Initial Evidence for Representational Guidance of Learning Discourse

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Little work to date has addressed the effects that problem/solution representations have on collaborative learning processes. This paper outlines empirical and theoretical reasons why the expressive constraints imposed by a representation and the information that a representation makes salient may have important effects on students' discourse during collaborative learning. It then reports initial results from a pilot study. Students worked together in pairs on hypertext-based "science challenge" problems. Pairs used either free text, matrix or graph representations of evidence, with two groups assigned to each kind of representation for a total of six groups. Analysis of discourse transcripts suggests that these representations have quite different effects on the extent to which students discuss evidential relations.

Keywords: **Collaborative Learning Discourse, Representational Tools**

1 Introduction

Decades of research into cognitive and social aspects of learning have developed a clear picture of the importance of learners' active involvement in the expression, examination, and manipulation of their own knowledge, as well as the equal importance of guidance provided by social processes and mentorship. Recently these findings have been reflected in software technology for learning: systems are now providing learners with the means to construct and manipulate their own solutions while they are being guided by the software and interacting with other learners. My work is within this spirit, providing representational tools in support of collaborative learning. *Representational tools* may range from basic office tools such as spreadsheets and outliners to "knowledge mapping" software. Such tools help learners see patterns, express abstractions in concrete form, and discover new relationships [4, 8]. These tools can function as *cognitive* tools that lead learners into certain knowledge-building interactions [3, 7].

For a number of years, my colleagues and I have been building, testing, and refining a diagrammatic environment ("Belvedere") intended to support secondary school children's learning of critical inquiry skills in the context of science. The diagrams were first designed to capture scientific argumentation, and later simplified to focus on evidential relations between data and hypotheses. This change was driven in part by a refocus on *collaborative* learning, which led to a major change in how we viewed the role of the interface representations. Rather than viewing the representations as medium of communication or a formal record of the argumentation process, we came to view them as resources (stimuli and guides) for conversation [12, 17]. Meanwhile, various projects with similar goals (i.e., critical inquiry in a collaborative learning context) were using radically different representational systems, such as hypertext/hypermedia [6, 9, 13, 22]; node-link graphs representing rhetorical, logical, or evidential relationships between assertions [11, 14, 19, 20] containment [1], and evidence or criteria matrices [10].

Both empirical and theoretical inquiry suggests that the expressive constraints imposed by a representation and the information (or lack thereof) that it makes salient may have important effects on students' discourse during collaborative learning. Specifically, as learner-constructed external representations become part of the collaborators' shared context, the distinctions and relationships made salient by these representations may influence their interactions in ways that influence learning outcomes. However, to date little systematic research has undertaken to explore possible effects of this variable on collaborative learning, except for [5]. This paper motivates and describes our research and reports initial results from such a study.

2 Representational Guidance

The major hypothesis resulting of this work is that variation in features of representational tools used by learners working in small groups can have a significant effect on the learners' knowledge-building discourse and on learning outcomes. The claim is not merely that learners will talk about features of the software tool being used. Rather, with proper design of representational tools, this effect will be observable in terms of learners' talk about and use of *subject matter concepts and skills.* We have begun investigations to determine what features have what kind of effect. This section develops an initial theory of how representations guide learning interactions, and applies this analysis to make specific predictions concerning the effects of selected features of representational tools. The discussion begins with some definitions.

Representational *tools* are software interfaces in which users construct, examine, and manipulate external representations of their knowledge. Our work is concerned with symbolic as opposed to analogical representations. A notation/artifact distinction [16] is critical to the theory, as depicted in Figure 1. A representational tool is a software implementation of a representational *notation* that provides a set of primitive elements out of which representations can be constructed. (For example, in Figure 1, the representational notation is the collection of primitives for making hypothesis and data statements and "+" and "-" links, along with rules for their use.) The software developer chooses the representational notation and instantiates it as a representational tool, while the user of the tool constructs particular representational *artifacts* in the tool. (For example, in Figure 1 the representational artifact is the particular diagram of evidence for competing explanations of mass extinctions.)

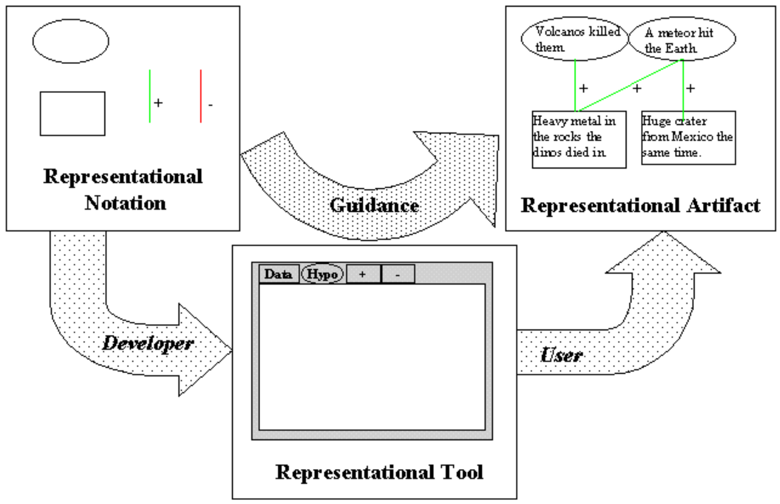


Figure 1 Representational Guidance

Learning interactions include interactions between learners and the representations, between learners and other learners, and between learners and mentors such as teachers or pedagogical software agents. Our work focuses on interactions between learners and other learners, specifically verbal and gestural interactions termed collaborative learning discourse.

Each given representational notation manifests a particular representational guidance**,** expressing certain aspects of one's knowledge better than others do. The concept of representational guidance is borrowed from artificial intelligence, where it is called *representational bias* [21]. The phrase *guidance* is adopted here to avoid the negative connotation of *bias*. The phrase knowledge unit will be used to refer generically to components of knowledge one might wish to represent, such as hypotheses, statements of fact, concepts, relationships, rules, etc. Representational guidance manifests in two major ways:

- *Constraints*: limits on expressiveness, i.e., which knowledge units can be expressed [15].
- *Salience:* how the representation facilitates processing of certain knowledge units, possibly at the expense of others [8].

As depicted in Figure 1, representational guidance originates in the notation, but affects the user through both the tool and artifacts constructed in the tool.

The core idea of the theory may now be stated as follows: Representational tools mediate collaborative learning interactions by providing learners with the means to articulate emerging knowledge in a persistent medium, inspectable by all participants, where the knowledge then becomes part of the shared context. Representational guidance constrains which knowledge can be expressed in the shared context, and makes some of that knowledge more salient and hence a likely topic of discussion. The discussion now turns to three predictions based on differences between representational notations.

2.1 Representational notations bias learners towards particular ontologies

The first hypothesis claims that important guidance for learning interactions comes from ways in which a representational notation *limits* what can be represented [15, 21]. A representational notation provides a set of primitive elements out of which representational artifacts are constructed. These primitive elements constitute an ontology of categories and structures for organizing the task domain. Learners will see their task in part as one of making acceptable representational artifacts out of these primitives. Thus, they will search for possible new instances of the primitive elements, and hence (according to this hypothesis) will be guided to think about the task domain in terms of the underlying ontology.

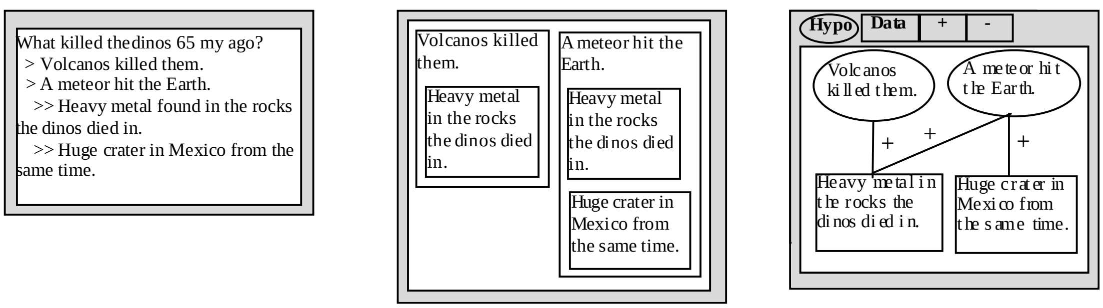
For example, consider the following interaction in which students were working with a version of Belvedere that required all statements to be categorized as either *data* or *claim*. Belvedere is an "evidence mapping" tool developed under the direction of Alan Lesgold and myself while I was at the University of Pittsburgh [18, 19, 20]. The example is from videotape of students in a 10th grade science class.

S1: So data, right? This would be data.
S2: I think so.
S1: Or a claim. I don't know if it would be claim or data.
S2: Claim. They have no real hard evidence. Go ahead, claim. I mean who cares? Who cares what they say? Claim.

The choice forced by the tool led to a peer-coaching interaction on a distinction that was critically important for how they subsequently handled the statement. The last comment of S2 shows that the relevant epistemological concepts were being discussed, not merely which toolbar icon to press or which representational shape to use.

2.2 Salient knowledge units are elaborated

This hypothesis states that learners will be more likely to attend to, and hence elaborate on, the knowledge units that are perceptually salient in their shared representational workspace than those that are either not salient or for which a representational proxy has not been created. The visual presence of the knowledge unit in the shared representational context serves as a reminder of its existence and any work that may need to be done with it. Also, it is easier to refer to a knowledge unit that has a visual manifestation, so learners will find it easier to express their subsequent thoughts about this unit than about those that require complex verbal descriptions [2]. These claims apply to any visually shared representations. However, to the extent that two representational notations differ in kinds of knowledge units they make salient, these functions of *reminding* and *ease of reference* will encourage elaboration on different kinds of knowledge units.



(a) Threaded Discussion: *limited representation of relation.* ***(b) Containment:*** *Implicit representation of relations.* ***(c) Graph:*** *Relationship as object of perception.*

Figure 2. Example of Elaboration Hypothesis

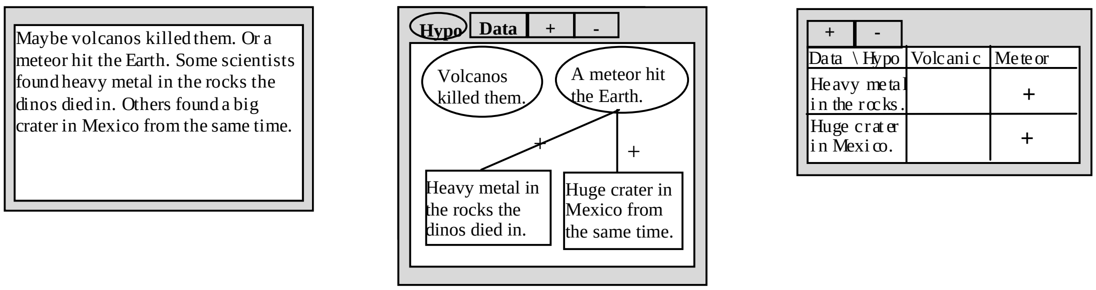
For example, consider the three representations of a relationship between four statements shown in Figure 2. The relationship is one of evidential support. The middle notation uses an implicit device, containment, to represent evidential support, while the right-hand notation uses an explicit device, an arc. It becomes easier to perceive and refer to the *relationship* as an object in its own right as one moves from left to right in the figure. Hence the present hypothesis claims that relationships will receive more elaboration in the rightmost representational notation.

The opposite prediction is also plausible. Learners may see their task as one of putting knowledge units "in their place" in the representational environment. For example (according to this competing hypothesis), once a datum is placed in the appropriate hypothesis container (Figure 2b) or connected to a hypothesis (Figure2c), learners may feel it can be safely ignored as they move on to other units not yet placed or connected. Hence they will not elaborate on represented units. This suggests the importance of making missing information salient.

2.3 Salience of missing units guides search

Some representational notations provide structures for organizing knowledge units, in addition to primitives for construction of individual knowledge units. Unfilled "fields" in these organizing structures, if perceptually salient, can make missing knowledge units as salient as those that are present. If the representational notation provides structures with predetermined fields that need to be filled with knowledge units, the present hypothesis predicts that learners will try to fill these fields.

For example, Figure 3 shows artifacts from three notations that differ in salience of missing evidential relationships. In the textual representation, no particular relationships are salient as missing: no particular prediction about search for new knowledge units can be made. In the graph representation, the lack of connectivity of the volcanic hypothesis to the rest of the graph is salient. Hence this hypothesis predicts that learners will discuss its possible relationships to other statements. However, once some connection is made to the hypothesis, it will appear connected, so no further relationships will be sought. In the matrix representation, all undetermined relationships are salient as empty cells. The present hypothesis predicts that learners will be more likely to discuss many relationships between statements when using matrices.



***(a) Text:** No relation is saliently missing.*

***(b) Graph:** Partial salience of missing relations.*

***(c) Matrix:** Salience of all missing relations.*

Figure 3. Example of Salient Absence Hypothesis

2.4 Predicted Differences

Based on the discussion of this section, the following predictions were tested in the study reported below. The symbol “>“ indicates that the discourse phenomenon at the beginning of the list (concept use, elaboration, or search) will occur at a significantly greater rate in the treatment condition(s) on the left of the symbol than in those on the right

Concept Use: {Graph, Matrix} > {Container, Text, Threaded Discussion}. The Graph and Matrix representations *require* that one categorize statements and relations. This will initiate discussion of the proper choice, possibly including peer coaching on the underlying concepts. The Container, Text, and Threaded Discussion representations provide only implicit categorization. Students may discuss placement of information, but this talk is less likely to be expressed in terms of the underlying concepts.

Search for Missing Relations: Matrix > {Container, Graph} > {Text, Threaded Discussion}. The matrix representation provides an empty field for *every* undetermined relationship, prompting participants to consider all of them. In Graphs or the Container representations, salience of the lack of *some* relationship disappears as soon as a link is drawn to the statement in question or another is placed in its container, respectively. Threaded Discussion does not specifically direct searches toward missing relationships.

The Elaboration hypothesis was not tested independently of the Search hypothesis in this study.

3 An Initial Study

This section reports on an initial study that was conducted to identify trends suggesting that there is a phenomenon worthy of further study; and to refine analytic techniques. Specifically, the study examined how the amount of talk about evidence and the amount of talk about the epistemological status of propositions (empirical versus theoretical) differed across three representational tools, and provided qualitative observations to guide further study.

3.1 Design

Six pairs (twelve participants) were distributed evenly between three treatment conditions in a simple between-subjects design. The three treatment conditions corresponded to three notations: Text, Graph, and Matrix. These notations differ on more than one feature, such as ontology, whether inconsistency relations are represented, and visual and textual notations. I intentionally chose this research strategy (instead of manipulating precisely one feature at a time) in order to maximize the opportunity to explore the large space of representations within the time scale on which collaborative technology is being adapted.

3.2 Method

3.2.1 Participants

Middle-school boys were recruited by my assistant (Cynthia Liefeld) from soccer practice. Two pairs of participants were run in each of the three conditions. Each pair consisted of boys who knew each other, a requirement intended to minimize negotiation of a new interpersonal relationship as a complicating factor.

3.2.2 Materials

Software. Three existing software packages were used: Microsoft Word (Text), Microsoft Excel (Matrix), and Belvedere (Graph). Groups using MS Word were not prohibited from using its typographical devices such as different typefaces, styles, lists, etc. We did not restrict participants' appropriation of typographical devices for organizing information, but neither did we encourage any particular use of the textual medium. Groups using MS Excel were provided with a prepared matrix that had the labels "Hypotheses" and "Data" in the upper left corner, and cells formatted sufficiently large to allow entry of textual summaries of the same. Participants were specifically told to enter hypotheses as column headers, data as row headers, and to record the relationships in the internal cells. The Graph condition used Belvedere. The version of Belvedere used (2.1) provides rounded nodes for hypotheses, rectangles for data, and links for consistency and inconsistency relations between them. Hypothesis and data shapes are filled with textual summaries of the corresponding claims.

Science Challenge Problems. Participants were presented with "science challenge problems" in a web-browser. A science challenge problem presents a phenomenon to be explained (e.g., determining the cause of the dinosaur extinctions, or of a mysterious disease on Guam known as Guam PD), along with indices to relevant resources. For example, one can obtain lists of articles posing possible explanations of the phenomenon, reporting empirical findings from fieldwork or laboratory work, or explaining basic domain concepts. These are relatively ill-structured problems: at any given point many possible knowledge units may reasonably be considered. The materials we used were modified from the classroom versions of science challenge problems developed by Arlene Weiner and Eva Toth.[1] The experimental version excluded hands-on activities, links to external sites and activity guide.

Computer Setup. The computer screen was divided in half as shown in Figure 4. The left-hand side contained the representational tool -- any one of Text, Graph (shown), or Matrix. The right hand side contained a web browser open to the entry page for the science challenge materials.

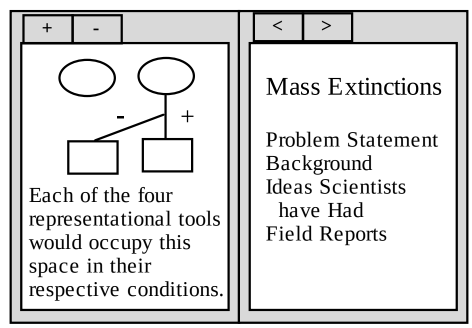


Figure 4. Screen Layout for Studies

3.2.3 Procedure

Participants were seated in front of a single monitor and keyboard. After an introduction to the study and signing of permission forms, participants were shown the software and allowed to practice the basic manipulations such as creating and linking nodes or filling in matrix cells. This training did not involve any mention of concepts of evidence or of the problem domain.

Participants were then presented with the problem statement in the web browser on the right. The problem solving session was initiated when they were instructed to identify hypotheses that provide candidate explanations of the phenomenon posed, and to evaluate these hypotheses on the basis of laboratory studies and field reports obtained through the hypertext interface. They were instructed to use the representational tool during the problem solving session to record the information they find and explore how it bears on the problem. Participants were responsible for deciding how to share or divide use of the keyboard and mouse. The procedure described in this paragraph was repeated, first with a "warm-up" problem, and then with the problem for which data is reported below (Guam PD). Sessions were videotaped with the camera pointed at the screen over the shoulder of one of the participants.

3.3 Results

Analysis was based primarily on coding of transcripts of participants' spoken discourse, and secondarily on participants' representational artifacts.

[1] Available at http://lilt.ics.hawaii.edu/belvedere/materials/index.html.

3.3.1 Coding and Analysis of Discourse

Pilot study videotapes from the six one-hour problem-solving sessions were transcribed and segmented. A segment was defined to be a modification to the external representation or a single speaker's turn in the dialogue, except that turns that expressed multiple propositions were broken into multiple segments. Segments were coded using the QSR Nud*ist software package.

The following codes provide the dependent variables of interest. *Epistemological Classification* codes discourse about the epistemological status of a statement, including classification as empirical (e.g., "that's data"), theoretical (e.g., "that's a hypothesis, isn't it?") or discussion of the choice (e.g., "do you want me to go data or hypothesis?"). In the present study we only wanted to see whether the tools differed in their prompting for making this choice, so did not discriminate these subcategories. Sub-dimension *Evidential Relation* is applied to segments where participants discuss or identify the nature of the evidential relationship between two statements. The codes are *Consistency* (e.g., "it's also for," "that confirms"), *Inconsistency* ("so that's against," "with this one, no, conflicts, right?"), or *Equivocal*, applied when participants raise the question of which relationship holds, if any, without identifying one specifically ("is that for or against?," "it can neither confirm nor deny"). In some cases, evidential relationships were apparently being expressed in terms of the representational primitives provided by the software (e.g., "connect these two"). These utterances were also coded with the appropriate Evidential Relation category, but marked with the Level code (discussed below) so that such "tool-level talk" could be distinguished during the analysis. Topic sub-dimension *Other Topic* codes segments not coded as one of the above topics. The "other" codes include *On-task* (e.g., "are we done with this?"), *Off-task* (e.g., "what's for lunch?"), or *Unclassifiable* (e.g., "uh," mumbles, etc.).

The remaining coding dimensions are used to select out relevant segments for particular analyses. *Mode* indicates whether the segment is coded for its *Verbal* content or for an action taken on the *Representational* artifact. The final two dimensions only apply to verbal segments. *Level* is applied only to Epistemological and Evidential Verbal segments, and indicates whether an utterance made direct use of epistemological or evidential concepts (e.g., "supports," "hypothesis": *Conceptual*) or was expressed in terms of the software (e.g., "link to this," "round box": *Tool-based*). *Ownership* indicates whether the participant was merely reading text that we provided (Recited) or expressing their own ideas (Non-Recited).

Coding was performed by two of my assistants (Chris Hundhausen and Laura Girardeau). Questions of interpretation, problematic segments, etc. were discussed among the three of us during meetings, but the coding itself was done independently. Inter-rater reliability was computed using the Kappa statistic across all of the categories described above, producing a value of 0.92 (n=1942).

Table 1. Summary of Verbal Coding

Verbal segments tested: nesting indicates subset selection; % are of "Not Off-Task"	**Text**		**Graph**		**Matrix**	
	N	***%***	***N***	***%***	***N***	***%***
Non-Recited	778	*n/a*	626	*n/a*	537	*n/a*
..Not Off-Task	694	100	613	100	508	100
….Evidential Relation	4	0.58	32	5.22	100	19.69
……Consistency	3	0.43	21	3.43	54	10.63
……Inconsistency	1	0.14	6	0.98	35	6.89
……Equivocal Evidential	0	0.00	5	0.82	11	2.17
……Conceptual	3	0.4	9	1.47	43	8.46
……Tool-Based	1	0.1	23	3.75	57	11.22
….Epistemological Classification	39	5.62	57	9.30	36	7.09
……Conceptual	19	2.74	33	5.38	7	1.38
……Tool-Based	20	2.88	24	3.92	29	5.71

Selected results of coding are shown in Table 1, focusing on segments coded as Mode=Verbal, and showing both counts and percentages for each of the three treatment groups. Percentages are taken relative to Non-Recited on task utterances, shown in the second row. Counts and percentages for Evidential Relation are broken down in two orthogonal ways: by whether the relation was Consistency, Inconsistency, or Equivocal; and by whether the talk about evidence was Conceptual or Tool-Based. Epistemological Classification was broken down by Conceptual or Tool-Based. Due to the small sample size we did not perform statistical testing in this preliminary study.

3.3.2 Qualitative observations

The document created by one Text group contained no expression of evidential relations, and the transcript of verbal discourse for this group contained no overt discussion of evidential relations. All of the discussion of evidence in Text occurred in the other group at the end of the session (the longest session in the pilot study), at which time they also added several expressions of evidential relations. A document produced by one of the Graph groups is notably linear, in spite of the fact that Graph is normally considered a nonlinear medium. A pattern of *identify information, categorize information, add it to the diagram, link it in* is typical of interactions in this transcript. This pattern of activity, which leads to the linearity of the graph, is consistent with the competitor to the Elaboration hypothesis: participants may feel that the primary task is to connect each new statement to something else, after which it can be ignored. Finally, the Matrix artifacts were especially striking because participants were not specifically instructed to fill in all the cells, yet they did so. The transcripts illustrated participants' systematic identification of evidential relations as they worked down the columns, and in one case their appropriate use of the table to rule out a hypothesis that they had proposed.

3.4 Discussion

Recall that the Search hypothesis predicts that participants will be more likely to seek evidential relations when using representations that prompt for these relations with empty structure (Text < Graph < Matrix). The row labeled "Evidential Relation" is relevant to the Search hypothesis. This row counts, for each treatment group, the percentage of verbal segments that were coded with any one of the three evidential values (Consistent, Inconsistent, Choice). The results appear to be consistent with the Search hypothesis: Text=0.58% < Graph=5.22% < Matrix=19.69%. This trend holds even when limited to Conceptual expressions of evidential relations: Text=0.43% < Graph=1.47% < Matrix=8.48%. Note however that a substantial portion of talk about evidence in the Graph and Matrix conditions is tool based (about two-thirds of Graph and half of Matrix evidential utterances are tool-based). This is as expected, since these tools, unlike Text, provide objects that may be referred to as proxies for evidential relations.

The breakdown of Evidential talk according to the type of relation shows the influence of the exhaustive prompting of Matrix. In Text and Graph, participants focused primarily on Consistency relations, a possible manifestation of the confirmation bias. Treatment was more balanced in Matrix, with almost half of the talk about evidential relations being concerned with inconsistency or equivocal relations. This may be because Matrix prompts for consideration of relationships between all pairs of items: participants are more likely to encounter inconsistency or indeterminate relations when considering those they may have neglected in the Graph or Text conditions.

Addressing the Concept Use hypothesis, we found that 5.62% of Text, 7.09% of Matrix and 9.30% of Graph utterances were concerned with the classification of new information as *data* versus *hypothesis* or their equivalents. We believe that Text would have been lower, except that the instructions for all three conditions directed participants to consider and record hypotheses and empirical evidence. Text participants, like others, complied with these instructions, for example, by labeling propositions as “Data” or Hypothesis.” Graph’s greater proportion of epistemological classification talk is explained by its most explicit use of visually distinct shapes to represent data and hypotheses.

4 Conclusions

Overall, the results are encouraging with respect to the question of whether there is a phenomenon worth investigating. Differences in the predicted directions were seen in both talk about evidence and about the epistemological status of statements. However, this sample data cannot be taken as conclusive. Caveats, all of which are being addressed by ongoing work, include the small sample size (hence no test of significance), the lack of a learning outcomes measure, and the need for a more direct test of the claim that representational state affects subsequent discourse processes. Furthermore, analyses based on frequencies of utterances across the session as a whole fail to distinguish utterances seeking evidential relations from those elaborating on previous ones (i.e., between the Search and Elaborate hypotheses), or to show a causal relationship between the state of the representation and the subsequent discourse. A more sophisticated coding is required to test whether the representation or salient absence of a particular (kind of) knowledge unit influences search for or elaboration on that unit. All of these deficiencies are being addressed in a study underway at this writing. Pending the results of this study, plans for future work include attempts to replicate selected results in distance learning situations, both synchronous and asynchronous. This line of work promises to inform the design of future software learning environments and to provide a better theoretical understanding of the role of representational guidance in guiding learning processes.

References

1. Bell, P. (1997, December). Using argument representations to make thinking visible for individuals and groups. In Proceedings of the Computer Supported Collaborative Learning Conference '97, 10-19. University of Toronto.
2. Clark, H.H. & Brennan, S.E. (1991). Grounding in Communication. In L.B. Resnick, J.M. Levine and S.D. Teasley (Eds.), Perspectives on socially shared cognition (pp. 127-149). American Psychological Association.
3. Collins, A. & Ferguson, W. (1993). Epistemic forms and epistemic games: Structures and strategies to guide inquiry. Educational Psychologist, 28(1): 25-42.
4. Goldenberg, E. P. (1995). Multiple Representations: A Vehicle for Understanding Understanding. In D. Perkins, J. Schwartz, M. West, & M. Wiske (Eds.), Software goes to school: Teaching for understanding with new technologies (pp. 155-171). New York: Oxford University Press.
5. Guzdial, M. (1997, December). Information ecology of collaborations in educational settings: Influence of tool. In Proceedings of the 2nd International Conference on Computer Supported Collaborative Learning (CSCL'97) (pp. 91-100). Toronto.
6. Guzdial, M., Hmelo, C., Hubscher, R., Nagel, K., Newstetter, W., Puntambekar, S., Shabo, A., Turns, J., & Kolodner, J. L. (1997, December). Integrating and guiding collaboration: Lessons learned in computer-supported collaborative learning research at Georgia Tech. In Proceedings of the 2nd International Conference on Computer Supported Collaborative Learning (CSCL'97) (pp. 91-100). Toronto.
7. Lajoie, S. P., & Derry, S. J. (Eds.). (1993). Computers as Cognitive Tools. Hillsdale, NJ: Lawrence Erlbaum Associates.
8. Larkin, J. H. & Simon, H. A. (1987). Why a diagram is (sometimes) worth ten thousand words. Cognitive Science 11(1)*:* 65-99. 1987.
9. O'Neill, D. K., & Gomez, L. M. (1994).The collaboratory notebook: A distributed knowledge-building environment for project-enhanced learning. In Proceedings of Ed-Media '94, Vancouver, BC.
10. Puntambekar, S., Nagel, K., Hübscher, R., Guzdial, M., & Kolodner, J. (1997, December). Intra-group and intergroup: An exploration of learning with complementary collaboration tools. In Proceedings of the Computer Supported Collaborative Learning Conference '97 (pp. 207-214). University of Toronto.
11. Ranney, M., Schank, P., & Diehl, C. (1995). Competence versus performance in critical reasoning: Reducing the gap by using Convince Me. Psychology Teaching Review 4(2).
12. Roschelle, J. (1994, May). Designing for cognitive communication: Epistemic fidelity or mediating collaborative inquiry? The Arachnet Electronic Journal of Virtual Culture.
13. Scardamalia, M., Bereiter, C., Brett, C., Burtis, P.J., Calhoun, C., & Smith Lea, N. (1992). Educational applications of a networked communal database. Interactive Learning Environments, 2(1), 45-71.
14. Smolensky, P., Fox, B., King, R., & Lewis, C. (1987). Computer-aided reasoned discourse, or, how to argue with a computer. In R. Guindon (Ed.), Cognitive science and its applications for human-computer interaction (pp. 109-162). Hillsdale, NJ: Erlbaum.
15. Stenning, K. & Oberlander, J. (1995). A cognitive theory of graphical and linguistic reasoning: Logic and implementation. Cognitive Science 19(1): 97-140. 1995.
16. Stenning, K. & Yule, P. (1997). Image and language in human reasoning: A syllogistic illustration. Cognitive Psychology 34: 109-159.
17. Suthers, D. (unpublished). Designing for Internal vs. External Discourse in Groupware for Developing Critical Discussion Skills. Presented at the CHI95 Research Symposium, May 6-7. 1995, Denver CO. Available: http://lilt.ics.hawaii.edu/lilt/papers/chi95learning.ps
18. Suthers, D. & Jones, D. (1997, August). An architecture for intelligent collaborative educational systems. Paper presented at AI-Ed 97, the 8th World Conference on Artificial Intelligence in Education, Kobe.
19. Suthers, D., Toth, E., and Weiner, A. (1997, December). An integrated approach to implementing collaborative inquiry in the classroom. In Proceedings of the 2nd International Conference on Computer Supported Collaborative Learning (CSCL'97) (pp. 272-279). Toronto.
20. Suthers, D. and Weiner, A. (1995, October). Groupware for developing critical discussion skills. Paper presented at CSCL '95, Computer Supported Cooperative Learning, Bloomington, Indiana.
21. Utgoff, P. (1986). Shift of bias for inductive concept learning. In R. Michalski, J. Carbonell, T. Mitchell (Eds.) Machine Learning: An Artitificial Intelligence Approach, Volume II (pp. 107-148). Los Altos: Morgan Kaufmann.
22. Wan, D., & Johnson, P. M. (1994, October). Experiences with CLARE: a Computer-Supported Collaborative Learning Environment. International Journal of Human-Computer Studies.