Collaborative Representations: Supporting Face to Face and Online Knowledge-building Discourse

Daniel D. Suthers
Department of Information and Computer Sciences
University of Hawai`i at Manoa
1680 East West Road, POST 303A
suthers@hawaii.edu

Abstract

The present widespread interest in the use of electronic media for presents an unprecedented opportunity for leveraging the computational medium's strengths for learning. However, existing software tools provide only primitive support for online knowledge-building discourse. Further work is needed in supporting coordinated use of disciplinary representations, discourse representations, and knowledge representations. This paper introduces the concept of representational guidance *for discourse along with results of an initial study of this phenomenon in face to face situations. The paper then considers the requirements for supporting asynchronous online knowledge-building discourse, finding existing computer mediated communication tools to be particularly deficient in supporting artifact-centered discourse. A solution is proposed that coordinates discourse representations with disciplinary and knowledge representations.*

1. Introduction

There is a great deal of interest in the use of electronic media for learning, across the age spectrum from K-12 through university and lifelong learning, in both proximal and distance learning situations, and across a diversity of disciplines. This situation presents a great opportunity for leveraging the computational medium's strengths for education: its representational and analytic capabilities, its interactivity and networking support for collaboration. Yet in this opportunity lies responsibility on the part of educators, policymakers and technologists to adopt technologies specifically designed and proven to support learning. We need to explore how computation enables new forms of support for interaction in learning, not just cobble together the available electronic media, nor just "deliver" conventional but ineffective pedagogical approaches over the wire.

Decades of research on learning and instruction have shown the importance of learners' active participation in expressing, testing, and revising their own knowledge. In particular, two sets of findings are relevant: the impact of representational aids, such as dynamic notations, knowledge maps, simulations, etc., on individual problem solving and learning [14, 15, 16, 19, 20, 24, 28, 32, 43]; and the importance of social processes such as collaboration and mentoring to learning [3, 17, 27, 29, 41]. Yet, there is a lack of research on how these techniques – representational tools and collaborative learning – may be constructively combined. Although a plethora of *disciplinary representations* are available (consider scientific visualizations in fields such as meteorology and physics, the various representations of molecular structure in chemistry, and modeling tools such as UML in computer science), existing tools for collaboration provide only primitive support. For example, present-day software environments for distance learning are typically composed of standard Internet media and tools such as web-pages, chat rooms and threaded discussions without reconsideration of the support they provide (or fail to provide) for learning discourse, and without coordination with disciplinary forms of representation. There is an immediate need to develop empirically grounded theories of design of electronic media for discourse in learning. Fundamental research is needed under two perspectives:

1. *From representations to learning interactions:* Any given representational system has its own affordances, restricting what can be represented and making certain information more salient than others. How can these representational affordances be leveraged to guide the content and dynamics of collaborative learning interactions?
2. *From learning interactions to representations:* How can we construct active representational media in which learners find it natural to record their discourse, problem solving activities, and emerging knowledge to support learning by reflection, mentoring, and assessment?

In this paper I report on work that addresses the first perspective above, specifically the effects of alternate representations for critical inquiry in science on verbal discourse during proximal (co-present) collaboration between learners. I then discuss the need to extend this research to asynchronous (anytime, anyplace) collaboration, where the use of representational tools for the discourse itself, and hence the second perspective above, becomes more critical. In particular I focus on how to combine the two perspectives to provide explicit representational support for knowledge-building discourse.

2. Representational Guidance

The major hypothesis of this work is that certain representational features of software used by learners will have educationally significant effects on the learners' discourse (including verbal and written discourse and other interactions such as gestures). Collins & Ferguson's [5] "epistemic forms/games" and Roschelle's [25] view of representations as "mediating collaborative inquiry."

I distinguish between representational *notations*, the representational *tools* (e.g., software) in which these notations are realized, and representational *artifacts* that one might construct in a notation using a tool. Each given representational notation manifests a particular *representational guidance*, expressing certain aspects of one's knowledge better than others do. Representational guidance includes *constraints:* limits on expressiveness, and on the sequence in which information can be expressed [33] and *salience:* how the representation facilitates processing of certain information, possibly at the expense of others [16]. Representational guidance originates in the notation, but affects the user through both the tool and artifacts constructed in the tool.

My thesis may be stated as follows: Representational tools mediate collaborative learning interactions by providing learners with the means to express their 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. This research is driven by three component hypotheses.

1. *Representational Notations Bias Learners Towards Particular Ontologies.* A representational notation provides a set of primitive elements out of which representational artifacts are constructed. Learners will see their task in part as one of making acceptable representational artifacts out of these primitives. Thus, they will be guided to think about the task domain in terms of the underlying ontology.
2. *Salient Knowledge Units Receive More Elaboration.* Learners will be more likely to attend to, and hence elaborate on, the knowledge elements 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. Two representational notations that differ in kinds of knowledge they make salient will encourage elaboration on different kinds of knowledge.
3. *Salience of Missing Knowledge Units Guides Search for New Knowledge.* If the representational notation provides structures with predetermined "fields" (or functional equivalents) for organizing knowledge elements, and unfilled fields in these organizing structures are perceptually salient, then learners will try to fill these fields.

3. Empirical Studies

I am conducting studies to test the hypothesis that this representational guidance influences discourse and learning outcomes in ways that can be predicted from the constraints and salience of the notation. This work was initiated based on the observation that various software environments that were developed for the goal of supporting critical inquiry in a collaborative learning context were using radically different representational systems. Examples include hypertext/hypermedia [8, 13, 21, 28, 40]; node-link graphs representing rhetorical, logical, or evidential relationships between assertions [23, 31, 36]; containers or "claim frames" [1], and evidence or criteria matrices [22]. Yet, little systematic research had been undertaken to explore possible effects of this variable on collaborative learning (except [7]). See Suthers [34, 35] for a full review.

My colleagues and I undertook a pilot study that examined how the quantity of talk about evidence and the quantity of talk about the epistemological status of propositions (empirical versus theoretical) differed across three representations of the evidential relationships between data and hypotheses: *Text*, *Graph*, and *Matrix*. We used Microsoft Word for Text, Microsoft Excel for Matrix, and Belvedere [36] for Graph. We did not restrict participants' appropriation of MS Word's 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 2.1, which 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. Based on the previous hypotheses, I made the following predictions:

1. *Talk about Ontology:* There will be more discussion of the epistemological status of statements (empirical or theoretical) in representations that require classification of statements of such. Furthermore, the effect will be greatest where the classification is represented by an explicit visual feature rather than implicitly: Text < Matrix < Graph.
2. *Talk about Evidence:* There will be more discussion about the evidential relationships between statements when a representation of such relationships is provided. The effect will be greater when relationships are represented with an explicit object (a link or an annotation) rather than merely by spatial placement, and greatest when all possible relationships are prompted for by empty fields: Text < Graph < Matrix.

Detailed description of these hypotheses and predictions may be found in Suthers [34, 35]. It should be noted that the “<” symbol expresses predictions about effects on discourse processes, and does not make a value judgement. Whether and when more talk about epistemological status and/or evidential relations is desirable is a separate instructional decision.

3.1. Method

Six pairs (twelve participants) were distributed evenly between the three treatment conditions in a simple between-subjects design. Two pairs of middle-school boys were run in each of the three conditions. The participants were presented with “science challenge problems” in a web-browser. A science challenge problem[1] 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. The computer screen was divided in half, containing the representational tool and a web browser open to the entry page for the science challenge materials. Participants used a single monitor and keyboard. After training on the software, they were presented with the problem statement. 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. First they worked with a "warm-up" problem, and then with the problem for which data is reported below.

[1] The problems were developed by Arlene Weiner and Eva Toth, and modified for laboratory use. The original versions are available at http://lilt.ics.hawaii.edu/belvedere/materials/index.html.

3.2. Results

The analysis was based primarily on coding of transcripts of participants' spoken discourse, and secondarily on participants' representational artifacts. Pilot study videotapes from the six one-hour problem-solving sessions were transcribed and coded. Coding was performed by two of my assistants (Chris Hundhausen and Laura Girardeau) achieving a Kappa of 0.92 (n=1942). The results reported below focus on on-task, verbal utterances.

Talk about Ontology: 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.

Talk about Evidence: The percentages of verbal segments that were coded as being concerned with evidential relations are Text=0.58% < Graph=5.22% < Matrix=19.69%. This trend holds even when evidential relations expressed in term of the software tool (e.g., “link this”) are removed: Text=0.43% < Graph=1.47% < Matrix=8.48%. About two-thirds of Graph and half of Matrix evidential utterances are tool based. This is 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.

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 striking for its linearity (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, indicates an alternative to hypothesis 3 (prompting for missing knowledge units): participants may feel that the primary task is to connect each new statement to something else. Once they have done so it can be ignored. In contrast, the Matrix artifacts were especially striking because participants were not specifically instructed to fill in all the cells, yet they did so. The transcript illustrates participants' systematic identification of evidential relations as they worked down the columns, and their appropriate use of the table to rule out a hypothesis that they had proposed. See Suthers [35] for further discussion of results.

3.3. Discussion

Overall, the results are encouraging with respect to the question of whether there is a phenomenon worth investigating. However, this sample data cannot be taken as conclusive. A study underway at this writing is addressing the small sample size and other limitations of the pilot study. See also [38] for a classroom study that showed the superiority of Graph over Text in terms of quality of students' final artifacts.

Future plans for study of representational guidance include a study in which participants interact at a distance via a "chat" window instead of face to face. This will enable a comparison of how the roles of representations change when grounding costs increase [4] because participants can no longer gesture directly at objects and lack the implicit awareness of the other's orientation towards the shared artifact. Of particular interest due to recent trends in education at all levels is *asynchronous collaborative learning*. I now turn to discussion of needs in this area.

4. Asynchronous Collaborative Learning

There is a significant trend towards computer mediated distance collaboration in educational contexts ranging from K-12 through university to life-long professional development of adults. This trend is exemplified by three projects in which I am involved. I will first describe these needs before turning to ways in which current technology fails to meet the needs.

4.1. Example Applications

The K-12 example is Hawai`i Networked Learning Communities (HNLC), an initiative in science, math and technology education.[2] Hawaii's small rural schools do not have, and cannot be expected to sustain, a faculty with expertise in a full range of science and technology disciplines. This situation is ironic given that Hawai`i manifests a rich range of natural phenomena and is the home of science and technology resources used by scientists worldwide. HNLC will provide Hawaii's rural students with access to these resources through distance collaboration and remote sensing technology and in coordination with the state's strategic plan for systemic standards-based reform. HNLC presents the challenge of long term support for online discourse about rich and constantly changing data sets. A related objective of HNLC is the exploration of alternative methods for assessment in science, including use of knowledge mapping tools such as Belvedere. Such knowledge mapping tools should be well integrated with the data representations and associated discourse.

Due to unprecedented demand and salary levels in industry, many computer science students leave their graduate programs prematurely, and other qualified and talented students defer or decline admittance to graduate study for economic reasons. Distance education through Asynchronous Learning Networks (ALN; [18]) has the potential to significantly reduce this problem by enabling professionals to acquire advanced skills through graduate study without leaving their industrial positions. To address this problem, we are developing ALN versions of our ICS Bachelor's and Masters degree program as well as other degrees.[3] A key component of a high quality computer science graduate program is intensive collaboration and apprenticeship with faculty and with other students on the design, implementation, and evaluation of innovative software technology. We intend to provide the technological and methodological infrastructure necessary for such collaborative apprenticeships by life-long learners at a distance. Representationally rich distance collaboration technology will play an important role in this work. For example, facilities for talking about the artifacts of software engineering (e.g., interface mockups, class diagrams, source code) will become increasingly important as our degrees go online.

A national consortium of public school districts known as the Institute for Learning (IFL) and based at the Learning Research and Development Center of the University of Pittsburgh is engaged in systemic

[2] http://lilt.ics.hawaii.edu/hnlc/, funded by the National Science Foundation's Rural Systemic Initiatives.
[3] http://www.aln.hawaii.edu/, funded by the Sloan Foundation.

professional development for standards-based reform. During my prior employment at LRDC I initiated a project entitled “NetLearn: Networked Learning Communities for Educational Reform” to use technology in support of this work,[4] and continue to play a role in the design of the NetLearn software. The IFL currently functions primarily through seminars and site visits. The software is intended to enable IFL to conduct its business at a distance through asynchronous means. There is a particular need for interfaces in which educators can study, annotate, and discuss digital examples of teacher and student work that illustrate a collection of principles of effective instruction developed by the IFL. These educators should also be able to collaboratively construct their own conclusions concerning how to change their classroom practices.

4.2. Summary of Ideal Requirements

In all of these applications, substantial issues arise concerning the design of representational media *for* conversation – *discourse representations* – in addition to the design of representational media *about* which conversation takes place – *disciplinary* and *knowledge representations*. In particular, there is a need to better understand how discourse, disciplinary and knowledge representations are used together in asynchronous collaboration contexts, and to design discourse representations for more effective coordination with the other two.

Consideration of the above application areas leads to the following desiderata. Online discussion environments should allow the inclusion of visual artifacts, such as data graphs, videos of teacher and student work, or problem solutions under construction (e.g., knowledge maps, software designs, etc.). These artifacts should exist outside of individual messages (i.e., attachments are not sufficient), and stay visible during the conversation. Participants should be able to change the artifacts under discussion change in a natural way, leading to a new conversation space if necessary. Ideally, it will be possible to carry on a discussion about a *collection* of artifacts. Participants would be able to browse through the artifacts, and refer to individual artifacts (ideally, parts of artifacts) in their contributions.

The above requirements are intended to replicate some of the advantages of face to face conversation. The remaining requirements leverage the advantages of the computational medium to address the fact that online conversation may be conducted asynchronously over a number of days. In addition to viewing the chronological flow of the conversation, one should be able to find all contributions that refer to an artifact or part thereof, in effect recovering portions of the conversation that are about that artifact. Contributions in a conversation about an artifact may also be organized or clustered by concepts they share, such as common criteria or issues with the artifact. Finally, participants should be able to construct and access an explicit representation of their shared conclusions. We now consider current technology for computer-supported discourse in light of these needs.

5. Computer Mediated Communication

Computer Mediated Communication (CMC) is an active area of research specifically concerned with the effects of various electronic media on quality of group interaction [2]. For example, a large body of research concerned with comparisons between *types* of media for education (e.g., electronic correspondence, videoconferencing and traditional classroom instruction) repeatedly shows that there is no significant difference in learning outcomes [26]. This research typically does not study design choices (such as representations) *within* a given medium. My own work suggests that further studies are merited to optimize the design of representations for CMC.

5.1. Coherence and Convergence Problems

This view is corroborated by other work that documents problems with conventional CMC discourse tools such as “chat rooms” and threaded discussions. Problems of incoherence can be traced to bandwidth and timing problems [9]; while lack of convergence is due in part to the inherent divergence of the hierarchical reply structure [10]. Threaded discussions organize contributions under subject “threads” using reply and chronology relations. The representation is based on the historical development of the discussion rather than its conceptual content, making it difficult to quickly grasp and assess the status of the discourse and hence to make contributions that move it forward [39]. The addition of categorical labels on contributions (e.g., [13, 30]) can provide information about their intended role, yet does not escape the fact that the primary organization is an artifact of the discourse history. Similarly, CSILE’s “knowledge maps” [11] are not knowledge maps at all, but rather maps of reference relations between contributions. I believe that many of these problems can be addressed by supporting construction of explicit knowledge representations during online collaborative learning discourse. However, before I describe the proposed solution I must first discuss another weakness of existing CMC technology.

[4] http://www.lrdc.pitt.edu/netlearn/, funded by a US Department of Education’s Technology Innovation Challenge Grant.

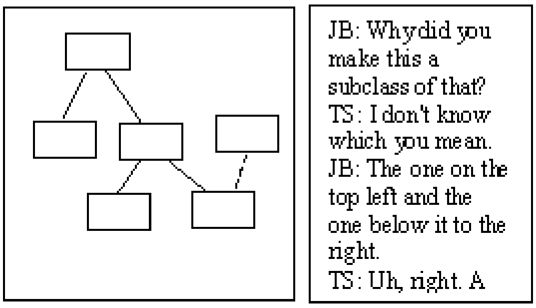

Figure 1. Parallel CMC

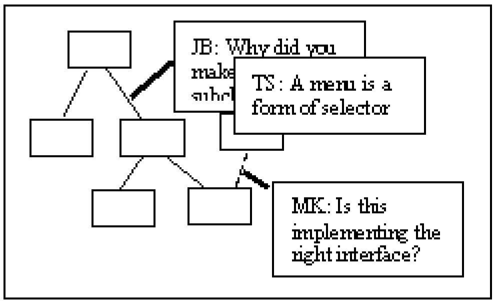

Figure 2. Embedded CMC

5.2. Forms of Artifact-Centered Discourse

In face to face discussions we often reference and manipulate external artifacts (sketches, pictures, and objects). Interaction with the artifacts is an essential part of the work of the participants. This will also be true – or should be true – of online learning. For example, HNLC students may need to discuss remote sensor data and record their interpretations of that data. Students in our online computer science degree programs will need to create and discuss software designs. Yet the online world provides only impoverished support for discourse about artifacts. Many products for CMC or ALN are not designed to establish and carry on a discussion in the context of a visual artifact that can be annotated and referenced. Other tools support annotation of textual artifacts, but do not support discourse beyond these localized comments. I briefly review these two extremes before proposing an alternative.

In typical ALN tools (such as WebCT, http://www.webct.com/), discussion tools and shared artifacts are displayed on entirely different screens. This is hardly conducive to online discourse about artifacts. One can work around this problem by manually opening two windows and placing the discussion tools next to the artifacts under discussion. I call this arrangement *parallel CMC*. There is no communication or coordination between the discourse and disciplinary representations.

NetMeeting is a well-known synchronous example: one can share applications and carry on discussions in a separate chat window. In informal studies conducted by two of my directed study students, users collaborating to debug a software program in NetMeeting preferred to embed their discussion directly in the artifact (as comments) rather than switching between the artifact and chat. Although screen space and cursor control were also factors in these sessions, this preference may be understood in terms of cognitive load theory [37]. Tasks and materials that require split attention between two sources of information that must be integrated lead to increased cognitive load. Another problem is that deictic reference must be accomplished through sometimes-awkward linguistic means, as suggested by the hypothetical example of Figure 1. Physically merging the two sources of information can address these problems, motivating the next form of CMC to be discussed.

An *embedded* discourse representation embeds comments directly on or in the display of the artifact under discussion. For example, the University of Hawaii's Outreach College has developed an environment for online communities known as Maile (http://www.maile.hawaii.edu/) which is now in active use at the University. In Maile's Writing Exchange, students can post samples of their writing, whereupon others can insert their comments directly in the original prose. Other examples include Microsoft Word's comment facility and CoNote [6]. All of these examples are text-based. Figure 2 shows a hypothetical graphical example: notes attached to nodes and links in a diagram.

Because the discourse always takes place in the context of the artifact, embedded CMC has the advantages that it is easier to refer to parts of the artifact or to recover the portion of the discussion that is concerned with a given part. Some empirical evidence supports this approach. Guzdial [7] compared "anchored collaboration" (embedding links to discussion threads within artifacts of interest) to newsgroups in undergraduate classes, finding that longer threads of discussion took place with anchored collaboration. Wojahn, *et al.* [42] performed an experimental comparison of "split-screen," "interlinear" (embedded) and "aligned" (side by side) interfaces for collaborative annotations, and found no significant difference in time to task completion but significantly fewer communications in the split-screen representation, which apparently presents the greatest distance between the artifact and the annotations and hence cognitive load in processing them.

Disadvantages include the fact that the record of discourse is fragmented across the artifact, making it more difficult to get a sense of the whole discussion or to notice relevant relations between discussions about different parts of the artifact, as well as the possibility that the artifact becomes cluttered with comments. We would

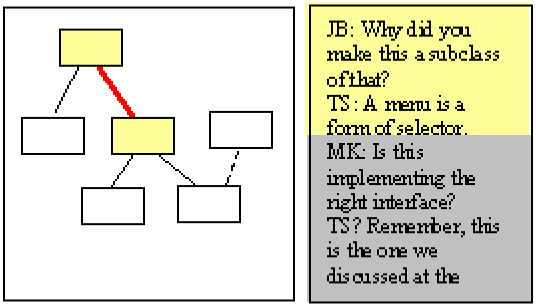

Figure 3. Linked CMC

like to be able to recover chronological versions of the discourse, and perhaps to index into the discourse in different ways other than by artifact component or by chronology.

The tradeoff between parallel and embedded CMC can be resolved by providing discourse and artifacts with independent representations optimized for the needs of each, but providing a logical linkage between the two that can be viewed in virtually embedded ways if needed. Such linked CMC representations might take several forms. In one form, discourse and disciplinary representations are displayed side by side, as in Parallel-CMC, retaining the reply structure and chronology of the discourse. The difference is that all contributions are referenced to an object or region in the disciplinary representation: one or more objects must be selected before entering a note. Selection of a discourse contribution would result in highlighting of the object discussed by that contribution, disambiguating terms such as “this” and “that.” Selection of a disciplinary object would result in highlighting of the relevant discourse contributions. It should also be possible to switch between parallel and embedded representations. One should be able to create a note in one representation and view it in another. This approach resolves the tradeoff between the typically linear structures of parallel discourse tools and the contextual indexing of embedded discourse representations. My hypothesis is that linked CMC, properly designed, can improve coherence and convergence of CMC by collecting together topically related contributions. This is a general solution, applicable to any online artifact-centered discourse, but I am particularly interested in its applications to supporting knowledge-building discourse within learning communities.

6. Online Knowledge-Building Discourse

Up to this point I have described two lines of work. One (under perspective #1) works from knowledge representations to discourse, exploring how the design of representations for critical inquiry might improve the quality of collaborative learning discourse. The other (under perspective #2) works from discourse to representations, exploring how representations might be improved to better support and record artifact-centered discourse. In this section I describe how these two lines of work might converge to support online knowledge-building discourse.

The key idea is to have learners use an inquiry-oriented representation (such as Belvedere) to capture their emerging knowledge, and make this knowledge representation itself a subject of artifact-centered discourse (alongside other disciplinary representations). Thus the artifact under discussion also serves as a representation of the knowledge emerging from that discussion. This knowledge representation helps support the quality of the online discourse because (1) the representational primitives were designed to guide effective discourse and because (2) it provides, via the Linked CMC facility, a way to focus the discourse, anchoring contributions in terms of their relevance, maintaining coherence and encouraging convergence. This synergistic arrangement fills the missing “middle space between communication and information interfaces” [12].

Disciplinary representations such as graphs of data, pictures, and simulations provide foundations for knowledge-building. They should also be available for inspection and discussion. My research group is now experimenting with ways to integrate discourse, knowledge, and disciplinary representations, generally working as follows. When a user wants to make a new contribution to the discussion, that user either selects one or more objects in the knowledge representation or creates a new one. An object in the knowledge representation may be associated with a disciplinary representation, which will be displayed in a different panel when that object is selected. Other users encountering this material later on can select the object in the knowledge representation and see both the associated disciplinary representation and the associated discourse. The result is that all discourse is referenced to the knowledge representation being built and the disciplinary representations on which the work is based, focusing the discourse and making it easier to find relevant contributions later.

I conclude with several research hypotheses concerning this linkage between discourse, disciplinary, and knowledge representations. First, learner-constructed knowledge representations will be better suited for solving problems of coherence and convergence than the reply and chronology relations of typical threaded discussion tools. Second, learning outcomes (not just process differences) will be enhanced because of the dual advantage that discussion occurs in the context of disciplinary artifacts and the knowledge representations play a continuing functional role in supporting discourse. Third, teachers adopting this technology will be able to focus more on learning objectives with this technology because it explicitly prompts for knowledge-building. Fourth, these representations will enable us to develop methods of assessing group collaboration in online learning because they provide a summary knowledge representation with links back to a record of the discourse process.

7. Summary

The present widespread interest in the use of electronic media for learning at all levels from K-12 to university and adult education presents an unprecedented opportunity for leveraging the computational medium's strengths for learning: its representational and analytic capabilities, its interactivity and networking support for collaboration. In spite of the known importance of representational aids and of social processes, there is a lack of research on how representational tools and collaborative learning may be constructively combined, and existing tools for collaboration provide only primitive support.

After reviewing the theoretical analysis of the role of constraints and salience in representational guidance that motivated this work, I reported on results of an initial study that suggested that appropriate representational guidance may result in increased consideration of evidential relations during an investigation. This work was undertaken in face-to-face collaborative situations. Looking towards the future of asynchronous collaborative learning, I summarized the needs of three ALN applications and compared these to the state of current CMC tools. Such tools were found to be particularly deficient in supporting artifact-centered discourse. I then proposed a combined solution that provides explicit representational support for artifact-centered knowledge-building discourse. Continued work in this area will contribute to an empirically grounded theory of design for discourse within representationally rich collaborative learning environments and inform the design of the next generation of software and associated instructional and assessment strategies for asynchronous learning.

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