostly used SpeakEasy as an adjunct to the topics they were studying in class and participated in the discussion over a period of weeks as an ongoing homework assignment.

The houses project included a SpeakEasy component specifically tied to the project, again completed primarily as homework, whereas this project was conducted primarily in class. Although this online collaboration did play a role in the project, it was face-to-face collaboration that illustrates our point about how social supports for learning are an important (perhaps inevitable) design concern in any project. Students participating in the project were following the model in the course to which they had become accustomed: work in pairs or triples, mostly in class, over an extended period of time. This project was slightly longer than most; the students usually did 3-day to week-and-a-half-long projects, whereas this project took over 2 weeks. Because the project took place near the end of the semester, it was interrupted by testing and field trips slightly more than other projects (especially during spring semester); therefore, it took nearly 3 weeks of calendar time.

7. FOSTERING PRODUCTIVE COLLABORATION

The research method was based on iterative refinement in the design experiment tradition (A. Brown, 1992; Collins, 1992), although I had at least one planned compelling comparison between class periods with slightly different treatments each semester the curriculum was run. Initially, student design practices and motivation were the primary research focus, but eventually social configurations were the predominant theme in the research, as we designers tried to effectively link work occurring at individual, dyadic, and whole-class scales. As noted elsewhere in this volume, the entire KIE team was aiming at a moving target. The relation students had to technology, particularly the Internet, changed radically during the course of the research project; whereas our initial runs of KIE involved instructing students in what blue, underlined text signified, later runs had students bringing not only surfing skills but also strong preconceptions about the Internet to class. In addition, this project, as the last one of the semester, was heavily influenced by the developing culture of scientific discussion and evidence that was the hallmark of KIE in those years. Although we did not initially envision learning about claims and evidence as one of the central features of KIE, by the end of the research program it was one of the defining features of our approach; this project then was a product of this evolution of goals. On a related note, the role of resources (typically called evidence in the classroom) was one that shifted in the classroom culture both throughout the semester-long curriculum and in this project. We refined our presentation of resources to try to encourage students to make use of them in a way that was consistent with the goals of a learning-through-design project. The “How Far Does Light Go?” project discussed earlier (Bell, chap. 6, this volume) was a driving force in this direction of using scientific argumentation as a core aspect of the KIE software and KIE projects, as was our need to make effective use of the information resources on the Internet despite their varying applicability, appropriateness, and trustworthiness.

Historical reconstruction is always tricky, but luckily there are a lot of primary sources to consult. Each semester, the overall structure of the project and of the resources was built into the KIE software files for the project, allowing a more accurate than usual reflection on exactly what changed at each iteration. The titles I give each iteration represent my own post hoc characterization of the project at that time, although the overall description is consistent with discussions of the project at the time. Students began with the introductory screen shown in Fig. 7.1, which remained essentially unchanged throughout the iterations.
Design a Desert House

Your assignment is to use your knowledge of heat, temperature, and energy to design a dwelling for use in the desert. Remember that deserts not only get very hot in the daytime but also very cold at night. The house must be comfortable in both the day and at night. All design decisions must be backed up with scientific evidence or principles.

In order to design a good house, first we'll look at a few existing house designs and decide why each one might or might not be good for desert climates. You will be discussing which houses are best with other students on the SpeakEasy.

FIG. 7.1. Opening screen for the “Houses in the Desert” project.

The Nature of the Task: Maintaining Comfort in the Desert

Before exploring the nature of the student activity, it is informative to examine the nature of the design task set before the students. The main design goal is to maintain a comfortable temperature inside the dwelling, even though deserts have extremely high temperatures in the daytime and extremely cold temperatures at night. The main design constraint is that we told students not to rely primarily on fuel-consuming heaters and air conditioners.

In the real world, there are several strategies used to solve this problem. Heat gets in and out of a house through three primary methods—conduction, radiation, and convection—and houses' properties for each kind of heat transfer can be manipulated. In modern buildings such as office buildings, conductive insulation is an important strategy. Greater insulation of the building allows any powered heating, ventilation, and air conditioning systems present to be more effective. Another important strategy is to manage the impact of radiant heat. For instance, lighter colors can be used to reflect more radiant heat energy in the daytime, or darker colors can be used to absorb more light energy in preparation for cold nights. Radiant heat transfer is the reason for foil coatings on fiberglass insulation materials; whereas foil is highly conductive, it also reflects radiant heat that the house would otherwise radiate or absorb. Windows may be used to create a greenhouse effect for heating (light energy enters and is converted to heat) or may be specially coated to avoid this effect if overheating is a concern. In preindustrial and traditional architectural styles, the primary way to accommodate daily temperature swings is to use thermal inertia (a concept only briefly touched on in the curriculum). For instance, adobe houses in New Mexico have a very high heat capacity; the walls take a long time to heat up in the daytime, and they radiate heat (taking a long time to cool) in the nighttime. The ultimate heat capacity strategy is used by cave dwellers such as some of the Native Americans in the American Southwest; the earth, with its nearly infinite heat capacity, helps maintain a constant temperature inside the dwelling. Other important strategies include use of natural ventilation or evaporative cooling to help cool houses (or their inhabitants) when they are uncomfortably hot.

As designers, our hope for the students was that they would approach this problem armed with the concepts they had previously been working with: They had spent a great deal of time studying thermal conductivity and insulation and the role of temperature differentials in heat flow (i.e., heat flows from hot to cool materials, and insulative materials slow this process.) We also hoped they would apply their understanding of how light is converted to heat energy when it is absorbed (although students had not studied radiant transmission of heat through infrared light, they were taught that visible light is converted to heat when it is absorbed by nonreflecting materials such as black construction paper; this was the subject of several in-class laboratory investigations and was further emphasized in another KIE project; Davis, chap. 5, this volume).

Iteration 1: Deductive Model

In the first iteration, the Houses design team viewed the design project largely as problem solving with some extra opportunities for creativity. Given what students had learned, we expected them to be able to come up with a highly insulated house as a solution, and our activities were focused on hinting to students that this might be sensible. Almost as an afterthought, we added in a small amount of information...
about heat capacity and specific heat, anticipating that high-achieving students might make use of this information as well.

**Survey Evidence (Read Science Information, Three Examples).** The survey evidence activity was the initial activity and involved reading web pages and advance organizers for those pages from the KIE evidence database. The first three evidence pages were built by the Houses team as examples of houses; one was a poorly insulated wooden house with specific discussion of how hard it was to keep, the second was a straw bale house being built by a group of students at Swarthmore (with description of how straw houses are exceptionally well insulated), and last a house of mud with information about the Native American Mandan tribe and the mud dwellings they constructed in the Dakotas. We also included evidence pages about the R value (insulating properties) of various materials, a summary of a laboratory the students had done previously on conduction and insulation, and two examples of the relation between light and heat (a story of what happens when leaving a car at the beach with closed windows and a story about wearing white vs. black T-shirts at the beach). Students were asked to read the evidence pages, discuss them with their laboratory partner, and summarize some of the features of the three example houses on a worksheet. The worksheet had columns for the houses of wood, mud, and straw, and column one (the house of wood) had been filled out. Rows prompted students for the building materials and heat properties, color and energy conversion, information on the windows, and other notes on each house. This activity took place in class.

**Evidence Search (Internet Search).** In the next step, students were asked to search the Internet and find two pieces of evidence (two Web sites) “that will help design a house for the desert: either a type of material that might be good for the desert, or an example of a building in the desert.” Students were asked to fill out a worksheet again, listing the keywords they searched on, how useful the search results were, whether they saved the page (using a bookmarking tool integrated with KIE), and why they saved the page if they did. Again, students worked together in pairs in class.

**Synthesize Evidence.** This step was designed to help hint to students how to reason through the design by supporting them through key design decisions: color and materials. The activity involved completing a worksheet titled “Synthesize Evidence,” which is shown in its entirety in Fig. 7.2.
Note that the worksheet is targeted toward constructing an argument for a particular set of design choices. We hoped that by focusing on material, windows, and color, students would realize these were the three aspects of the design problem that would be most likely to influence the thermodynamic properties of their house.

Discuss Three Houses (SpeakEasy). This activity was the only portion of the project that students completed on the computer individually, although we frequently saw students' laboratory partners observing and commenting verbally on the online participation. Each student logged into SpeakEasy, the online discussion tool, where they were presented with a topic and some seed comments comparing the three example houses: the house of wood, the house of straw, and the house of mud. The online discussions encompassed groups of approximately 15 other students in the other sections of the course. Because students were randomly assigned to discussion groups, any given student would only have a few others in their discussion group from the same class period and almost never shared a discussion group with their laboratory partners for the project. Students had time in class to make at least three comments on the topic.

Design Your House (Worksheet). Finally, after exploring the options through the evidence synthesis and the discussion, students were asked to design their houses on an online worksheet (a ClarisWorks® document) with prompts for certain kinds of description of their house and space for students to use the online drawing tools to sketch their house. Students then saved the pages as HTML and published them.

Iteration 1: Room for Improvement

Although students were engaged by this project, the Houses designers were disappointed with certain outcomes that became the focus of later revisions. In particular, our attempt to lead students to a particular design strategy (insulating the house to isolate it from its thermal environment) failed. They found that students weren't clear on our goals for the project and instead treated it as a purely creative or expressive project. In one particularly telling instance, one student was observed laboriously and miserably drawing individual bricks of his house using the painting tools in ClarisWorks®. When asked why, he replied that he thought his drawing had to look good to get a good grade. He was relieved to hear that it wasn’t, but it was illustrative nonetheless that he had misunderstood the point of the assignment until the last step. This overspecificity and overemphasis of surface features was also a problem previously encountered in the Aliens on Tour activity.

Naive Designs. One disadvantage of our approach was that students made naive designs. The students' designs were unrealistic, and they knew it. Few took the strategy we had expected of insulating the house by using materials known to be good insulators such as Styrofoam®, which appeared in the chart of R values as the most insulating and which the students had tested in experiments on heat conduction.

Close to Examples. One unanticipated consequence of our initial sequence was that students made heavy use of examples in their designs. In our case, this meant using the house of wood, the house of straw, or the house of mud as a model. Unfortunately, many chose the house of wood to emulate because it was the most “normal” looking house, even though the online evidence pages explicitly described how poorly insulated it was, how expensive it was to heat in winter, and so forth. The house of straw had tremendous insulation properties (with an R value of 40), but students viewed the house as a novelty. Thus, students tried to generalize from examples but didn’t necessarily attend to the features of those examples we thought were most important, a typical educational problem (Anderson, Farrell, et al., 1984; Linn & Clancy, 1992; Lovett & Anderson, 1994).

Little Science Rationale. Related to the students’ naive designs and focus on aesthetics was their lack of scientific justification for their design decisions. Students did not see the relevance of the activities leading up to the house design on their own designs and thus didn't incorporate this information into their project. For instance, students might state that their house would stay warm at night but would not justify this claim with the examples, Internet evidence, or their own laboratories from earlier in the semester.

No Chance to Iterate; Design Fixation. Perhaps the most predictable outcome of the structure of the project was that because students were not forced to iterate their design process, they became victims of design fixation. Students would draft an initial house design (probably without considering the heat flow properties of the house) but would then be unwilling to change the house later when it became apparent that the house had undesirable heat flow properties. The design worksheet reinforced this problem because students who might
spend a great deal of time drawing a house design in ClarisWorks, I would be reluctant to put that effort in all over again.

**Iteration 2: Changes**

For the second run of Houses, we made five major changes to the structure of the project to address the prior weaknesses. First, students began the project with an initial design and ended with a final design, encouraging them to revise their work. Second, we introduced a new worksheet as part of the project, the Heat Flow Analysis Worksheet. Here we asked students to (mentally) simulate the heat flow properties of their design during cold and warm parts of the day. We considered using Thermal Modeling Kit, simulation software developed previously under the CLP project (see Linn & Ilsi, 2000, for more information), but decided against this, first due to the time it would take students to simulate a house, and second because the software emphasized thermal conductivity and did not accurately represent thermal inertia and heat capacity. Third, we added additional opportunities for students to summarize and synthesize science information we thought should be relevant to their decision making. These took the form of formal prompts throughout the project via worksheets, software, and verbally in class. Fourth, we reduced the importance of searching for information on the Internet for two reasons. One problem was that we overestimated students' ability to conduct effective search—although we found students far more savvy about searching the Internet in later runs due to the explosion in Internet popularity. Another problem with searches was that many of the words students wanted to use as keywords were nearly impossible to search on. Windows and Adobe brought up tens of thousands of hits on the trademarked software products but few on the building materials, and searching on houses or housing nearly always uncovered real estate listings instead of information about architecture. The fifth major change we made to the project was to demote the importance of drawings by moving them offline (to paper worksheets) and encouraging sketching rather than detailed drawing.

**Iteration 2: Highly Structured Model**

Iteration two of Houses contained seven rather than five separate steps, although the amount of time on task was roughly the same; the notable exception to this was adding some homework at the beginning of the project.

**First Design.** To combat design fixation and to ensure students had multiple designs to reconcile, we added the first design activity. In class, students were introduced to the design problem as before with a minicourse and discussion about the desert climate. However, the introduction was timed to end at the end of the period. In the last few minutes of class, each student was given an initial design worksheet; every student was to individually complete their initial design as homework for the next day. Although some students did not complete their projects individually (either because they disobeyed instructions or because they completed the assignment as make-up work), most teams had at least two designs to start with. We also encouraged students to take an extra, abbreviated design worksheet whenever they made a redesign during the project.

In addition, the initial design worksheet included some analysis; students were asked to use a visual representation of heat flow. Students were prompted to draw two copies of their house, one for day and one for night. Students drew arrows showing the direction and magnitude of heat energy flow on each drawing, following an example provided on the worksheet. This arrow-based representation had been encountered briefly in a simulation activity earlier in the semester using the Thermal Modeling Kit software.

**Survey Evidence.** Students surveyed a combination of the three house examples and some science information as before.

**Synthesize Evidence.** As before, students completed a worksheet that encouraged students to make and justify design decisions about materials, color, and windows.

**SpeakEasy.** As before, students participated in a discussion of which of the three example houses from “Survey Evidence” would be best in the desert.

**Synthesize SpeakEasy.** This time, partly to collect data on the impact of the SpeakEasy and partly to get students to reflect further on their understanding of the three examples, students individually completed an in-class worksheet. This worksheet repeated one of the three sets of questions from the initial design asking students to choose the best material for the house and to justify their decision. As an embedded comparison, half of the discussion groups had threaded discussion in their SpeakEasy discussions and half had discussions structured around pros and cons of individual houses. Students participated equivalently in both conditions with no obvious differences in
comment quality. However, significantly more students using threaded discussions changed their views about what material a house should be built of than students in the control (pro–con) condition (Hoadley, 1999). This is an example of the types of embedded comparisons that allowed us to test some of the theories driving our design. In this particular case, we were testing our hypotheses about students benefiting from the social representations in SpeakEasy (as opposed to the effect of time on task, self-explanation effects, or the effects of exposure to other students’ explanations). The Houses designers and other KIE group members continued research on this topic through other planned comparisons.

**Evidence Search.** In this iteration, evidence searching was diminished in importance by making it an optional activity at the end of the project; if students had time, they could search the Internet for additional information. We provided additional scaffolding in the form of hints with search strategies such as using verbs instead of nouns, narrowing searches, widening searches, and so forth. We also added a feature that allowed students to view the results other students had saved from their own searches so items found in one period could be rediscovered by students in a later period.

**Design Write-up.** The design write-up was essentially the same, with the difference that graphics were not included in the online description of the design. The ClarisWorks* document stated “If you would like to include graphics in your web page, you need to get permission from the teacher. We will only include pictures if they help explain the science behind your design.” Very few students took advantage of this option.

**Iteration 2: Room for Improvement**

This iteration was successful in helping students focus more on the design decisions and on justifying those decisions. However, the run indicated three lingering problems. First and foremost, students continued to create relatively simple designs that did not use good strategies for maintaining constant temperature. Although the designs were better, they were still closely tied to the examples or to aesthetically motivated inventions. A second problem was that students found the heat flow analysis difficult and often presented incorrect analyses of how heat would flow into and out of their houses in hot and cold weather. We were not entirely surprised by this because the arrow rep-

representation was somewhat unfamiliar to the students (it had only been used during the brief Thermal Modeling Kit activity), but their drawings often indicated problem conceptions at a very basic level of the sort described earlier in the CLP project (Linn & Hsi, 2000). A third problem was that students had no shared criteria for what constituted a good solution. This became apparent when students started using the shared search tool to share “good” Web sites with one another; we were often quite surprised with what students found worth saving or sharing, and the students themselves often saw little value in the sites other students had found. We had hoped that the online discussions would help students develop shared criteria for the designs through social scaffolds, but this apparently was not occurring.

**Iteration 3: Changes**

The design team introduced five changes in Houses to continue to improve the focus on scientific concepts and to help students develop a wider range of design ideas linked to the science. This iteration of Houses introduced a new, explicit focus on problem definition. To improve the science focus and the analysis, we strengthened the initial introduction to the problem (before the individual homework that became the initial designs) by including explicit problem definition activities such as in-class discussion of the day–night heating and cooling cycle in the desert, a discussion of ground and surrounding interaction (which way heat flows between ground and air in day and night), and a discussion of how light is the major source of heat in the daytime. To improve students’ analysis using the heat flow analysis worksheet, we expanded the in-class, out loud support of the arrow representation of heat flow by walking students through an example.

To improve the opportunities for shared criteria, we introduced critique and class discussion of several examples, beginning with the Enertia House Web site, a commercial site on a passively cooled house. There were other opportunities for critique and class discussion (see following).

To increase the effective use of examples and reduce the students’ use of examples without effective science criteria, we refined the prompts in our design document template, added a library of preselected examples that students could browse, and used class discussion to focus on science ideas rather than specific examples. This was also reflected in a shift of SpeakEasy topics; students no longer discussed three examples but instead discussed “Does adobe work in the desert? Why or why not?”
We also added a 10 min. video skit to help make design rationale more obvious in examples; this (staged) video featured two graduate students with whom the class was familiar debating the merits of an insulation strategy (such as the straw house) versus the merits of thermal storage and heat capacity strategy (such as the mud house). We believed that embedding this social representation would help scaffold students to focus on the science issues in the discussion.

Iteration 3: Conceptual Model

I term this iteration the conceptual model version of Houses because of the strong focus on science concepts and a reduced focus on generalizing from our three primary examples. We also continued our work on how social representations could support the project by embedding several comparison studies. One study divided the class periods into conditions in which some students spent more time on social critique (pinups of designs, developing alternatives in a whole-class fashion), whereas other class periods had additional time for Internet search and examination of our design library, a “library cart” model that provided preselected examples of student and expert designs.

**Define Problem.** On the first day, students participated in a whole-class discussion on the problem, including heat properties of the desert, and surveyed a Web site on heat in the desert climate. Students were introduced to the Enertia House example, which the teacher explained. The SpeakEasy discussion was introduced and started at this time (students could participate at any time throughout the project rather than at a designated time in the project). Students took required notes in the KIE system on problem definition with the prompts “Our problem is . . .” “What we need to figure out is . . .” and “Our design needs to . . .”

**Initial Design.** As homework, students completed an initial design worksheet for the next day. This worksheet included a pretest survey (new for this iteration) that focused on design goals and criteria in addition to the design decisions and heat flow analysis used in prior semesters.

**Survey and Search.** The survey and search portion of the project combined what was previously two separate steps. Rather than providing a short list of must-see evidence including the houses of straw, mud, and wood and then sending students to search the Internet, students were provided with a short list of must-see evidence and then given access to a design library that included examples such as the three used in prior iterations, along with more complex ones taken from the Web. As with prior KIE projects, not all of the sites were trustworthy or applicable to the desert problem, therefore students had to be discriminating. In this run, we recycled some examples from the first KIE project students encountered. “Sunlight, SunHeAT!” was a project developed this particular semester by Jim Slotta as an introduction to the KIE software, to asking questions in science, and to the conversion of light energy into other forms of energy (including heat and kinetic energy). As the Web expanded, more examples suitable for this project were available online, and we incorporated several into our project.

**Critique and Refine.** In this project activity, students critiqued their own designs and came up with a new, combined design for the two-person team. The comparison groups differed in whether this included social critique through sharing designs and discussing them in class or more analytic critique using a worksheet designed to help them self-analyze the design.

**Discuss.** The discuss phase began by showing the video in class of two people debating an insulation strategy versus a heat storage strategy.

For students who had not yet completed their SpeakEasy discussion obligations (three comments), this step provided a checkpoint; students were instructed to finish their required minimum comments before moving on to later phases. The discussion did remain open for additional contributions and was not graded until the end of the project; therefore, students could contribute more after this time if they wished.

**Analyse Your Design.** In this stage, students completed a detailed heat flow analysis worksheet for the design they were intending to turn in. For many students this step forced an additional redesign. The heat flow worksheet was supported by an in-class discussion of how to use the arrow representation.

**Final Report.** In this iteration of the activity, students stopped using an online worksheet and instead used the note-taking features in the Mildred guide to enter their designs. This effectively prohibited students from including pictures in their final design report. The final report represented the students’ final design and included prompts
for changes the students had made during the design process (to ensure they had made changes). We encouraged students to support all design decisions with evidence, which drove a few more groups to redesign or to go back to the design library to justify their decisions. Although these post hoc rationalizations did not always force redesign when they should have, they did seem successful in getting students to engage with the science concepts.

Iteration 3: Room for Improvement

The concept-centered approach did recover the focus on science concepts but at the expense of the design problem. The ideas we presented were often too abstract for students to apply or discuss, and few of the ideas brought up in discussions made it into student designs. Although we had the sense that the self-critique and discussions helped move the classes toward shared criteria for the designs, they still had trouble with analysis of the heat flow properties and still did not arrive at a consensus on criteria that would improve the design outcomes.

Iteration 4: Changes

Although we as researchers had been experimenting with social scaffolds throughout the development of this project, the fourth iteration saw the most use of social means to help students with the design task; the design team for Houses made extensive use of the notion of shared criteria to help students link science concepts to the design task. Although the project retained many of the techniques we had found successful to this point, including the use of a library of examples to help students understand the design space, this version of Houses represented a shift in focus from supporting individual decision making to fostering group norms and social iteration on the designs. We added more in-class discussion of the problem definition with an eye toward invoking laboratories and principles the students had previously encountered to create explicit, shared criteria for what success would mean in the design problem. The design report was even more explicitly spread out over multiple steps with instructions that students should share and respond to each other’s designs. We also introduced an innovative way to help students regroup after the online discussion and synthesize that discussion’s implications for their own designs. The design library concept was further expanded to encompass both evidence surveying and evidence search. Finally, par-

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alleling our shift in the curriculum as a whole, we emphasized the importance of argumentation and evidence as a means to persuade others. Rather than trying to improve student designs directly in this iteration, we tried to improve students’ scientific arguments for or against their designs. This proved to be a powerful change for the better.

Iteration 4: Collaborative Design

This iteration retains the basic steps from the cart iteration but strengthens the collaborative aspects of the project.

Define Problem. As mentioned previously, the define problem phase was introduced to students as a chance to develop class-wide criteria for what constituted a good design; a whiteboard was used by the teacher to brainstorm criteria for success in the desert, and the class discussion included a discussion of the problem definition prompts. Each laboratory group still had to answer these prompts in the project (“Our problem is . . .” “What we need to figure out is . . .” and “Our design needs to . . .”).

Initial Design. The initial design task was changed so that even students’ initial design assignment included some analysis tasks such as predicting heat flow at noon and midnight. Many of the prompts to help students analyze the heat flow properties of their designs were textual rather than based on placing the heat arrows, giving students a chance to use both verbal and pictorial representations for their ideas.

Survey Evidence. In our design library, we expanded the number and complexity of examples. We also encouraged students to share good sites they had found not only through the shared search interface but also out loud. The teacher, walking around the room, would encourage groups with sites he found important to share verbally with the class. URLs were written on a chalkboard by the teacher in addition to posting in the Web-based interface.

Discuss and Refine. As before, students took a pre- and post-SpeakEasy survey on their current thinking on design decisions. Unlike before, students were asked to read every comment in a heavily seeded discussion on how to best design a house for the desert. Students watched the video as before, and these ideas we also expressed in the SpeakEasy discussion. We embedded another comparison in
this particular run. Half the students watched a video with enhanced social features such as coherence of ideas within an individual for the video and the SpeakEasy discussion; in the control condition, the same arguments were made in the same order but neither design strategy was identified with only one of the actors.

Organise Ideas. This activity represented a new combination of familiar activities for the students. In the past, they had become familiar with presenting arguments in a discussion using SpeakEasy and with organizing evidence to support a point of view using the SenseMaker software. In this iteration, we asked students to take the seed comments from the discussion they had just participated in and, using the SenseMaker, organize the comments by dragging them into claim frames (see Bell, chap. 6, this volume).

Gather Evidence. The gather evidence activity was a reframing of the search and survey activity; rather than looking for ideas for student designs, the activity was presented as gathering evidence to support the particular student design. The teacher made clear during this phase that the projects would be graded on how well-supported the designs were with evidence rather than solely the quality of the design alone.

Critique and Refine. As in the prior iteration, this activity was intended to allow students to share designs and critique them. In this iteration, the teacher presented a nonstudent design and helped the students reason through analysis of the design’s strengths and weaknesses. Then the teacher selected several student designs and had them put their designs up for everyone to see and the whole class discussed them. Finally, students used a new online tool to post their designs for others to see and contribute feedback on the design. This system, like all of the search utilities we used, was created by Cuthbert (Cuthbert & Hoadley, 1998a). Every team had some feedback on their design, and students were responsible to try to improve their designs based on the feedback, either by making design changes or by better justifying their choices.

Final Report. The final report, as before, included prompts for student justification of their design decisions with evidence—students could either enter this justification as text or include links directly in their reports because recent changes to the KIE software included the student notes and the URLs from their evidence gathering in the same file. This iteration yielded by far the best student designs, including good arguments linking their design choices to the science principles they had covered earlier in the semester. Because of the social externalization, students often iterated on their designs more than in the past and made marked progress toward the shared criteria the class had developed on what constituted a good design.

Lessons Learned

We set out to explore how design projects could help students learn science and to study the ways collaboration could help support learning. In iterating and refining our tools and activities, we arrived at better and better ways to support student learning and refined our own understanding of our learning goals. We retained many of the same curriculum steps but reorganized and reframed them to develop a more robust curriculum design pattern. Had we initially studied the motivational or learning effects of our earliest interventions, we might not have arrived at our ultimate conclusions based on our best practice application of the technology and curriculum—that helping students develop shared criteria about good scientific argumentation and design and effective processes for self-improvement were the key to advancing understanding in these project-based learning activities. Our lessons learned are summarized (and presented as design principles) in Table 7.1.

Good Design Practice Enhances, Not Detracts, From Good Science. One of the most important lessons learned from this experience was that the trade-off we had perceived between good design and good science was a true one. We had originally thought that we could either emphasize design skills and support students in creating good houses or we could emphasize science and support students in using heat flow concepts. However, through a more authentic approach to the problem and embedding design in social argumentation, we could not only get students to apply and link their existing science understandings but also to learn new science relevant to the problem, yielding much better house designs. It is unclear whether specific training in design methods would have helped, but what is clear is that students benefited from encountering some of the real complexity of the problem and from having their learning grounded in the problem context. By emphasizing a rational process rather than just specific examples, architectural principles, or even scientific principles, the students were able to consolidate and extend their understanding of thermodynamics while designing desert houses.
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Design Strategies Help Kids Learn From Examples Without Copying From Them. It proved to be difficult to walk the line between providing examples that encouraged copying (without comprehension) and providing examples that allowed students to apply their scientific knowledge without reinventing the wheel. Once our emphasis in the instructions we gave the students shifted from specific design examples to more general design strategies, we could decouple the principles from the examples and help kids step back from the specifics of individual examples. Introducing this distinction between strategies and examples helps students keep them separate in their own classroom discourse. It serves as an important lesson for us as educational designers too; we should perhaps focus our research efforts on creating and communicating design strategies and design principles rather than just artifacts or specific curricular units (see Baumgartner, chap. 11, this volume). We have attempted to take this lesson to heart and step back from instances to discuss broader strategies throughout this volume.

Use Collaboration for Modeling and Scaffolding. A third important lesson was that collaborative tools should be used to help model and scaffold students as they work through difficult problems. Although this is an old lesson (Collins, Brown, & Holm, 1991; Dewey, 1954), it is one that is important to revisit in each curricular or technical design. Whereas specialization (such as in the jigsaw method; Aronson & Yates, 1983) or burden sharing (Johnson, Johnson, et al., 1986) are often primary excuses for collaborative learning activities, the real benefits come from allowing the successes of the classroom to come through in modeling and consensus on criteria for success and to help scaffold students as they do their hard intellectual work. By orienting our design process toward better justification and argumentation, students improved not only their designs but also the connection between those designs and the science principles we were trying to teach. This may be the most important legacy of KIE in that our entire curriculum evolved in this direction of helping students turn information into arguments and thereby into personal knowledge. Far from detracting from the science domain knowledge, the process-oriented approach helped students develop a much better understanding of heat, light, and temperature.

Selected Research Results

What’s the bottom line on learning through design? Three findings bear repeating. First, we were able to use design activities successfully to help students learn and integrate their understanding across a range of topics. Even though the entire curriculum was geared to help students develop an integrated understanding, the Houses project succeeded at helping students develop and demonstrate an understanding that spanned disparate topics of heat energy, conduction and insulation, and light energy. Second, although the KIE project’s explicit goal was to improve student learning outcomes of science activities by iteratively refining the activity, we achieved not only better learning but better collaboration and better designs. Social supports for learning were required to make this project work. Third, although the challenge of creating a collaborative design activity is imposing, we successfully tapped student enthusiasm in a way that was not possible in our earlier work. This project was rated on surveys one of the most enjoyable of the entire semester, and several students have since
mentioned the activity when returning to their middle school for visits. One student even considered a career in architecture after the project; in another case, a student spent hours at home creating a scale mockup of their house design even though this was not part of the assignment. This type of enthusiasm is presumably less related to the topic than it is to the project type; in designing, students could indulge their creativity as well as participate in collaborative teams while working toward a common, authentic goal.

Multiple Levels of Design in Collaborative Learning Settings

It is instructive that many of our perceived problems with this project were eventually solved by developing the right sort of collaborative context for the students to work in, and this lesson generalizes across the entire range of KfE projects as well. Our initial research and project designs were aimed at improving how individual students cognitively engaged the materials and experiences we could provide with the new medium of the Internet, and this was an important component of their eventual success. However, as noted earlier, the hallmark of KfE eventually became that of a classroom using the Internet as one tool among many in a culture of scientific discourse, debate, argumentation, and inquiry. The CLP project had prepared us to examine the ways we could establish a context for individuals or pairs to engage with data collected in microcomputer-based laboratories. With KfE, we opened the door to a much more social inquiry process, one in which claims had to be argued and supported with evidence, one in which information sources had to be critically examined, and one in which students had to come to consensus on shared criteria for the designs that they produced. The Houses project, like the others, got many things right in the early iterations, but we had to evolve the tools, activities, and teacher support to help create a collaborative context in which the thinking we were after could happen. This occurred over the course of our engagement with participants in the setting; in the case of this chapter, with Doug Kirkpatrick’s classroom. Extending this process to include other local contexts was an important phase of work of KfE moving toward the WISE era (see Baumgartner, chap. 11; Bell, chap. 10; Shear, Bell, & Linn, chap. 12; and Slotta, chap. 9, this volume).

Saying we need to provide social supports for learning is one thing; actually doing it is another. Collaborative learning is messy. When local context and local culture are a central part of the phenomenon one wishes to study, an intimate relation with the context is paramount. Designing activities and technologies for collaborative learning relies on a number of phenomena at different time scales, from the momentary cognition of students to the development of classroom practices over months or years (Barab & Kirshner, 2001; Lemke, 2001). As designers of collaborative activities that involved technology, we had to work to refine our interventions on a number of levels. Surprisingly central was the way we helped students understand not only what to do but also how to view the social contexts we were creating (such as treating a design project as an extension of the scientific argument making they had been performing all semester). As new sorts of activities arise, they entail new communication genres and may even require new literacies. This is no small, one-off task, but a question of sustained effort within a particular context. As we invent new technologies, it is incumbent on us to develop new visions of practices or curriculum design patterns with those technologies, to be attuned to unintended outcomes, and to shepherd the technologies through changes in a changing world. As educators, we recognize that what we create is more than the sum of some software or worksheets—we create living examples of learning environments that teach us about learning, both as researchers or psychologists and as educators.

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ENDNOTE

1. This nomenclature is slightly misleading. Generally, all information resources were called evidence, whether or not the information was used in supporting or refuting a claim (a more traditional notion of evidence). In particular, when we sent students to Web sites, we called each site evidence. We explicitly considered both “good” and “bad” evidence, not only based on how applicable the information was to the argument being made but also based on how trustworthy or comprehensible the information was and whether or not it was based on some empirical data. Thus, a more accurate term might have been possible evidence to describe that this was information for consideration in relation to the students’ own understanding and in relation to the arguments students were making but that it might or might not actually be evidentiary in the nature of the classroom discourse.
Bibliography


BIBLIOGRAPHY


Dewey, J. (1896). Original letter to the Trustees of the University of Chicago arguing for the creation of a Laboratory School.
BIBLIOGRAPHY


Washington, DC, American Association for the Advancement of Science Press: 471–496.


BIBLIOGRAPHY


