A Visualization of Group Cognition: Semantic Network Analysis of A CSCL Community

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Abstract: This paper reports our progress in using the Knowledge Space Visualizer (KSV) as a tool for formative assessment of online discourse. Whereas social network analysis has been used in research on computer-supported collaborative learning, it only examines the social structure of discourse participants, and does not provide information about the content of the discourse. We discuss two types of networks as they relate to online discourse: *structural* and *semantic*. The initial findings indicate that the KSV can be used to visualize a Knowledge Forum database, and can provide a fine-grained semantic analysis that may enable teachers and students to locate the key ideas around which collective learning may takes place.

Introduction

Sawyer (2006) identifies knowledge building as one of five major educational models produced by the learning sciences. As an educational framework, it aims to make the processes by which experts create new knowledge more prominent and feasible in schools (Bereiter & Scardamalia, 1993; Scardamalia & Bereiter, 2006). One of the most important features of the model is that students' effort is directed at advancing the collective knowledge in a community (Scardamalia, 2002). Students are not just attempting to understand things for themselves, but aim to add something new to what is known in the community. In most implementations in schools, students use Knowledge Forum®, a software environment specifically designed to support knowledge building, to share and collaboratively improve and synthesize ideas (Scardamalia, 2003). Knowledge Forum also provides a trace of how the community's ideas develop over time.

Although considerable progress has been made in the last decade to develop innovative classroom practices based on the knowledge-creation model in a variety of school subjects (see www.ikit.org and kbtn.cite.hku.hk), advances in assessment of electronic discourse have lagged. We believe that the development of a suite of assessment tools is urgent, particularly tools that teachers and students can use to self-assess and reflect on the nature of their work on Knowledge Forum. Previous studies have used content analysis to examine a variety of issues including knowledge advancement (Hakkarainen, Lipponen, & Järvelä, 2002; van Aalst, 2009; Zhang, Scardamalia, Lamon, Messina, & Reeve, 2007), but these methods are too labor-intensive to inform how students can improve their own knowledge-creation efforts. Analysis tools have been available for the last decade which students and teachers can use to examine participation patterns, such as note writing and reading and social network analysis (Burtis, 1998; de Laat, Lally, & Lipponen, 2007). While these techniques provide information about the social structure of students' collaborative discourse, they reveal little about how ideas are developing. They do not, for example, provide insight into questions such as "are the ideas of students becoming more coherent with one another other over time?" Computer-assisted visualizations or representations that capture both social and semantic features of the online discourse appear to hold much promise tools for self-assessment and reflection on knowledge-creation efforts at the community level.

The goal of this paper was to consider the nature of such representations and to explore the use of one visualization and assessment tool, the Knowledge Space Visualizer (KSV; Teplovs and Scardamalia, 2007; Teplovs, 2010). This work is part of a larger project, which will study the formative assessment *practices* by teachers and students, and will seek to develop a theory of formative assessment that uses data embedded in online environments like Knowledge Forum. However, in the present paper we report our initial exploration into the nature of the representations and what they reveal about the extent to which knowledge creation was occurring.

Background

Formative Assessment

In various forms, assessment drives educational practice (Biggs, 1996). It is therefore important for innovative educational approaches from the learning sciences to demonstrate that quality outcomes are obtained. However, it is equally important to understand how collaborative processes contribute to such outcomes. For example, how do we know whether discourse in Knowledge Forum is likely to lead to collective knowledge advances? How does new knowledge diffuse in a database?

We use the concept of *formative assessment* to frame our work: assessment that is used by students and the teacher to enhance learning, while the learning process still is in progress (Scriven, 1967). Interest in formative assessment received a new boost after the major review by Black and Wiliam (1998), who showed substantial positive impacts of formative assessment on learning. However, these practices seem to focus on such the provision of feedback on student work (e.g., tests and projects) and in-class questioning. Several authors have criticized the theoretical underpinnings of formative assessment (Perrenoud, 1998; Taras, 2005), and Black and Wiliam (2009) have recently proposed a theory of formative assessment that refers to self-regulated learning and situates formative assessment in an overall pedagogical framework. Most authors treat formative assessment as something that stands apart from the learning process. We rather consider it as a form of *inquiry* and as part of knowledge creation itself. Regardless of whether students are assessing their own work or whether they are advancing community knowledge by, for example, determining if forest fires are caused by human activities, the underlying process is the same: they use available evidence to ask questions and test hypotheses. This perspective requires that students have data about their own inquiry, which they can use to reflect on their progress and plan future actions. Such data are available but very complex. Students and teachers need sufficiently simple representations that can inform their reflection.

Latent Semantic Analysis and the KSV

In the last decade, much attention has been given to "assessing" information on the Web to improve the performance of search engines. One example is Google's use of the PageRank algorithm to analyze the structure of the Web to identify the most influential Web pages, in combination of an index of the relevance of a Web page to a query (Brin & Page, 1998; Maslov & Redner, 2008). Latent Semantic Analysis (LSA) is another approach to the problem that uncovers the underlying semantic structure (meanings) of a network of documents (Landauer, 2007).

LSA is a *vector space* approach. One constructs a matrix (a table) in which the columns are types documents (e.g., books, chapters, essays, paragraphs, or computer notes) and the rows different terms (words or phrases); the entries are the numbers of occurrences of the terms in each of the documents. This matrix generally has a very large number of dimensions (e.g. when the "documents" are all the novels written in English or the entire Web), so mathematical techniques are used to produce a matrix of more manageable dimensions that is a reasonable representation of the whole vector space. The most common technique is Singular Value Decomposition (SVD). To make an assessment, one then constructs and compares vectors in the SVD. Vectors can contain information about the terms in a document, about the documents that use a specific term, or a combination. Geometrically, vectors are "similar" if they can be said to point in the same general direction, and if their lengths are comparable. For example, if the cosine of the angle between two vectors is 0.866 (in which case the corresponding angle is 30 degrees), the vectors can be said to point in the same general direction; if the length of one is 1.45 and the other 1.52 (rather than, say, 4.45 and 0.15) that would provide another indication of their similarity.

The Knowledge Space Visualizer (KSV; Fujita & Teplovs, 2009; Teplovs, 2010) is a Java-based tool that was developed to visualize networks of Knowledge Forum notes. It uses visual representations as well as quantitative network metrics to characterize idea-based networks. Exhaustive similarity measures between notes are recorded as latent semantic links between notes. These links, and the explicit semantic links afforded through referencing, rising-above and building-on functionality of Knowledge Forum, are then made available to the KSV. The KSV is capable of recreating the two-dimensional representation of collections of notes in Knowledge Forum, but it also provides computer-assisted positioning algorithms to facilitate the visualization of networks of notes.

Collective Knowledge Advancement

According to Bereiter and Scardamalia's knowledge creation theory (Bereiter, 2002; Scardamalia & Bereiter, 2006), students in a knowledge creation classroom work progressively and collaboratively on a number of shared topics, and their collaborative inquiries lead to the advancement of individual and collective knowledge. Knowledge advancement is treated as a community rather than individual achievement (Scardamalia & Bereiter, 2006). Collective knowledge resides in conceptual artifacts (ideas and theories) in the community's discourse rather than inside individual minds. Also, according to Stahl's (2006) notion of group cognition, collective knowledge is interactively achieved in discourse and cannot be simply attributable to any particular individual mind.

These ideas suggest that any theoretical exploration, or practical assessment, of the advancement of community knowledge depend on the degree to which researchers and teachers are able to accurately describe and evaluate the content of discourses occurring in a collaborative knowledge creation community. However, despite emphasis and progress in developing collaborative inquiry in CSCL research, little attention has been given to the assessment of collective learning (van Aalst & Chan, 2007). Thus, little is known about the nature of collective knowledge and group cognition, and in practice teachers are still limited in their ability to assess how collective knowledge actually is formulated and advanced, although CSCL researchers and classroom teachers have put great efforts to design various technology-enhanced collaborative learning environments.

Network analyses of CSCL

There are at least two significant factors underlying the above issues. First, research on CSCL often epistemologically focuses on individual learning outcomes rather than collective knowledge growth (Stahl, Koschmann, & Suthers, 2006). Perhaps this problem can be attributed to the influence of cognitivism, which stresses individual learning and personal cognition. Second, methodological alignment with the social nature of collaborative learning has led many researchers to examine interactions and participation patterns, using social network analysis (SNA; de Laat, Lally, Lipponen & Simons, 2007; Cho, Gay, Davidson, & Ingraffea, 2007). SNA considers a CSCL community as a *network* in which individual learners are represented as nodes, and the relationships between learners are represented as edges connecting those nodes. The edges indicate collaborative actions such as note reading, building-on, and referencing other notes. Current studies on the application of SNA to CSCL research converge at two basic aspects: network properties of a CSCL community, and participatory characteristics of individual learners. The first of these is mainly concerned with the issues such as network density of a collaborative learning community, and emergent cohesive cliques. The second aspect seeks answers to the following questions (de Laat, et al, 2007): Who is involved with the collaborative learning task? Who are the active participants? And who is participating peripherally? Current SNA studies rely primarily on mathematical computations of the frequency of ties between learners, and ignore the *content* of artifacts notes and the connections in meaning between the notes (Stahl, 2006).

For formative assessment, it is necessary to locate and describe knowledge creation in collaborative discourse. In network models of cognition, knowledge is represented as a network in long-term memory, in which nodes correspond to the cognitive units (in the form of concepts or schema), and the relations between the cognitive units are represented as links (Bruning, Schraw, & Norby, 2004). By analogy, group cognition can be defined as a network of the conceptual artifacts collectively created in a collaborative learning process. As information units, conceptual artifacts (Bereiter, 2002; Scardamalia & Bereiter, 2006) are the objects of collaborative work on knowledge creation, which take the form of notes created and posted by individual learners in Knowledge Forum. This implies that collective knowledge and group cognition can be studied and assessed from the perspective of network analysis. Therefore, we differentiate two types of networks existing in a CSCL community: *networks of people* and *networks of notes*. The former can serve to assess the interactive and participatory patterns of students, the latter can function as a representation of collective knowledge and group cognition.

However, as noted earlier, most research has concentrated on the patterns of social interaction between students rather than networks of conceptual artifacts. Of course, one may argue that a social network of people in a CSCL community operationally corresponds to a profile of the network of notes created by those people. Social networks of people only capture at most two features of notes – authorship or readership. Most SNA studies in CSCL examine patterns of social interaction between the CSCL participants, rather than the relation between students' ideas embedded in the notes from the perspective of collective knowledge and group cognition. Therefore, comprehensive formative assessments of collaborative learning must entail a multi-faceted network analysis of notes generated in a CSCL discourse. Stahl (2006) pointed out that the meaning of the group-level constructs such as group cognition constitutes a network of semantic references within the group interaction, and collaborative learning can be viewed as the interactive construction of this referential network. In this sense, collective knowledge and group cognition produce a semantic network of conceptual artifacts (notes), that is, a network system based on shared meaning (Doerfel & Barnett, 1999).

We may ask what a semantic network of notes looks like, how researchers or classroom teachers can identify the semantic networks of notes that emerge in a CSCL process, and what is the role of semantic network of notes in assessing collective knowledge advancement and group cognition.

This paper introduces our preliminary attempt to address these issues related to formative assessments of CSCL. Taken together, the above analyses of the distinction between the network of people and network of notes suggest that networks of notes can be established in two manners. Furthermore, we propose two sub-types of network of notes: *structural (physical) network* and *semantic network.* A structural network of notes or people refers to a visible network of notes or people whereby the linkage between notes or people is physically established by any one of the collaboration operations, such as note reading, building-on, and referencing in a Knowledge Forum database. An inquiry thread (Zhang, et al., 2007), defined as a series of notes that share a problem and constitute a conceptual stream in a collaborative inquiry, manifests the limitations of the studies on the spatial threads of notes, as well as structural network of notes in understanding the formation and advancement of collective knowledge and group cognition in a collaborative inquiry discourse. An inquiry thread represents a semantic connection between notes by content analysis of each individual note, namely, and therefore is a semantic network of notes from a network analysis perspective. Similarly, Manca, Delfino, and Mazzoni (2009) introduced a semantic coding scheme aiming to obtain a relatively complete picture of social interactions among people in a web forum that the structural (physical) network construct cannot provide. However, these methods require manual coding of note content, which is very labor-intensive. Because of the two considerable drawbacks—the amount of labor involved and their reliability—teachers may hesitate to use them for formative assessment. Our study is an attempt to meet this challenge, and uses the KSV, an innovative visualization and assessment tool of collective knowledge, to automatically identify the emergent semantic networks of notes under a pre-set condition with reference to semantic closeness between them, and the as structural networks of notes in a CSCL discourse.

Research Context and Methods

The KSV was used to study part of a Knowledge Forum database created by a class of 41 Form 4 (Grade 10) students taking physics at a secondary school in Hong Kong. The database had approximately 880 notes, which were distributed over several views (shared workspaces) in Knowledge Forum. The teacher had several years of prior experience with Knowledge Forum, and was attempting to align her classroom teaching more with the knowledge-creation model, particularly by encouraging student-to-student classroom talk. The students' presentations and the talk that followed appeared to break with the more typical classroom discourse in Asian classrooms in which students do not ask many questions (Li, 2009). The curriculum consisted of three units of study: heat and temperature (3 months), mechanics (6.5 months), and waves (1.5 months).

In this classroom it was difficult to integrate the use of Knowledge Forum on a daily basis. Rather, it was used during specific periods to follow up classroom learning and to support the two projects. For example, during the heat and temperature unit, the class as a whole discussed thermal questions such as how to keep a drink warm as long as possible (Linn & Hsi, 2000) and why people lived in igloos, which are made from ice and would intuitively seem cold. Students also used Knowledge Forum to discuss their solar cooker designs, and in this, they were asked to refer to physics concepts and phenomena such as the greenhouse effect and methods for focusing energy from the sun on a beaker of water at the center of their solar cooker. During the mechanics unit, students similarly used Knowledge Forum to discuss puzzlements about Newton's laws and their analysis of motion on rides at an amusement park. Although the amount of work in Knowledge Forum was not as extensive as in some published studies, the computer notes that were generally focused on the tasks at hand and contained explanations in which students used relevant science ideas, although a substantial number of notes dealt with the logistics of projects.

Results

The Knowledge Forum database had several comprehensive views for two units of study: heat and temperature, and mechanics. Each unit had several sub-topics. For example, the students studied mechanics by discussing how the cable car works in the view called 'Cable Car'. This view was spatially separated from the 'Mechanics' view.

Two Types of Network of Notes

Two kinds of network were generated with the KSV. Figure 1 shows structural networks, and Figure 2 semantic networks. The directional lines in the structural network represent links between notes by note building-on. The lines in the semantic networks in Figure 2 are non-directional, suggesting that the notes are linked to one another in *meaning*, which is reciprocal. The color of node denotes a participant in Knowledge Forum (electronic version of the paper).

Mathematically, semantic closeness between notes in KSV is quantified as the cosine between vectors representing their content. High cosine values denote semantically similar note content (Teplovs & Scardamalia, 2007). The KSV allows us to set a link visibility threshold. When the cosine between any two notes exceeds this threshold, the KSV joins the notes with an edge (shown in Figure 2). The lower the threshold is, the more semantic links between notes in the network are displayed. In this study, the semantic coefficient was set at 0.75. Semantic links between notes are invisible in Figure 1 because KSV allows users to choose either of the two types of network.

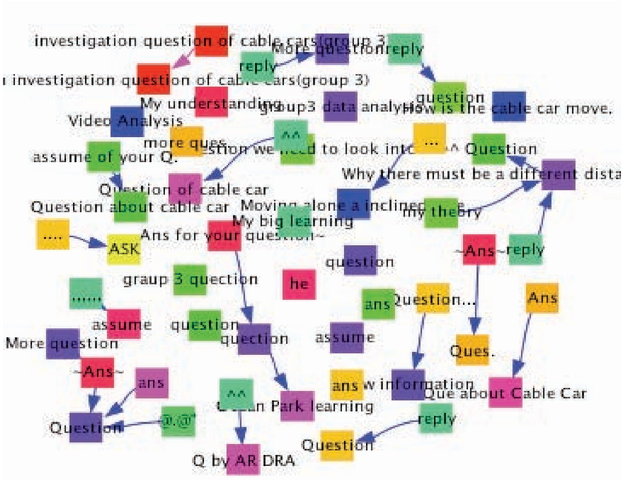

Figure 1. Obtained structural network in the Cable_car view

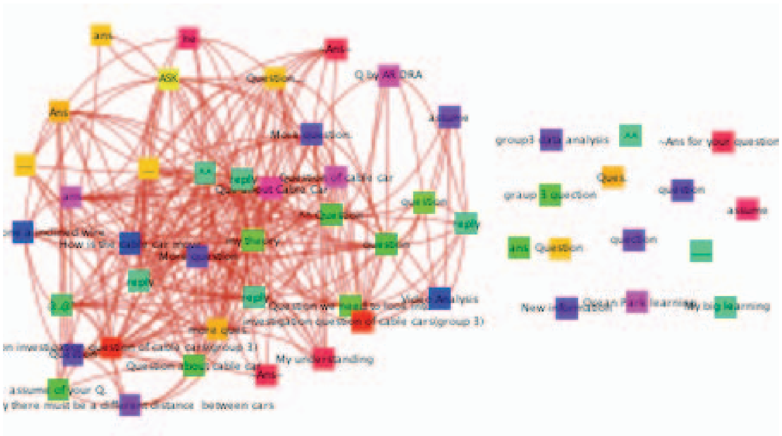

Figure 2. Obtained semantic network in the Cable_car view

Visually, the number of lines in the structural network is obviously much less than that in the semantic network, implying that many notes are linked to one another semantically but not structurally. This finding can be quantitatively reinforced by the contrast of the network properties between them. The Cable_car view contains 52 notes, 2391 words in total. The average size of note (i.e., words/notes) is 45 words. There are 22 lines (physical note links) in the structural network, which correspond to 22 physical actions (i.e., note building-on or referencing) that took place while the students collaboratively worked on that topic in Knowledge Forum. There are 281 links in the semantic network. In SNA, degree refers to the number of lines incident with each node in a graph; network density is defined as the ratio of the actual number of lines to the maximum possible lines, with a value falling within the range between 0 and 1 (Wasserman & Faust, 1994). The density of the semantic network is .212; the density of the structural network is .017, much less than the former. This finding implies that for a collection of notes in the Cable Car view, its semantic network is much cohesive than the structural network. The notes that are not linked to one another by a physical collaborative learning action are not necessarily disconnected with each other semantically.

Visualization of Group Cognition

In the design of a KF database, the notes embedded within a view often converge at the same discussion topic. For example, the Heat view was intended to be a workspace where students collaboratively learned the concept of heat. In practice, a classroom teacher may want to examine how student online discussions in Knowledge Forum unfolded around the shared topic.

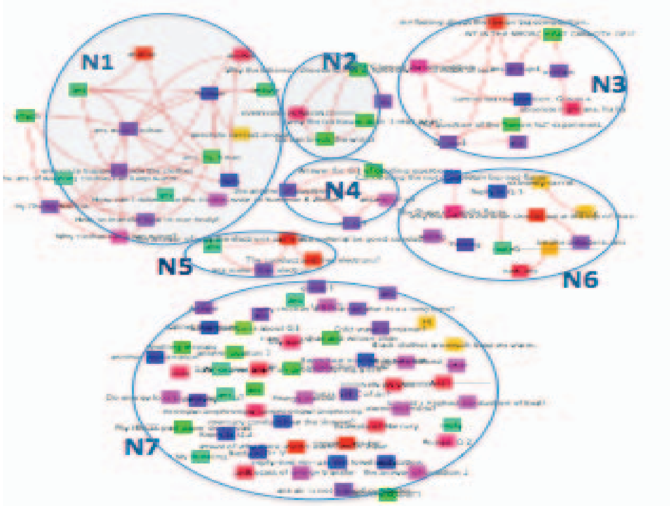

Figure 3. Obtained semantic networks within the Heat view

Table 2: The main overlapping words in each sub-semantic network

Sub-networks	Main overlapping words
N1	clothes (24) body (17) air (16) energy (14) warm (10) feel (6) transfer (6) cold (5) theory (5) trap (5)
N2	ice (11) live (7) house (4), outside (3)
N3	ice (16) energy (14) lemon (12) tea (11) loss (9) heat (8) specific (7) water (6)
N4	heat (10) copper (9) water (7) specific (6) energy (5) capacity (5) conductor (3)
N5	free (10) conduct (5) electrons (5) electron (5) metal (4) energy (4) shell (4) atom (3) heat (3)
N6	air (17) copper (9) water (9) gravity (7) flame (6) electrons (6)
N7	theory (33) air (23) energy (22) heat (20) liquid (13) ice (12) water (11) density (11

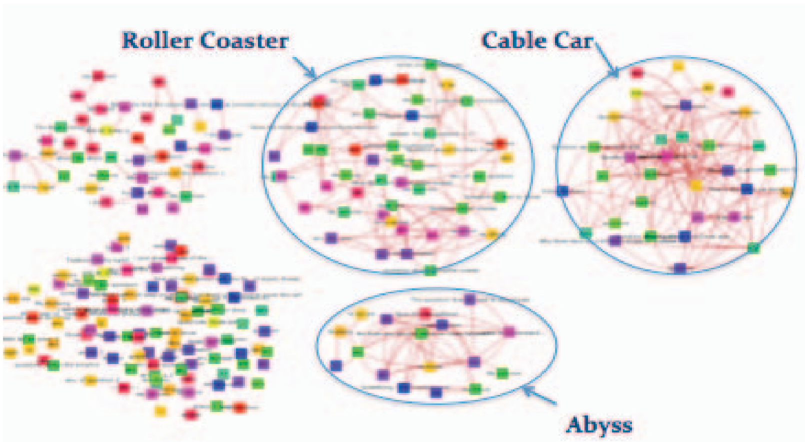

Figure 4. Sub-topics in the semantic network of notes in the Mechanics view

Figure 3 shows that the KSV revealed that there were seven clusters of notes within the general semantic network of the Heat view. These clusters can also be viewed as semantic sub-networks. Table 2 shows the major theme for each semantic sub-network. For example, the students who wrote the notes within N1 primarily were trying to understand the concept of Heat by connecting it to the daily life phenomena such as clothing from the perspective of heat transfer. Shared meaning of the notes in N3 seems to converge on heat transfer in liquids such as lemon tea, and water. Similar findings can be seen from the semantic network of another view in the same KF database shown in Figure 4 (Mechanics). Three themes in the view Mechanics can be identified by latent semantic analysis: Roller Coaster, Cable Car, and Abyss. Similarly, this finding suggests that students collectively worked on several sub-topics under the Mechanics view.

We conducted an inquiry thread analysis (Zhang et al., 2007) on the Heat view, and found seven inquiry threads (i.e., principal problems). Four themes identified in the inquiry thread analysis correspond to the first five semantic networks (i.e., sub-discussion topics) shown in Table 2. This provides some preliminary evidence that the KSV can reliably uncover sub-discussion topics that emerge in the discourse of collaborative knowledge creation.

Conclusion

This study demonstrates a combination of computer-assisted content analysis and network analysis for formative assessments of CSCL, which is aligned with the appeal for developing innovative methodologies for analyzing participation and discourse processes in CSCL (Lipponen, Rahikainen, & Hakkarainen, 2002).

We can draw at least the following tentative conclusions. First, semantic network analysis offers an alternative approach for examining the relationship among the computer notes in a CSCL community in terms of shared meaning making, other than the traditional network analyses that mainly concentrate on the participation patterns of students. This expands the scope of formative assessments of collaborative learning by empirically revealing and conceptualizing two kinds of network of notes (i.e., structural network vs. semantic network). Second, various sub-discussion topics uncovered by latent semantic analysis in the heat view reveals the complexity of collaborative learning dynamics. This finding implies that collective learning in this class unfolded by breaking down a general concept/theory (e.g., Heat, Mechanics) into a number of sub-discussion topics (i.e., inquiry threads). Third, the notes with a certain semantic closeness may illustrate the workplace whereby collective knowledge might be forged due to the shared meaning of those notes. The overlapping words in a semantic network to some degree facilitate the visualization of the key meanings of the conceptual artifacts of group cognition. For the purpose of formative assessment of collective learning, the use of the KSV as an assessment tool provides a fine-grained semantic analysis that may enable teachers and students to locate the key ideas around which collective learning may takes place. It was found in this study that identification of the sub-topics within a view is generally aligned with inquiry thread analysis (Zhang et al., 2007). However, thread analysis used in that study was time consuming, because the theme of each thread of notes (shared topic) required labor-intensively content analysis of each Knowledge Forum note. Fourth, many current studies in assessment of CSCL use a whole CSCL community as unit of analysis, which might be appropriate when research is to assess student participation patterns by SNA throughout a CSCL process. Our study suggests that individual views as unit of analysis be appropriate as well for assessing the processes of collaborative knowledge construction and creation.

Our preliminary analyses using the KSV have yielded some findings regarding the characteristics of semantic network and the potential for further exploring the role of this kind of emergent networks in assessing how knowledge creation proceeds collaboratively in a Knowledge Forum database. Thus far, we still know little about the role of these emergent semantic networks in formative assessments of collaborative knowledge creation. The present study is just starting point along this direction. We believe that in order to have efficient and productive formative assessments of CSCL, semantic network analysis should be adopted along with other types of analysis such as content analysis of the notes within a selected semantic network.

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