Using Argument Representations to Make Thinking Visible for Individuals and Groups

Philip Bell

Cognition and Development Area, Graduate School of Education
University of California, Berkeley

Abstract

This paper describes how an argument representation tool called SenseMaker has been used to promote science learning with middle school science students during a debate activity. The argumentation tool is one component of the Knowledge Integration Environment (KIE) Internet-based learning suite for science education. The argument representations make student thinking visible during individual and collaborative activities in the classroom. The paper elaborates on how the cognitive mechanisms and learning goals shaped the design of the SenseMaker software and presents results from several formative classroom trials of the tool. Student arguments vary based on their epistemological beliefs about the nature of science. Students report using the SenseMaker tool to support both individual and collaborative learning during their classroom projects.

Keywords—argument-building, classroom debate, conceptual change instruction, knowledge representation tools, Internet, science education

SenseMaker Rationale

The Web continues to become more ubiquitous in our culture and our schools. Many metaphors have been used to better understand the Web's role in education, including thinking of it as a library or as an on-line textbook. Although these metaphors may be appropriate for subsets of Web resources, the approach taken by this research is to view the Web as a whole as "evidence"—where students can be actively engaged in interpreting, critiquing, and constructing arguments using these information resources. Over the past three years, the KIE project has taken this approach to build a framework for Internet-based curriculum and custom software tools. The design of KIE has been shaped by cognitive research performed within classroom settings.

How can students best be supported (or scaffolded) when engaging in the construction of arguments using scientific evidence from the Web? What do students learn from engaging in such activities? A number of software development efforts—including CSILE (Scardamalia & Bereiter, 1991), the Multimedia Forum Kiosk and the SpeakEasy (Hsi & Hoadley, 1997)—have explored how technology can support group argumentation and knowledge construction. Much has been revealed about how groups can productively collaborate using these tools, however, there is not yet an accepted approach for supporting students with scientific criteria as they engage in this process. This paper briefly describes research on these issues surrounding our design of an argument-building tool called SenseMaker that attempts to combine appropriate scientific criteria and representations into the learning process. The long-term goal of this research is to explore the use of SenseMaker as a knowledge integration tool and to infer design principles for software tools that support argumentation during classroom debate activities.

The SenseMaker Argumentation Tool

SenseMaker is one software component of the Knowledge Integration Environment (KIE). Overall, KIE represents a cohesive set of software tools and a project-based framework for middle and high school science curriculum that is focused around Web resources (Bell, Davis, & Linn, 1995; Linn, Bell, & Hsi, in press). In KIE, students engage with Web resources as pieces of scientific evidence to be interpreted, explored, and applied to their science projects. KIE seeks to promote a more integrated student understanding of complex science concepts and processes. The KIE framework includes a project-based curriculum structure to scaffold students' science activities along with appropriate software tools used as part of those activities. Custom KIE software includes a Web-based discussion tool, an on-line guidance system called Mildred, and the SenseMaker argumentation software. Students move between the various software components that make up the learning environment as appropriate for their activities at the time.

Our goal is to provide students with learning opportunities and tools that will help them express and reflect on their conceptual ideas about phenomena, explore and compare their ideas to those of others, and make sound discriminations between the set of models under consideration. Over the past two years, we have improved our understanding of how to scaffold students as they use the SenseMaker argumentation tool as part of a knowledge integration process. This research explores the relationships between students' use of the software, their individual learning and cognition, and the collaboration occurring in the classroom.

SenseMaker Design & Functionality

SenseMaker provides a spatial and categorical representation for a collection of Web-based evidence (see Figure 1). This paper describes students engaging in a debate project about the properties of light. Using SenseMaker, they group evidence items into categories and create scientific arguments based on their understanding of the topic. The SenseMaker software allows small groups of students to organize and annotate a collection of evidence associated with a project that can then be shared with others. Within the software students work with *evidence dots* representing individual pieces of evidence on the Web and *claim frames* corresponding to conceptual categories (or groupings) for the evidence. Claim frames can be interrelated by hierarchically nesting one inside of another. For example, in Figure 1 the claim "Light gets dimmer over distance, but doesn't go out" supports the "Theory 1: Light Goes Forever Until Absorbed" claim in which it is nested (this larger claim represents one of the main theories under debate in that particular classroom project). Students place evidence dots within the claims which they are interpreted as supporting, and they can be duplicated so that evidence items can be categorized under more than a single claim if desired.

The design of the SenseMaker software was influenced by trade-offs between the instructional goals for the software, research on student argumentation, and the history of scientific

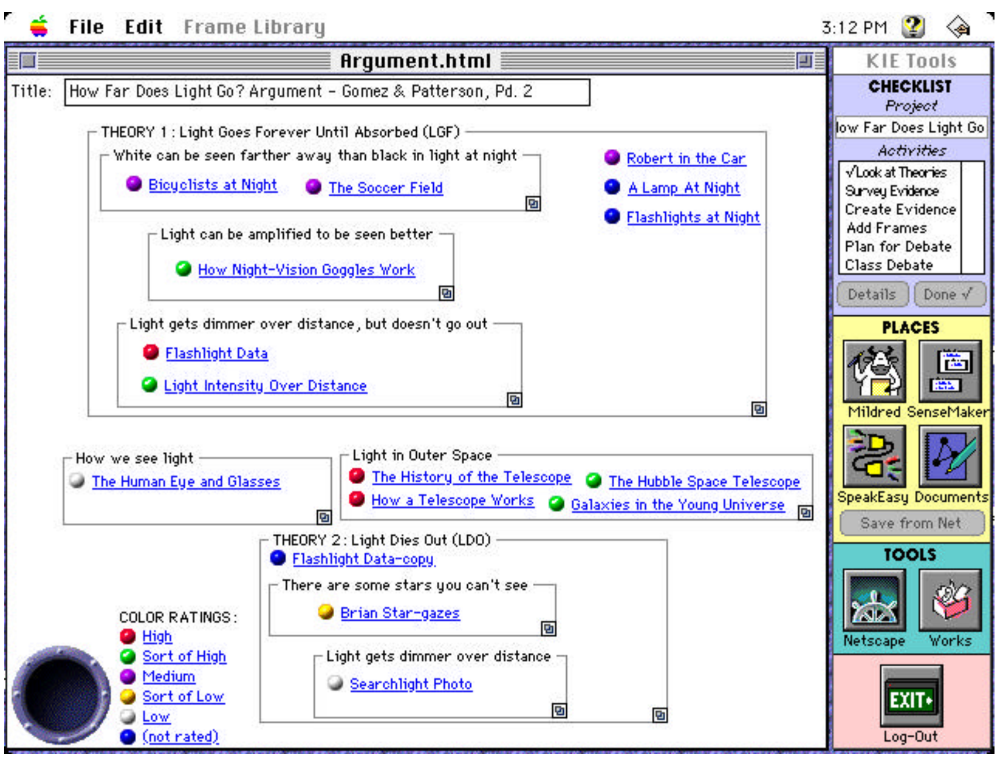

FIGURE 1. SenseMaker argument jointly constructed by a student pair for use in a classroom debate about the properties of light.

FIGURE 2. Mildred, the guide & note-taking software component in KIE.

argumentation. The software is designed to enable student construction of arguments that are rooted in their own conceptual understanding while also being constrained such that they conform to central aspects of scientific argumentation (e.g., using evidence to support scientific claims or conjectures).

Students are typically asked to take notes on the evidence and claims associated with a project (as shown in Figure 2). As they do this, KIE also includes a way for students to rate the evidence and claims along specific dimensions (e.g., low to high usefulness). When students change the rating for a piece of evidence, its dot color in the SenseMaker representation correspondingly changes (shown as shades of gray in Figure 1). Students elaborate on their scientific ideas in the Guide component and use SenseMaker to develop broad conceptual categories in which to group the evidence. Taken together, these tools allow student groups to develop structured arguments for their theoretical positions in the debate.

Theoretical Background for SenseMaker

A variety of research has focused on understanding how students can benefit from engaging in scientific argumentation. As described by Koslowski (1996), students should be encouraged to coordinate their theoretical ideas with supporting or contradictory evidence. In attempting to do so, however, it has been found that many young children tend to: (a) focus on evidence that directly demonstrates intuitive ideas in a naive realist manner, (b) preferentially consider a single piece of evidence rather than a set, and (c) equate theories with potential "truths" (Driver, Leach, Millar & Scott, 1996). This is likely to strongly influence how students build arguments to support their theoretical positions. Given these findings, technology may be able to facilitate students' construction of more scientific arguments.

A number of software environments address argument construction including CSILE (Scardamalia & Bereiter, 1991), SpeakEasy (Hsi & Hoadley, 1997), Belvedere (Cavalli-Sforza, Weiner, & Lesgold, 1994), Convince Me (Schank, 1995), and Euclid (Smolensky, Fox, King, & Lewis, 1988). Tools that support argumentation come in two varieties: (a) discussion-based tools that support the dialogical argumentation of a group (e.g., CSILE or SpeakEasy) or (b) knowledge representation tools that support the construction of rhetorical arguments by individuals (e.g., Euclid or SenseMaker). It is important to note that each variety involves both individual and collaborative uses although these aspects may be distinct.

In addition to incorporating the psychological dimensions of argumentation, these environments should also embody aspects of the philosophical dimensions of scientific argumentation. For example, Toulmin's (1958) proposed structure for scientific arguments—involving data, warrants, backings, and conclusions—influenced the design of an early version of the Belvedere software (Cavalli-Sforza, et al., 1994). Rather than presenting students with a comprehensive tool for constructing arguments in science, SenseMaker provides an intermediate representation—involving evidence, claims, and explanations—that is readily approachable to a broad range of students and capable of focusing their conceptual work.

Their is also a component to this work related to students' understanding of the nature of science. One might easily hypothesize that students with different views of the scientific process, for example, might construct qualitatively different types of arguments. Given the SenseMaker representation, one might also hypothesize that students working with the software would gain an increased appreciation for how scientific claims can be supported with evidence and how different scientific claims may or may not be related to each other—aspects which are both obviously represented in the SenseMaker interface.

MAKING THINKING VISIBLE. The design of KIE and SenseMaker has been guided by an instructional framework called scaffolded knowledge integration that has been derived from many careful studies in classrooms (Linn, Bell, & Hsi, in press). The framework is predicated on a "repertoire of models" view to describe student cognition during science learning. Rather than having highly coherent mental models or theories that drive their opinions, the repertoire view acknowledges that learners often have relevant pieces of knowledge and intuitions about a topic that may not initially be well connected (diSessa, 1994; Linn, diSessa, Pea & Songer, 1995). Given the repertoire perspective, the scaffolded knowledge integration framework provides instructional design principles about the appropriate conceptual level for content and how to provide social supports for learning (among others). A central component of the framework involves *making thinking visible* for the students. SenseMaker accomplishes this particular goal by serving as a tool for constructing explicit knowledge representations that are understood by the teacher and students. Cognitive apprenticeship (Collins, Brown & Holum, 1991) called for "making thinking visible" to students, although we have extended the idea to include three distinct forms:

1. **Modeling Expert Thinking**—SenseMaker can be used to model the scientific arguments of expert or historical scientists. For example, we have successfully introduced the SenseMaker tool to students by presenting them with competing historical arguments from Isaac Newton and Johannes Kepler about the relationship between light and color.

2. **Providing a Process to Support Individual Reflection**—A more common use of SenseMaker is to engage a small group of students (or individuals) in the construction of their own argument about a particular topic. As they elaborate their argument, they are making their understanding of the evidence and the scientific ideas involved with the topic visible in their argument representation. One design goal is for the argument representation to promote cognitive reflection in the individual students as they engage in the sense-making process.

3. **Promoting the Collaborative Exchange and Discrimination Of Ideas**—The organization and structure provided by the SenseMaker representation becomes an easy way for a group to communicate and compare their differing perspectives on a topic. In other words, the joint construction of a SenseMaker argument by a small group can then be shared and compared with arguments from other small groups. In the process, particular conceptual and epistemological ideas of the groups are made visible and can easily become productive topics of conversation.

Since SenseMaker arguments are Web objects themselves, students can share their representations with other individuals electronically or they can be broadcasted over the Web for simultaneous viewing. It is important to realize that the learning that occurs for the students collaborating on the design of an argument may not be fully depicted in the argument representation itself. The SenseMaker representation can only be taken as a shadow of their actual understanding of the topic. For the students, however, the representation is an artifact that can support and shape their reasoning. Students working on the joint construction of a SenseMaker argument often engage in productive discussions focused on knowledge integration issues (e.g., when students in a small group have differing interpretations for a piece of evidence).

With SenseMaker we hope to present students with the opportunity to integrate their knowledge through both individual and group mechanisms. That is, we encourage students to engage their prior knowledge about a particular topic, make their thinking visible in their SenseMaker argument, collaborate with others by comparing their arguments or exchanging perspectives on the evidence, and to forge new connections between their scientific ideas and instances of phenomena that those ideas can help explain. For this research, it is important to explore which students engage in these various learning events and which of the events lead to instances of knowledge integration.

Recent classroom studies involving SenseMaker have explored potential relationships between students' SenseMaker arguments, their epistemological ideas, and their changes in conceptual understanding.

Research Methods

A middle school physical science class participating in the KIE research project at the University of California, Berkeley uses the SenseMaker tool. Approximately 180 students distributed over six class periods participate each semester. Over 800 students have used the SenseMaker software in their classroom projects. In this investigation, students complete six weeks of laboratory experiments on the topic of light involving the collection and analysis of real-time data. Topics covered in the curriculum include: light sources, vision, reflection, absorption, energy conversion, diffuse reflection, and light intensity over distance.

Then students carry out a debate project called "How Far Does Light Go?" where they contrast two theoretical positions about the propagation of light. Their inquiry on the debate topic involves the interpretation and critique of a set of Web-based 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 more of the naive realist view that "light dies out as you move further from a light source." During the activity, it is quite common for students to make statements such as "if you can't see light, then it can't be there" (Linn, Bell, & Hsi, in press). Many students initially align themselves with the "light dies out" perspective—although they do so for a variety of underlying reasons. The SenseMaker software guides organization of evidence in the project into an argument and makes students' underlying justifications available for productive individual and group reflection.

Students begin the project by stating their personal position on how far light goes. They then begin exploring and developing an understanding of the evidence. Students also create some evidence based on their own life experiences and further refine an argument for one theory or the other using SenseMaker. Student teams present these final arguments as part of a classroom discussion and respond to questions from the other students and the teacher. Students conclude by reflecting upon issues that came up during the project and once again state their opinion about how far light goes.

Data sources used for this research include: (a) a written assessment of conceptual understanding administered at the beginning and end of the semester, (b) a written assessment given at the beginning of the semester that explores students' epistemological ideas about science, (c) the SenseMaker arguments and evidence notes produced by student pairs during the debate project, (d) a self-report completed by students after the debate project on how they made use of the SenseMaker software, and (e) videotape and field notes of students during the debate project.

Results

This section summarizes research on students' learning during the How Far Does Light Go? debate and the SenseMaker arguments they construct. This includes an investigation of the individual and collaborative uses of SenseMaker as they influenced student learning.

Do students make conceptual progress?

Students develop a principled understanding of science by engaging in KIE projects. At the beginning and end of the semester, students complete a written assessment of their understanding of the topics covered by the curriculum. One question asks students to reason about an everyday situation where the driver of a car is approaching a distant bicyclist at night. Students are asked to describe the distance the light travels away from the car and why. The question assesses the principal scientific idea of the How Far Does Light Go? project. Student explanations to the test questions were coded into categories representing full use of the instructed conceptual model for light, a partial use of the instructed model, some other causal model, or a descriptive or vague response. Figure 3 presents

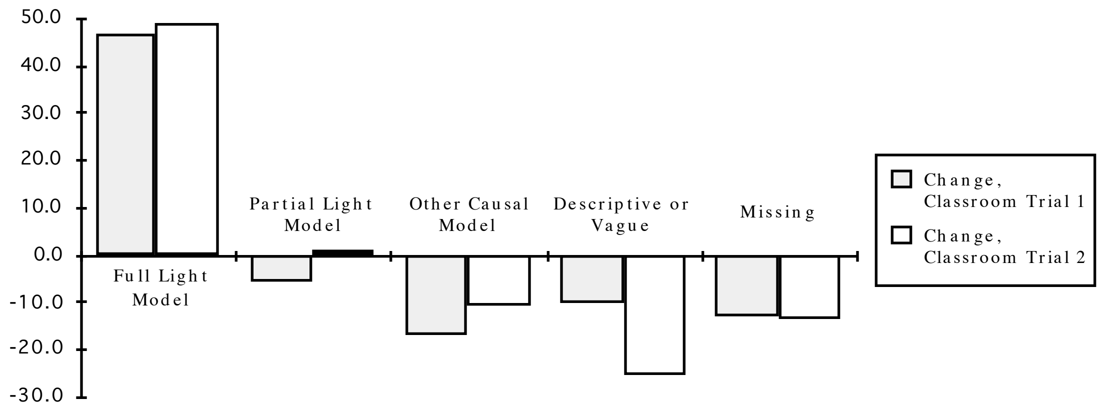

FIGURE 3. Percent change in students' use of the instructed light model on the debate project question for two successive classroom trials (post-test minus pre-test response for each category, N=176).

changes in student responses from the pre-test to post-test on the car and bicycle question. For two different classroom trials of the project and software, the graph shows the change in post-test response levels compared to pre-test responses for each category. Almost half the students in the class are moving into the full instructed model category by the end of the class.

Can middle school students construct arguments that are scientific?

As the SenseMaker software and the How Far Does Light Go? debate project have been improved, there have been corresponding improvements in student arguments. Arguments have continued to become increasingly elaborated and individually differentiated.

Compare the argument displayed in Figure 4 to the one shown in Figure 1. Each argument is an artifact of the inquiry process each group engaged in as they explored the evidence. If these groups were asked to compare their final arguments, they might start out by discussing why they categorized the Searchlight Photo evidence or Brian Star Gazes evidence as supporting different theories in the debate. Or, they may discuss why they created different claim frames to group the evidence. These simple differences in claim frames and evidence categorization can lead to substantive discussions about differing conceptual ideas between students.

When scaffolded with appropriate criteria and engaged in a sense-making process, students did not have difficulty conjecturing about how evidence may be related to the debate at hand. When we analyzed students' evidence notes in detail we found that they used scientific warrants (or conjectures) over 70% of the time to connect evidence to the debate. This is in contrast to students offering simple descriptions of the evidence, which they did 18% of the time. This finding corroborates Reiner, Pea, and Shulman (1995) who found that when students were engaged in a more authentic scientific inquiry process with light phenomena, their explanations shifted from being descriptive to including more causal conjectures.

Can a frame library help students build arguments?

From early classroom trials with SenseMaker, it was clear that students needed scaffolding as they created new frames (or categories) for their evidence. In the most recent trial, we included a Frame Library feature in the SenseMaker software as a menu of possible frames students could use. The library was designed to model for students good examples and criteria for new conceptual categories. Students created many more conceptual frames using the Frame Library version than in previous trials. Over 70% of the students reported finding the Frame Library as being useful. However, student reasons for liking the library were varied. Some liked how it modeled the basic idea of frames. Others found it useful for finding words to suite their specific ideas. For example:

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Because if something is on the tip
of your tongue, or you have a good
idea but the words can't come out,
you can get help from the library
[to] form some things you might want
or need.
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As we assess the specific learning events associated with these new frames during future analysis we will focus not only the initial process of incorporating new frames into an argument but also on secondary effects once that

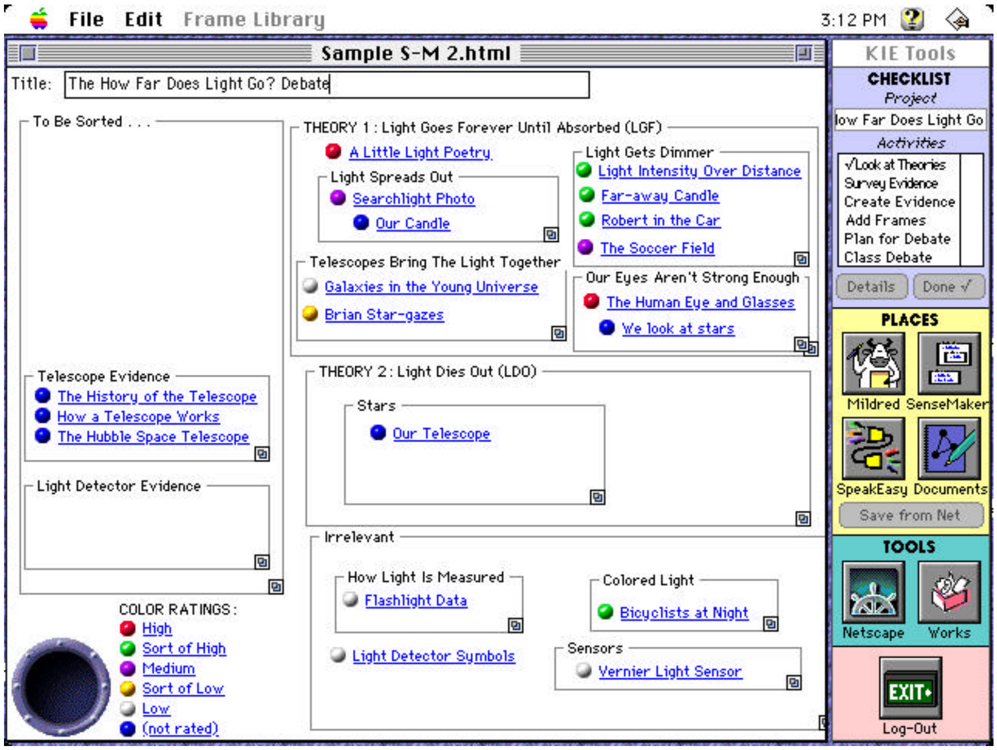

FIGURE 4. Another SenseMaker argument constructed by a student pair for use in the same classroom debate about light as represented in Figure 1.

argument was used as an artifact during communication with others.

Are student arguments related to their ideas about the nature of science?

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. The present research further investigates this finding by exploring potential relationships between students' epistemological beliefs and the arguments they create while working on the How Far Does Light Go? debate. In other words, if student beliefs about the nature of science influence their knowledge integration, we may detect this influence in the scientific arguments they create. Students' beliefs about the nature of science were found to be connected to the SenseMaker arguments they construct. Students with a more dynamic view of the scientific process created arguments that included more multiple warrants (or scientific conjectures) in their evidence explanations ($r=.16$, $n=172$, $p<.04$) and used more frames from the Frame Library to categorize the evidence ($r=.18$, $n=172$, $p<.02$). The epistemology test was administered three months prior to students' construction of the SenseMaker arguments during the How Far Does Light Go? project. Since the observed correlations are relatively small (although statistically significant), it may be the case that only a subset of students are guided by their general epistemological beliefs during science class or alternatively that all students are guided to a limited degree by their epistemological beliefs about science.

How do groups of students benefit from argument representations?

SenseMaker arguments can also foster meaningful collaboration between students by making thinking visible between the individuals involved. Videotapes of students collaboratively constructing arguments show that learning events present themselves as students work with SenseMaker during the joint construction of their arguments. For example, the SenseMaker interface makes student thinking visible to the students as they categorize evidence into frames and rate the evidence items. On numerous occasions, the act of making these "visible" decisions within the software lead to productive discussions among the students within a small group.

A second set of collaborative uses for the argument representations occurred during the classroom debate associated with the project. As student groups presented the details of their arguments during the most recent classroom trial, their SenseMaker representation was electronically broadcast (or "pushed") to the computers of the other student groups in the class. This use of Web push technology allowed students to easily compare arguments as they debate. Given that SenseMaker had become an accepted representation for depicting knowledge claims along with evidentiary support, many students asked specific questions about the SenseMaker arguments of the presenting group after visually comparing it to their own.

Do students value the individual and collaborative uses of SenseMaker?

As detailed in the previous sections, SenseMaker can involve both individual and collaborative uses during KIE projects. After the most recent classroom trial, students were asked if argument construction before the classroom debate (an individual-focused use) or argument comparison during the classroom debates (a collaboration-focused use) constituted more of a learning experience for them personally. Student responses were coded into categories of like-responses and the results are shown in Tables 1 and 2 along with prototypical examples of each category. Looking across all response categories, students were almost evenly split in terms of how SenseMaker supported collaborative- and individual-focused learning, 46% versus 40%, respectively. (Unique student statements that occurred only once accounted for 9.7% of the responses and were not included in the tables.)

COLLABORATIVE USES. Within our theoretical view of learning, students are each marshalling, communicating, and restructuring a repertoire of conceptual models as they engage in classroom activities. This process is viewed as including both individual and collaborative mechanisms. Table 1 shows student responses involving collaboration-focused uses for SenseMaker. The top response category describes how students are aware of the expansion of their repertoire of ideas during collaboration. One student wrote:

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[SenseMaker] shows me different
ideas of people and lets me think
about what other people think. It
kind of widens my horizon.
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However, beyond just expansion in the number of ideas under consideration, it is also desirable for students to discriminate between these ideas. As indicated by the second most prevalent student response, discussing different SenseMaker arguments in a group setting provides a means of comparing and discriminating between different ideas. In the words of another student:

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You can't learn anything from your
own work. You must see what other
people think to compare ideas and
learn more.
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Beyond having the collaborative uses of SenseMaker actively influence how they are thinking about the topic, 8% of the students also reported that it simply provides a window onto the thinking of others. This category represents a more passive collaborative use of the representations.

INDIVIDUAL USES. Many students found that

Collaboration-Focused Response Category	*Student Example*	*Percent (N=176)*
Social Expansion of Repertoire (accretion only)	"I think you learn more from other people because you already know what you have in your idea, but you may learn new things from other people, like what they thought about other things. Maybe the other people have a better idea which makes you think for a while."	18.8%
Social Discrimination of Repertoire	"I already know what I believe and what I support so I do not need to see what I believe as much as seeing someone else's ideas. By seeing other people's ideas you can see why they think things and the reason they think that. It could change your opinions."	15.3%
Provides Window onto Thinking of Others	"I think this because it shows how each person think, which evidence supports what, how each different person feels and views each piece of evidence."	8.0%
Collective Strategy	"Because there are many more people involved and thereby you can learn something from everyone."	2.8%
Prefers Passive Watching	"I learn more by listening and hearing things rather than reading them."	1.1%

TABLE 1. Collaboration-focused uses for SenseMaker students reported as helping them learn the most during the debate project. Categories are listed from most to least frequent (N=176).

Individual -Focused Response Category	*Student Example*	*Percent (N=176)*
Promotes Individual Thinking (general)	"You don't really learn what other people tell you. You mostly learn what you have figured out for yourself."	13.1%
Promotes Individual Learning (specific)	"I feel creating our own SenseMaker argument w/ the evidence & frames helped me learn more 'cause w/out it, I would learn anything from the presentations. I need to first know my opinion before being swayed by other people."	10.8%
Promotes Individual Expression (no explicit learning reference)	"This let my evidence be organized. It helped us to support our theory by using our ideas with evidence to support these sub-ideas."	10.2%
Prefers Self-Understanding	"I learn more from creating arguments myself because I know exactly what I'm thinking and sometimes it's hard to understand what people are trying to say. However, if someone explains something very thoroughly and coherently then I might learn more from them, so it varies."	3.4%
Prefers Active Creation	"Because you learn more in the process of doing than by looking at something that's already done."	2.3%

TABLE 2. Individual-focused uses for SenseMaker students reported as helping them learn the most during the debate project. Categories are listed from most to least frequent.

SenseMaker promotes individual-focused learning during the debate project. As shown in Table 2, the most frequently cited individual-focused response describes how SenseMaker promoted more thinking about the topic in general terms. One student described this by saying:

> Making your own [SenseMaker] is a hands-on experience and gives you a chance to really think about your opinion.

Beyond talk of it supporting general thinking, 11% of the students described how they learned from constructing their SenseMaker argument in specific terms. One student reflected on the process of categorizing evidence into frames:

> You put a lot of thought into what fits in what category, and you need to analyze the evidence yourself before you create frames. So, I find that I learn more because I see all how one piece of evidence may fit in w/ two or more categories.

The final prominent response category that was individual-focused describes how SenseMaker allows individuals to express their own ideas:

> I felt that I learned more creating my own because I put my past experience and knowledge into it. I know the author was a creditable [sic] source.

Note the difference between this last quote which stresses building off of one's prior knowledge compared to the student who talked about not being able to "learn anything from your own work." It is clear that students have very different preferences for their own learning and they most likely make use of SenseMaker in very different ways. It affords both individual and collaborative uses. These self-reports need to be corroborated with students' actual uses during the debate project, but we are encouraged by students' perceived uses for the SenseMaker software. The students' self-reports reflect many of the original design goals for the software.

Conclusions

Middle school students are capable of creating arguments with the SenseMaker software that are quite complex, personally relevant, and scientific. This paper describes how argument representations can make student thinking visible. Specific individual and collaborative uses of the SenseMaker argument representation are afforded by its design. At an individual level, features of the interface (e.g., evidence being placed within claim frames) allows for student self-expression of ideas and can promote individual reflection on prior knowledge. Student arguments also connect to their individual epistemological beliefs about the nature of science. At a collaborative level, SenseMaker representations can make student thinking visible during collaboration with peers and teachers. It was common for students to accept SenseMaker representations as an account of how other groups were thinking about the debate topic and evidence. Collaborative work around the argument representations can help students expand their repertoire of models and help them discriminate between these different perspectives.

There is also a balance to be struck between supporting individual- and collaboration-focused learning opportunities with software and curriculum. There were almost equal numbers of students who preferred using SenseMaker individually as well as collaboratively to further their learning. This finding may well relate to underlying differences in student learning strategies and calls for designing learning environments and curriculum that can be flexibly used by students with different preferences.

Engaging students in argumentation using evidence from the Web can be a knowledge integration activity. This integration can result from individual as well as collaborative mechanisms of making thinking visible. If we better understand how these mechanisms can be facilitated in complex classroom settings through the design of software tools like SenseMaker, technology will then be able to be used more powerfully as a learning partner in today's classrooms.

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Author's Address

Philip Bell: Graduate School of Education, University of California, 4533 Tolman Hall #1670, Berkeley, CA, 94720.
pbell@socrates.berkeley.edu
http://www.kie.berkeley.edu/people/yuppo.html