Model-Based Feedback Supports Reflective Activity in Collaborative Argumentation

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Abstract

The research reported in this paper is part of an ongoing research program investigating computer support of coherent reasoning in individuals and groups. Drawing from research investigating reasoning with a theory-based computer model, we have developed a computer learning environment designed to help students create, manage, and evaluate arguments. In attempting to "convince" the *Convince Me* program, students are encouraged to reflect on their reasoning strategies. We present results from a classroom intervention that highlight how the program's representations provide a structure for collaborative argument building and mediate communication among students, prompting them to engage in shared explanatory and reflective activity. The results also suggest that feedback from the program's simulation of argument coherence encourages even greater student reflection on argument construction and evaluation.

Keywords—collaborative argumentation, argument coherence, knowledge representation tools, science education

Convince Me, a "Reasoner's Workbench"

The ECHO Educational Project (EEP) research group at the University of California, Berkeley has been studying reasoning with a connectionist model, ECHO, that simulates coherent reasoning based on the principles of the Theory of Explanatory Coherence (TEC). TEC attempts to account for how people decide the plausibility of beliefs asserted in an explanation or argument based upon a few "hall of fame" principles of reasoning (cf., Thagard, 1992). The ECHO model represents arguments as a network of nodes with explanatory and contradictory links and treats hypothesis evaluation as the satisfaction of constraints determined from the explanatory relations, TEC's principles, and from a few numerical parameters. When the network settles, hypothesis and evidence nodes mutually supporting coherent explanations are activated and may be considered "accepted." Research findings indicate that ECHO usefully models students' reasoning in diverse domains, predicting which beliefs students will accept or reject as they consider a problem or controversy (e.g., Ranney & Thagard, 1988; Schank & Ranney, 1992).

The EEP research group hypothesized that if ECHO helped model and predict human reasoning, it might also help students examine their reasoning processes and develop more coherent arguments. We developed the *Convince Me* program and curriculum to make it easier to use the ECHO simulation model (Schank, Ranney & Hoadley, 1994) and have found that it serves as a useful pedagogic tool to support students as they build and evaluate arguments (Ranney, Schank & Diehl, 1996; Siegel, 1999). In the words of students who used the program in laboratory studies:

> I think [*Convince Me*] can be useful for people to help them step through how they analyze things or how they think.

> I think [*Convince Me*] is useful because when I look at the issues, I look more in depth instead of just look at what appears obvious.

While our laboratory assessments involved students working individually with the program, our current research in high-school classrooms is examining the use of *Convince Me* as a tool to support collaborative argumentation as well.

Why Collaborative Argumentation?

Two central assumptions about effective learning are evident in today's educational research literature: (1) children learn through a process of constructive engagement with the world—the world of people, of materials, of activities, of ideas; and (2) learning happens most effectively when children engage in activities that are functional—have purpose and integrity to them (Greeno, Collins & Resnick, 1996). These assumptions suggest that students should learn skills and knowledge in the context of working cooperatively on complex, authentic tasks (Brown, Collins & Duguid, 1989). An extensive body of research indicates that collaborative learning can be a successful teaching strategy, promoting learning and cognitive development through the resolution of conflict and controversy, the co-construction of ideas, and the giving and receiving of explanations or elaborated help (Slavin, 1990; Webb & Palinscar, 1996). Engaging students in collaborative argumentation promotes the use of reasoning strategies and encourages the elaboration and justification of various positions.

What is essential for the success of this “social mediation of individual learning” is the active, constructive participation of the individual students who articulate, reflect on, and modify their understanding (Salomon & Perkins, 1998). Often teachers’ experiences with collaborative learning in their classrooms are not consistent with researchers’ claims for increased student learning (Antil, Jenkins, Wayne & Vadasy, 1998). Students may fail to communicate; they may contribute unequally to the work; they may fail to assure that every group member learns; they may feel social pressure to accept the ideas of their peers without understanding them (Linn & Burbules, 1993). Collaborative activities must be carefully structured and supported so that each student has an opportunity to learn. Computers can be an important tool in supporting collaborative instruction through the creation of interactive learning environments that guide students through complex inquiry activities, prompt student discussion, and provide interactive representations to support student reflection (e.g., Koschmann, 1994).

How Can Computers Support Collaborative Argumentation?

Computer environments can support collaborative argumentation by scaffolding the argumentation process, by providing opportunities for explanation and reflection and by helping students keep track of and refer to ideas under discussion. A number of researchers have developed courseware and curricula intended to help students engage in productive discussion and improve their reasoning skills. The CSILE (Scardamalia & Bereiter, 1993) and SpeakEasy (Hoadley, Hsi & Berman, 1995) environments are both discussion-based tools that support the argumentation process for a group of students as they engage in research on a topic. SenseMaker (Bell, 1997) and Belvedere (Cavalli-Sforza, Moore & Suthers, 1993) are two knowledge representation tools, like *Convince Me*, that enable the display of a scientific controversy from multiple perspectives and that aid individuals (or small groups of students) in analyzing evidence and visualizing the relationships between theories and evidence. While SenseMaker and Belvedere both provide general advice from a computer coach that guides students in using evidence to support theories, *Convince Me’s* simulation provides individual feedback to students on argument coherence.

Convince Me Design

Just as explaining something to another person can help one understand something, entering an argument into *Convince Me* can help students make sense of their own beliefs. *Convince Me* provides both a means of explicating and revising arguments and a “reasoning engine” for coherence-based assessments of one’s beliefs. The program helps students to organize their arguments, providing a structure that supports them in constructing a scientific argument. The program’s scaffolding includes structuring the argument construction, providing interactive memory aids, and challenging students to justify the means by which they attain their beliefs (through the ECHO model simulation).

The interface structures an argument by breaking down the process of building an argument into steps that identify hypotheses and evidence and the explanatory and contradictory relations that join them (see Figure 1). Feedback on the coherence of a student’s argument is provided in the form of a correlation between (a) the student’s believability ratings for an argument’s propositions and (b) the simulation model’s activations. After comparing their ratings with ECHO, students can modify their argument or ratings or change ECHO's parameters to better model their individual reasoning styles. The program provides students with multiple representations of an argument’s structure including a relational listing and interactive diagram. These features of the *Convince Me* interface, in addition to the simulation’s feedback, embody aspects of the ECHO simulation model; thus providing a support for students to adopt the model while working with it within the activity of argument construction and evaluation. For example, the diagram, in the form of a network of units connected by links, provides an isomorphic representation of the argument's conceptual structure and makes abstract ideas and relationships concrete. This spatial representation enables a holistic, qualitative, evaluation by the student—one that augments the quantitative evaluation provided by the simulation. Two features were added to the program specifically to support classroom instruction. Prompts in the student reflection notebook encourage students to reflect on their argument and the feedback from the ECHO model, and the argument checklist suggests strategies that students can use for argument evaluation.

Convince Me provides students with the means to construct and manipulate their own knowledge while being guided by the program and interacting with other students. The *Convince Me* program with it's model of coherent reasoning is designed to *make thinking visible* by modeling expert thinking, supporting individual reflections, and promoting the collaborative exchange of ideas (c.f., Collins, Brown & Holum, 1991). Even when students are working individually with *Convince Me*, the program appears to provide a *social* context of reflection and explanation from which students benefit. The following comments from students indicate that they reflect on their *Convince Me* arguments as if they were explaining them to another student:

> When [*Convince Me*] disagreed with you, that showed that there were some aspects of the argument that you failed to perceive.

> [*Convince Me*] made me justify my thought processes and many times I had to question them and find other ways to approach a problem.

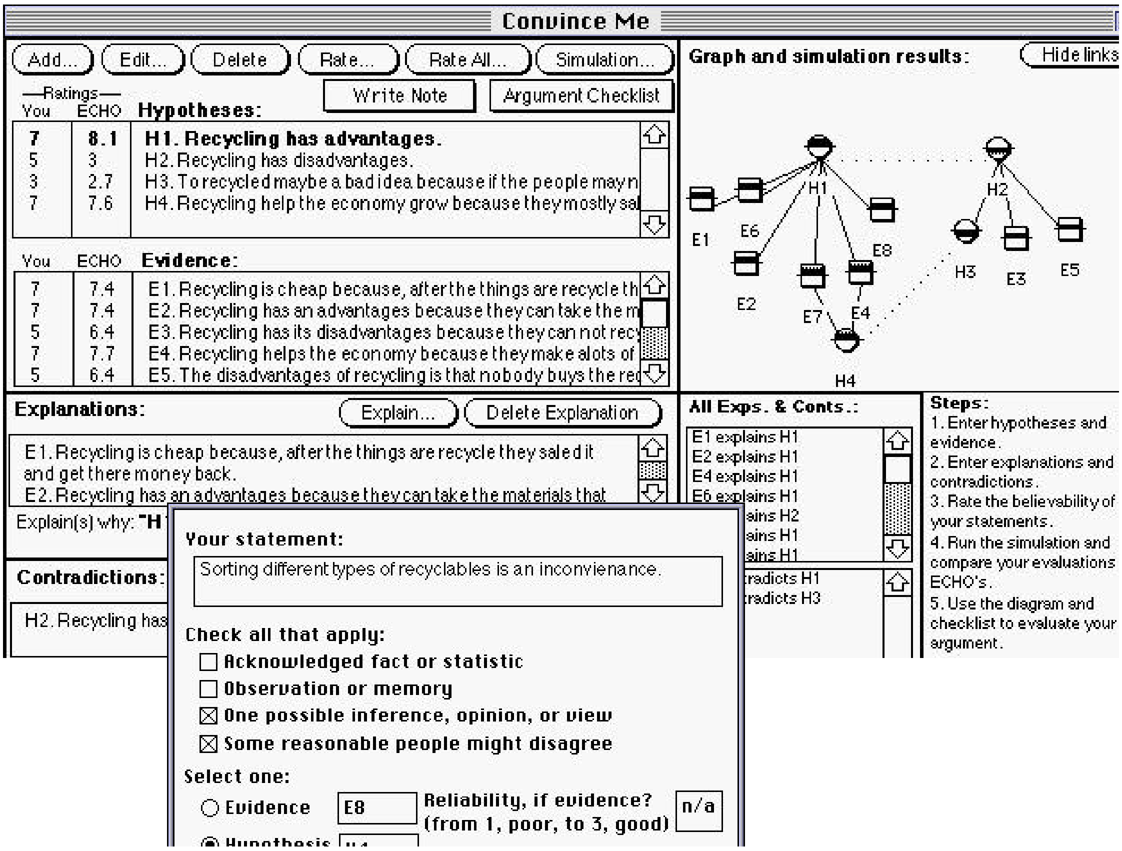

Figure 1. *Convince Me* interface shown with statement editing dialog box and feedback from the ECHO simulation model (under ECHO ratings).

Research Design

This paper reports on a recent application of *Convince Me* in a 9th grade science classroom. Prior laboratory-based research indicates that when using the program with a reasoning curriculum, students are more likely to reflect on and change the fundamental structure of their arguments, and their beliefs are more in accord with the structures of their arguments (cf., Schank, 1995). The current research was conducted to examine the specific influence of the ECHO model-based feedback on argument coherence for students working individually and collaboratively with the *Convince Me* program.

Students in four urban, ninth-grade, Integrated Science classes were assigned to four comparison groups: (1) students working individually without feedback from the ECHO simulation model (Indiv-No-Model, n=21), (2) students working individually with feedback from the simulation model (Indiv-Model, n=19), (3) students working in pairs without feedback from the simulation model (Pair-No-Model, n=20), (4) students working in pairs with feedback from the simulation model (Pair-Model, n=22). The *Convince Me* program was integrated into an existing four-week curriculum unit on waste management. All students worked for an hour each to construct four arguments (one per week) using the *Convince Me* program. Students engaged in classroom discussion, laboratory activities, and homework that provided the information necessary to construct each argument. Computer logs recorded the students' interactions with *Convince Me* while building and revising arguments. The log provides data on argument construction (classification of propositions, order of argument construction, believability ratings), argument revision (what students change and when), use of *Convince Me*'s argument representations (changes made to the diagram, running simulation for ECHO model's feedback), final arguments (content, structure and coherence), and student reflections on the ECHO model's feedback.

A variety of instruments were used to assess students' understandings and performance, and selected computer activities were videotaped to document student use of the program. The results reported in this paper represent the following data sources: (a) a representations questionnaire where students rated the usefulness of each of the features in the program's interface (e.g., diagram, dialog-boxes), (b) computer log reports of students' actual use of the program's features during argument construction, evaluation, and revision, (c) students' *Convince Me* arguments and evaluation notes, (d) an argument evaluation test, and (e) video and field notes of students working with *Convince Me* in each of the four conditions. Two trained researchers coded all free-response answers in the exercises, and agreement for conflicting categorization (less than 5% of responses) was negotiated.

Results

The results presented in this section highlight the supports that the program features and simulation model feedback provide for individual and collaborative reflection on students' arguments. The results support the conclusion that the presentation of one's ideas to another—whether student or computer—provides the motive to formulate a clear opinion, and to check that opinion against another point of view. This process of explanation and reflection, in turn, leads to a better understanding of the curriculum content and scientific reasoning process.

Student Grouping

There was a strong effect of student grouping (and model use, see below) on argument construction and use of program features supporting argument reflection, which resulted in increased knowledge of scientific argumentation for students working in pairs. Several factors of student interaction likely contribute to this general result, including time on task, content of discussions, and use of program features. These factors appeared to lead pairs of students to engage in useful reflection on the content and structure of their arguments.

Time on Task. Students working together were able to construct an initial argument faster than students working individually, which gave them more time to reflect on their argument and make revisions. A two-way analysis of variance (anova) indicates a significant main effect for grouping ($F[73,1]=39.21$, $p<.0001$), but no main effect for model use and no interaction. Students who worked in pairs spent two-thirds of the time on initial argument construction as students working individually. One reason for this time difference lies in the amount of material that students could draw upon to build their arguments. Students working together were able to pool their knowledge and their resources, including homework assignments and class notes. The amount of time devoted to off-task behavior may also be a contributor to the difference in time for argument construction. In the video episodes recorded, the average time for off-task behaviors among pairs of students was about one minute, or a few conversational turns, versus more than five minutes for students working without a partner.

Reflection on Argument Content and Structure. In addition to more time for reflection, conversations between students working together provided the opportunity for reflection on argument content and structure as students debated the categorization of statements, the reliability of evidence, the believability of statements, and the explanatory and contradictory connections among statements. For example, in one videotaped episode, disagreements over what is observable and whether a fact can have a low reliability led a pair of students to debate both the content of their argument and epistemological concerns about the nature of hypothesis and evidence. While students who were working individually also engaged in conversations with neighboring students, these discussions were generally brief exchanges concerning process (e.g., help in using the program or in following task instructions) versus content or structure.

This reflection on argument content and structure is displayed in the students' responses to the argument evaluation test. A two-way anova indicates a significant interaction between grouping and model use ($F[66,1]=6.26$, $p=.01$; see Figure 2) which was further investigated with post-hoc pair-wise comparisons. A Fisher's PLSD analysis indicated significant differences in means between the Indiv-No-Model group and each of the three other experimental groups. Students working in pairs (and/or students working with ECHO model feedback) performed higher on the scientific argumentation evaluation test than students working individually without feedback from the ECHO model.

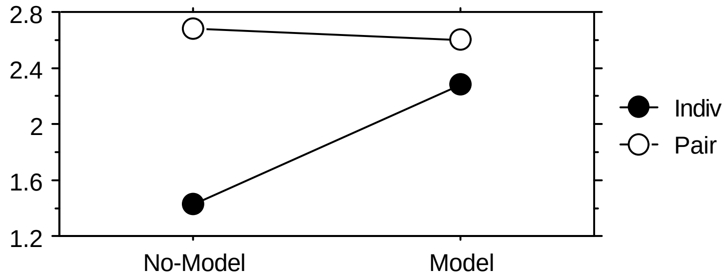

Figure 2. Mean scores for argumentation evaluation test (max = 4).

These students also referred more to an argument's structure in their responses. Table 1 presents some examples of responses that were categorized according to the source of knowledge used to answer the argument evaluation questions. A three-way mixed anova with source of knowledge as the repeated measure indicated a significant interaction among grouping, model use and source of knowledge ($F[75,2]=4.01$, $p=.02$), which was further investigated with post-hoc tests of pair-wise comparisons under separate one-way anovas for each category of source of knowledge. A Fisher's PLSD analysis indicated a significant difference in means between the Indiv-No-Model group and each of the three other experimental groups for the "structure" category. Students working individually and without feedback from the ECHO simulation model made fewer references to the structure of an argument during argument evaluation.

Structure Category (refers to structure of the argument)
• You could either add more evidence supporting H2 or delete evidence that supports H1.
• Less believable cause H2 would have more evidence and the computer only knows what you tell it.
Content Category (refers to specific information given in the argument)
• I think H1 because somebody had tried it and found out that is evidence.
• [Add] better evidence--more than one sentences about water cycle.
Real Life Category (refers to personal knowledge or experience)
• I think they would pick #2 because it is faster if you use cold water. I try using hot water to make ice cube before, and it takes longer to freeze than the cold water.

Table 1. Categories for responses from argumentation evaluation test.

Representational Scaffolding. The reflective activities engendered by working in pairs resulted in students making consistent and effective use of the supportive features and representations in the *Convince Me* program. An analysis of computer logs from students' argument construction indicates that students working in pairs engaged in a wide variety of reflection activities. A two-way anova indicated a significant main effect of grouping (and model use, see below), but no significant interaction between grouping and model use, on reflection activities such as entering comments in the reflection notebook or using the argument checklist to evaluate their argument ($F[73,1]=12.09$, $p<.001$), using the diagram to visualize the argument ($F[73,1]=3.96$, $p=.05$), revising categorization or reliability ratings for propositions in the argument ($F[73,1]=4.08$, $p=.047$), and utilizing proposition dialog box prompts to categorization propositions ($F[73,1]=7.84$, $p<.01$).

Video records of students working in pairs indicate that partners prompted one another to use the diagram to visualize their argument, to use the proposition dialog box prompts to categorize their statements, to enter comments into the reflection notebook, and to use the argument checklist to evaluate their argument. In addition, students used the program features to support their point of view in a debate with their partner over the content or structure of their argument. These students found the program's scaffolding very useful as evidenced in their responses on the "representations" questionnaire. A two-way anova indicated a significant interaction between grouping and model use ($F[66,1]=77.24$, $p<.001$) which was further investigated with post-hoc tests using pair-wise comparisons. A Fisher's PLSD analysis indicated significant differences in means between the Indiv-No-Model group and each of the three other experimental groups. Students working in pairs (and/or with feedback from the ECHO model) perceived the program features to be more useful than students working individually without feedback from the ECHO simulation model.

Pragmatic Category • The [diagram] is useful because it connects to all evidence or hypothesis that goes together. Is easier to tell which statement is connected to the other. • [The listing] is useful because it shows you how the information that is here gets to the diagram.
Conceptual Category • [With the proposition dialog box] I learned that the quality and reliability of an evidence is important. • [The ECHO feedback] helped me figure out what was wrong with my evidence and hypothesis.

Table 2. Categories for responses from representations questionnaire.

Students working in pairs also reported receiving conceptual, as well as pragmatic, benefit from the program features. Table 2 presents some examples of responses that were categorized according to the perceived pragmatic (i.e., helping to use the program) or conceptual (i.e., helping to build an argument) attributes of *Convince Me*'s program features. A two-way anova indicated a significant main effect of grouping ($F[60,1]=10.29$, $p<.01$) and model use ($F[60,1]=16.52$, $p<.001$), but no significant interaction ($F[60,1]=.29$, $p=.59$). Students working in pairs reported more conceptual benefit from the program representations than students working individually.

Simulation Model Use

Just as working in pairs increased student performance by providing the time and opportunity for reflection, working with feedback from the ECHO model also increased student performance by challenging their argument representation and encouraging reflection on the structure of their arguments. In their responses on the representations questionnaire, students commented that the simulation model was useful for two reasons: (1) to see another point of view or opinion, and (2) to help revise an argument to make it more clear.

Evaluating Arguments. In order to understand the ECHO model's evaluation of their argument coherence, students must first understand the principles of the Theory of Explanatory Coherence that are reified in the model. Then students must apply those principles to the structure of their argument to interpret the model's predicted activation ("belief") values. The following dialogue provides an example of students using the feedback from the ECHO model to reflect on and revise their argument so that it better represents their beliefs:

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S1: [Reading prompt in student reflection notebook.]  "I(We) think
    my(our) ratings and ECHO's are somewhat different because…"  Why?
S2: Dunno. What's the ones that are different. [Pointing to ratings.]
S1: Uh::: look there.  H3 is way...
S2:                     Yeah, what up with that.
S1:                                   It's low cause of that other one.
S2: Oh yeah::: The one, the hypothesis 'bout people and pets.  There,
    yeah, H5.  It says why people might not be sick from the chemicals.
S2: Okay, but this one doesn't go with nothin'… hm:::…it's like
    independent. [Pointing to H5 evidence node in diagram without links.]
S1: Yeah but it's supposed to conflict with that, 'cause it might not be
    sure. [S1 adds a contradictory link from H3 to H5.]
S2: Wait for it.  Wait::: for it.  Now.  There it is.  [Pointing to the
    new link that appeared in the diagram].
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The above dialogue and comments from the student reflection notebooks indicate that students are able to correctly interpret the feedback from the ECHO model based upon the structure of their argument. Results from the argumentation test also provide support for the conclusion that students were able to avoid the mistake of thinking that the model "understands" the content of their argument, and to focus instead on how they structured their argument. As reported above, students who received feedback from the ECHO simulation model (like students working in pairs) scored higher on the argumentation exercises than students in the Indiv-No-Model group and were more likely to refer to the structure of arguments in their evaluations.

Revising Arguments. The influence of the feedback from the ECHO model on student reflection is clear in the types of revisions made to arguments. Seventy-five percent of students receiving feedback from the model made intrinsic argument changes, that is changes to an existing argument structure, in an attempt to make their argument more convincing to the program. Only 20% of students working without model-based feedback made intrinsic revisions. In the dialogue above, a pair of students realize that they have forgotten to add a contradictory link between a hypothesis and a piece of evidence, and they believe that this is why the ECHO model's rating for the hypothesis is higher than theirs. When commenting on the model's evaluation of their argument, they write, "We didn't do the supports right and the evidence was not so good as we told [the model] it was."

Representational Scaffolding. Like the students working collaboratively, students working individually with the simulation model made consistent and effective use of *Convince Me's* representational scaffolding. These students used the program features to build a clear and consistent argument and to evaluate the feedback from the ECHO model. A two-way anova indicated a significant main effect of model use on reflection activities such as entering comments in the reflection notebook or using the argument checklist to evaluate their argument ($F[73,1]=44.02$, $p<.001$), using the diagram to visualize the argument ($F[73,1]=26.54$, $p<.001$), revising categorization or reliability ratings for propositions in the argument ($F[73,1]=24.84$, $p<.001$), and utilizing proposition dialog box prompts to categorization propositions ($F[73,1]=11.77$, $p<.01$).

Overall, students receiving feedback from the ECHO model used the diagram more than double the number of times as students in the No-Model groups. In fact, every student in the Model groups made use of the diagram at least twice; whereas, in the No-Model groups, 37% of the students made no use of the diagram at all, and 10% used the diagram only once. For example, in the dialogue above, two students recognize a missing contradictory link in their argument using the diagram. They identified the missing relationship because of the high rating that the model assigned to the unlinked node. As discussed above, students were clearly aware of the relationship between their argument structure and the simulation model's evaluation. Over 90% of students working with model feedback used the proposition dialog box prompts consistently to help them categorize their statements; while, 75% of students working individually without model feedback used this feature inconsistently or not at all. This reflects the students' understanding that the ECHO simulation model feedback depends upon the hypothesis/evidence distinction. Students interacting with the ECHO model paid close attention to the categorization of their statements, as also evidenced by the number of times they changed a statement's categorization–more than twice as often as students working without model feedback.

Conclusions

The project described in this paper supports individual and collaborative argumentation in the classroom with computer-mediated instruction. *Convince Me* aids students in generating and analyzing arguments, providing feedback from a general computational model that yields predictions about the plausibility of an argument's propositions. The specific instructional activity setting for each group of students participating in this research project was determined by the social mediation available to the student (cf., Tharp & Gallimore, 1988; activity settings). This in turn helped to determine the specific sub-goals and motivations of the student, resulting in different outcomes for the students in each group. As the instructional activity setting increased in the complexity of interaction—with the addition of a partner or feedback from the ECHO model, reflection and evaluation became primary motivations and the program features became more useful mediators leading to increased understanding of scientific argumentation.

The introduction of a partner into the activity setting produces the motivation to cooperate, to explain oneself clearly, and to reach consensus. This type of interaction leads to sense-making communication in which students must grapple with multiple views of the argument. This type of interaction also leads to the use of program features and representations necessary to coordinate activity (c.f., Enyedy, Vahey & Gifford, 1997). Since the nature of the task in this curriculum was cooperative, disagreements had to be resolved which led to debates and consensus building.

The introduction of the simulation model into the activity setting produces the motivation to construct an argument that the model evaluates as coherent. This type of interaction also supports sense-making activity in which students grapple with an alternate view of the material and attempt to reach a consensus. The use of program features and representations is also important in this type of interaction by helping students to focus on the salient aspects of their argument.

In some cases, the benefit of grouping was added to the benefit of model use, resulting in greater use of program representations by students in the Pair-Model group. This suggests that the contribution of the model and grouping are not necessarily equivalent. Both the model and collaboration challenge students to clearly and completely express their ideas; however, the model also focuses student attention more so on the structure of their argument, while collaborating with another student serves to decrease the cognitive load in task management.

The results of this investigation demonstrate that the use of the *Convince Me* program to improve scientific reasoning need not be limited to individual interactions. *Convince Me* is able to support students in their scientific problem-solving activities while serving as a forum for collaborative argumentation. Students did occasionally have irreconcilable differences concerning the believability of propositions, the reliability of evidence, or the categorization of a proposition that they expressed in the student reflection notebook. It may be useful to develop a tool that would allow pairs of students to receive feedback from the ECHO simulation model based on their individual belief ratings. However, it is possible that this type of individualized feedback would negate the need for negotiation and lead to a decrease in explanatory conversations between the students.

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