Using a Computer-Supported Collaborative Learning Environment (CCLE) to Promote Knowledge Building Pedagogy in an Undergraduate Strength of Materials Course

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Introduction

National conversations about higher education in general and undergraduate engineering education in particular have focused on the need to develop 21st century skills and to educate students to be active participants in a rapidly evolving knowledge economy1-3. Such skills include the ability to engage in life-long learning, to communicate effectively, and to function on multidisciplinary teams while engaged in authentic, real-world problems that require new learning and the creation of coherent explanations of complex phenomena. Knowledge Building (an instructional approach in which students work as a community to solve a problem that requires they advance their collective understanding through a sustained discourse4-8) is an ideal pedagogy for developing many of these capacities. Students engaged in Knowledge Building not only develop a deeper understanding of the technical content of the subject they are studying, they also develop a wide array of non-technical 21st century skills7,9.

Knowledge Building (KB) begins with a question or problem, often rooted in observation and developed by the students themselves, such as why does a glass window pane crack with a particular pattern when subjected to a large temperature differential? Students are encouraged to generate and post their ideas and theories about the topic and build directly on the ideas of others. This discourse is supported through a computer-based asynchronous collaborative learning environment such as Knowledge Forum (KF)10. The workspace preserves an on-going record of the discourse so that participants can return to earlier ideas for reflection, synthesis, and refinement. In the process, students develop a questioning attitude, learn to identify personal and collective gaps in knowledge and understanding, become self-directed learners who are capable of bringing in new sources of authoritative information, viewing such information from multiple perspectives in support of theory-development, and ultimately learn to take collective cognitive responsibility for idea advancement11-14.

The guiding principles of Knowledge Building, here distilled from several sources5, 7, 15, include:

- Working at the cutting edge of knowledge, which includes asking productive questions, identifying knowledge gaps and inconsistencies, and posing questions that extend the edge of understanding of the community;
- Engaging in progressive problem solving, which includes making continual efforts at theory building, explanation and idea improvement;
- Engaging in collaborative effort, which includes building on the ideas of others with a focus on advancing collective understanding;
- Monitoring one’s own understanding and the understanding of the group, which includes developing a metacognitive awareness of self and community;
- Constructive use of authoritative information from diverse sources, which includes examining such information from alternative perspectives to advance collective understanding.
The literature on KB is extensive, but the majority of work is based in K-12 settings. Implementing KB pedagogy in higher education presents challenges different from those facing K-12. Among these are a thirteen-week semester, limited face-to-face time, the constraints of providing expected content and coverage in a sequential undergraduate curriculum (especially true in engineering), and preconceived notions of knowledge and understanding on the part of students\textsuperscript{16}. Indeed, college students’ existing theories of learning and knowing often get in the way of KB. Students often take a strategic approach to learning by the time they enter college\textsuperscript{17}, focusing on the production of a final deliverable that they are being graded on, and directing their efforts accordingly. With such a conceptualization of learning, group work is often approached as something to be divided and conquered. Knowledge Building emphasizes idea improvement rather than end product, and this requires groups to sustain a community discourse. Typically, this is quite a different focus for students, often experienced as ambiguous and sometimes even resisted for this reason.

A group of college faculty at our institution has been working to advance efforts using KB pedagogy in a wide variety of courses across multiple disciplines and developmental stages. Most of the efforts to date have been based on a single, semester long focus around a particular problem or topic. The faculty group has found that arriving at the “right” problem and sustaining student focus and effort for an entire semester is not always feasible. The work presented here represents an investigation into the use of KB pedagogy in shorter, focused episodes.

The primary research question of this study is to determine whether Knowledge Building and community idea improvement can happen over the course of short (1-2 week) timescales. A sub-question of the study is to see whether and how KB is affected by perceived accountability structures. The evidence for addressing these questions comes from the KB discourse itself. A sub-goal of the work is to continue the development of tools needed to analyze KB discourse.

**Learning Environment**

Data was collected from a four-credit, semester-long undergraduate Strength of Materials course taught in the spring of 2014 with fifteen students enrolled at Smith College. The majority of students were sophomores majoring in engineering science. All but one student had prior experience with Knowledge Building from the pre-requisite course at our institution.

Knowledge Forum itself is an online asynchronous environment where users post notes within views that are accessible to all members of the learning community. A key feature of the software is the ability to build on the notes of others in order to advance understanding. Build-on notes generate arrows that connect the originating note to the growing network of knowledge building threads. Users can also upload files, videos, and images within a given note, and can link to web sites or reference existing notes in their posts. Figures 1 and 2 show the Knowledge Forum views for the two KB episodes analyzed in this paper, referred to throughout as the Knowledge Gaps and Collaborative Exam Question views, respectively.
Figure 2: Collaborative Exam Question View in Knowledge Forum
An important component of successful Knowledge Building is the creation of a classroom environment that is supportive of the underlying principles of KB in which students feel safe to stretch themselves and take the intellectual risks required to advance both individual and collective understanding. Developing student buy-in is critical. Such buy-in requires students to recognize that knowledge creation is often a collaborative endeavor, which relies on participants’ ability to identify gaps in understanding and to ask good questions as well as posit and revise theories as new information and perspectives become available. The instructor for this course employed a number of techniques in an effort to create such a classroom environment. First, because the course continually revisits key concepts at a deeper level as we pursue the central question of the class (“how strong is strong enough?”), students very quickly appreciate that their knowledge and understanding in the domain of mechanics is emergent and evolving. In addition, the class spends time discussing the artificial nature of the semester as a relevant unit of time for demonstrating “mastery”, and the instructor emphasizes advancement along a continuum rather than achievement of an end-state of absolute understanding. Informal conversations about teaching and learning include discussion of Carol Dweck’s concept of cultivating a growth mindset¹⁸, students’ conceptions of generous vs. selfish learning, and the importance of being honest with ourselves and others about what we don’t know as a starting point; that is, recognizing our knowledge gaps whenever we engage with the subject, taking steps to fill those gaps, as well as helping others to bridge their gaps and those of the community as a whole. While none of these practices are a formal component of Knowledge Building pedagogy, the culture and tone that they help to establish are highly supportive of KB.

The first episode of short-term Knowledge Building analyzed in this paper was designed to be relatively low-stakes. The goal was to have students develop the habit of identifying and bridging knowledge gaps and to respond to other students’ gaps in an effort to foster individual metacognitive awareness and to develop some initial sense of collective responsibility for advancing understanding. On the first two homework assignments, students were prompted to review class notes and readings for the week and post at least one note identifying knowledge gaps as well as building on at least one note posted by someone else in the Knowledge Gaps view shown in Figure 1. This work was not assessed as part of the homework grade, but would be included as part of an overall Knowledge Building grade for each student at the end of the semester.

The second KB opportunity came in the form of a collaborative exam question and was designed to be higher-stakes. The exam itself was a one-week open-book take-home exam with three traditional problems to be completed individually (worth 25% each), and a ⁴th collaborative KB question (worth 25%) to be investigated using Knowledge Forum. The exam itself was worth 15% of the final course grade. The seed question for the exam originated from a promising student question that had emerged after watching a one-hour NOVA special on the making of Samurai Swords¹⁹. Although the exam question was collaborative, grading was individual, based on each individual student’s contributions to idea advancement. Instructions for the collaborative question were:

“There is a new view in Knowledge Forum called “Collaborative Question for Exam 1.” In it, I have re-posted a note that was originally posed as a question related to the Samurai Sword
video. Review the handout on “guiding principles for knowledge building” and read the short NY Times Op-Ed posted there (“How to get a job at Google”). You will probably want to watch the video again after taking a look at the question. Then, as a class, develop your theories and advance your collective understanding related to this question. I am interested in seeing high quality collaborative knowledge building, where there is “collective cognitive responsibility” taken for the advancement of knowledge as it relates to this question. I am less concerned with arriving at a final “correct” answer. Remember, bringing in additional authoritative sources is highly encouraged, including technical articles, videos, etc. if you can find them. It would be wise to log in to KF several times per day during the course of this week to keep the ideas advancing.

The New York Times OpEd piece referenced in the instructions makes the case for why this kind of work and thinking is important in real world settings and was included to provide motivation for this approach. The note containing the initial question, originating from a student in the class, is shown in Figure 3. This second KB episode was distinct from the first in two respects. First, it was a relatively higher stakes experiment because it was part of a graded exam. Second, the episode was more directed toward the advancement of understanding with respect to a single initial question in contrast to the more open-ended structure of the Knowledge Gap work.

![Figure 3: Original student note serving as the basis for the collaborative knowledge building exam question](image)

Assessment Methods

Assessing the effectiveness of Knowledge Building is an ongoing challenge in the community of instructors who employ it as pedagogy. As is the case for analyzing episodes of oral discourse, the analytic approach and tools used to analyze written discourse must be adapted to the content, students, purposes, and other contextual factors. The analytic approach described here builds on the work of Zhao and Chan. An initial list was developed for categorizing KB moves exhibited within student notes. Using an iterative Grounded Theory approach three of the authors read
and discussed each note (a total of 50 notes in the Knowledge Gaps view and 33 notes in the Collaborative Exam Question view), subsequently refining categories and developing subcategories (Table 1). These same three individuals then re-read all 83 notes and developed a consensus on the coding of every KB move that was made (in many cases, notes fell into multiple categories). Successive levels of subcategories represent more sophisticated knowledge building within a category, and notes were scored between 0 (lowest) and 3 (highest) for all but the last two categories, which were scored at a level of 0 or 1. This scoring system allowed us to examine both the percentage of all notes in a view that exhibited KB moves of a certain type, regardless of the quality (e.g. questioning), as well as the total score in a given category relative to the maximum possible score in that category (assuming that any note exhibiting a particular type of move could potentially score at its maximum level). This latter measure gave an indication of the quality of KB within each major category. In addition to analyzing the two views in question, we were also able to analyze the work of each student within each of these views in the same manner.

<table>
<thead>
<tr>
<th>Major Category</th>
<th>Subcategory</th>
<th>Description</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epistemic Inquiry:</td>
<td>Factual</td>
<td>Asking for facts or information</td>
<td>“Are there any materials that have an entirely non-linear stress/strain relationship?”</td>
</tr>
<tr>
<td>Questioning</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Explanatory –</td>
<td>Seeking to improve gaps</td>
<td></td>
<td>“I was wondering what the potential benefits or uses might be of a brittle material?”</td>
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<td>personal focus</td>
<td>in personal understanding</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Explanatory –</td>
<td>Seeking to improve</td>
<td></td>
<td>“What type of steel does the table given in the previous post use? What type of steel... doe Kihara use? Does this blackbody radiation</td>
</tr>
<tr>
<td>collective focus</td>
<td>collective understanding</td>
<td></td>
<td>curve change significantly depending on how much carbon is added to the iron? How do the foreign carbon atoms in the metal affect the</td>
</tr>
<tr>
<td></td>
<td>(can be implied or</td>
<td></td>
<td>blackbody radiation effect at the atomic level?</td>
</tr>
<tr>
<td></td>
<td>explicit)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Epistemic Inquiry:</td>
<td>Superficial</td>
<td>Providing facts or information, or providing simple claims (opinions) with</td>
<td>“The yield point is calculated using the offset method”</td>
</tr>
<tr>
<td>Explanation</td>
<td></td>
<td>no supporting evidence</td>
<td></td>
</tr>
<tr>
<td>Elaborated</td>
<td>Makes a claim supported</td>
<td></td>
<td>“Yes, reinforcing concrete with a polymer or steel in conjunction with a rebar will increase the</td>
</tr>
<tr>
<td></td>
<td>by reasons, evidence,</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>analogies or examples</td>
<td></td>
<td></td>
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<tr>
<td>Conceptual Processing: constructive use of authoritative information</td>
<td>Superficial</td>
<td>Provides new authoritative information in isolation; not used in support of a new or developing idea</td>
<td>“<a href="http://www.thewarren.org/GCSERevision/engineering/soldering.html">http://www.thewarren.org/GCSERevision/engineering/soldering.html</a> link very simply defines soldering and welding”</td>
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<tr>
<td>Idea-supportive – singular perspective</td>
<td>Brings in new authoritative information in support of an idea (could be new or developing)</td>
<td>“<a href="http://link.springer.com/article/10.1007%2Fs00707-010-0308-7">http://link.springer.com/article/10.1007%2Fs00707-010-0308-7</a> According to this article, the tatara is maintained at temperatures below the melting point of steel – between 1200 °C and 1500°C. It seems that Kihara doesn’t have to be as meticulous as we thought…”</td>
<td></td>
</tr>
<tr>
<td>Idea-supportive – alternative points of view</td>
<td>Examines authoritative information from alternative perspective(s) to advance collective understanding/further develop an idea</td>
<td>“The video tells us that the process yields steel with varying carbon because the steel does not fully melt. Part of what makes the steel good is the variation in the yield. Every bit of ore has a different experience inside the tatara: gets mixed with more or less carbon and (a different perspective) reaches a different temperature.”</td>
<td></td>
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</table>
| Epistemic Agency: metacognition | Individual | Demonstrates individual awareness of own personal state of understanding | “I’m a little confused about this. If concrete is well bonded to steel and the steel can experience more strain without fracturing, won’t the…"
Table 1: Descriptions of categories for coding student discourse

In addition to the coding analysis described above, student reflections on the collaborative exam question were analyzed to identify specific themes regarding metacognitive awareness of the knowledge building process.

**Results**

The results reported here include an analysis of the type and quality of Knowledge Building in the two short-term KB environments. We first examine the data in the aggregate, in order to address the question of whether there is any evidence to support the hypothesis that substantive Knowledge Building can happen in shorter-duration episodes. The aggregate data also allow us to address the question of whether the accountability structure (i.e. low vs high stakes) influences the nature of the type and quality of Knowledge Building in the two environments being analyzed. Individual student data regarding type and quality of KB are then examined to gain...
further insight into patterns of student behavior that emerge in these two different accountability structures. Finally, the broad-brush analysis of student reflections regarding the higher stakes episode provide data regarding the nature of the metacognitive awareness that students developed through this form of Knowledge Building. In the Gaps environment, students contributed a mean, median, and mode of four notes each, with a high of ten, and a low of one. On the exam question, students contributed a median and mean of three notes each (mode of two), with a high of five and a low of one.

Figure 4 demonstrates the results of analyzing all of the student notes as a whole to examine the type and quality of KB exhibited by the entire learning community in the Knowledge Gaps vs. Collaborative Exam Question situations. In the Knowledge Gaps environment, the full range of KB moves was exhibited (bottom), with the largest percentage of notes involving explanation (60%), metacognition (55%) and questioning (45%). Almost no strategic talk was evident, and social talk (supporting discussion) was only seen in 25% of the notes. Not surprisingly, the lowest cognitive category was working with authoritative information (only 20% of notes). The quality of the KB exhibited in the Knowledge Gaps view was fairly high (top), with the quality of questioning being highest (75% of maximum), followed by working with authoritative information and explaining (both at 65%). The quality of metacognition in the knowledge gaps view was the lowest of all of the categories (45% of maximum possible).

In the Collaborative Exam Question, all categories of KB were observed, with the exception of strategic talk (Figure 4, bottom). By far, the predominant activity was explaining (85% of all notes), followed by metacognition (55%), working with authoritative information (50%), and socially supportive talk (42%). The least frequently observed category was questioning (fewer than 40% of all notes). The quality of the questioning was quite high, however (top), at almost 100% of the possible maximum score attainable in that category. The quality of KB in the other categories was also quite high (working with authoritative information (close to 80% of maximum), explaining (75% of maximum), and metacognition (60%). Overall, the quality of the KB seen in the higher stakes exam KB was higher than that seen in the Knowledge Gaps KB (top), suggesting that the accountability structure does indeed influence the quality of KB exhibited, but not necessarily the range.

Analysis of individual students’ KB moves identifies two main patterns of behavior in relation to accountability structures: (1) students who “up their game” when the stakes are high (exam vs. gaps) and (2) students who exhibit the same quality of KB, regardless of the stakes. For example, Figure 5 (Student 1) shows the assessment of a student who exhibits a broader range of KB moves on the collaborative exam question when the stakes are high (bottom), with a higher quality of KB in the higher stakes situation as well (top). By contrast, Student 2 (Figure 6) exhibits a roughly comparable range of KB moves on the exam (bottom), yet the quality of the KB is identical in both the low (knowledge gaps) and high (exam) stakes situations. Approximately a third of the class fell into each of these two categories, with the remaining third falling somewhere in-between (quality was higher in some categories in the exam view, but lower in others).
Figure 4: KB assessment for the learning community as a whole, showing the range of KB moves exhibited (bottom) as well as the quality of the KB (top) in both the Knowledge Gaps and Collaborative Exam Question views.
Figure 5: Student 1 KB Assessment showing greater range of KB moves (bottom) and higher quality of KB (top) in the higher stakes Collaborative Exam vs. Knowledge Gaps episodes
Figure 6: Student 2 KB Assessment showing roughly similar range of KB moves (bottom) of comparable quality (top) in both KB views.
When student reflections on the Collaborative Exam KB were analyzed, the following main themes were identified: an awareness that knowledge can be advanced further by the community versus individually; an awareness of the incomplete nature of the state of understanding of the community; the value of constructive challenges and competing theories, and a conception of Knowledge Building as the development of coherent understanding (Table 2).

<table>
<thead>
<tr>
<th>Themes</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knowledge is advanced further collectively rather than individually</td>
<td>“I appreciate how we all thought of so many things that might have been going on in the furnace. It would be hard for one person to come up with all of those ideas. We collectively advanced the level of knowledge of the group, and I personally found the experience to be very educational.”</td>
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<tr>
<td></td>
<td>“From others, I was able to broaden my understanding”</td>
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<td></td>
<td>“The key moment for the development of my thinking on this came early in the week with [X]’s and [Y]’s posts in which they pointed out that at high temperatures the color variation between temperatures is much smaller than at low temperatures.”</td>
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<tr>
<td></td>
<td>“Then [X] was able to bring in a point that changed my understanding of the problem.”</td>
</tr>
<tr>
<td>An awareness of the incomplete nature of the community’s knowledge</td>
<td>“Our knowledge isn’t in any way complete… We still need to know a lot about what happens on the atomic level as well as on a larger scale to the iron ore.”</td>
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<tr>
<td></td>
<td>“We still have some huge gaps in understanding… A good experimental next step if we had unlimited resources would be to heat a very low and a very high carbon steel and measure the color spectrum emitted from each.”</td>
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<tr>
<td>The value of constructive challenge and competing theories</td>
<td>“My ideas have been refined, overturned, and supplemented with alternative theories that I never would have even considered.”</td>
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<td></td>
<td>“There were constant constructive challenges to the dominant discourse which I feel is very important in advancing the knowledge of the group. Challenges push the knowledge towards being more correct.”</td>
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<tr>
<td>Knowledge Building as the development of coherent understanding</td>
<td>“The most challenging part of this problem was connecting seemingly unrelated theories together and seeing the bigger picture. It required the integration of knowledge in three different fields – physics, metallurgy, and chemistry.”</td>
</tr>
</tbody>
</table>

**Table 2:** Major themes in student reflections on the Knowledge Building that occurred as part of the collaborative exam question
Discussion

Due to the many challenges associated with implementing longer duration (e.g. semester-long) Knowledge Building work in higher education settings, the primary research question of this study was to investigate whether Knowledge Building can happen over the course of shorter duration timescales. The data provide evidence to suggest that successful Knowledge Building can, indeed, occur over 1-2 week periods. The discourse contains evidence of high quality questioning that is focused on improving collective rather than solely individual understanding, substantive elaborated explanation that often synthesizes multiple threads of discourse and idea development, and the constructive use of authoritative information, examined from multiple perspectives, in support of advancing collective understanding. In addition, the data provide evidence that, even in the short term, students exhibit both metacognitive awareness and agency.

A sub-question of the study was to examine whether the perceived accountability structure (low-stakes vs. high-stakes) affects the type and quality of Knowledge Building exhibited by students. Not surprisingly, this appears to be the case in the aggregate, although when individual student behavior is examined, a more nuanced picture emerges. Some students clearly increased both the range and quality of their contributions to Knowledge Building when the perceived stakes were high, while others exhibited a comparable level of strong effort regardless of the accountability structure. Summarizing a body of research by social scientists, Bain\textsuperscript{17} describes these two types of students as “strategic learners” versus “deep learners.” Strategic leaners often look like deep learners because they shine in the classroom, but their fundamental motivation is different. As Bain notes, “they focus almost exclusively on how to find out what the professor wants and how to ace the exam. If they learn something along the way that changes the way they think, act, or feel, that’s largely an accident. They never set out to do that” (p 36). By contrast, deep learners learn in pursuit of their own learning goals, “us[ing] much deeper approaches even when no one [has] prompted them to do so..., [They use] strategies that [are] most likely to produce understanding, critical thinking, creativity, and adaptive expertise” (pp 40-41).

It is important to note that the aggregate differences seen in the type and quality of Knowledge Building in the two scenarios cannot solely be attributed to differences in the accountability structures. The nature and goals of each scenario were quite different, with a more open-ended and diffuse structure for the knowledge gaps view, compared to a more focused question for the community to grapple with on the exam question. In that context, it makes complete sense, for example, that there is more sophisticated use of authoritative information evident in the collaborative exam question discourse than in the knowledge gap discourse, or that there is more socially supportive discourse present in the exam question where failure to advance the community’s understanding carries personal consequences and success depends on positive engagement and good will of the entire community.

The assessment rubric developed for the purposes of this study provides a useful analytical tool for advancing our understanding of online discourse. One weakness, however, is that the rubric doesn’t address the issue of sustained idea development; the question of how one might trace the development of an idea across multiple threads of discourse over time is a much more challenging question and poses a fruitful area for further investigation.
One confounding factor that is not addressed by this study is the extent to which prior experience with Knowledge Building enables students to engage in higher quality KB over time. All but one of the students in this particular course had prior Knowledge Building experience in the prerequisite course, of the longer-term variety (i.e. focused work over an entire semester). An additional fruitful area of future investigation would to examine whether such prior experience is necessary for successful short term Knowledge Building, and the extent to which multiple shorter-term Knowledge Building endeavors can lead to higher quality Knowledge Building over time.

Conclusion

In this paper, we have presented an analysis of student discourse in the computer-supported collaborative learning environment of Knowledge Forum from an undergraduate Strength of Materials course in order to assess whether Knowledge Building can occur over short-term (1-2 week) duration timescales. The data suggest that high quality Knowledge Building can, in fact, occur on this timescale. In addition, we find that both the type and quality of Knowledge Building (i.e. questioning, explanation, constructive use of authoritative information, and metacognition, all in service to collective idea advancement) is influenced by the accountability structure of the Knowledge Building context. Student reflections indicate the development of an awareness that knowledge can be advanced further by the community versus individually; that the state of understanding of the community is always improvable; that constructive challenges and competing theories are important for developing collective understanding, and that the development of coherent understanding between areas of knowledge that may initially seem disparate and disconnected is a key component of Knowledge Building.

Bibliography


