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Promoting Students' Argument Construction and Collaborative Debate in the Science Classroom

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The focus of this chapter is to detail how students were supported in argumentation and debate as they explored information from the Web and what was learned in the process. Students were provided with various forms of educational infrastructure to support their argumentation and debate. To the degree possible, connections are made between the design that was enacted in the classroom and the outcomes observed. In this way, readers will be able to understand what in the learning environment contributed, in complex ways, to the observed student learning and interaction.

Argumentation and collaborative debate are central features of intellectual inquiry in the natural sciences; however, they rarely find their way into the science curriculum (Newton et al., 1999). I distinguish collaborative debate from other popular forms of debate used in school (e.g., Lincoln–Douglas style debates associated with high school speech classes) by emphasizing that the debates that proved to be most beneficial to science learning were focused on the collective exploration of issues and evidence by the group of students—and not on norms associated with winning at all costs or never admitting weaknesses from a theoretical perspective. The program of research I describe in this chapter has explored how argument construction and collaborative debate could be promoted in the science classroom for the dual purpose of having students learn science while also learning about the nature of science.

LEARNING SCIENCE WHILE ENGAGING IN THE EPISTEMICS OF SCIENCE

Historically, approaches to science education have often explored the teaching of science content and process as separate educational endeavors. The results have not been particularly satisfying. Frequently, students learn scientific content quite removed from learning about the nature of scientific inquiry. Not surprisingly, they develop a view that scientific knowledge is immutable and that inquiry is always a straightforward process. Students are frequently asked to engage in generalized forms of a scientific method quite apart from specific lines of inquiry, leaving them unable to understand how inquiry and understanding are intertwined pursuits. In the last 10 years science educators have investigated ways of not separating the learning of science into dichotomous content and process experiences (Krajcik, Blumenfeld, Marx, Bass, et al., 1998; Linn, 2000b; Reiser, Tabak, et al., 2001). These integrated approaches successfully engage students in forms of scientific inquiry as they simultaneously develop scientific knowledge that is grounded and relevant to scientific and personal life situations. The scaffolded knowledge integration framework (Linn, Bell, et al., 1998; Linn & Hsi, 2000) informs the development of curriculum that interleaves the exploration and refinement of conceptual knowledge as students are engaged in appropriate, derivative (or prototypical) forms of the epistemics of science.

A powerful outcome of this kind of integrated approach is that students develop rich conceptual knowledge while also learning about the epistemics associated with the nature of science. Students rarely understand the degree to which scientific knowledge changes over time (Collins & Shapin, 1986; Songer & Linn, 1991); however, a knowledge integration approach focused on argumentation and debate provides compelling educational contexts in which to develop an understanding of the dynamic nature of scientific knowledge production and refinement (Bell & Linn, 2001).

MAKING THE DYNAMIC NATURE OF SCIENCE VISIBLE TO STUDENTS

Scientific knowledge is precious to our global society. For better and for worse, knowledge from the natural sciences has increasingly influenced our activities, health, and livelihood over the last century. It is formulated, tested, applied, refined, and rejected in complex ways

that are highly dynamic and socially mediated. Debate and argumentation are constituent mechanisms associated with this knowledge work of science.

Typical science instruction can easily promote static views of scientific knowledge (Collins & Shapin, 1986; Songer & Linn, 1991; also see Bell, chap. 10, this volume, for a further exploration of these issues). Certainly efforts to standardize learning outcomes—which serve to focus educational outcomes mostly on specific content to be learned—reinforce this static depiction of scientific knowledge. Given the dynamic and social nature of the scientific enterprise, this is an unfortunate outcome. Students should learn how scientific understanding unfolds over time and intersects with the interests and arenas of society. As described in the following design narrative, formulating instruction as argument construction and collaborative debate offers the possibility to promote a dynamic and social view of scientific knowledge construction in ways that bear more epistemic fidelity to the intellectual mechanisms of the natural sciences.

DESIGN NARRATIVE: LEARNING ABOUT THE NATURE OF LIGHT THROUGH ARGUMENTATION AND DEBATE

From a subject matter perspective, it is difficult to overstate the importance of understanding the electromagnetic spectrum, of which visible light is only a minor subset. Light is an exceedingly complex natural phenomenon; however, humans' everyday reliance on it makes it an ideal focus for the science curriculum. The Computer as Learning Partner (CLP) project had elected to focus about one fourth of its curricular time on the topic of light. Through scaffolded experimentation (Linn & Hsi, 2000), students learned about light sources and receivers, light intensity over distance, reflection, absorption, scattering (diffuse reflection), and energy conversion. To further promote students' integrated understanding of light as a unique and virtually ever-present form of energy, the research group decided to culminate the 5-week curriculum sequence with an overarching debate activity (Weinland, 1993). The substantive focus of this debate project—called "How Far Does Light Go?"—was on an exploration of evidence related to the farthest extent of light's propagation from sources of illumination. In its original form, it was a worksheet activity including a dozen evidence items that were anecdotal descriptions consisting of one to three sentences. After being used, studied, and refined over several iterations, this version of the How Far Does Light Go? curriculum project was converted into the Internet format of the Knowledge Integration Environment (KIE). The light debate was the first KIE project to be used in the classroom (Bell, Davis, et al., 1995).

The KIE version of the How Far Does Light Go? debate project takes about 8 to 10 days to run in the classroom. Students explore a dozen relevant multimedia evidence items—including movies, simulations, complex Web pages of information, and some of the original anecdotal accounts—construct explanations and arguments about how the evidence relates to the debate topic, and then engage in a whole-class debate about the issues, claims, and evidence.

Iterative Refinement of the Collaborative Debate Activity

The evidence focus for the KIE research project was strongly influenced by several CLP curriculum activities that supported students in working with pieces of potential evidence as a form of scientific inquiry. The line of research described in this chapter began with the observation and analysis of the mature paper-based version of the light debate activity from the CLP curriculum.[1] Having observed significant promise for integration with information technology, I selected the debate project as a long-term focus of research and conducted five subsequent design research iterations. I detail all six iterations in the following sections.

Observational Iteration 1: Short and Simple Paper Design. The original paper-based version of the How Far project ran in three 50-min class periods. Students were initially presented with the debate topic (how far light can travel) along with two competing theories that were used to frame the debate—the scientifically normative theory that "light travels forever until absorbed" and the intuitively aligned theory that "light dies out as you move farther away from a light source." Students stated their initial position in the debate and then, working in pairs, they explored the collection of 12 anecdotal evidence items over the course of a class period or two. Students created an argument by selecting pieces that supported and contradicted their stated position. Evidence consisted of brief, textual evidentiary items such as "Brian looks up at one part of the sky on a clear night, and doesn't see any stars. When he looks through his telescope, however, he can see stars." The activity culminated in a student debate in which pairs would present the evidence they had identified that supported their stated position and responded to questions from other students. Students then individually had the opportunity to state their final position in the debate.

The selection of the two competing theories for the debate was carefully done. The normative position makes sense—educators want students to ultimately consider and understand the scientific perspective on the debate. The light goes forever position was framed at an intermediate level that was accessible to the students. The other intuitively aligned theory bears further discussion. The light dies out perspective succinctly frames a theoretical position that seems defensible in a superficial sense; it is a position that many students find compelling. It was crafted to fit with humans' phenomenological experience with light—as we move farther away from a light source, the intensity of the light drops off and the illumination seems to disappear or die out. In a manner that builds on student's prior knowledge, the light dies out theory allows students to connect and build on their current understanding of light. Overall, the debate topic was framed such that an explanation aligned with the normative theory necessitates an integration of knowledge about light from the CLP curriculum—knowledge of light intensity over distance, reflection, absorption, and energy conversion. That is, the overall framing of the debate project was aligned with the pedagogical focus of the curriculum: the integration of understanding.

Observational Iteration 1: The Social Dynamics of Classroom Debate. Research about this initial iteration focused on the social dynamics of the classroom debate: the role of the teacher during the debate, the nature of student questions and responses, patterns of interaction about the subject matter, and dimensions of the talk that seemed to promote or hinder learning. The research methods used to analyze the debate discourse involved a psychological coding of discourse moves made by participants (cf. Resnick, Salmon, et al., 1993) and a weak form of conversation analysis in which segments were analyzed in an attempt to understand the perspectives and meanings of the participants.

Students generated over 90% of the turns of talk during the classroom debate; it was a student-centered discussion. Given that the teacher only accounts for about 10% of the turns of talk during a classroom debate, it is possible that his role could be underestimated with that statistic. In contrast, analysis of the debate discourse showed that the teacher was playing several fundamental roles during the debate. First, they were framing the nature of the task to the student pairs and moderating the discussion for participation and consideration of ideas to be as equitable as possible. Second, they asked many questions initially during the question-and-answer portions of the debate to model the nature of appropriate questioning for students. Third, the teacher inquiries were balanced and probing questions for both of the theoretical sides of the debate; they did not play favorites or indicate directly which theoretical position was more valid. However, they did allow for a consensual view to emerge and to be elaborated in the public space over the course of the debate. These findings lead to the following design principle for orchestrating collaborative debates in the classroom:

> *Specific design principle: The role of the teacher during a classroom debate should be to moderate equitable interactions, to model appropriate question asking, to probe theoretical positions of the debate in equal measure, and to serve as a translator between students—all in the fewest turns of talk as possible.*

The paper-based debate activity allowed students to engage collaboratively in a prototypical form of scientific debate. The conversation analysis indicated that students asked relevant, probing questions of each other and brought out-of-school experiences into the discussion as evidence; these questions often led to elaborated explanations for student ideas and positions. Students were regularly elaborating, testing, refining, warranting, and possibly discarding their ideas about the debate topic. The following principle captures the purposes of the classroom debate with respect to the students' interactions:

> *Specific design principle: When engaged in a collaboratively focused debate discussion, students can safely share, explore, test, refine, and integrate their scientific ideas.*

The primary drawback associated with this paper-based iteration of the project hinged on the nature and entailments of the anecdotally derived evidence. Compared to what would subsequently be used, the evidence was quite simple—although it was personally relevant and somewhat compelling to the students. The pieces of evidence did not allow for any inclusion of data—only briefly described hypothetical experiences related to the debate topic. The sparse pieces of evidence led to impasses consisting of stated differences of opinion that were not resolvable because data or detailed information was not associated with the evidence. Subsequent versions of the project in KIE moved away from these simple depictions of scientific evidence.

Iteration 2: Multimedia Representations of Evidence and the First KIE Learning Environment. The How Far Does Light Go? debate was the first KIE curriculum project developed and used in a classroom. In keeping with the design of the KIE learning environment, students would explore the Web-based evidence items. As an adaptation of the paper-based activity, I developed multimedia evidence items (in collaboration with other research group members) to parallel the anecdotal, textual items from the previous successful version. Figure 6.1 shows stills from one of the KIE multimedia evidence items created called "Bicyclists at Night." Generally, the multimedia evidence included data and detail related to the evidence item that was an elaboration of the notion of evidence in the paper-based version of the project.

For each piece of evidence students were prompted (using ClarisWorks template files) to state its relevance to the debate. The KIE system did not easily allow for the customization of prompts for each piece of evidence—a feature that the research group would build into the next generation Web-Based Inquiry Science Environment

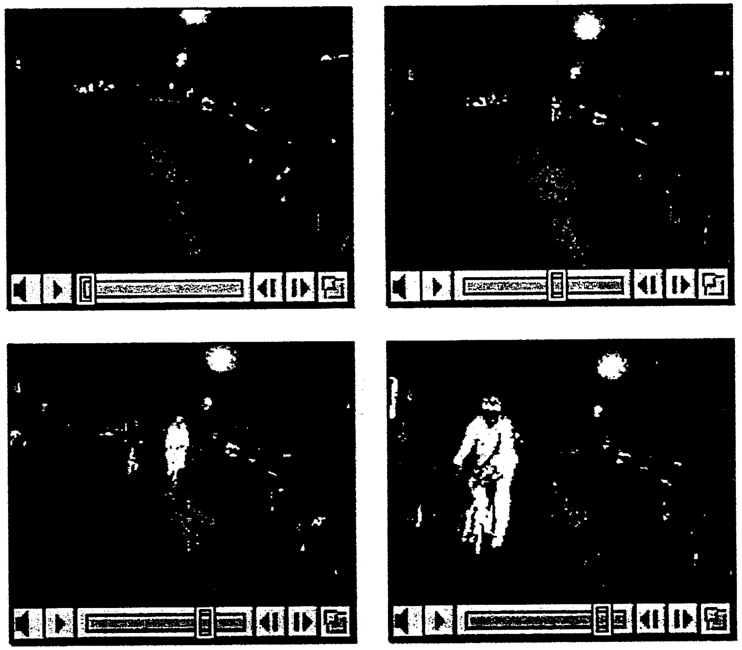


FIG. 6.1. Frames from the "Bicyclists at Night" movie evidence used in the light debate project.

(WISE) environment—so students were responding to generic, sentence-starter prompts for causal explanation of the form "This evidence is relevant to the debate because. . . ." However, students could receive any number of conceptual hints specifically relevant to each piece of evidence—available through the Mildred bovine science guide component.

Iteration 2: The Mystery of Media Representation on Interpretation. The transition from paper- to Internet-based inquiry allowed for a comparison study to be conducted that analyzed how students interpreted evidence in different media formats and marshaled the pieces in their arguments. The multimedia evidence items created—which included stills, movies, and interactive simulations—were designed to be as conceptually isomorphic to the original textual items as possible. Half the students received a blend of textual and multimedia evidence items and the other half received the complementary set (which was also a blended set).

Because each isomorphic text–multimedia evidence pair was conceptually similar, one might expect students to work with the items in a similar manner. However, dramatic differences were found. Students marshaled the evidence in support of different ideas and even positions in the debate. This media effect was fueled by common, idiosyncratic differences in terms of how the evidence pairs were interpreted. Figure 6.2 shows one of the more dramatic differences of interpretation (in terms of how the evidence supports one theory or the other).

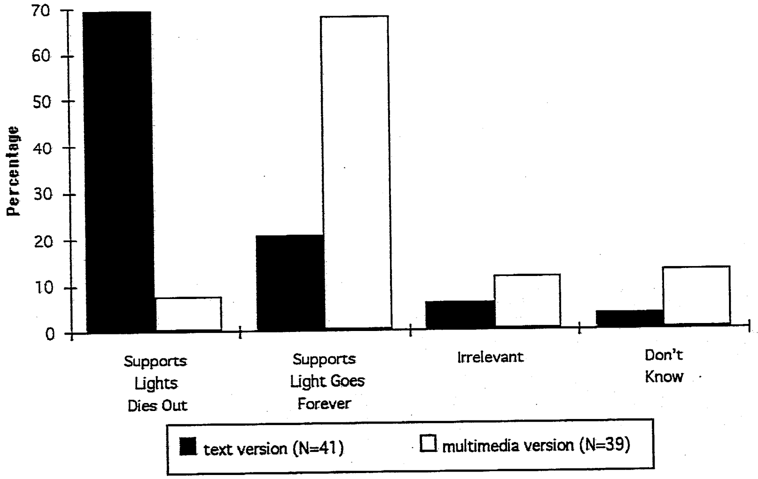


FIG. 6.2. Difference in interpretation of two conceptually isomorphic evidence pieces rendered in text and multimedia (the media effect).

There are many possible reasons why the media effect seemed so prevalent from the paucity or prevalence of data in the items to the epistemological stance of what counts as compelling scientific evidence to students (e.g., a telescope image being more compelling than an anecdotal description of the same). Perhaps the most compelling reason for the media effect is to associate the effect with a more established phenomenon from the assessment literature—the sensitivity of interpretation to surface characteristics of items (see Pellegrino et al., 2001, for more about this phenomenon). Although the underlying conceptual ideas were designed to be isomorphic, the surface characteristics were sometimes different. Students seemed to be taking these surface details into account as they worked with the evidence. We as educators learned that significant care needed to be taken in terms of understanding precisely how students would interpret and work with specific evidence presented in KIE, leading to the following design principle. For this reason, we have often needed to pilot evidence items and analyze written evidence explanations to understand how students generally engage with the piece and then decide if that fits within the overall purposes of the curriculum project in question:

> *Specific design principle: The media representation of scientific evidence significantly influences the interpretation of that evidence by students.*

The conversion of the project from the paper-based format to presentation within the Internet learning environment was largely successful. Learning gains measured through conceptual items indicated the same degree of conceptual change during the project (Bell, 1998). In addition, students were having the opportunity to engage with more sophisticated pieces of evidence and were prompted (e.g., by Mildred, the bovine science guide described by Davis, chap. 5, this volume) to think more deeply about the evidence and apply more sophisticated criteria to the evidence items. Although over the course of the six iterations the research team never dramatically improved the number of students that developed an integrated understanding about the specific debate topic—about 20% of the students started with a deep understanding of how far light goes and about 40% more students developed that deep understanding as a result of the debate project—almost all students made conceptual progress (Bell, 1998; Bell & Linn, 2000).

The analytical phase of this iteration also included a facet-based analysis (Minstrell, 1989, 2001) of the chunks of student reasoning involved in their written evidence explanation (see Bell, 1998, for details). This led to several dozen regularly occurring facets associated with student thinking about light. A cluster analysis of the co-occurrence of specific facets within the evidence explanations indicated that distinct, logically consistent sets of ideas were associated with the defense of the two theoretical positions (i.e., they each had a distinct facet cluster). This analysis provided details into the array of conceptual ideas and the interconnected knowledge that students typically possess about the light propagation topic. It provided a pedagogically useful description of the conceptual change landscape involved with the particular subject matter at hand. This "cluster map" was used to inform the further shaping of the How Far Does Light Go? debate instruction.

During Iteration 2, it seemed clear that students were overly focused on particular evidence items during the project. Rather than consider the entire corpus of available evidence—similar to the Popperian notion of the epistemics of science in which all evidence is considered and counterevidence sheds important light on the status of theories—students would fixate on one or two pieces they believed strongly supported their perspective. In addition, the arguments constructed seem to be relatively thin—students would categorize evidence relative to the two debate positions, but they were not elaborating on what the theoretical stances actually meant from their perspective. This led me to imagine the introduction of a new software tool, SenseMaker, which included a particular knowledge representation to support students in argumentation with more epistemic fidelity to arguments in science.

Iteration 3: Introducing Representational Infrastructure for Making Thinking Visible During Argumentation. To respond to the evidence fixation issues identified in the prior iterations, I designed, prototyped, and tested the SenseMaker argument editor as part of the light debate project. As shown in Fig. 6.3, SenseMaker provides an overview (or a "helicopter view") of the entire corpus of evidence associated with the project. It is a knowledge representation tool that allows for the coordination of claims (boxes) and evidence (dots) to create parsimonious argument maps. From the perspective of the epistemics of science, the tool was designed to reinforce the evidence–claim distinction, promote their coordination, and support students in working with the entire evidence corpus. SenseMaker is an argument editor that can be seeded with theoretical positions at the start of the project as a scaffold. It is a structured inscriptional system that allows students to express their personal understanding of the evidence.

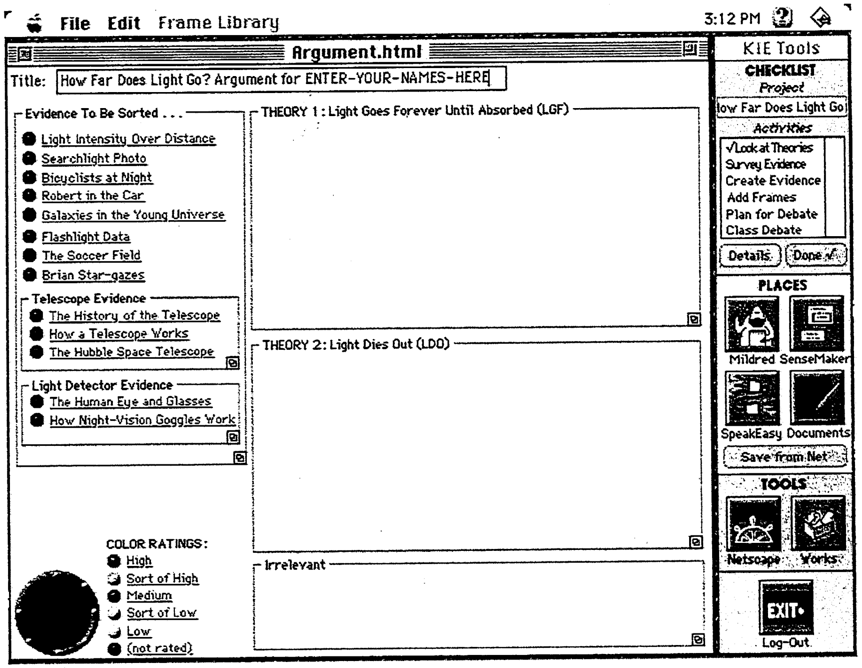
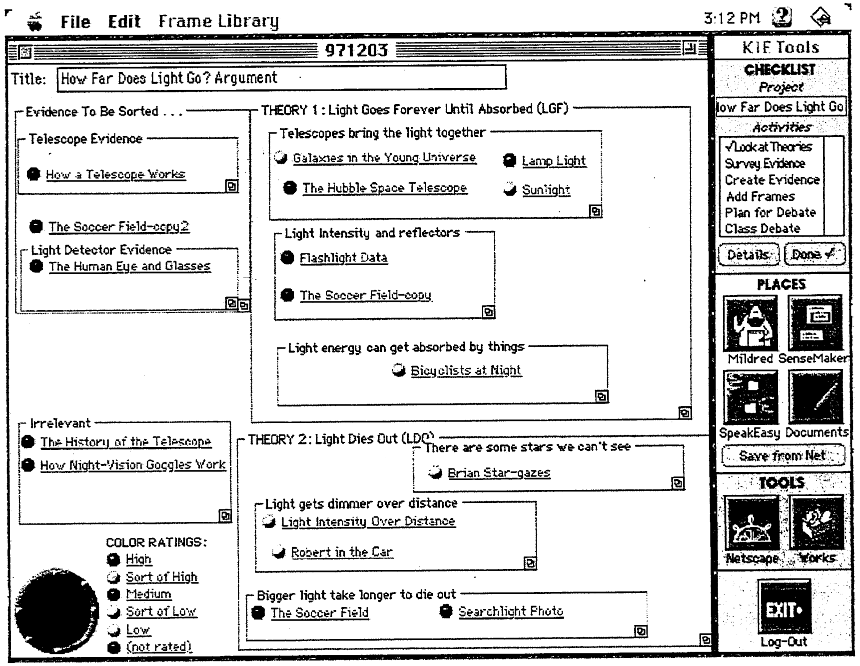


FIG. 6.3. Starting layout for the SenseMaker argument map used by students to represent coordinations of claims (boxes) and evidence (dots) associated with the debate topic.

Iteration 3: Unanticipated Uses of the Helicopter View of Argumentation. The tool was introduced to students in a lock-step activity structure—they organized evidence with claims after having already explored all of the evidence individually and having crafted corresponding evidence explanations (described in more detail in Bell, 1998, in press). The SenseMaker argument maps were a novel representation from the perspective of the students. It became immediately clear that it needed more of an introduction than was possible in this iteration. Students needed to become fluent with the intended use of the argument map representation. However, students were still largely successful in categorizing the evidence relative to the theoretical positions of the debate in this initial use, and a few student groups created a new conceptual frame of their own design to add to their argument maps.

The categories created were not what had been originally intended. It was thought that students would represent their conceptual ideas (e.g., "light gets dimmer over distance") as organizing, nested claim frames in the argument map. In practice, only one third of the students created frames of this kind. Another one third created categorical frames (e.g., "binocular evidence"), and the last one third created frames that were logistically useful to the authors during the debate (e.g., "good to avoid during debate"). Although all of these frames could be considered useful, for the goal of promoting conceptual change it was thought that conceptually focused frames would be the most useful in that it would make student thinking the most visible within the argument representations. Subsequent iterations addressed this issue as I describe following.

In this iteration, however, it did become evident that the introduction of the SenseMaker argumentation infrastructure was supporting many students in considering the entire corpus of evidence associated with the project. Other research has shown that students tend to predominantly focus on single instances of evidence—when they attend to it at all—to inform their claims and arguments (see Driver, Leach, et al., 1996, for a discussion of this phenomenon). Before the use of SenseMaker, students had often been basing their personal opinion on individual pieces of evidence they found to be compelling, often ignoring other contradictory pieces of evidence. Unless there are grounds for excluding specific pieces of evidence, a central epistemological goal in the natural sciences is for theoretical knowledge to account for the entire corpus of empirical evidence relevant to a topic. A compelling goal for science education would be to help students develop an understanding of the mechanics of developing an argument that attempts to take into account a corpus of empirical evidence along with an appreciation of why such an epistemic practice is beneficial with regard to the construction of a causal, theoretical explanation of phenomena of the natural world. By exploring an evidence collection and being asked to represent and coordinate the set in the SenseMaker argument representation, students are encouraged to not fixate on individual pieces. Figure 6.4 shows a completed SenseMaker argument map created by a student pair working on the How Far Does Light Go? project. Developing an argument that involves making sense of an evidence collection is an affordance of the argument map representation used in SenseMaker (Bell, 1998) and another argumentation tool called *Belvedere* (Toth et al., 2002). Thus, these knowledge representation tools support the epistemic practices associated with having students make sense of patterns in all relevant data as they coordinate



Title: How Far Does Light Go? Argument

Evidence To Be Sorted . . .
Telescope Evidence
● How a Telescope Works
● The Soccer Field-copy2
Light Detector Evidence
● The Human Eye and Glasses

THEORY 1 : Light Goes Forever Until Absorbed (LGF)
Telescopes bring the light together
● Galaxies in the Young Universe
● Lamp Light
● The Hubble Space Telescope
● Sunlight
Light Intensity and reflectors
● Flashlight Data
● The Soccer Field-copy
Light energy can get absorbed by things
● Bicyclists at Night

Irrelevant
● The History of the Telescope
● How Night-Vision Goggles Work

THEORY 2: Light Dies Out (LDO)
There are some stars we can't see
● Brian Star-gazes
Light gets dimmer over distance
● Light Intensity Over Distance
● Robert in the Car
Bigger light take longer to die out
● The Soccer Field
● Searchlight Photo

COLOR RATINGS:
● High
● Sort of High
● Medium
● Sort of Low
● Low
● (not rated)

How Far Does Light Go
✓Look at Theories
Survey Evidence
Create Evidence
Add Frames
Plan for Debate
Class Debate

FIG. 6.4. Completed SenseMaker argument map showing how one student pair interpreted the evidence corpus and theorized about the debate topic.

theory and evidence in their constructed arguments, as summarized in the following design principle:

> *Specific design principle: Make evidence collections visible. When students attend to evidence in their argumentation, they tend to fixate on individual pieces. Argument representations promote student consideration of a corpus of evidence during argument construction.*

SenseMaker was designed to promote students' theorizing, to support evidence–theory coordination, and to make their thinking visible during classroom debate. There are a couple of relevant trade-offs involved with its design and use that are worth mentioning. First, I settled on presenting a particular representational form to students for them to become fluent with and use for their argument-building efforts. This did not need to be the case. One can imagine supporting students in developing their own epistemic representations that could easily look quite different and be more personally meaningful to students. However, given the desire to allow students to easily compare their constructed argument maps with those of other students and due to time constraints in most classrooms (especially involving the use of computers), a standardized form for the argument maps was preferred in this case. A second trade-off has to do with the representation selected. It is best thought of as an intermediate, or prototypical, form of scientific argumentation. A representation could have been employed that has greater fidelity to the nature of scientific explanation or was elaborated for other means, but I gravitated to an intermediate representation that would have a milder learning curve without sacrificing the epistemic goals at hand.

Most importantly, the use of this principle is contingent on a larger system of design decisions that involve supporting science learning through scaffolded evidence-based inquiry (see Bell & Linn, 2000, for more details). The focus on the corpus of evidence only makes sense in that pedagogical context. The argument map representation itself has been used for a variety of topics with diverse fields within the natural sciences; it is quite general as a scientific knowledge representation in that regard. (This design principle, as embodied in variations of the SenseMaker argument map representation, is currently being studied in the support of students' historical inquiry; more specifically, variations on the argument map representation appear to be well suited for microhistorical controversies, although some changes were needed to account for the multiple causality more typical of historical explanations.)

As important as it is to represent a collection of evidence in an argument representation, I have found it useful for that collection to consist of a shared corpus for students to explore as part of the curriculum project. An alternative would be to allow pairs of students to explore different collections of evidence. It is likely that this alternative approach could be used to promote the development of distributed expertise within the classroom (A. L. Brown, Ash, et al., 1995).

What are the possible benefits of using a shared evidence corpus for all students in a class? First of all, a shared corpus allows the classroom teacher to develop pedagogical content knowledge relevant to supporting students with their engagement with the evidence and thinking about the project topic (Wilson et al., 1990). Predictably, each piece of evidence cues prior knowledge somewhat systematically from the students. Pieces of evidence of different forms also benefit from particular interpretation practices associated with understanding that piece. For example, an evidence item that depicts a specific laboratory experiment calls for an interpretation of details from the experiment and the associated data generated.

Another important consequence associated with using a common corpus of evidence is that it helps establish common ground for discourse in these learning communities as they explore and debate the project topic (Edwards & Mercer, 1987). That is, the corpus allows groups of students along with the teacher to work toward a shared understanding of the same phenomena and theoretical ideas. In a related manner, students will often invoke common life experiences as a form of evidence in their verbal arguments to make their arguments more compelling and understandable. For this very reason, I also have students extend the shared corpus of evidence with instances of this evidence from their own personal life experiences. It also allows students to connect the project topic to their own lives and develop more of an integrated understanding of the topic:

> *Specific design principle: Shared corpus of evidence. Engaging classes of students with a common corpus of evidence will allow the teacher to more quickly refine usable pedagogical content knowledge and instructional strategies related to the topic. It will also help establish an increased degree of common ground during classroom discussions.*

Iteration 4: Activity Structures for Argument Construction. SenseMaker was still not being used in a sophisticated manner by most of the students as of the third iteration of the project; there were only select instances of innovative uses. The fourth iteration attempted to better introduce the idea of argument map representations and more systematically support students in using the argumentation tool during their argument construction process to get broader compelling use of the tool by students. It was thought that more extensive use of the argument map representation was necessary: A 2-day curriculum project was developed that simply introduced students to SenseMaker, and the How Far Does Light Go? project was amended to fully integrate the use of the SenseMaker tool into the activity structure whereby students survey each piece of evidence.

Iteration 4: Fostering Causal Argumentation Incrementally. Designing the software for a new learning technology tool is only the first step of the necessary educational design process. For tools in which specific uses are imagined or desired, it then becomes necessary to design instructional experiences and activity structures that help students develop fluencies related to the desired use of the tool.

In this particular case, the lock-step activity structure used in the third iteration was thought to be somewhat problematic. Students segmented the use of the tool from their work with the evidence because work with the evidence items and the argument map were in sequence. In the fourth iteration, the SenseMaker argument maps became the central organizing representation of the argumentation process. In this integrated activity structure, students surveyed evidence from the argument map, created their evidence explanations, and categorized the evidence before moving on to the next piece. The argument map was thereby slowly constructed over the course of days in an incremental fashion in conjunction with their interpretation of the evidence and their authoring of evidence notes. Students developed their argument maps more slowly over time. These three activities became an integrated intellectual experience for most students, leading to a more coherent and refined argument:

> *Specific design principle: Students created more elaborated arguments when an activity structure was promoted whereby the use of the knowledge representation tool was integrated into their interpretation and theorizing about evidence.*

Yet what is the quality of the arguments being created by students? Is it unreasonable to expect middle school students to know how to productively coordinate evidence and theory? That is, do students have an epistemological facility for engaging in such evidence–theory coordination if they were to receive appropriate supports and enculturation? Researchers have documented how students do not come to science class understanding this type of argumentation (Driver, Leach, et al., 1996; Kuhn, 1991). However, structural analysis of the arguments created by students revealed that students regularly coordinate evidence and theory when provided with these supports during instruction (see Bell, 2002; Bell & Linn, 2000).

At least in part, I believe that it is because both evidence (dots) and theoretical claims (frames) are components of the ontology of the SenseMaker software. The active coordination of evidence and theory in the representation also supports the epistemic goals of knowledge being the object of inquiry in science and the importance of understanding the reciprocal relation between theory and data. This creation and tethering of evidence and theory is the inquiry students are engaged in during these controversy-focused debate projects. Through this particular depiction of scientific argumentation (which is an intermediate form, as mentioned earlier), students are being introduced to an important form of scientific knowledge—another goal associated with epistemic understanding.

This principle is motivated by the image of science represented in the epistemic goal that students understand the reciprocal relation between theory and data. The epistemic game of interest here focuses on a coordination of evidence and theoretical claims associated with the topic of inquiry:

> *Specific design principle: Theory–evidence coordination. Left to their own accord, middle school students rarely incorporate instances of evidence into their arguments about science. Argument representations should promote theory and evidence presence, distinction, and coordination.*

Yet how exactly are students coordinating evidence and theory? Are these coordinations descriptive connections or causal conjectures or something else? Actually, structural analyses of student arguments showed that 70% to 80% of the evidence explanations composed by students involve trying to use or establish causal warrants related to the debate (Bell, 1998; Bell & Linn, 2000). Only 15% of the explanations on average relied on phenomenological description to try and establish a connection between evidence and theory, leading to the following design principle:

> *Specific design principle: Causal theorizing. Students produce arguments that predominantly include causal conjectures connecting empirical evidence and theoretical conclusions when they are supported in a process of authoring prompted explanations. Such theorizing is further supported when it becomes the focus of community discussion in the classroom.*

Iteration 4: Room for Improvement. In the fourth iteration students were introduced to the SenseMaker argumentation tool during a 2-day activity in which they constructed arguments based on the scientific principles and evidence (interpreted data) associated with their laboratory experiences with light. It was thought that building an argument about their prior laboratory work would help promote further knowledge integration by bringing it all together into one argument map. At the same time, I hoped they would learn about argument map representations. It was a plausible approach, but it did not pan out as desired. Students were still generally confused about the argument map representation and were not accustomed to revisiting all of their prior classroom activities in this kind of synthesis effort.

Apart from some early learning of the SenseMaker interface, it was not thought that students developed any significant fluency with the tool or the representation through this introductory activity. This still left this strand of research with a palpable problem: how best to introduce students to the possibilities and features of the knowledge representation tool.

Iteration 5: Exploring the Past to Argue About the Present. I decided to try modeling expert use of the SenseMaker tool to the students. The 2-day introductory project was redesigned and expanded to a 3-day exploration of a historical debate: a hypothetical argument between Johannes Kepler and Sir Isaac Newton about the relation between light and color. Not only was the project a reasonable subject matter extension of the light curriculum, but it introduced the nature of expert arguments, the personal nature of theorizing and interpretation of evidence, and the historical prevalence of argumentation and debate in science.

Kepler theorized that light and color were distinct phenomena—that colors were produced when pure white light picked up and actually carried colors (which were a natural kind of their own). Through experimentation Newton developed a theoretical alternative: that white light is composed of different specific colors of light. For the brief curriculum project, several relevant pieces of historical evidence were authored. Students were asked to interpret arguments of Kepler and Newton—presented as SenseMaker argument maps—and then author their own new argument map using SenseMaker with the same pool of evidence.

This modeling of expert use of the SenseMaker tool proved to be quite beneficial. Students learned a bit about light and color while coming to understand argument maps in a relatively complex way and learning the software interface. The project modeled the desired prototypical form of scientific argument—the coordination of knowledge claims and evidence—and demonstrated the personal creative act involved with interpreting evidence and making conjectural claims about a topic. Fluency with this prototypical representation is quite attainable but is contingent on a broader emphasis on how knowledge is constructed and refined in science. To this end, care needs to be taken to promote a disciplinary understanding of the nature of evidence, theory, and explanation in science as it varies from everyday reasoning. Importantly, the project also showed that two scientists could disagree about pieces of evidence based on their own ideas about the subject matter. This seems to have allowed students more expressive freedom in representing their own ideas and coordinations of evidence in their argument maps:

> *Specific design principle: Introducing argumentation through the exploration of a historical debate between scientists allows students to understand aspects of scientific argumentation and the creativity involved with theorizing and coordinating with evidence, as well as how individual ideas can shape one's interpretations of evidence and constructed arguments.*

Iteration 5: Promoting a Blended Argument Representation. Building on the principled focus on evidence–theory coordination through an engagement with an evidence collection that is shared, I now describe how SenseMaker can serve as an inscriptional system for representing students' scientific ideas, notions, conjectures on one hand and various perspectives (hypotheses, positions, solutions, or propositions) about the controversy topic associated with the project. Although both dimensions of this knowledge—student and topical—come to be represented, they become interrelated (or blended) in the actual representation. This is typically an interaction of how the representation was originally designed by the project developer or teacher and how the students represent their understanding and conjectures visibly in the representation.

Before the project begins in the classroom, the SenseMaker representation is set up with some initial theoretical structure built into it in the form of competing claim frames. In this regard, it is useful to map out the competing perspectives associated with the controversy. In the How Far Does Light Go? project, there are claim frames for each of the theories and for irrelevant evidence (as shown in Fig. 6.3). Note that apart from looking to the topic for guidance in the initial design of the representation, it has also been useful to represent positions that will resonate with students initial thinking about the topic—to give them a way to easily represent their personal understanding in their argument map. The blend of the student thinking within the perspectives associated with the topic can promote active sense making and perspective taking on the part of students (see Bell, 1998, for details):

> *Specific design principle: Represent student thinking and topical perspectives. Promote the use of the argument representation as a blended representational medium that depicts (a) students thinking and theorizing about the controversial topic (based on their*

prior and evolving understanding) and (b) different perspectives associated with the controversy.

Iteration 5: Room for Improvement. As described in Iteration 4, it was observed that students were very savvy at authoring causal warrants for evidence. Interestingly, they were still having difficulties creating frames in their SenseMaker arguments. Due to the causal theorizing in their evidence explanations, I knew it was not due to a lack of ideas—it seemed like they could not abstract the embedded ideas into more general conceptual frames. During the fifth iteration of the How Far Does Light Go? project, I experimented with the use of a frame library—a list of conceptual ideas that students could consider making into frames in their argument maps. Because the goal was to just promote theorizing, the frame-library list includes scientifically normative as well as alternative conceptions. It provided further modeling as to what was desired in the argument maps along with some specific suggestions. The frame-library list proved to be useful enough to students that I built the library into the SenseMaker software for use in the sixth trial.

Iteration 6: Perspective Taking Promotes Argumentation and Learning. Given the educational goals of the KIE research group, the How Far Does Light Go? curriculum project was running pretty well at this point. Also, with most of the educational package developed, refined, and integrated in this curriculum sequence, it was now possible to pose a theoretical question through a compelling comparison of two hypothesis-driven variations in the educational package. Were students better off developing an argument for their original position in the debate, or was it more helpful to support students in thinking about both perspectives in the debate? These two alternatives became the "personal scope" and the "full scope" conditions in the sixth iteration of the project. Three of the six periods of students were in the "personal scope" condition and were told they would defend the theoretical position they initially identified with about how far light goes. The other three periods of students—who were in the "full scope" condition—were told that they should prepare to defend either theoretical perspective as they constructed their argument. When the debate arrived, the teacher and I allowed students to defend the theoretical position they believed in at the time, as we had not had luck in a previous iteration asking students to defend a position they did not believe in.

Did the perspective-taking activity structure influence students' learning, or did students learn more by being asked to bolster their initial position? The results were compelling. In the "full scope" condition that promoted perspective taking, there was a gain of 57% of students who developed a full scientific understanding of light propagation by the end of the semester compared to a gain of 39% of students doing the same in the "personal scope" condition (Bell, 1998). Further, I found that students with a low prior knowledge of light actually benefited more from the perspective-taking activity structure than students who had some knowledge of light. Being in the "full scope" condition led to more conceptual theorizing in student argument maps, especially among students who initially were aligned with the non-normative light dies out perspective. This indicates a powerful effect of perspective taking: that the activity structure scaffold better supported the development of an integrated understanding than asking students to just explore, refine, and be responsible to their initial opinions about the debate topic:

Specific design principle: Compared to allowing students to refine their initial position in a debate, students engaged in a perspective-taking activity structure theorize more in their argument maps and evidence explanations and develop a more integrated understanding of the subject matter in the process.

Iteration 6: Promoting Scientific Discussion During Classroom Debates With Argument Maps. In the How Far Does Light Go? curriculum projects (and other WISE and Science Controversies Online Partnerships for Education debate projects), students present their scientific arguments constructed in small groups during a culminating whole-class debate after they have investigated the corpus of shared evidence. Without the use of argument map representations, most students rely on a rather straightforward rhetorical strategy as they participate in the debate: They present just their strongest pieces of evidence to the class, trying to bracket the discussion to those particular evidentiary pieces and the related reasoning. There is good reason for students to begin their argument with the pieces of evidence they found to be most compelling. However, for reasons discussed during the third iteration, students should be accountable for the corpus of evidence available for a given topic (with obvious caveats pertaining to time constraints).

The SenseMaker representation has been used in a number of classrooms as supplemental intellectual infrastructure for argument construction and debate activities. In addition to scaffolding the argument construction of individuals or pairs of students (as described previously), the resulting argument maps can also be used as collaborative, comparative artifacts with each one representing the understanding, albeit only partially and abstractly, of particular participant groups during the culminating debate activity (see Bell, 2002, for more detail). In the sixth iteration the argument map representations were incorporated into whole-class debates in science classrooms and their influence on the discourse dynamics has been studied using conversation analysis methods. More specifically, as student pairs present their argument to the class, their argument map was web-casted to all of the computers spread around the room. Students in the audience could then compare their printed argument maps with that of the presenting group (see Fig. 6.5 for a symbolic representation of this setup).

When argument maps were used in this manner, the discourse patterns involved with the classroom debate shifted. Student presentations still took the form of highlighting their strongest pieces of evidence. However, questions from students in the audience focused largely on evidence *not* mentioned by the presenters. After some initial modeling by the teacher and researcher, students regularly engaged in the practice of asking student presenters about evidence that they had ruled as being irrelevant to the debate or had theoretically interpreted differently than others in the classroom. The argument maps became representational infrastructures that allowed students to compare interpretations of evidence (or underlying scientific ideas). Audience members used the maps to hold presenters more accountable to the corpus of evidence involved with the project. The maps provided a social mechanism for the unpacking of student thinking in a very focused way. Students had spent days building their scientific arguments about the evidence, basically amassing intellectual capital about the topic that was cashed in during the debate discussions in ways that established learning opportunities around the epistemological and conceptual issues involved:

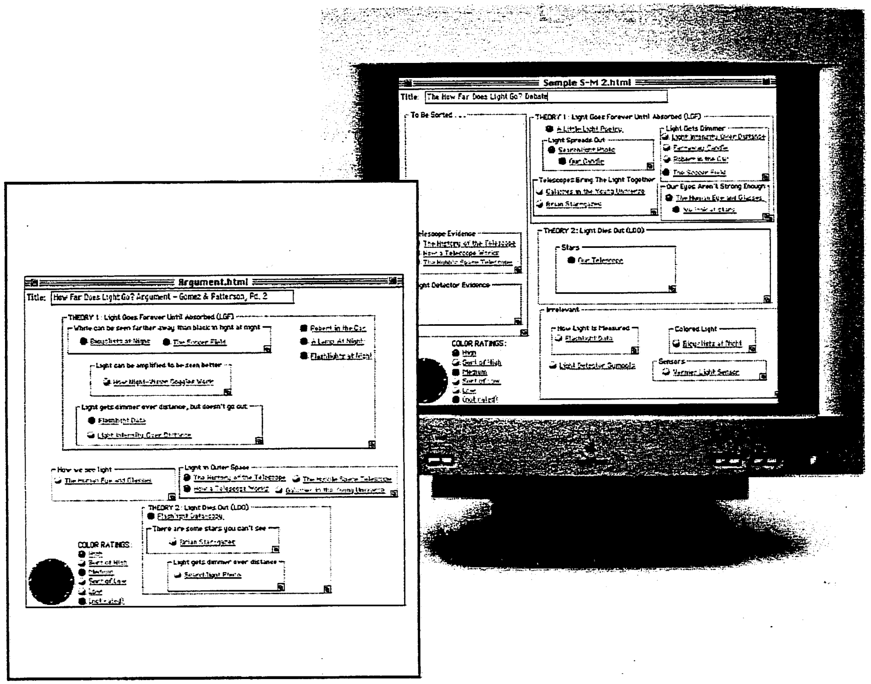


FIG. 6.5. Picture detailing the comparative use of argument maps during whole-class debate presentations and discussions. Students compare their own printed argument map (left) to the map created by the presenters projected on computer screens in the room (right).

> *Specific design principle: Debate infrastructure. Use argument map representations comparatively during whole-class debate presentations to promote accountability to the body of evidence under consideration.*

Iteration 6: Promoting Epistemological Sophistication Through Argumentation and Debate. One might wonder if all of this argumentation and debate lead to the same degree of understanding of the debate topic, then why bother with the KIE approach. In short, it is because students are learning about the nature of science in significant detail in addition the their development of integrated conceptual understanding. During the sixth iteration, I posed epistemological questions to students about argumentation and debate in science to gauge their degree of epistemological sophistication before and after the How Far Does Light Go? debate project. Categorical coding of student responses indicated that students developed a greater understanding of the evidentiary basis of scientific argumentation, the general connection between argumentation and learning, and the social refinement of their own integrated understanding during the debate activity (see Bell & Linn, 2000, for details).

Given that students seem to have difficulty understanding the evidentiary nature of scientific argumentation (Koslowski, 1996; Kuhn, 1993) and the social dimensions of science (Driver, Leach, et al., 1996), this documented statistical shift is an important mark of epistemological sophistication that should be considered an important educational outcome of the same importance, if not greater, as the conceptual understanding of some particular subject matter. With this increased degree of sophistication, students are more likely to approach scientific information and sense making in productive ways. Debate in science will less often be perceived as arbitrary, unproductive, or mysterious.

CONCLUSIONS

Argumentation and Debate as Core Intellectual Practices of the Natural Sciences

How does scientific knowledge progress over time? One might think that the settled, factual knowledge of science simply accumulates. Certainly new experiments lead to new knowledge about the natural world. Yet new knowledge often displaces old knowledge. Relativity offered a significantly different alternative to the Newtonian model of motion. Accumulation is not a sufficient epistemological model in and of itself. At the cutting edge of scientific knowledge, there are often competing notions or models being explored. Technology and experimental design is brought to bear on the issues. Arguments are mounted and debates come about.

I frame debate and argumentation as the exploration of a theoretical controversy involving the coordination of evidence with theoretical ideas. It seems incontrovertible that argumentation and debate are central mechanisms that drive the advancement of scientific knowledge (as well as knowledge in other disciplines). The history of science is full of accounts in which competing hypotheses and models have been explored around a specific scientific topic through theoretical and experimental means. Kuhn (1970) described how different theories attempting to describe the same phenomena can advance until the approaches are incommensurable in terms of the language and concepts used. Such distinctions can lead to paradigm shifts in scientific fields as a debated topic is resolved.

In the natural sciences, argumentation and debate operate at many different time scales and in numerous formal and informal venues. Controversies can span generations or be resolved in a matter of days or months. Latour (1987) documented scientific debates occurring on specific scientific hypotheses over the course of years, months, or even days. For example, he described in detail how two research laboratories explore competing notions of growth hormones. Therefore, there is reason to believe that in addition to being a historical lens on which to view scientific events across generations (i.e., the Kuhnian sense), debate is also an active, day-to-day, operational construct for scientists. Indeed, Latour (1987) spent significant time documenting the competitive nature of science. One need only investigate accounts of current controversies in science to see central aspects of debate represented. I explore this idea in depth in chapter 10 (Bell, this volume).

Scientific debates play out within the formal venues of the primary and secondary scientific literatures. They surface publicly in scientific society meetings and privately in informal research group meetings and bar room gatherings of scientists. They partially, and frequently imperfectly, show up in the mainstream press. The research in this chapter is predicated on the assumption that argumentation and debate are central features of substantive intellectual work in the natural sciences. An entailment of this assumption also needs to hold in that argumentation and debate in the natural sciences need to follow epistemic rules and norms of practice that allow for their characterization—at least at a level of detail that might be characterized as a prototypical form appropriate for students. Of course, such systematic characterizations of argumentation are somewhat commonplace in philosophy (e.g., Toulmin, 1958). Such forms have been characterized by Collins and Ferguson (1993) as epistemic forms.[2] With these assumptions in mind, the focus of this research then becomes how students can be educationally engaged in such prototypical forms of argumentation and debate such that they can make sense of diverse information sources and develop a more integrated understanding of science.

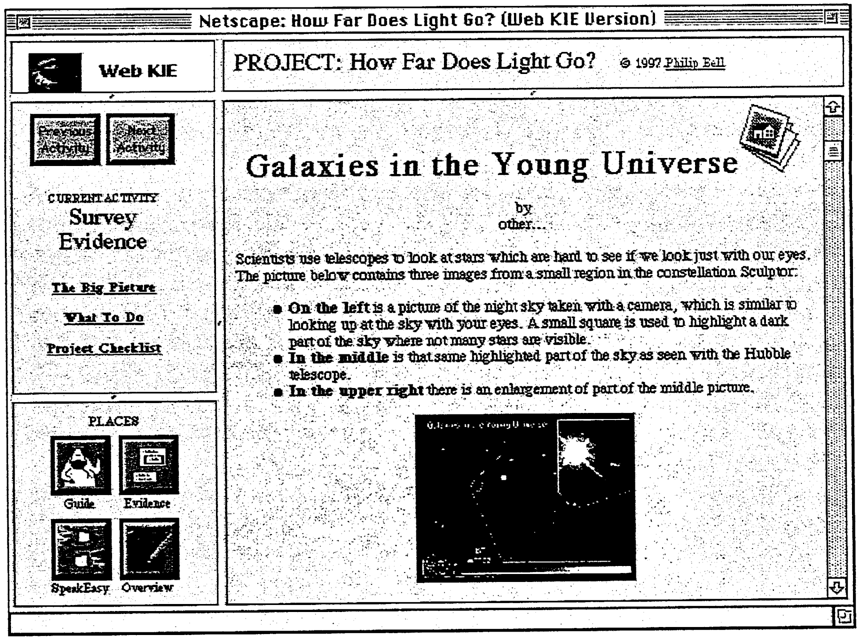
Supporting Student Learning Through Argumentation and Debate—Mission Impossible or a Matter of Scaffolding?

Student argument maps can serve as learning artifacts that provide a window onto their thinking about the science as well as about the nature of science. I have used analyses of these artifacts to understand student learning from the designed curriculum as well as the nature of their epistemological sophistication (Bell, 2002; Bell & Linn, 2000). Most middle school students have not experienced a structured debate activity in school. They probably experience argument construction mostly within the confines of their English and social study classes. Fostering argumentation and debate in the classroom can seem like unknown pedagogical territory to middle school science educators. Developmental psychologists studying the growth of argumentation strategies and abilities (Koslowski, 1996; Kuhn, 1991, 1993) have highlighted that several dimensions of the intellectual activity prove to be quite difficult for adolescents, including the coordination of evidence and theory, consideration of multiple perspectives, the construction of rebuttals, and other metacognitive features of argument. It is important to realize that most of these developmental studies are conducted under information-lean and relatively unscaffolded conditions. In contrast, the program of research I described in this chapter has indicated that compelling arguments and generative debate experiences can be scaffolded in middle school science classrooms. Students may not have been able to spontaneously engage in these performances, but when they are tuned into the epistemic game at hand and supported in their inquiry, they can indeed engage in such intellectual activities and develop a more integrated understanding of complex science topics in the process.

EPILOGUE: PUSHING THE LEARNING ENVIRONMENT THROUGH THE BROWSER

Over the course of the software and curriculum iterations in KIE, the World Wide Web—as it was described at the time with some cumbersomeness—continued to thrive and mature as a technical platform. When Netscape® Version 3.0 showed up (with integrated Javascripting), we realized that it would be possible to push more of the KIE learning environment functionality through the web browser directly. Rather than relying on the careful coordination of half a dozen local Macintosh® applications, it started to become possible to embed more of this functionality into the web experience itself. This shift in the technological implementation cannot be understated with regard to the corresponding technical support issues. The minimum technical requirements would become a recent browser with decent simultaneous browsing capabilities for all the machines to be used.

Building on the new scripting functionality and support for frames in the Netscape browser, I developed a web-centric version of the How Far Does Light Go? debate that is still in use at the time of this writing, although the research group has improved upon it a couple of times more with the development of versions of the WISE environment. Figure 6.6 shows what is called the "WebKIE" version of the How Far Does Light Go? debate.



PROJECT: How Far Does Light Go? © 1997 Philip Bell

Galaxies in the Young Universe

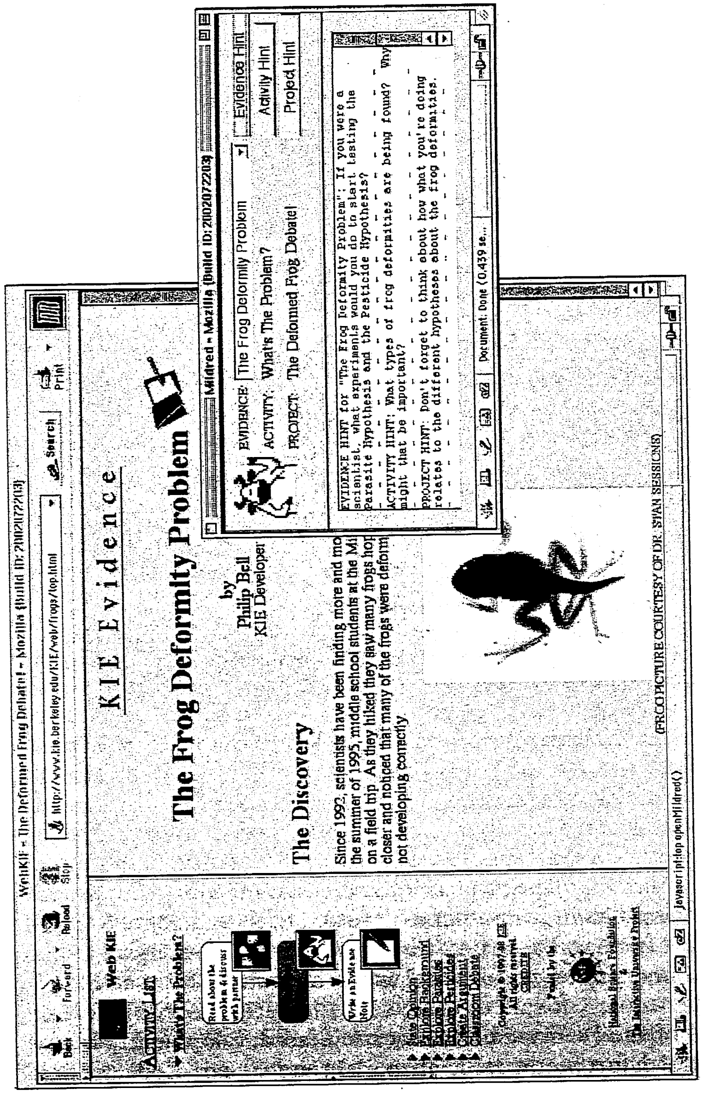
by
other...

Scientists use telescopes to look at stars which are hard to see if we look just with our eyes. The picture below contains three images from a small region in the constellation Sculptor:

- **On the left** is a picture of the night sky taken with a camera, which is similar to looking up at the sky with your eyes. A small square is used to highlight a dark part of the sky where not many stars are visible.
- **In the middle** is that same highlighted part of the sky as seen with the Hubble telescope.
- **In the upper right** there is an enlargement of part of the middle picture.

FIG. 6.6. The Web Knowledge Integration Environment (KIE) implementation of the How Far Does Light Go? debate project provided some of the core KIE functionality directly through the Web browser rather than using custom software components.

The WebKIE implementation was like taking a step backward with regard to some of the functionality that had come to be present in the full KIE suite of tools; this was necessary given the instabilities of the technical platform and the approach taken at the time. However, once this implementation direction proved sound, the KIE research group conducted a series of design meetings to come up with an approach whereby we could include more of the evolved functionality of KIE and even extend it further. Based on those group design meetings, I implemented the first prototype for what would become WISE (see Slotta, chap. 9, this volume, for more details on the design of WISE) within the context of the Deformed Frogs curriculum development partnership (described further in Bell, chap. 10, and Shear, Bell, & Linn, chap. 12, this volume). Figure 6.7 shows this early precursor to the WISE environment (which has gone on to be used by tens of thousands of students). It includes the first time that the inquiry map provided procedural scaffolding—an elegant, although perhaps somewhat static, solution to the scaffolding of student inquiry and to the orches-



KIE Evidence

The Frog Deformity Problem

by
Philip Bell
KIE Developer

The Discovery

Since 1993, scientists have been finding more and mo
the summer of 1995, middle school students at the Mi
on a field trip. As they hiked they saw many frogs hop
closer and noticed that many of the frogs were deform
not developing correctly.

(FROG PICTURE COURTESY OF DR. STAN SESSIONS)

EVIDENCE: The Frog Deformity Problem
ACTIVITY: What's The Problem?
PROJECT: The Deformed Frog Debate!

EVIDENCE HINT for "The Frog Deformity Problem": If you were a scientist, what experiments would you do to start testing the Parasite Hypothesis and the Pesticide Hypothesis?

ACTIVITY HINT: What types of frog deformities are being found? Why might that be important?

PROJECT HINT: Don't forget to think about how what you're doing relates to the different hypotheses about the frog deformities.

FIG. 6.7. The Web Knowledge Integration Environment (KIE) implementation of the deformed frogs mystery project was the immediate precursor to the Web-Based Inquiry Science Environment learning environment. It included a clickable inquiry map for procedural scaffolding and provided integrated access to different tools (e.g., Mildred, the bovine science guide component).

tration of numerous tools and information resources without having to resort to a strictly sequenced interface. All these versions of the debate activity refined the underlying curriculum design pattern. Each new version took advantage of the prior work with the pattern.

These environments proved to be incredibly productive educational resources to fuel argumentation and debate in the science classroom. As I have described in this chapter, many details of the design and appropriation need to be carefully considered as they are systemically and culturally rooted within a specific learning community. Further research on supporting student learning through the exploration of scientific controversy with information technologies built on and refined these design principles and research findings (see Bell, chap. 10, this volume, for details). I believe this line of research is still compelling given the new forms of access to information ecologies via cell phones to personal digital assistants to wireless communicators, and the promises and complications of research from the natural sciences seem only to be becoming more prevalent. Educators need to understand how to support individuals and groups in developing an integrated understanding of controversial issues of science and make sense of the diverse pieces of scientific information they encounter across the breadth of their life activities.

ENDNOTES

1. The development and refinement of the original paper-based version of the "How Far Does Light Go?" project was conducted by Weinland (1993) in collaboration with the other members of the CLP group.
2. It is certainly worth mentioning that argumentation and debate are likely to vary across disciplines and even subfields within the natural sciences. The prototypical forms put forth in this research should not be taken to be any sort of universal grammar for argumentation and debate in the natural sciences. In fact, given that much empirical work in the various corners of scientific practice remain to be conducted, the prototypical form model presented should at best be taken to be an initial educational treatment.