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Scientific arguments as learning artifacts: designing for learning from the web with KIE

Philip Bell, College of Education, University of Washington, USA; e-mail: pbell@u.washington.edu and Marcia C. Linn, Graduate School of Education, University of California at Berkeley, USA; e-mail: mclinn@socrates.berkeley.edu

We designed Knowledge Integration Environment (KIE) debate projects to take advantage of internet resources and promote student understanding of science. Design decisions were guided by the Scaffolded Knowledge Integration instructional framework. We report on design studies that test and elaborate on our instructional framework. Our learning studies assess the arguments students construct using the Knowledge Integration Environment debate project about light propagation and, explore the relationship between students' views of the nature of science and argument construction. We examine how students use evidence, determine when they add further ideas and claims and measure progress in understanding light propagation. To a modeate degree, students' views of the nature of science align with the quality of the arguments.

Designing for knowledge integration

Promoting knowledge integration can improve science understanding and help students become lifelong learners (Linn and Muilenburg 1996). In this research, we explore the relationship among: (a) design elements in the Knowledge Integration Environment (KIE); (b) characteristics of student arguments; and (c) students' views of the nature of science. By knowledge integration we refer to a dynamic process where students connect their conceptual ideas, link ideas to explain phenomena, add more experiences from the world to their mix of ideas and, restructure ideas with a more coherent view.

With the goal of learning how to promote knowledge integration, we carried out a series of studies in the Computer as Learning Partner project that resulted in the Scaffolded Knowledge Integration framework (Linn 1992, 1995, Linn *et al.* 1998, Linn *et al.* 1993). This framework guided the design of the KIE studied in this research (see Bell *et al.* 1995). We report on *design experiments* that study the relationship between curriculum design decisions and students' knowledge integration in complex classroom settings (Brown 1992, DiSessa 1991). One goal of these design experiments is the articulation of principles to guide future curriculum and software design. In this research, we test the power of principles from the Scaffolded Knowledge Integration framework by design elements of the KIE following these principles and then examining students' knowledge integration when using the newly-designed elements.

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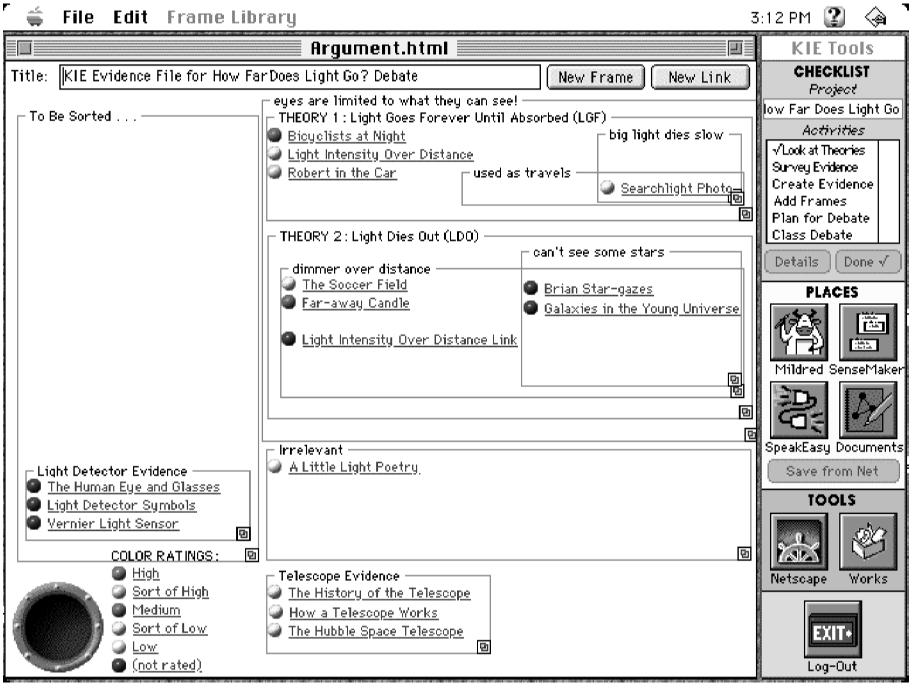
The 'how far does light go?' project

This research examines the overall impact of one KIE curriculum project as well as aspects of argument building software called SenseMaker and a guidance component called Mildred. In the debate project called 'how far does light go?' (hereafter abbreviated to 'how far . . .?'), students contrast two theoretical positions about the propagation of light (see Bell 1998 for a more detailed discussion). To prepare for the debate, students critique a set of networked multimedia evidence derived from both scientific and everyday sources. The first theoretical position in the debate is the scientifically normative view that 'light goes forever until it is absorbed', while the second position is the naïve realist view that 'light dies out as you move further from a light source'. One common view expressed by students is, 'if you can't see light, then it can't be there'. Many students initially align themselves with the 'light dies out' perspective - although they do so for a variety of underlying conceptual reasons.

Students begin the project by stating their personal position on how far light goes. They then explore and develop an understanding of the evidence. Students explore how the science in class relates to their own lives. Toward this end, students are encouraged to develop evidence from their own lives that relates to the debate. After creating some evidence of their own, students further refine an argument for one theory or the other. Student teams present their arguments as part of a classroom discussion and respond to questions from the other students and the teacher. When 'how far . . .?' concludes, students are asked to reflect upon issues that came up during the project and once again state their opinion about how far light goes. This debate project is the capstone activity for the light portion of the curriculum. Students pull together and integrate their knowledge from the experiments they conducted on light, as well as their own personal experiences.

How far does light go?: making science accessible. The 'how far . . .?' project represents a sustained investigation for students and asks them to link existing and new ideas. Thus, it implements the first tenet of the Scaffolded Knowledge Integration framework: selecting accessible and generative goals for learning. Science projects that allow students to connect new information to personal and established ideas and, distinguish among compelling alternatives, support and encourage knowledge integration. Elsewhere, we have described how the conceptual model used in this instruction for light was designed to make the nature of light and light-related phenomena accessible for middle school students (Linn *et al.* 1998). Conceptual accessibility is but one dimension of science we wish to make available to students. The 'how far . . .?' debate project encourages students to link and connect their observations to theoretical perspectives and to use evidence from everyday experience to build a more cohesive and robust set of ideas. Furthermore, by evaluating and incorporating complex and often ambiguous evidence found on the internet, students learn appropriate criteria for assessing knowledge claims found in information resources and practice skills they can use to support lifelong learning.

The SenseMaker argument building tool: making thinking visible. To 'make thinking visible', the second element of the Scaffolded Knowledge Integration framework, KIE features the SenseMaker argument editor. This tenet that calls for making thinking visible is related to the cognitive apprenticeship principle of the same



Title: KIE Evidence File for How Far Does Light Go? Debate

Figure 1. Argument jointly constructed for the 'how far . . .?' project by a student pair using the SenseMaker software.

name (Collins *et al.* 1991). SenseMaker (shown in figure 1) allows students to construct and edit their arguments using a graphical representation. They review evidence from the world wide web, each item being represented by a dot in the SenseMaker argument. Students then make their thinking visible by describing and grouping the evidence using frames. Students begin with frames for the two sides of the debate: 'light goes forever until absorbed' and, 'light dies out'. They can add new frames within existing frames or outside the existing frames. Evidence for arguments is represented with a dot and a link to its internet location, such as *The Hubble Space Telescope*. Students can place evidence in more than one frame if they choose. Thus, SenseMaker helps students by making the process of organizing evidence into claims visible. SenseMaker serves as a knowledge representation tool for the students and the teacher by making three distinct forms of thinking visible:

(1) *Modeling expert thinking*: SenseMaker can allow students to inspect the scientific arguments of expert or historical scientists. Students, for example, are usually introduced to the SenseMaker tool by reviewing competing arguments from Newton and Kepler about the relationship betwen light and colour.

(2) *Providing a sense-making process to support individual reflection*: SenseMaker can engage students in the construction of their own arguments about a topic. As students elaborate their argument, they are making their understanding of the evidence and the scientific ideas involved

with the topic visible in their argument representation. We designed SenseMaker to help students keep track of their argument and to promote subsequent reflection. This study investigates how individuals use SenseMaker to make thinking visible.

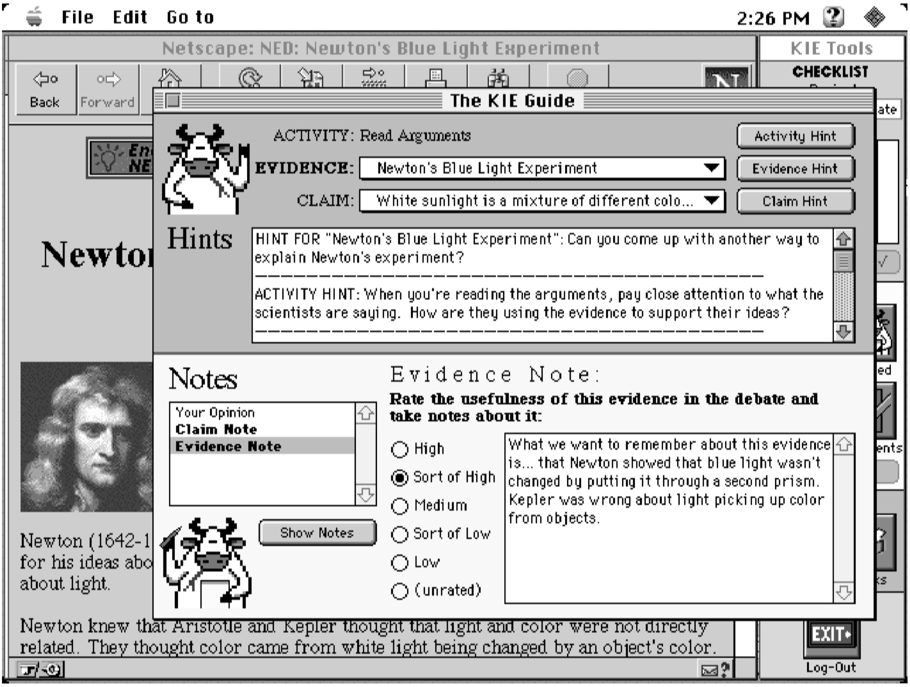
(3) *Promoting the collaborative exchange of ideas* - SenseMaker can help a group of students communicate and compare their differing ideas as they construct their argument. The joint construction of a SenseMaker argument provides a group the opportunity to reveal their particular conceptual and epistemological perspectives. The SenseMaker argument is an artifact of their joint inquiry. Additionally, the SenseMaker arguments can become shared artifacts within a classroom. The argument that has been constructed by a group can be shared and compared with arguments constructed by other groups. Such comparisons can reveal differences in conceptual and epistemological ideas held by the students and, become a productive focus for class discussion. Student thinking is being made visible to the group.

Mildred guidance and note-taking: supporting autonomy and reflection. As students work with SenseMaker, they also make extensive use of the Mildred guide component. Taken together, these tools support a tenet of the Scaffolded Knowledge Integration framework relating to autonomy.

To promote autonomy, the third element of the Scaffolded Knowledge Integration framework, students produce explanations for the evidence they review and describe how it contributes to their argument (see figure 2). The process of giving explanations is scaffolded in two ways. Firstly, students are prompted with sentence starters that include: ‘as we prepare for our debate and think about this evidence, we want to remember . . .’ and, ‘in considering how well this claim explains all the evidence, we think . . .’. Secondly, students can request hints about either the activity or the evidence. Hints are designed to highlight salient aspects of the project to students. Example hints and notes are shown in figure 2. The prompts and hints support students as they thoughtfully engage with the scientific evidence and claims associated with a project.

Classroom debate: a social context for knowledge integration. Debate is a central feature of science and holds largely untapped promise for science education (Bell 1996, 1998, van der Valk 1989). The ‘how far . . .?’ project implements the fourth element of the Scaffolded Knowledge Integration framework, taking advantage of the social context of learning in two ways. First, students work in pairs on their projects, each collaborating on the construction of explanations and arguments and secondly, the debate is an important social context for science learning as long as an equitable forum is created (Burbules and Linn 1991). Furthermore, the ‘how far . . .?’ debate engages students in knowledge integration by scaffolding the process of considering the views of others. In planning their debate presentation, students consider the points others might raise. During the debate, students are required to prepare questions for each presentation, thus reflecting on ideas presented by others. They must also respond to questions after their own debate presentation.

Overall, the ‘how far . . .?’ project using the KIE software suite implements the Scaffolded Knowledge Integration framework and has the potential for encourag-



ACTIVITY: Read Arguments

EVIDENCE: Newton's Blue Light Experiment

CLAIM: White sunlight is a mixture of different colo...

HINT FOR "Newton's Blue Light Experiment": Can you come up with another way to explain Newton's experiment?

ACTIVITY HINT: When you're reading the arguments, pay close attention to what the scientists are saying. How are they using the evidence to support their ideas?

Your Opinion
Claim Note
Evidence Note

Evidence Note:

Rate the usefulness of this evidence in the debate and take notes about it:

○ High
● Sort of High
○ Medium
○ Sort of Low
○ Low
○ (unrated)

What we want to remember about this evidence is... that Newton showed that blue light wasn't changed by putting it through a second prism. Kepler was wrong about light picking up color from objects.

Newton (1642-1 for his ideas abo about light.

Newton knew that Aristotle and Kepler thought that light and color were not directly related. They thought color came from white light being changed by an object's color.

Figure 2. The Mildred guidance and note-taking component.

ing knowledge integration. In the results section we analyse evidence indicating that the project is successful.

Argument as knowledge integration activity

Do the arguments students create in the 'how far . . .?' project show evidence of knowledge inegration? Increasingly, researchers in science education have focused on the artifacts students create because they help designers improve instructional effectiveness and, because they shed light on the nature of learning (Wisnudel *et al*. 1997). Many research groups have studied student science projects as part of portfolios (Clark 1996, Linn 1997), primarily because they believe these sustained activities will improve learning.

In our work, we study the arguments students create in order to determine whether our environment fosters knowledge integration and to identify specific strengths and limitations of the curriculum. Bannon and Bødker (1991) have called for a study of activities and artifacts to inform the design of technology and develop principles for human-computer interaction. Although they attend to artifacts and activities around designed innovations, they opt to ignore cognitive issues such as knowledge integration. We believe a more productive focus is to investigate the process of knowledge integration as reflected in students' activities and artifacts.

Our analysis of the explanations created by students in their arguments is based on Toulmin's proposed micro-structure for arguments (Toulmin 1958). Figure 3 shows the structure of an ideal explanation relating a piece of evidence

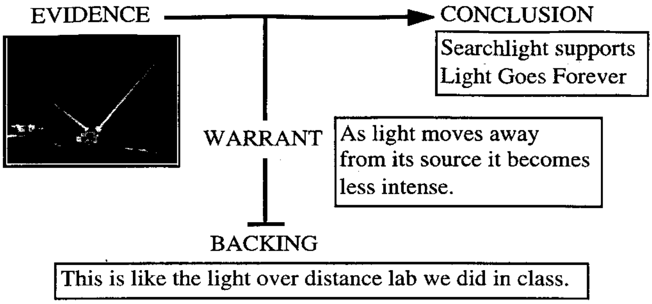


Figure 3. Dimensions of the argument analysis.

to the debate topic via the use of a warrant which has a backing provided. As we shall see, some students include descriptions of phenomena or their direct experiences in lieu of warrants. Our research connects student activities with the KIE software to the artifacts they produce. As a result we can develop principles for design to improve the process of knowledge integration.

We also examine the relationship between students' views of the nature of science and their propensity to construct arguments reflecting knowledge integration while doing KIE projects. Songer and Linn (1992) found that students with a dynamic view of the process of science were more likely to integrate their own knowledge during a science class than were those with a static view. Davis (1998) builds on that work to identify specific dimensions of students' beliefs. The present research further investigates these issues by exploring potential relationships between students' epistemological beliefs and, the arguments they create while working on the 'how far . . .?' debate. If students' beliefs about the nature of science influence their knowledge integration, we may detect this influence in the scientific arguments they create. Previous research shows that students can improve their beliefs about the nature of science when they engage in constructivist inquiry (Carey *et al.* 1989). Other researchers have posited a potential relationship between students' beliefs about the nature of science and argumentation, see Cavalli-Sforza *et al.* (1994).

Thus, our research investigates how aspects of KIE activities influence argument construction and examines the influence of views of the nature of science on this process. Identifying such relationships become an important focus for developing design principles that are localized to the specific contexts of debate activities and argumentation software.

Methods

We studied middle school students participating in the Computer as Learning Partner and Knowledge Integration Environment (KIE) research projects at the University of California, Berkeley. Six class periods and a total of 172 students carried out these activities in 86 pairs. Students performed six weeks of Computer as Learning Partner laboratory experiments and conducted another investigation of evidence in KIE (see Davis 1998), before working on the debate project which is the focus of this study. Students explored the topic of light by doing experiments involving the collection and analysis of real-time data. The topics covered by the curriculum included: light sources, vision, reflection, absorption, scattering (or diffuse reflection), energy conversion and light intensity over distance.

Students worked together in pairs on the 'how far...?' project. They spent approximately six days reviewing evidence and constructing their SenseMaker arguments. These arguments included explanations relating individual pieces of evidence to the debate and categorizing the evidence into theoretical frames. Students selected among frames and also developed new conceptual frames to descibe how they were interpreting the evidence. Students, during argument-building and the debate, considered the ideas of others and used them to refine their ideas. We distinguished frames reflecting the instructional design of the project and, unique frames reflecting out of class experiences and creative ideas. We categorized frames as shown in table 4: conceptual frames reflected the efforts at knowledge integration, whereas category frames identified superficial features of the evidence and debate frames helped organize the evidence for use in the debate itself.

Student arguments

Students received 13 items of evidence and were encouraged to develop an explanation for each. Each explanation for an evidence item composed by students was coded using the categories in table 1. This included the type of explanation

Table 1. Coding scheme for argument characteristics

Evidence explanations in arguments	
Length:	None [0] Short [1] - approx. one sentence length Medium [2] - approx. two to three sentences in length Long [3] - more than three sentences
Clarity:	Clear or Unclear
Type:	Description - a re-telling or summarization of the evidence Single Warrant - contains a scientific conjecture about the evidence Multiple Warrant - contains more than one scientific conjecture Other - irrelevant evidence
Warrant source:	Instruction - presented in instructional materials Unique - not presented in instructional materials Both - students use both instructed and unique warrants
Backings:	Cited Other Evidence Cited Experiments Cited Life Situation
Frames created for the argument	
Type:	Conceptual, Categorical, Debate, or Other
Source:	Instruction - presented in instructional materials Unique - not presented in instructional materials
Evidence added to argument	
Source:	Instruction - presented in instructional materials Unique - not presented in instructional materials

employed (description, single warrant, multiple warrant), the type of backings used (if any) and the length and clarity of the explanation.

Backings are used in arguments to substantiate warrants in explanations. Citing a class lab could back a theoretical idea such as light absorption. When students used explanations as warrants, the scoring recorded whether it was a unique construction or derived from the instructional materials. Instructed warrants were those included in the instructional materials - typically, the ‘light dies out’ and the ‘light goes forever until absorbed’ ideas. Unique warrants employed consist of scientific ideas learned in other parts of the curriculum, new conjectures and connections made among instructed notions. Using all of the explanations created in a SenseMarket argument, aggregate percentages were calculated for each of the categories.

Student activities

To understand how students engaged in the KIE activities and how they produced artifacts, we studied their interactions with the learning environment. As students worked in KIE, their actions were logged and time-stamped. This study specifically investigated student use of the Mildred guidance component. Students construct their arguments about evidence on the Web using both the SenseMaker and Mildred software components. As they compose explanations in Mildred, students can ask for hints about the activities, evidence and claims involved with the project (see figure 2). We studied the frequency with which students requested hints and the type of hint requested.

Beliefs about nature of science

Students completed a survey which probed their beliefs about the nature of science. For instance, students were asked to describe how they know when they truly understand a science topic and comment on why scientists engage in controversy (e.g., about suspected life on Mars). We distinguished between beliefs about scientific process and beliefs about learning strategies (Davis 1998). Student responses to several multiple choice responses were aggregated to produce a score for each dimension (see table 2). Strategy and process belief dimensions were significantly positively correlated with each other ($r = 0.39$, $n = 172$, $p < 0.0001$). The SenseMaker arguments were constructed by students approximately three months after they completed the survey about science beliefs.

Results and discussion

Our results address four questions. First, did students change their conceptual understanding as the result of this project? Second, what specific activities did students undertake? Third, what sorts of arguments did students construct? And fourth, how do student beliefs about science relate to their activities and arguments?

Table 2. Dimensions of students' epistemological beliefs (see Davis 1998 for details)

Process belief: Students' beliefs about the process of science	
Static:	Scientific knowledge is static Controversy results from scientists not considering each other's ideas
Dynamic:	Scientific knowledge is dynamic Science involves discovery Scientists try to understand evidence and relate it to other things they know
Strategy belief: Students' beliefs about science learning strategies	
Memorize:	Memorization is the best approach to learning science
Understand:	Understanding is the best approach to learning science

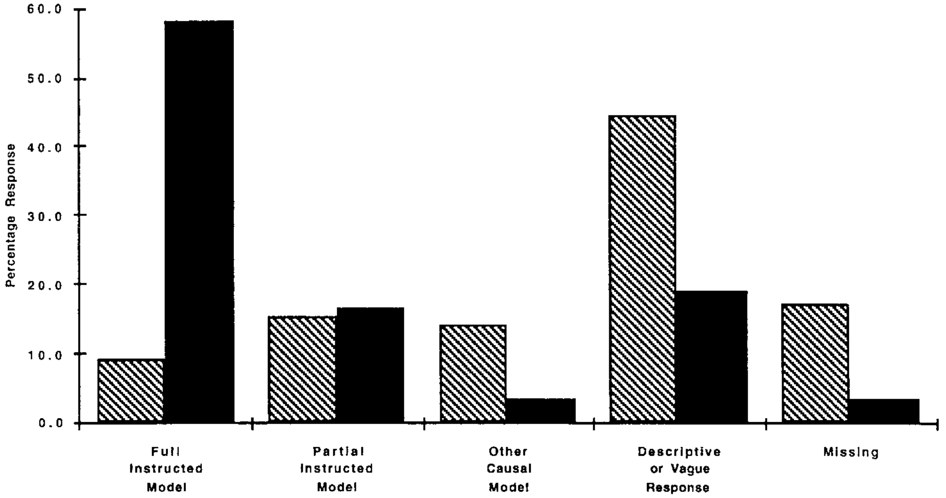


Figure 4. Changes in students' conceptual understanding of the 'how far...?' topic from pretest to post-test, N = 172.

Did students make conceptual changes?

Students participating in the 'how far...?' debate acquired a more normative and robust understanding of how far light goes. As shown in figure 4, almost half of the students move into the category of using the normative model at the end of the project. Most students shift away from descriptive or vague responses on the pretest, although some are also moving away from other non-normative causal explanations. Change from pretest to post-test on the 'full instructed model' category was significant ($t[175] = 11.67$, $p < 0.0001$).

What activities did students undertake?

Overall, students engaged in the 'how far...?' debate enthusiastically and completed all aspects of the project. On average, students wrote explanations for 11.5 of the 13 items of evidence. Furthermore, the number and length of explanations were significantly positively correlated ($r = 0.33$, $n = 86$, $p < 0.003$). That is,

Table 3. Use of Mildred guidance in KIE

Hint requests	*Mean*	*St. Dev.*
Requests for activity hints	3.83	(3.73)
Requests for evidence hints	5.12	(9.19)
Requests for claim hints	0.56	(1.3)
Total requests for hints	9.51	(11.15)

students who wrote more explanations, wrote longer ones suggesting that students had sufficient time to craft their notes. In addition, students took advantage of hints from Mildred (see table 3). Each group requested an average of 9.5 hints to help them think about their project and there was substantial variability between groups for each type of hint requested. Students used Mildred in different ways.

Classroom studies using SenseMaker have shown that students have difficulty creating new conceptual frames (or categories) for their evidence (Bell 1998). In this study we provided students with a list of suggested frames in order to model good frame criteria. Students took advantage of this modelling. Students used the frames provided to organize their evidence. They also added an average of 1.2 frames. Compared to past use of SenseMaker, students framed out their arguments to a greater degree. There was sustained variability from group to group with regard to frame additions.[1]

The frames students created went beyond the ‘how far . . .?’ curriculum materials. Students created four times as many unique frames as instructed frames. In other words, students elaborated their arguments using frames that were based on their own conjectures and categories for the evidence. The frequency of conceptual, category and debate frames created by students is shown in table 4 along with examples from each category. Students created frames of each type to an equal number.

Table 4. Frames used in SenseMaker arguments

Type of frame	*Mean*	*SD*	*Student examples*
Conceptual	0.45	1.08	‘light gets dimmer over distance’ ‘light gets used up as it travels’ ‘not all light is visible by the human eye’ ‘light reflection’
Categorical	0.37	0.87	‘flashlight evidence’ ‘astronomy related’ ‘advertisements’ ‘true life experiences’
Debate	0.38	0.84	‘best things to discuss’ ‘don’t use in debate’ ‘very useful’ ‘good evidence’
Unique	0.98	1.5	—
Instructed	0.23	0.52	—

Table 5. Means and standard deviations for argument characteristics

Evidence explanations	*Mean*	*Std. Dev.*
Explanations (total of 13 possible)	11.5	(2.8)
Explanation length (in sentences)	1.5	(0.4)
Descriptions (percentage)	18.3%	(17.8%)
Warrants (percentage)	70.5%	(20.5%)
single warrants (percentage)	47.6%	(19.1%)
multiple warrants (percentage)	22.9%	(21.9%)
Other (percentage)	10%	(11%)
Unique warrants (percentage)	60.1%	(22.4%)
Instructed warrants (percentage)	26.4%	(26.2%)
Backings (average number)	0.13	(0.4)
Evidence added	*Avg.*	*SD*
New evidence	1.6	(1.7)
Unique evidence	1.1	(1.4)
Instructed evidence (same evidence in multiple frames)	0.5	(1.0)

What sorts of arguments did students produce?

Students created explanations for project evidence as well as descriptions of the new evidence they created. Student explanations generally rely on warrants but not backings, and students tend to conjecture rather than describe.

More warrants than descriptions. Overall, most students use warrants for their arguments, not descriptions. On average, students include warrants in over 70% of the argument explanations - compared to less than 20% who use purely descriptive 'explanations' (see table 5). This difference between the use of warrants and descriptions is a positive indicator of a productive scientific inquiry. Other research has identified a connection between engaging students in more authentic scientific inquiry and less use of descriptions in student explanations about light phenomena (Reiner *et al.* 1995). The dominant use of warrants in students 'how far . . .?' arguments indicates that students are engaged not in simple description of the evidence but, instead are attempting to tether the evidence to the debate through scientific conjectures. As the evidence used in the 'how far . . .?' project often depicts complex situations, an idealized scientific explanation may involve multiple warrants. On average, use of multiple warrants showed up in just under a quarter of the students' explanations (22.9%), with single warrants accounting for almost half of the explanations overall (47.6%). The use of multiple warrants is highly variable and, a subset of students produce such explanations, as will be discussed later.

More unique warrants than instructed. The 'how far . . .?' project serves as a capstone integration project, where students link and coordinate the different aspects of their light understanding and integrate their ideas. To confirm this goal we found students used 60% unique warrants in their arguments versus only 27% instructed warrants (see table 5). In other words, students integrated ideas from beyond the context of the immediate curriculum project into their arguments.

Backings rarely included spontaneously. The total number of backings used in the arguments was low and highly variable between groups. Only nine of the 86 groups spontaneously included backings in their arguments. We conjecture that students omit backings because they assume their audience already knows about them. This finding is also consistent with Toulmin's (1958) idea that backings only come up in arguments after a warrant has been called into question. Additionally this is consistent with research showing that students have difficulty imagining threats to their arguments (e.g., perspective-taking, role-playing) and research that has documented how rare it is for students to spontaneously include counter-arguments in their arguments (Kuhn 1993).

Frame creation connected to evidence explanation. Students who wrote more explanations also created more conceptual frames. The creation of new frames is significantly positively correlated with the total number of explanations found in the argument ($r = 0.33$, $n = 86$, $p < 0.003$). Furthermore, the creation of conceptual frames is correlated with the inclusion of more explanations ($r = 0.21$, $n = 86$, $p < 0.05$); whilst the number of unique frames was correlated with the number of explanations within an argument ($r = 0.29$, $n = 86$, $p < 0.008$). These relationships suggest that students who produce more explanations make more links among their ideas and thereby create more unique, conceptual categories.

Students using KIE were encouraged to create new frames as they surveyed the evidence and recognized conceptual patterns. Thus, the relationship between conceptual frame creation and evidence explanations also reflects benefits of the scaffolding of activities provided by KIE.

Unique evidence used to bring in previous experience and knowledge. Students were encouraged to add additional evidence from their own life experiences to their SenseMaker arguments. This served a dual instructional purpose of bolstering their arguments, while also helping students to relate the debate topic to their own lives. The addition of evidence to the arguments was correlated with the creation of unique warrants within that argument ($r = 0.30$, $n = 86$, $p < 0.006$), suggesting that students who added evidence were integrating their ideas from beyond the project. In addition, students who added unique evidence to their arguments also created more unique claim frames ($r = 0.23$, $n = 86$, $p < 0.04$). Students who incorporate both unique evidence and frames are attempting to reconcile current instruction with their previous experiences and knowledge.

Explicit perspective-taking was relatively rare. Perspective-taking with the evidence is also an important knowledge integration strategy. This characteristic of the arguments was represented by students placing the same evidence into more than one frame (see table 6). Students who can explain the same evidence from different perspectives in the debate, have an additional degree of integrated understanding. One out of every two groups, on average, added copies of the initial evidence to their arguments.

Hint usage related to more scientific arguments. Hints are intended to help students engage more productively in scientific inquiry and to better understand the evidence. In fact, students who requested more hints from Mildred also included more warrants in their arguments ($r = 0.27$, $n = 86$, $p < 0.02$) and fewer descriptions ($r = -0.24$, $n = 86$, $p < 0.03$). In particular, students who asked for evidence hints also included more warrants in their evidence explanations ($r = 0.26$, $n = 86$, $p < 0.02$); these explanations were also more often unique constructions ($r = 0.25$, $n = 86$, $p < 0.03$). Students who make use of the hints available from the guidance component in KIE build arguments which are more scientifically normative.

Gender differences. There were several differences betwen the arguments created by female and male students. Female students composed explanations which were slightly longer than those of male students (1.6 versus 1.4 mean length in sentences, $t(173) = 2.2$, $p < 0.04$). Female students also used significantly more multiple warrants in their arguments - 26.4% of their explanations employed multiple conjectures versus 18.7% for male students on average ($t(173) = 2.34$, $p < 0.03$). Male students also composed twice as many unclear explanations than female students ($t(173) = -2.0$, $p < 0.05$), although the overall number was still low. These results are consistent with findings that females write more coherent essays than males (e.g., Hyde and Linn 1988).

Nature of beliefs and argument construction

Does any of the variability found in these arguments reflect differences in students' beliefs about the nature of science and learning? Do students with a more sophisticated understanding of scientific processes create their better arguments during the 'how far . . .?' project? We correlated scores on the dynamic beliefs and process beliefs survey with characteristics of student arguments (see table 6). Beliefs about the nature of science were associated with several argument characteristics including the frequency of warrants used to explain the evidence and the number of frames used to form an argument. Use of backings was negatively related to beliefs about the scientific process. Students who see science as dynamic (high process beliefs) create more complex arguments and are less likely to use backings in their arguments. A few students see the need for backings initially in their arguments, although backings are often the focus of discussions during the actual classroom debate. Nevertheless, those who included backings in their arguments also wrote longer notes. We conjecture that students who elaborate their arguments also add backings.

Table 6. Significant correlations between argument characteristics and beliefs about the nature of science

Argument characteristics	*Process beliefs*	*Strategy beliefs*
Warrants	0.19 ($p < 0.02$)	N.S.
Multiple warrants	0.16 ($p < 0.04$)	N.S.
Unique warrants	0.18 ($p < 0.03$)	N.S.
Backings	−0.17 ($p < 0.03$)	N.S.
Creating frames	0.18 ($p < 0.02$)	N.S.
Use of multiple frames	0.16 ($p < 0.04$)	0.25 ($p < 0.002$)
Unfinished notes	−0.16 ($p < 0.05$)	N.S.
Placing evidence in multiple frames	0.16 ($p < 0.04$)	0.25 ($p < 0.002$)

Note: N.S.

We distinguished unique and instructional warrants in student arguments. The process beliefs dimension was significantly positively correlated with the use of unique warrants, that is, conjectures not coming directly from the instructional materials (see table 6). Similarly, the process beliefs dimension was positively correlated with the addition of frames to an argument. Students with a more sophisticated sense of scientific understanding as dynamic theorized more in their arguments by including more unique warrants and conceptual frames. Within a capstone project designed to promote the integration of student ideas, we would expect students to be pulling in scientific ideas from outside of the project.

The indication of perspective-taking - placing the same evidence item into multiple frames - was significantly correlated with the learning strategy and process beliefs dimension. Students who explore the interpretation of evidence from different conceptual frames within their SenseMaker argument have a more dynamic view of science. Students who also view science learning as understanding concepts rather than memorizing facts, also recognize the importance of understanding scientific evidence from both sides of the debate.

Designing for knowledge integration through argumentation and debate

Design and use of a two week debate project in the classroom for this research represents a complex endeavour. The instructional designers and teachers must make myriad decisions at the stages of conceptualization, design and implementation. From our research on the 'how far . . .?' project and KIE, we have begun to identify pragmatic pedagogical principles which can inform the design of similar, debate-based instruction and argument-building software. We call these pragmatic pedagogical principles because they guide practical, classroom decisions and practical instructional design discussions. They provide elaborations of, our scaffolded knowledge integration framework (Linn and Hsi in press):

Pragmatic pedagogical principle: connect to personally-relevant problems. In a debate project, provide a corpus of evidence from multiple sources including everyday and scientific items that are complex and ambiguous. Encouraging students to explore a debate topic with a range of evidence means they can link their ideas and experiences and generalize their knowledge. Evidence that students can actively understand and incorporate into their arguments must connect to their experiences. Didactic attempts at knowledge-telling thwart efforts to make connections.

When constructing arguments, children often focus on a single piece of evidence rather than considering an entire set (Driver *et al.* 1996). Encouraging students to explore a debate topic with a set of evidence items encourages students to avoid becoming fixated on a particular piece. The inquiry process needs to involve the set of evidence items in a visible manner as is done in SenseMaker. A set of complex and ambiguous evidence allows students to bring their relevant ideas to bear on the debate. Recent analyses reveal that it can lead to productive peer interaction and to scientifically authentic discussion.

Pragmatic pedagogical principle: scaffold students to explain their ideas. The KIE guide component, called Mildred, scaffolds student explanations using hints, focusing questions and sentence-starters to guide student inquiry. Hints can focus explanations on warrants derived from prior knowledge rather than simple phenomenological descriptions. Many of our successful hints derive from close study of the student explanations in prior classroom trials. Scaffolds should also provide criteria for proper interpretation of the evidence (e.g., examining the credibility of its source). However, students need the option of changing the prompt to one that is personally meaningful, if necessary.

KIE also scaffolds the argument construction process with SenseMaker. Students construct arguments that connect their ideas. The SenseMaker interface elements - evidence dots and claim frames - work well with middle and high school students. SenseMaker supports students in combining the evidence in productive ways. It also models critical aspects of the argumentation process for students. The KIE frame library also scaffolds the argument process. The frame library conveys the intended use and criteria for frames. It also allows students to select ideas while not detracting from causes. Students begin with a few orienting frames in their SenseMaker argument (one for each theory and one for irrelevant evidence). Too many initial frames could easily stifle customization of the argument. Personally created frames, combined with the frame library frames, support group discussion in an open debate forum by providing points of similarity. When students create unique frames they also advance the discussion by bringing new ideas to the attention of the group.

KIE also makes visible the procedures for an activity in the form of an online checklist. We have found that the checklist allows a shift in the tenor of class activity from a procedural to a conceptual exploration.

Pragmatic pedagogical principle: encourage knowledge integration around the nature of science. We have begun to establish connections between students' beliefs about the nature of science and the arguments they go on to construct. It is also likely that students' images of science are changed by engaging in scientific argumentation and debate. Making this process of scientific debate visible to students contributes to their refinement of the images of science. For instance, students can come to better understand evidence, argument and debate by investigating historical controversies (Bell 1998, Hoadley 1999).

Pragmatic pedagogical principle: make individual and group thinking visible and equitable during debate projects. KIE provides students with a meaningful knowledge representation that allows them to express and exchange their conceptual ideas. By allowing students to make their thinking visible in their arguments using SenseMaker, we enable students to compare and discuss competing perspectives for understanding the debate topic (Bell 1997). Such representations also provide a valuable assessment for the teacher.

Creating a public forum which allows an equitable exchange among all students is essential for productive classroom debates. Students need to feel comfortable expressing their ideas and critiquing those of others. The teacher can model appropriate questioning by being even-handed to all sides of the debate and not openly taking a position. Another approach is to provide students with an electronic means of carrying on discussions where anonymity is an option (Hsi and Hoadley 1997).

Conclusions

In conclusion, this research reports on learning and design studies to illustrate that argument-building in a classroom debate project can promote knowledge integration. Learning studies illustrate how students construct arguments so as to learn science. Design studies suggest guidelines for future instructional designers.

Argument-building and Knowledge Integration

This research demonstrates that the activities implemented in their Knowledge Integration Environment's 'how far . . .?' project elicit student arguments which offer evidence for knowledge integration. Students using the Knowledge Integration Environment construct arguments that typically include warrants for evidence and personally relevant conceptual ideas. In addition, students restructure and communicate their understanding by adding new frames based on the evidence they investigate; they learn from each other by viewing the argument representations created by other classmates; whilst overall, students also make conceptual progress in understanding light. The project elicits knowledge integration that goes beyond the instructed structure and motivates students to restructure their ideas in unique ways.

All of these factors contribute to our finding that the 'how far . . .?' project achieves the goal of furthering knowledge integration. The project serves as a capstone science project by helping students link and connect the materials that they have studied in class experiments to their own personal experiences and to novel evidence.

Our results also support the idea that students were engaged in a productive scientific inquiry during the 'how far . . .?' project. Koslowski (1996) has argued that scientific inquiry cannot rely solely on a covariation of events but requires a 'bootstrapping' off of personal, theoretical ideas. As illustrated in KIE evidence explanations and student debate, instruction should help students realize that science inquiry often involves creative, conjectural acts not just close observation and description (Driver *et al.* 1996). This analysis shows how middle school students construct arguments: they use unique conjectures (or warrants) in their explanations. A few employ multiple warrants in their explanations, although most omit backings for their warrants.

Nature of science

Knowledge integration progress accompanies a dynamic view of science as might be expected. Students who engage in knowledge integration activities in science class are also more likely to have a dynamic view of the nature of science. Students who respect that science is dynamically changing and involves the construction of arguments, also personally engage in the construction of arguments. Students who dispute the assertion that the science principles in textbooks will always be true tend to restructure and add to their knowledge as they come to understand how far light goes.

What is the relationship between these two phenomena? Would it be possible to enhance students' knowledge integration by instructing them about the nature of science? Or alternatively by activating students' interests in the nature of science, can one modify their views about the nature of science? We have some evidence for the view that engaging students in knowledge integration and argument construction enhances their understanding of the nature of science. Students at the post-test displayed a greater propensity to believe in a dynamic nature of science than did those at the pre-test (Davis 1998).

Gender

This paper reports one of the few gender differences in patterns of knowledge integration found in our research with the Computer as Learning Partner and the KIE projects. In this research, we find that female students compared to males are more likely to provide multiple backings and write longer explanations for evidence, suggesting that females may broadly demonstrate more knowledge integration in their explanations than males. This result resonates with findings that females often outperform males on short answer- and essay-standardized tests and, on standardized tests involving projects (Gipps and Murphy 1994). These findings help to clarify the results about the essay- and short answer-examinations and suggest a need for replication.

These findings may reflect that females, on average, are slightly more likely than males to make broad connections among their ideas. Females may prefer to refine their full set of connections rather than focus on a few ideas. Such a tendency might benefit individuals writing essays because typically essays involve incorporating a broad range of information. In contrast, this propensity might be less useful for answering questions that require selecting a single strategy and pursuing it rapidly. The general pattern of making multiple links and connections amongst ideas is more appropriate for domains that are filled with conflicting notions. The propensity to discard ideas and focus on a few notions is more compatible with fields that can be reduced to a powerful principle or require overcoming distracting and conflicting views. Although females and males followed slightly different knowledge integration patterns, this propensity had no impact on their overall performance. Males and females made equivalent progress in understanding light from the 'how far . . .?' project.

Ideally, instruction would help students develop both of these patterns as well as distinguish when they should be used. In practice, some students may still prefer principles while others seek to organize a broad range of empirical findings.

Design principles for classroom debate activities

Our design studies sought to characterize design principles to promote knowledge integration. The 'how far . . .?' project was designed using the Scaffolded Knowledge Integration design principles. This study confirms the benefit of those principles for crafting activities that support knowledge integration. In addition, the results of this project suggest some refinements to the Scaffolded Knowledge Integration principles.

Firstly, the overall design of the project makes science accessible by offering evidence with multiple connections to students' personal experiences. In the 'how far . . .?' project, students interpret internet evidence using their personal understanding and, also generate their own unique evidence based on their life experiences. These activities allow students to introduce unique elements into their arguments and make connections between the instruction and their personal understandings. Our finding that students introduce unique ideas and restructure their arguments based on incorporating unique information, confirms the success of the design for promoting knowledge integration. The associations between the generation of unique arguments and frames and views of the nature of science, suggest that in making science instruction accessible we should also help students consider multiple views of the nature of science and engage in knowledge integration around that topic.

The second principle of the Scaffolded Knowledge Integration framework concerns making thinking visible. SenseMaker, in this work, is a software tool intended to facilitate argument construction and make thinking visible to individuals and groups (Bell 1997, 1998). The success of SenseMaker in supporting students' scientific inquiry bolsters the benefits of reifying the structuring of information for students. Previously, making thinking visible has referred primarily to either modelling thinking processes or making a particular phenomena like heat flow visible. Making the structure of an argument visible with SenseMaker augments our understanding of the mechanisms that can help students visualize and become engaged in the process of knowledge integration. These findings are consistent with benefits reported for concept mapping (Novak and Gowin 1984).

The third element of the Scaffolded Knowledge Integration framework, promoting autonomy, was represented in the 'how far . . .?' project with project scaffolding. KIE provides an activity checklist and Mildred, the cow guide, to encourage note taking or provide hints. Students vary in hint usage. Some use a large number of hints, while others use none. This reinforces the principle of encouraging multiple approaches to autonomous learning, making hints available for those students who need assistance in autonomous learning, as well as allowing individuals who wish to continue to learn without interference to do so. Davis (1998) reports on the benefits of varied prompts for students consistent with this finding. Students benefit from choice in taking advantage of activities that might promote autonomy. In related work, equal numbers of students prefer individual and collaborative use of SenseMaker to support their learning during the debate (Bell 1997). In addition, if students are effective in making choices concerning which activities to utilize in fostering their knowledge integration, then hints and prompts can get in the way.

The fourth element of the Scaffolded Knowledge Integration framework, promoting effective social interactions to support knowledge integration, was also implemented in the 'how far . . .?' project. The structure of the debate activity helps students learn from each other (Bell 1998). The overall success of the activity shows the general benefits of the social context for this activity.

Overall, our learning and design studies suggest the benefits of looking closely at the activities students perform, linking those to the artifacts students create, analysing the artifacts to determine whether the activities achieved their intended cognitive objectives and abstracting these findings into a framework to help other designers. This approach demonstrates the advantage of iterative, principled cycles of refinement for creating powerful instructional materials. To take advantage of the disparate knowledge and experiences held by students, activities need to help students learn from each other and sustain the process of knowledge integration. Students benefit from different learning partners so activities need to provide a mix of opportunities to maximize knowledge integration.

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Note

1. Frame-building has been promoted further in subsequent research. Contributing factors that proved to be important included: modelling the use of the tool by multiple, historical scientists; integrating the list of potential frames into the software as a frame library; and developing students' meta-knowledge about argumentation and knowledge representation tools in general (for details see Bell 1998).

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