Belvedere: Engaging Students in Critical Discussion of Science and Public Policy Issues[1]

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Abstract: We describe "Belvedere," a system to support students engaged in critical discussion of science issues. The design is intended to address cognitive and metacognitive limitations of unpracticed beginners while supporting their practice of this complex skill. Both prior psychological research and formative evaluation studies with users shaped the interface design. We discuss our design rationale, describe our formative evaluation studies and provide examples of student sessions, and discuss ongoing work with the argumentation advisor.

Introduction

An early and persistent interest in designing software systems to support argumentation resulted in interesting work with hypertext systems and with graphical interfaces for argument construction (Conklin & Begeman, 1987; Fischer, McCall, & Morch, 1989; Smolensky, Fox, King, & Lewis, 1987; Streitz, Hannemann, & Thuring, 1989). For the most part, these systems are designed to provide either a medium for a generic competent reasoner, or support for a specialized expert user in a specific professional practice. For example, Euclid (Smolensky et al., 1987) provides a graphical representation language for generic argumentation; gIBIS (Conklin & Begeman, 1987) and JANUS-Argumentation (Fischer et al., 1989) record the process of design in order to support and critique it in accordance with established methods in the design community. More recently a number of groups have begun work designed to support young students *while they learn* to engage in "knowledge-building" and reasoned discussion (O'Neill & Gomez, 1994; Scardamalia & Bereiter, 1991).

This paper describes the design rationale and formative evaluation of a system called "Belvedere," a graphical environment with advice on demand intended to support the development of scientific argumentation skills in young students. These students can not be presumed to have either the skills of constructing scientific arguments or the specific knowledge of a domain. The design of Belvedere addresses the cognitive and motivational limitations and requirements of these unpracticed beginners, as presented in the psychological literature and as we encountered them in formative testing with 12-15 year olds in a lab study and in 10th grade classrooms in an inner-city public high school. A main goal of our system is to stimulate critical discussion that would not otherwise take place. We therefore designed Belvedere's representations and functionalities to be used as objects of discussion as well as a medium of discussion. In this paper, we discuss our design rationale, describe our formative evaluation studies and provide examples of student sessions, and discuss the design of an automated argumentation advisor.

Design Rationale

We begin by discussing how a software tool can address students' limitations and provide support and guidance for students' participation in critical discussion of science and public policy issues. Some detailed comments on the design follow.

1. Students may not recognize abstract relationships implicit in scientific theories and arguments about them. Belvedere uses diagrammatic representations that provide users with concrete manifestations of the abstract structure of theories and related arguments. Ideas and relationships are represented as objects that can be pointed to, linked to other objects, and discussed. Belvedere's repertory of specialized shapes and links makes particular kinds of relations salient to the students and makes the argument relations understandable to the system so that advice can be given. The diagrams can also help students identify the overall structure of an argument as well as weaknesses and points where further contributions can be made (Smolensky et al., 1987; Streitz et al., 1989).

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2. Students have difficulty keeping track of important elements of a complex debate. Argumentation diagrams can serve as visual reminders that help students keep track of important points. An advisor, described below, can also help students focus on particular aspects of a complex issue.

3. Students lack scientific argumentation criteria. Unlike everyday argument, scientific argument is generated under criteria for acceptability such as coverage, consistency with physical laws, simplicity, and empirical support. Unlike advocative argumentation such as adversary law (Rissland, 1984), scientific arguments make data-gathering procedures, boundary conditions, possible problems, and unresolved questions completely explicit. In Belvedere, we are experimenting with an on-request advisor intended to expose students to standards of evaluation that may not exist in their current peer groups. It is also expected to stimulate further inquiry when students have reached an impasse. This advisor highlights objects in the diagram as possibly needing attention and offers hints based on principles of maximizing a theory's coverage, consistency, and empirical support.

4. Students have limited knowledge of scientific domains. Belvedere provides facilities for authoring online knowledge resources that can be accessed by students, and provides additional resources in the form of modest collections of information in several scientific fields that students can access and copy. Recent extensions enable Belvedere to function as a World Wide Web browser.

5. Students lack the intrinsic motivation of practitioners. Small-group work and the production of documents that will be used by others can provide peer motivation and a sense of authentic activity that teacher- and evaluation-centered work may not provide (Braddock & McPartland, 1993; O'Neill & Gomez, 1994; Scardamalia & Bereiter, 1991; Slavin, 1990) To support small group collaboration while allowing each student equal opportunity for input, Belvedere is networked so that students can work concurrently on the same diagram. The reified arguments enable students to jointly focus on and discuss the same claim, simultaneously and independently address different points, and switch between joint and independent work without losing track of the discussion.

Selected Design Details

Belvedere is implemented in the Common Lisp Interface Manager and ISI's LOOM, and runs in both Lucid Common Lisp on Decstations and Macintosh Common Lisp. We describe several aspects of the implementation briefly here, and discuss the advisor in a later section.

The Graphical Language. We use graphic shapes like ellipses, octagons, rectangles, etc. to represent theories, claims, empirical observations, etc. (see figures). A special "undefined" shape is provided for use when the epistemological status of a statement is not obvious. Text (given by students or copied from other information resources) provides the propositional content of these statements. Similarly, different kinds of links between shapes represent different logical and rhetorical relations between the different statements. (The representations are not to be confused with concept mapping, which relates concepts rather than propositions). Colors are available to distinguish different viewpoints such as different theories or the contribution of each user. A primitive freehand drawing tool is also provided to enable users to extend the representational repertory. Labels can be displayed for either shapes or links or both, and users can optionally change the labels and the shapes. The graphical forms we provide for argument representation are loosely based on the analysis developed by the philosopher Stephen Toulmin (1958). We and our colleagues Violetta Cavalli-Sforza and Alan Lesgold have adapted Toulmin's fundamental representations to scientific argumentation by providing (1) salient graphical representation of different types of argument roles, (2) negative as well as positive links, and (3) enclosure and multiple linkages to accommodate complex arguments.

The Display. Belvedere is a symbol system for the expression of logical and rhetorical relations within a debate. We want users to focus cognitive effort on the debate rather than on learning to use the program. Thus we made the interface look familiar by using command and icon layouts similar to those of typical drawing programs. We help maintain the students' focus on their understanding of the theories and controversies, rather than on every graphical detail of their diagrams, by automating some of the secondary aspects of the work. For example, graphical shapes are created with a default size, and resize themselves to fit their contents. When an object is moved, its links follow it to retain the logical connection. Other tools such as the automated advisor provide further relevant functionality not available in drawing programs.

Management of Multiple Applications. In our initial studies with students sharing a single machine, some students appeared frustrated when limited to mouse operation while a partner dominated the input. To avoid censorship based on ownership of I/O devices, we enable separate machines to display a shared document. Thus

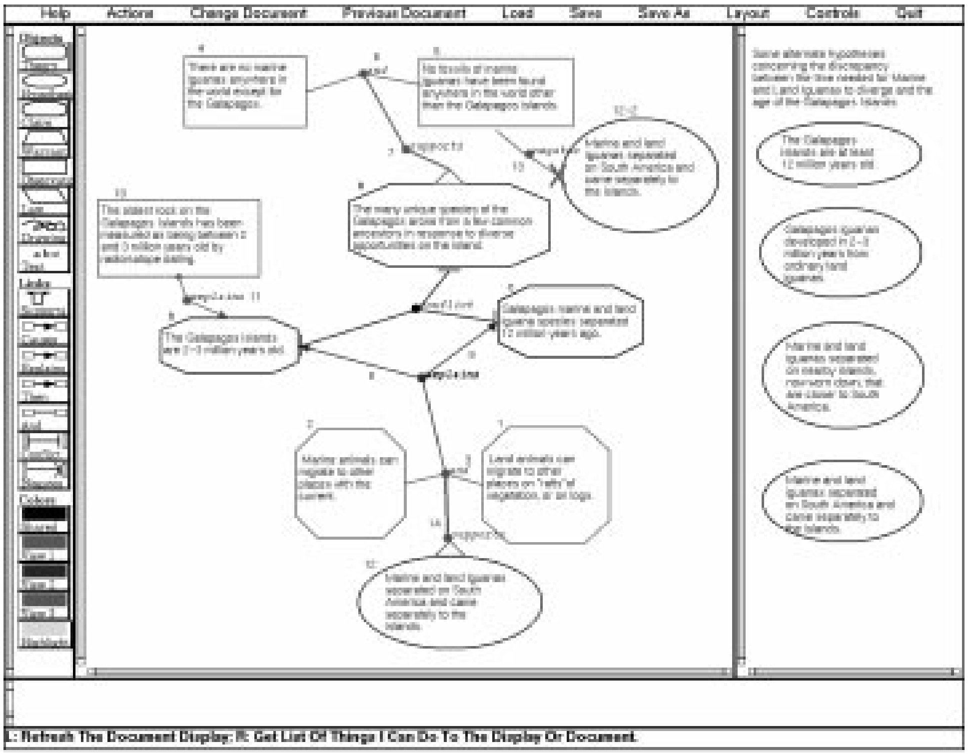

Figure 1: Diagram by “Emin” and “Mo,” Galapagos Iguana Anomaly, early version of Belvedere

students can work concurrently on a shared diagram. Additional functionalities were required to manage this so as to minimize unnecessary redisplay overhead and maximize the user’s focus on cognitive tasks. Users do not want to be distracted by a constantly changing screen while they are thinking. Also, two users should not change the same object simultaneously. We therefore “lock” an object as soon as a user starts to use it. When it is locked, other users can not modify it. Nor do they see the object changing: this would annoy someone pursuing their own thoughts, as well as involve excess redisplay overhead. When the user is done and releases the lock, a redisplay interrupt is sent to other users’ applications. This interrupt is delayed by any applications in which another user is editing, to avoid unexpected change of the context in which the user is working.

Formative Evaluation

Initial formative evaluation included several task scenarios tried with 8 paid subjects, ages 12 to 15, working alone or in pairs, in 17 different 2-hour sessions in our laboratory. Subsequent and ongoing evaluation is taking place in two 10th grade Research Methods classes in a low-SES urban public school. The evaluation is focusing on the usability of the interface and on how the design features of both Belvedere and the student’s task facilitate or interfere with the emergence of critical discussion.

Laboratory Sessions

We ran three sets of laboratory sessions, starting with an early prototype. In the first set each student worked individually but with the experimenters available for questions and to observe. Students were given the task of diagraming the argument structure of a text describing an early theory of mountain formation. In these sessions we were primarily concerned with usability of the interface and the suitability of the diagrammatic representation, and only secondarily with pedagogical issues. Considerable revision of interface details resulted from these sessions.

In the second set of sessions, students from the previous sessions worked in pairs using one computer. Each pair was asked to attempt to resolve an apparent anomaly for the Darwinian idea that the unique species of the Galapagos islands separated on the islands in response to opportunities there (“Galapagos Mystery,” 1992). According to molecular-biological dating, marine and land species of iguanas on the Galapagos appear to have diverged from a common ancestor about 12 million years ago, but radioisotope dating gives an age of only 3 million years for the islands. The initial conflict was presented in both textual and graphical form. Students had available a modest database of small pieces of information, most of which was relevant to the problem, although not always in obvious ways. Their task was to resolve the anomaly using this information. No advice or guidance was given in this exploratory study. Students spontaneously divided their work, with one controlling the mouse, the other the keyboard. We were encouraged by the amount of discussion we saw in some groups. However, in some cases the student who obtained the keyboard dominated and censored the other student's proposals for the diagram.

The third set of sessions was identical to the second except students worked with individual monitors accessing a shared drawing space and located side by side (close enough to see and point to each other's displays). This configuration was tested with two pairs of students (and subsequently many more in the schools). One pair, two girls, cooperated to a high degree in discussing what to do. Their diagram is reproduced in Figure 1, and portions of their dialogue are reproduced in Table 1. (The students chose pseudonyms. "Emin" was a freshman at an urban public school; "Mo" a sophomore at a suburban public school.) Initially *[3:57:45],* Mo proposes that the two species came separately to the islands by floating or swimming. Later *[4:28:45],* Emin discovers a report stating that that no marine iguana fossils have been found anywhere in the world except the Galapagos. Mo maintains her hypothesis despite this. Subsequently *[4:52:10],* Emin gently challenges Mo's conception. Note their extensive use of pointing to the diagram to simplify and coordinate their discussion. Later, we presented them with 4 alternate hypotheses to consider, shown in the far right of Figure 1. By the end of the session *[5:07:00],* Mo has changed her mind. The other pair of students, a boy and a girl, did not interact at all even though they each saw what the other was drawing. They seemed to implicitly agree on a division of screen space between them. It would be interesting to see how this pair's dynamics would have changed if forced to use a single set of devices.

An In-School Study

Recognizing that our sample was far from representative and that we need classroom involvement to develop our tools, we have been working with students and teachers in 2 classes of 10th grade students. One of the teachers, a biology teacher, suggested that we use AIDS as a topic, specifically a relatively recent debate concerning whether HIV causes AIDS. Using a published summary of the debate (Duesberg, 1988 versus Blattner, Gallo, & Temin, 1988), we quickly developed a small database for theories of the cause of AIDS. Eight formal sessions have been conducted (at this writing) in which two to three students worked on shared documents using adjacent machines. Figure 2 shows the argument diagram produced by one group of students after two half-hour sessions (which included the time needed to learn to use the Belvedere system for the first time). Note that it includes not only the argument against causation but also some beginnings of rebuttal to it.

We found that most students, even with little or no prior hands-on experience with Belvedere, had little trouble in mastering the rudiments of interacting with the program. Most students required no assistance or prompting at all to begin creating boxes and adding text to them. Students showed varying degrees of ability and willingness to type their own text, but nearly all of them learned how to do so with little or no assistance. In nearly all the sessions, students produced sensible diagrams, albeit not the diagrams we would have produced ourselves. Their use of shapes and link types was inconsistent. This is not surprising given that we deliberately did not provide them with definitions for the terms in these exploratory studies.

Although students differed in their ability and willingness to express themselves using Belvedere, they seemed to have clear opinions on the HIV/AIDS issue, and many brought in knowledge and personal experiences from outside the printed material we gave them. Although sometimes hampered by problems with network delays, with the interface, or with managing personal interactions with each other, most students were able to incorporate several points of the debate into their diagrams, drawing on the printed texts and/or the online information we provided them, even in the short span of a class period. We saw various opportunities for instruction in patterns of scientific reasoning, consistent with recent research on everyday and scientific reasoning (Kuhn, 1991). For example, some students could be instructed on discriminating observational evidence from claims and opinions. Some students make that discrimination but maintain their personal opinion despite evidence; they could be prompted to seek evidence to support their opinion. Students could be prompted to say what kinds of evidence would cause them to revise their opinion. Our current work with the advisor (which was not available at the time of these studies), seeks to take advantage of these and other opportunities.

[3:57:45] **Emin:** If there were no marine iguanas anywhere in the world except for the Galapagos, wouldn't that mean that they had developed from the land iguanas, and not from any other... the land–?
Mo: Um, well, they could've, but I think what, uhh–
Emin: Or they would've found, they might've found a climate, like, any other climate–
Mo: It says these two species separated about 12 million years ago, but maybe, like, and the islands weren't around then, so probably what happened is the marine iguanas died out by then everywhere else. Like, not by then, but by the time they got to the Galapagos islands they died off everywhere else, maybe. Does that make sense?
Emin: Yeah. So, do you want to put this in there, and then ... type what you just said? That they probably died out by then. [Ss discuss where to put it]
Emin: That would be an observation. [Mo moves #2, then #1, then link #3]

[4:28:45] **Emin** [upon opening document that states that no marine iguana *fossils* have been found anywhere in the world other than the Galapagos]: Uh-oh. [Emin points out contents to Mo; Mo groans]

[4:52:10] **Emin:** Look; the second one [points in R-pane], it kind of goes with these two top ones [points to #4 and 5], that they developed from ordinary land ones, because no fossils had been found, and no marine ones are anywhere else.
Mo: Umm... That could be connected to either this one, right here [mouses over #c], or it could be connected to these two [mouses over #4 and 5], I think. I think either way you could connect it. Because you could say that because they separated here [mousing over #c], they could've, umm, the marine could have died out, the marine iguanas, and then they could have, like, been reborn almost.
Emin: Why would they die out?
Mo: I don't know. [laughs] Somehow they could have died...
Emin: Died out on the islands? Because there were no fossils found anywhere else in the world.
Mo: Yeah... Well, they could've died out when those islands weren't around then. So they probably– They could've just died out wherever they were, and then, umm, the land iguanas, when they got to the islands, they, then in 2-3 million years, the marine iguanas developed from them.
Emin: But, you're saying that they died– that they were living someplace else and they died, and the land iguanas went to the Galapagos islands, and new marine iguanas were born again?
Mo: Because there's no proof that says that the original marine iguanas are the same as the ones that are right now. But I don't know–
Emin: Yeah, I see what you mean.
Mo: I don't know how I'd put it in, though. I'm trying to think how I should connect this [#12] to that [#3]. Uhh... [deletions] ... See, I think this [#2] and this [#1] sort of, umm, this, almost, these two things, the 'and' [#3] sort of supports that [#12], supports that the 'marine and land iguanas separated on South America and came separately to the islands'. Do you agree?
Emin: Say again?
Mo: This, like, I think that these two things right here [mouses over #1 and 2, then points at them with fingers], umm, together sort of support that [#12].
Emin: Why?
Mo: Because it says that *these* [#2] can migrate and that *these* [#1] can migrate, and *this* [#12] is they both could've migrated separately.
Emin: Ok, but if they migrated *separately*, how did the *marine* ones get there in the first place, if no fossils have been found elsewhere? They had to start out from someplace.
Mo: Oh. Well maybe they just haven't found any yet. [Emin laughs] The fossils are always beneath the water; maybe they just didn't, I'm sure it's hard to find fossils underneath the water.
Emin: They might've died on *land*. [laughs]
Mo: Maybe. But I think I'm going to put– I think we should put in a link between that [#3] and that [#12], but I don't know what. Supports? Do you think that supports it?
Emin: [reaches for sheet in front of Mo, looks at it] What's this one mean? 'Negates'?
Mo: It says that it can't be true.
Emin: Well, then, this [#12] would go to [?] *that* one [#5].
Mo: [pause] No; I still think they both could've, umm, because they lived in the water, they didn't have to start out anywhere. Do you know what I'm saying?

[5:07:00] **Emin:** Well, *I* think the answer is that just the land iguanas came from South America, by floating vegetation or whatever, and a subspecies developed off them which were the marine iguanas, since their fossils weren't found anywhere else.
Mo: I sort of agree with these two [points at bottom two ovals in R-pane], that the two kinds of iguanas separated on islands that are now worn down that are closer to South America, and then they both could have migrated to the Galapagos Islands, because marine animals– marine iguanas aren't found anywhere else, that would, like, explain that.
Emin: I'd like information on whether or not those islands, the worn-down islands... if there were fossils and stuff–
Mo: Yeah, more on if, uhh–
Emin: ... other possibilities.
Mo: Where they've searched for fossils, too.

Table 1: Selections from Dialogue Between "Emin" and "Mo"; Galapagos Iguana Anomaly

```
(def-advice self-support
     :advice "This looks like a circular argument. Is there a report or reason in this
                    group of statements that doesn't depend on accepting the rest of them?"
     :arguments (?x)
     :test (:and (statement ?x) (support-or-explain* ?x ?x)))
(def-advice support-competitor
     :advice "Could the empirical data that supports one theory can also support the other?"
     :arguments (?t1 ?t2 ?d)
     :test (:and (theory ?t1) (theory ?t2) (empirical ?d) (:not (:same-as ?t1 ?t2))
                    (supports* ?d ?t1) (:not (supports* ?d ?t2))))
```

Table 2: Example Advice Patterns (attributes used by preferences are not shown)

Advice on Demand

We have prototyped an automated advisor that gives advice on demand concerning ways in which an argument can be extended or revised. Advice is on-demand to avoid inappropriate intrusion into student discussion that may be taking place external to the computer environment. Advice is phrased as suggestions and questions because we cannot presume that an automated advisor has sufficient information to be imperative, and we want students to think about the advice, not just execute it.

Types of advice are defined in terms of patterns to be matched to the diagram, and textual advice to be given if there is a match. (The patterns match only to structural and categorical features of the graphical objects. The students' text is not interpreted.) Example advice patterns are given in Table 2. The advice applicable to a given argument graph is often more than a student can be expected to absorb and respond to at one time. When more than one instance of advice is applicable, a preference-based quicksort algorithm is used, following a mechanism used by Suthers (1993) for selecting between alternate explanations. Advice instances are sorted in priority order, and the highest priority advice is given. Objects that bind to variables in the patterns are highlighted in yellow when the advice is given, so the user can easily identify what the advice is about. If further advice is requested before the diagram changes, subsequent advice instances on the sorted list are used without reanalysis. We are investigating preferences that take into account factors such as prior advice that has been given, how that advice has been responded to, and various relationships between the currently applicable advice.

Coaching Student Contributions. We believe that the most important kind of advice is that which stimulates and scaffolds constructive activity on the part of the students. To give this kind of advice, we identify partial argument patterns in the argument constructed so far and indicate how the student could complete these patterns. For example, the advisor might find theoretical claims that have no empirical support and suggest that support be sought, or it might find competing theories where one theory is supported by some empirical observation and ask if the same observation can support the other theory (support-competitor in Table 2).

Addressing Illegal and Incoherent Constructions. "Illegal" constructions are those that use elements of the argument language in a manner inconsistent with their intended semantics. For example, a "support" link should not be used between data. "Incoherent" constructions are those in which the elements are each used legally, but in combinations that are semantically problematic. Examples include a loop of "support" links (self-support in Table 2), or a datum that both supports and undermines the same claim. An obvious approach would be to design the interface such that it is impossible to make "illegal" constructions. Then no advisor need be involved. However, one should be cautious in taking this approach with educational software, for two reasons. First, unlike typical "expert" user communities, our users do not yet share standard terminology and practice for argumentation or critical discussion. Second, in a learning environment we must consider the role of "errors" in the learning process. Errors that are so superficial that they are not likely to result in a useful learning experience should be addressed immediately. However, delayed feedback may be more appropriate for conceptual "errors" such as problematic patterns of argumentation. Prevention of these patterns would prevent users from engaging in processes of theory criticism and revision that are encountered in the real world.

Example Advice. Consider the diagram shown in Figure 2, constructed by two students at our public school site. The following advice is given (one by one and in this order) by our current, prototype advisor when applied to that diagram:

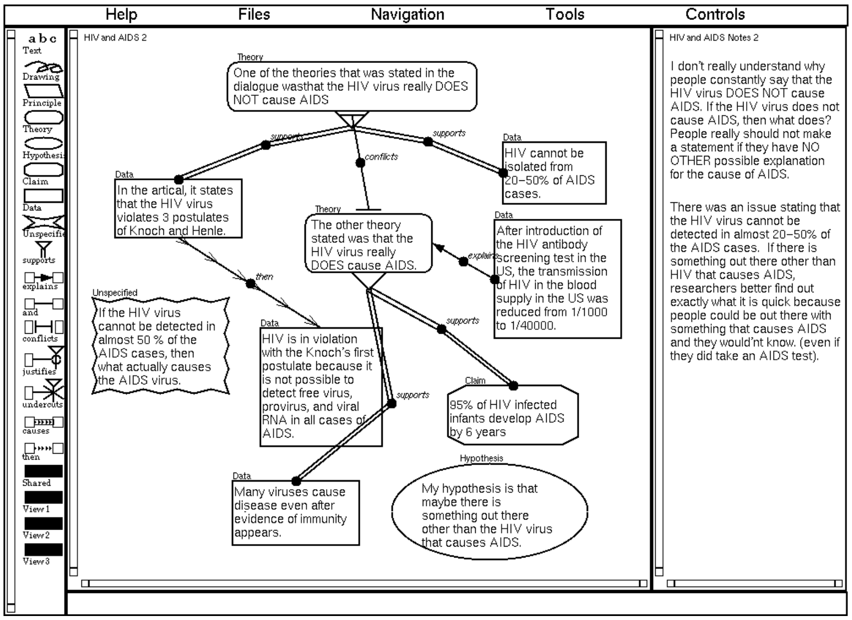

Figure 2: Diagram by Students on HIV/AIDS Issue.

1. Highlights the hypothesis (lower right); asks whether the students can say how this part relates to the rest of the diagram.

2. Highlights the same hypothesis and asks whether the students can find a way to support it, or show that it predicts or explains an observed phenomenon.

3. Highlights the two theories and one of the "Data" boxes that supports one of them and asks whether it is possible that the same data supports the other theory. ("Data" is a kind of "Empirical Observation." We changed terminology to match classroom conventions.)

4. Highlights the "explains" link (right of center), points out that ideas such as theories and hypotheses explain empirical observations, not the other way around, and tells the student an easy way to reverse the link. (We did not constrain drawing of links because we wanted to see what kinds of errors students make, whether other students detect the errors, and what, if anything, they learn from the errors. In the future we may give immediate feedback.)

We are developing a library of argument patterns and investigating the conditions under which advice based on each pattern stimulates productive critical discussion between students. In addition to those mentioned above, other kinds of advice that we have implemented include suggesting that a theory or hypothesis be formulated when none are present in the argument; asking whether there is another theory that provides an alternate explanation for the empirical data when only one theory or hypothesis is involved in the argument; and asking whether discriminating data can be found when there are two competing theories with identical support.

Design Lessons

In our work with students, some of the most productive critical discussion appeared to be stimulated by the diagramming activity, yet was not always captured in the resulting diagram. Because of this, we emphasize representations *the production and inspection of which stimulate critical discussion*, as well as other desiderata such as sufficient expressiveness to support communication between distant or asynchronous collaborators. This complicates the criteria for interface design, because we must decide when we are designing for conversation embodied *in* the diagrams versus designing to stimulate *external* conversation that may never be recorded (Roschelle, 1994). Users' discourse processes transcend the representational and computational resources provided by any support software. Thus, the utility of software features should be evaluated in terms of how well they stimulate the right kind of activity in the total human-computer system. We do not assume that local optimization of software support for isolated subtasks (e.g., making "correct" argument diagrams) always optimizes overall task performance. Rather, our main question is: What kind of discourse is facilitated or stimulated by each feature of the interface and of the task posed to the students, and what kind of discourse is inhibited?

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