

Quantified Measures of Online Discourse as Knowledge Building Indicators

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Abstract: This secondary data analysis examined a set of social interaction (e.g., social network patterns), content (e.g., questions, ideas), and lexical measures (e.g., academic words, domain terms) applied to a Knowledge Forum discourse database created by 22 fourth-graders as they investigated optics over a four-month period. Knowledge advancement was evaluated based on student portfolio notes focusing on the depth and breadth of their optical understanding. Correlations found between the measures of social interaction, content, and lexical usage in the discourse and the depth and breadth of student understanding help to empirically justify a set of online discourse measures that are sensitive to knowledge productivity. The results suggest a framework to inform the selection, creation, and integrated use of online discourse measures in research as well as design of automated assessment tools embedded in collaborative learning environments.

Introduction

The field of computer-supported collaborative learning (CSCL) faces the challenge to develop methodologically justifiable measures of collaborative knowledge building as a distributed and emergent process driven by students' diverse input. Intensive effort has been made to analyze and assess student online discourse using quantitative and qualitative methods (e.g., de Laat, Lally, Lipponen, & Simons, 2007; Guzdial & Turns, 2000; Koschmann, 2001; Meier, Spada, & Rummel, 2007; Stahl, 2006; Suthers, Dwyer, Median & Vatrapu, 2010). Quantified measures are diverse, analyzing participation rate, social network patterns, vocabulary use, content contributions, and so forth. Choices of research measures for a given study are often made based on theoretical considerations of what such measures mean and imply. There is a need to examine and justify the importance of these measures to collaborative knowledge building through systematic empirical testing, which will further provide a stronger research base for initiatives to create automated analysis tools (e.g., Rosé et al., 2008). To address this need, the present study applied a range of quantified measures to the same discourse database and examined their relationship to student knowledge advancement.

Knowledge building—the creation of knowledge as a social product through collective and sustained efforts—becomes pervasive in a knowledge-based society (Bereiter, 2002). Recent educational initiatives thus emphasize engaging students in collaborative knowledge building with the support of new technology environments. Achieving this goal requires educational changes from individual to collaborative processes and outcomes; from teacher-designed to student-driven goals and processes; from a focus on content coverage to that on depth of understanding; and from standard learning outcomes to student diverse expertise (Brown, Ash, Rutherford, Nakagawa, Gordon, & Campione, 1993; Scardamalia, 2002; Stahl, 2006; Zhang, Scardamalia, Lamon, Messina, & Reeve, 2007). Traditional assessment tools focus on individual learning processes and outcomes based on predefined learning objectives and curriculum standards. Although these tools can also be used in knowledge building and CSCL research; they reveal very little, if any, about collaborative processes, emergent and progressive understanding, and community knowledge advancement (Zhang & Chan, 2008). Thus, CSCL researchers face the challenge to develop and integrate new research measures and assessments.

Various research measures have been developed in the CSCL literature to analyze and assess collaborative knowledge building, often using student discourse as a primary data source. Three types of quantified measures have been widely used: (a) Content analysis (Chi, 1997), using coding schemes to categorize the nature of responses, types of questions, depth of ideas, evidence use, argumentation patterns, and so forth (e.g., Baker et al., 2007; Hakkarainen, 2003; Hmelo-Silver, 2003; van Aalst & Chan, 2007; Weinberger & Fischer, 2006; Zhang et al., 2007); (b) Socio interaction measures, focusing on contribution rate, reading rate, conversation threads (build-on trees), social networks of who reads or responds to whose postings (Aviv, Erlich, Ravid, & Geva, 2003; de Laat, Lally, Lipponen, & Simons, 2007; Guzdial & Turns, 2000; Hewitt & Teplov, 1999; Hewitt, Brett, & Peters, 2007; Howell-Richardson & Mellor, 1996; Zhang, Scardamalia, Reeve, & Richard, 2009); and (c) Linguistic markers of discourse, such as occurrences of epistemic words and domain-specific key terms in discourse (Hong & Scardamalia, 2008; Sun, Zhang, & Scardamalia, 2010). These measures have been informed by various CSCL theories and models to capture important aspects of collaborative learning and knowledge building. However, the significance of these measures in relation to student knowledge advancement has rarely been systematically examined, partly because different researchers tend to use different measures to analyze CSCL discourse from their own point of view (Hmelo-Silver, 2003).

On the basis of online discourse measures, efforts are made to create computer-based research tools to automate some of the analyses, such as using text classification technology to automate or aid content analysis (Law et al., 2007; Rosé et al., 2008), analyzing patterns of participation and interaction based on user log files (e.g., Burtis, 1998), and extracting, comparing, and clustering key terms used in online discourse through semantic analysis (Teplov & Fujita, 2009). Automated assessment tools are further designed and embedded in collaborative online environments to provide teachers and their students with concurrent feedback as their work proceeds (Scardamalia, Bransford, Kozma, & Quellmalz, 2010). With data mining and other computing technologies easing data analysis, the challenge becomes what to analyze and how to combine the different measures and rich amount of data based on a sound framework so researchers, teachers, and students can make meaningful interpretations and informed decisions.

In our recent research, we developed and adapted a set of research tools to examine collaborative knowledge building supported by an online environment. These included inquiry thread analysis for mapping out communal knowledge growth by identifying and tracing discourse contributions to different problem spaces (Zhang et al., 2007), social network analysis for evaluating collaboration and collective responsibility (Zhang et al., 2009), content analysis of student contributions and depth of understanding (Zhang et al., 2007, 2009), and lexical analysis of student discourse to examine the growth of productive written vocabulary in relation to scientific understanding (Sun et al., 2010). These measures were applied to the same dataset—an online discourse database of a Grade 4 classroom focused on optics. The goal of the present study was to conduct a secondary analysis of the above measures to identify significant indicators of knowledge building, which can inform the selection of CSCL research measures and the design of automated analysis and assessment tools.

Method

The Knowledge Building Context

The participants were 22 fourth-graders (11 girls and 11 boys) from an elementary school in downtown Toronto. This study analyzed their inquiry of optics conducted over a four-month period in line with principles and practices of knowledge building, supported by Knowledge Forum (Scardamalia & Bereiter, 2006). Knowledge Forum provides a communal, multimedia knowledge space, represented as different *views* (workspaces) corresponding to students' knowledge building goals. Students contribute *notes* to views to share and continually advance their ideas, using a set of interaction tools (e.g., build-on, rise-above, referencing) to engage in knowledge building discourse (see Figure 1 for a screenshot). Both the students and their teacher had multiple years of experience with knowledge building pedagogy and Knowledge Forum.



Figure 1. Knowledge Building Discourse in the Colors of Light View. Each small square icon represents a note, and a line connecting two notes represents a build-on.

During the optical inquiry, the fourth-graders generated problems of understanding, discussed diverse ideas and theories through face-to-face knowledge building discourse, conducted self-generated experiments and observations, searched libraries and the Internet, and shared new resources through cooperative reading. Along with these offline activities, they shared their questions, ideas, data, and information sources in Knowledge Forum for sustained discourse that extended and enriched their classroom conversations. The teacher experimented with having the whole class collaborate opportunistically to understand optics and to progressively identify important, related issues (e.g., light sources, how light travels, colors, lenses and mirrors, vision) to deepen the inquiry. Knowledge Forum provided the public space in which their collective works were

recorded, with new views created in line with emergent goals and linked to existing views. These interconnected views helped to keep the top-level goal center front and to keep the structure fluid: sub-goals were identified and elaborated in related views and small groups formed and reformed based on evolving needs. On a daily basis, students were free to explore any problem from any view in the database. They all took responsibility for the overall growth of the database. Near the end of the inquiry, each student wrote a reflective portfolio note to summarize what he/she had learned about light. Analyses of student portfolios and a pre- and post-test demonstrated productive advancement of knowledge (see Zhang et al., 2007 for details).

Measures of Online Discourse

The primary data source was student discourse in Knowledge Forum. Over four months, students created 287 notes in seven views (e.g., Shadows, Colors of Light, How Light Travels). The optical discourse database was a proportion of the data analyzed in several related studies (Zhang et al., 2007, 2009; Sun et al., 2010). This secondary analysis focused on three sets of measures that had been applied to this database, including social interaction measures, content-based coding, and lexical analyses. These measures are summarized in Table 1 and elaborated below.

Table 1: Measures of online knowledge building discourse.

Category	Measures	Explanations
Social interaction measures	Note contribution	# of notes authored per student, as an indicator of their contrition to the community space.
	Note reading percentage	% of notes read, as an indicator of knowledge sharing and information spread.
	Note reading network: in-degree and out-degree	Social network of who reads whose notes, with in-degree and out-degree indicating the extent to which a member receives and sends out note-reading contacts from/to different members, respectively.
	Note linking network: in-degree and out-degree	Social network of who links to whose notes through build-on, rise-above, and reference citation, with in-degree and out-degree indicating the extent to which a member receives and sends out note-linking contacts from/to different members, respectively.
	Note linking network: cliques	In a social network of who links to whose notes, a clique is a sub-network of members who have more note linking ties to each other than to members who are not part of the group. The number of cliques each student belongs to indicates the level of dynamic collaboration and idea contact.
Content measures	Problems	# of notes raising and addressing deepening problems about the topic.
	Personal ideas	# of notes that contributed student understanding and claims.
	Information sources	# of notes rephrasing or summarizing information from readings, the Internet, the teacher, parents, etc.
	Evidence	# of notes that test and justify ideas using experiments, observations, or life experiences.
Lexical measures	Inquiry threads	An inquiry thread is a conceptual stream of discourse that addresses a shared principal problem. The number of inquiry threads each student contributes to as an author indicates diverse participation in the community's knowledge space.
	Total words	Total words written per student in the online discourse.
	1 st 1,000 words	Percentage of the 1 st 1000 most frequent English word families used in student notes, as an indicator of limited vocabulary and writing.
	Academic words	The percentage of academic words (e.g., theory, hypothesis, approach) used in student notes, as an indicator of productive academic discourse.
	Domain-specific words	Student use of domain-specific words as an indicator of their appropriation of disciplinary discourse and knowledge.

Among other analyses of social interactions (e.g., note contribution, reading), we adopted a set of measures from social network analysis (Wasserman & Faust, 1994). In a social network, each community member is represented as a node, and a relational tie (e.g., build-on) between two members as a line. We used social network analysis to examine two types of social relations recorded by Knowledge Forum: (a) who read

whose notes, with reading peers' notes as a primary mean to understanding knowledge advances and challenges of the community; and (b) who linked to whose notes (i.e., created build-ons, rise-aboves, or references), as an indicator of complementary and connected contributions. Three measures were included in this analysis: (a) in-degree showing how many relational ties (e.g., reading, linking) a member received from peers, suggesting the level of his/her influence; (b) out-degree measuring the number of relational ties one sent out to other peers as an indicator of his/her effort to understand and build on peer contributions; and (c) clique analysis, which identified sub-networks each member belonged to in the note linking network, as an indicator of community-wide dynamic collaboration. A clique is "a sub-set of a network in which the actors are more closely and intensively tied to one another than they are to other members of the network." (Hanneman, 2001, p. 79)

Content analysis (Chi, 1997) was adopted to code: (a) questions identified by students in their notes (e.g., how do solar panels work?); (b) student personal ideas that presented their own theories and claims often labeled as "My theory" (e.g., "If there is no light, there can't be a shadow"); (c) information sources, to introduce new information from readings, the Internet, the teacher, or parents, etc., often labeled as "New information," and use the information to deepen their understanding; (d) evidence, to examine and deepen their understanding using findings from experiments and observations; and (e) inquiry threads contributed to. An inquiry thread consists of a series of discussion entries that address a shared principal problem and constitute a conceptual line of inquiry in a community knowledge space (Zhang et al., 2007). These entries may involve multiple physical threads of build-ons. For example, students in this study wrote 27 notes in an extended discussion about how rainbows are created, constituting an inquiry thread titled "Rainbows," with deeper questions progressively addressed leading to improved understanding. Within the communal knowledge space, 28 inquiry threads were identified, each beginning with the first note created and ending with the last note created or modified (see Zhang et al., 2007 a visual representation). Students engaged in the inquiry themes through opportunistic interactions based on their interest. Tracing student notes contributed to different inquiry threads helped to examine their emergent, diverse participation in the community's knowledge space.

Increasing use of sophisticated, low frequency words in free writing indicates growth of productive vocabulary and writing skills (Nation 2001). Thus, lexical frequency analysis was employed to examine student use of three types of words in their online discourse: (a) The first 1,000 most frequent word families in English (West, 1953). Low-proficiency writers tend to rely more on these basic word families in writing; (b) A list of academic words, including 570 word families that are typical of academic discourse across disciplinary areas, enabling references to other authors and findings (e.g., *assume*, *establish*, *conclude*) and processing of data and ideas (e.g., *analyze*, *assess*, *category*) (Coxhead 1998). Writers need to gain productive written control of the academic vocabulary in order to be recognized as a member of the academic discourse community (Corson, 1997); and (c) Domain-specific terms, which included 89 domain words related to light (e.g., names of optical concepts, devices and phenomena) identified from the Ontario Curriculum (Sun et al., 2010).

Assessing Knowledge Gains Based on Student Portfolio Notes

Assessing student understanding based on reflective essays or portfolios has been tested in a number of studies (e.g., van Aalst & Chan, 2007; Zhang et al., 2007). This study analyzed student portfolio notes to assess their knowledge gains focusing on two aspects: knowledge diffusion and depth of understanding.

Knowledge diffusion (or idea spread) becomes an important issue in learning contexts that encourage diverse participation and distributed expertise (Brown et al., 1993). Our analysis thus examined whether individual students could benefit from the community's knowledge advances in diverse inquiry themes to achieve adequate breadth of understanding beyond their personal focus. Specifically, the first author segmented each student's portfolio note into idea units—the smallest unit of text that conveyed a distinct idea about light. Each idea unit was coded in relation to the inquiry threads (themes) that emerged from the knowledge building discourse (e.g., how light travels, nature of shadows, eclipses, rainbows) (see Zhang et al., 2009 for details).

To look at the depth of student understanding, each idea unit was additionally rated in terms of epistemic complexity and scientific sophistication. Epistemic complexity indicates students' efforts to produce not only descriptions of the material world, but also theoretical explanations and articulation of hidden mechanisms, which are central to the focus of science (Salmon, 1984). A four-point scale (1 - unelaborated facts, 2 - elaborated facts, 3 - unelaborated explanations, and 4 - elaborated explanations), adapted from Hakkarainen's (2003) work, was used to code each idea unit (for details and examples, see Zhang et al., 2007). Scientific sophistication focuses on the extent to which a student has moved from an intuitive toward a scientific framework. It is gauged through coding students' ideas in their portfolio notes based on a four-point scale (1 - pre-scientific, 2 - hybrid, 3 - basically scientific, and 4 - scientific) (for details, see Zhang et al., 2007), which was informed by Galili and Hazan's (2000) facets-scheme framework for analyzing students' misconceptions in optics. To assess inter-rater reliability, two coders independently coded 12 portfolio notes, *Cohen's Kappa* = .83 for scientific sophistication, *Cohen's Kappa* = .75 for epistemic complexity (Zhang & Messina, 2010).

Epistemic complexity represents the level of complexity at which a student chooses to approach an issue. Scientific sophistication represents the level of success a student has achieved in processing an idea at a

certain complexity level. It is easier to convey a scientific idea at a factual level (e.g., “there are different colors in a rainbow”), but harder to provide a scientific explanation of a fact (e.g., elaborate what causes a rainbow and why the colors are always in the same order). The meaning of the scientific score of an idea is dependent on the level of its complexity. Therefore, a composite score was used to indicate the depth of understanding by multiplying the above two ratings, weighting the rating of scientific sophistication with the level of complexity (Zhang et al., 2009). For example, an idea rated as “1 - unelaborated facts” and “3 – basically scientific” will have a composite score of 3, while an idea rated as “4 - elaborated explanations” and “3 – basically scientific” will have a composite score of 12.

Results

To identify quantified measures of online discourse that may have a strong connection with student knowledge productivity, we calculated the correlations between these measures and the depth and breadth of student understanding, which represent two independent components of the learning outcome with virtually no correlation ($r = -.03$).

Social Interaction Measures

Table 2 reports the correlations between social interaction measures of the online discourse and the depth and breadth of student optical understanding gauged based on their portfolio notes. Student deep understanding of optics was associated with high rates of note contribution and note reading—both reading others’ notes and being read by others—in the knowledge building discourse, with significant ($p < .05$) or marginally significant correlations ($p < .10$). Two of the social network measures of note linking contacts are significantly correlated with the depth of understanding achieved ($p < .05$). Students with deeper understanding received more intensive note linking contacts from their peers and collaborated with multiple sub-networks of students through building on, rising above, and referencing one another’s work. There is a close to significant correlation between students’ in-degree in the note linking networks and the breadth of understanding achieved ($p < .10$), showing that students who understood a broader range of issues had received more note-linking contacts from peers in the knowledge building discourse.

Table 2: Correlations (Pearson r and p) between social interaction measures of online discourse and student optical understanding.

	Notes written	% of notes read	Note reading network: in-degree	Note reading network: out-degree	Note linking network: in-degree	Note linking network: out-degree	Note linking network: Cliques belonging to
Depth of understanding	.437* (.042)	.398 [†] (.067)	.519* (.013)	.398 [†] (.067)	.431* (.045)	.214 (.338)	.469* (.028)
Breadth of understanding	.198 (.377)	.105 (.644)	.308 (.164)	.061 (.788)	.364 [†] (.096)	-.068 (.765)	.159 (.478)

Note. [†] $p < .10$, * $p < .05$

Content-Based Measures

As Table 3 shows, student deep understanding is significantly ($p < .05$) or marginally significantly ($p < .10$) correlated to their efforts to generate and contribute personal ideas, identify and address deeper problems, and incorporate informative sources to help them better understand light. Not surprisingly, the breadth of their understanding achieved is strongly correlated to the number of inquiry threads—each addressing a principal problem—they contributed to during the optical discourse.

Table 3: Correlations (Pearson r and p) between the content-based measures of online discourse and student optical understanding.

	# of notes identifying problems	# of notes contributing personal ideas	# of notes incorporating new sources	# of notes using evidence	# of inquiry threads/themes contributed to
Depth of understanding	.582** (.004)	.365 [†] (.095)	.403 [†] (.063)	.260 (.242)	-.034 (.879)
Breadth of understanding	.296 (.182)	.288 (.193)	-.009 (.970)	.056 (.806)	1.000*** (.000)

Note. [†] $p < .10$, ** $p < .01$, *** $p < .001$

Lexical Measures

Table 4 displays the correlations between the lexical measures of online discourse and the depth and breadth of student optical understanding. The depth of their understanding is positively correlated to the total number of words students wrote and the occurrences of domain-specific words and academic words in their online notes. Student knowledge productivity is associated with their engagement in online written discourse that incorporates a larger number of domain-specific words in optics (e.g., *shadow*, *reflect*, *absorb*, *wave*) and epistemic, academic words that are characteristic of academic discourse (e.g., *hypothesis*, *conclusion*). There is a significant negative correlation between the depth of student optical understanding and the occurrence of the most basic, 1st 1,000 English word families in the online discourse, which indicates a limited level of vocabulary and writing. A significant positive correlation was found between the breadth of understanding and the number of unique domain words students used in their notes. Spontaneous incorporation of domain-specific words in online discourse suggests the expanding scope and richness of inquiry in a domain.

Table 4: Correlations (Pearson r and p) between the lexical measures of online discourse and student optical understanding.

	Total words written	% of the 1 st 1,000 words	% of the academic words	# of unique domain words	Total domain words
Depth of understanding	.646** (.001)	-.646** (.001)	.506* (.016)	.458* (.032)	.660** (.001)
Breadth of understanding	.250 (.262)	-.302 (.172)	.226 (.313)	.594** (.004)	.218 (.329)

Note. * $p < .05$, ** $p < .01$

Discussion

This study investigated a set of social interaction, content-based, and lexical measures applied to the same knowledge building discourse database. Examining their correlations with the depth and breadth of student understanding helped to identify and justify indicators of online discourse conducive to knowledge building. Several social interaction measures indicate productive discourse to achieve deep understanding, including the number of notes contributed, percentage of notes read, in-degree (being read by peers) and out-degree (reading peers' work) in the note reading network, and in-degree (being built on by peers) and dynamic memberships in cliques (sub-networks) in the note linking network developed through build-ons, rise-aboves, and referencing citations of peer ideas. Content-based discourse indicators associated with student deep understanding involve the number of notes contributing personal theories, identifying deepening problems, and incorporating new information sources, with student contributions to multiple inquiry threads strongly connected to the scope of their optical understanding. The number of notes reporting evidence is not significantly correlated to the depth of student understanding, possibly because this analysis only considered the frequency of evidence use. Additional measures might examine how evidence was used to support reasoning and discourse. Finally, all the lexical discourse measures have significant correlations to the depth of student understanding, including total words written, occurrences of academic words and domain-specific words (both total and unique words), and less frequent use of the 1st 1,000 English word families. Incorporating unique domain-specific words in the knowledge building discourse additionally suggests the expanding scope and breadth of inquiry.

The above-identified measures collectively characterize productive knowledge building discourse along four interrelated dimensions. (a) *Interactive engagement in extended discourse*, with community members understanding and successively building on to one another's intellectual input over time beyond short-threaded conversation turns (Engle, 2006; Guzdial & Turns, 2000; Suthers et al., 2010; Zhang et al., 2007, 2009). Students are thus expected to have a high note contribution rate, note reading percentage, in-degree and out-degree in the note reading network, and in-degree and clique memberships in the note linking network. (b) *Idea-centered, progressive discourse*, with students engaging in idea generation and improvement, expanding a shared base of knowledge, and identifying deeper challenges as their understanding deepens, harnessing sophisticated language tools to communicate and develop ideas (Bereiter, 2002; Hakkarainen, 2003; Hmelo-Silver, 2003; Zhang et al., 2007; Zhang & Messina, 2010). Such efforts are evident when students actively identify deepening questions, propose initial theories for peer input, and develop better theories and explanations. (c) *Constructive use of knowledge and language resources*, through making constructive use of authoritative sources and appropriating academic vocabulary and discourse (e.g., academic words, domain concepts) in the related domain areas to support idea development (Chernobilsky, DaCosta, & Hmelo-Silver, 2004; Hong & Scardamalia, 2008; Sun et al., 2010; Zhang et al., 2007). (d) *Student-driven, dynamic*

collaboration, with students identifying progressive goals and forming dynamic teams to address challenges emerged at the intersections of their interests. Analyses in this regard may examine student-generated questions and goals, distributed network patterns, and emergence of cliques in note link networks (Zhang et al., 2009). Efforts along the above dimensions help foster collective responsibility for knowledge advancement in a community (Scardamalia, 2002; Zhang et al., 2009).

In conclusion, this study provides empirical justification for a set of quantified measures used in the CSCL literature. The three types of measures that capture four dimensions of knowledge building discourse may be used as a framework to guide the selection and integrated use of research measures in specific contexts and development of new analyses to capture the interactional, cognitive, and linguistic processes of knowledge building. This framework can be further elaborated and used to guide the design of automated assessment and feedback tools in collaborative learning environments. Focusing on these and additional indicators, automated assessment tools may provide coherent and accessible analyses of the interactional, cognitive, and linguistic processes to aid student reflection on and improvement of knowledge building. Automated analyses focusing on various aspects of online discourse can be integrated to address pedagogically valuable questions, such as: Is there interactive engagement in extended discourse? To what extent are we improving our ideas and what contributions are evident? Are we engaging in productive writing and discourse? Are we enacting collective responsibility for knowledge building?

This investigation of online discourse measures was based on a small sample of 22 students, which has prevented us from conducting confirmative factor analysis to further test how the different indicators capture different dimensions of productive online discourse. Although this study focused on quantified measures only, complementary qualitative analyses have been reported elsewhere that helped to elaborate and contextualize the quantified patterns through detailed accounts (Zhang et al., 2007; Zhang & Messina, 2010). Further analysis will include additional measures of student knowledge growth (e.g. post-test scores) and examine correlations across the three types of knowledge building indicators.

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