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Applying Knowledge Building in an Engineering Class: A Pilot Study*

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Although knowledge building pedagogy is being used increasingly around the world to support deep learning and to prepare graduates for the knowledge economy, its potential for improving engineering education remains largely unexplored. In this paper we review knowledge building theory, present a pilot study applying knowledge building in an engineering class and discuss questions raised by the study. In the pilot study, knowledge building was applied in one engineering class with 20 students. A narrative approach was used to initiate student knowledge building efforts and Knowledge Forum software was used to both support and keep a record of the ongoing discourse. The discourse was then analyzed to see if it reflected the determinants of knowledge building. A student survey and student reflections were used to record student perceptions. Discourse analysis showed that knowledge building clearly took place as evidenced by higher-level formulations of the problems, increased engagement, and more complex levels of discourse. Most students participated fully in the discourse resulting in a shift to orientation on idea improvement. While the study's findings support the promise and potential for knowledge building in engineering, it also raised questions that need to be addressed to broadly apply knowledge building in engineering education. These include: What types of questions or problems of understanding are most effective for engaging a broad range of students and generating substantive discourse? How should instructors best facilitate the discourse? And how can a student's ability to use knowledge innovatively be most effectively assessed?

Keywords: community; discourse; knowledge building; narrative

1. Introduction

In the current and rapidly evolving knowledge age, societies are now being organized around the production of new knowledge in the same way that agrarian societies are organized around agriculture or industrial societies are organized around manufacturing [1]. The National Science Board [2] writes:

> Engineering thinking needs to be able to deal with complex interrelationships that include not only traditional engineering problems but also encompass human and environmental factors as major components. In addition to analytic skills . . . companies want engineers with passion, some systems thinking, an ability to innovate, an ability to work in a multicultural environment, an ability to understand the business context of engineering, interdisciplinary skills, communication skills, leadership skills, an ability to adapt to changing conditions, and the eagerness for life long learning. This is a different kind of engineer from the norm that is being produced now.

This vision of a new kind of engineer is strikingly similar to the qualities and characteristics that research in the learning sciences deems essential for success in the knowledge age. Sawyer [3] writes that success in the knowledge economy requires integrated and usable knowledge with a deep understanding of complex concepts; the ability to work creatively with ideas to generate new theories, products, and knowledge; the skills to communicate and participate in discourse; and the capacity for lifelong learning. Echoing the NSB, he notes that traditional educational practices are particularly ill suited to this task.

In this paper we will introduce knowledge building, a collaborative approach to engineering education designed to prepare graduates for the knowledge age [4]. Although knowledge building is being used increasingly around the world in a variety of educational settings, its potential for reforming engineering education remains largely unexplored. We will review knowledge building theory, present a pilot study applying knowledge building in an engineering class and discuss questions raised by the study.

2. Designing knowledge building learning environments in engineering education

Since the publication of *How People Learn* in 2000, having students develop deep understanding of what they are learning has been the sine qua non of research and development in education. Bransford, Brown and Cocking [5] place great emphasis on deep understanding because all the evidence points to the central role of understanding in determining whether knowledge is usable, transferable, can be employed to advance knowledge, and can be used in the creation of new knowledge.

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In the sciences, scholarship focused on learning and on the design and refinement of instruction that supports deep understanding, has led to a variety of pedagogies holding great promise for improving engineering and science education [3]. All these pedagogies are constructivist in that they view learners as active agents who develop new understanding through a process of building on and transforming their existing knowledge. One group of pedagogical approaches can be broadly characterized as inquiry-based. Learning by Design, Project-Based Science, and Problem-Based Learning are three such pedagogies [6–8]. Inquiry-based approaches seek deep understanding by engaging students in solving problems chosen to illuminate and thus scaffold students' discovery of important scientific principles.

A second group of pedagogies falls under the rubric of knowledge building. Knowledge building, knowledge creation, and expansive learning are three examples [9–11]. Knowledge building pedagogies emphasize the role of collaboration in knowledge creation, the crucial role of discourse, and a conception of knowledge as a set of continuously improving ideas rather than final truthful answers. Students are cast as knowledge workers, engaged in the same social, intellectual, and discourse practices found in all knowledge producing organizations.

There is a growing consensus that the most important problems facing engineers will require new knowledge, working with diverse teams and formulating solutions to problems that are still unknown [12].

The problems they encounter will often require intense cross-disciplinary collaboration around the creation of new knowledge. The Grand Challenges for Engineering [13] are good examples. Each of the challenges is a large-scale knowledge building problem. To make progress in addressing the challenges, engineers will need to participate in a "demanding sort of discourse, which presents problems in keeping things moving forward without shutting out objections and divergent ideas and in taking into account relevant facts without getting overwhelmed by complications." [9] The education of engineers should equip students for this kind of knowledge work.

It is striking to note that many of the principles and practices of knowledge building are also deeply consistent with the ABET Engineering Program Outcomes [A]-[K]. Most obvious is the ability to participate effectively on multidisciplinary teams, to communicate effectively, and to engage in lifelong learning; in addition, the broad-based inquiry of knowledge building inevitably provides a means to address many of the other outcomes in a way that supports the development of deep understanding. Citing IDEO's Tim Brown [14]:

> Many designers who are skilled technicians, craftsmen, or researchers have struggled to survive in the messy environment required to solve today's complex problems. They may play a valuable role, but they are destined to live in the downstream world of design execution . . . A creative organization is constantly on the lookout for people with the capacity—and just as important—the disposition for collaboration across disciplines. In the end, this ability is what distinguishes the merely *multidisciplinary* team from the truly *interdisciplinary* one.

2.1 Distinctive features of knowledge building

Knowledge building, as developed by Bereiter and Scardamalia, has been written about extensively, has formed the basis for considerable research, has been the conceptual focus of an international educational research community, and has led to the development of a web-based tool (Knowledge Forum) designed to facilitate sustained discourse [4, 9, 15–18]. The knowledge building approach has been employed in a variety of countries, grade levels, and subject areas. Science has been a focal discipline in knowledge building research; and successful knowledge building efforts have been reported in medical education as well as in other fields of advanced scientific education [19–20]. The research literature describing implementations of knowledge building, along with the well-articulated theoretical foundations of knowledge building, provide a conceptual and practical foundation from which to design an approach well suited to the education of engineers. Scardamalia [15] offers a comprehensive set of properties she views as determinants of knowledge building and the communities that support it. These include:

- Problems are what participants care about.
- Knowledge advancement is the explicit and shared goal of all participants.
- All ideas are treated as improvable.
- Advancing knowledge requires idea diversity; understanding an idea means understanding the ideas to which it is related.
- Participants work toward broader reformulations of the problem.
- Participants negotiate and work toward effective collaboration.
- The participant structure is inclusive; all are empowered, and expertise is distributed among participants.
- The discourse results in more than sharing of knowledge; it also refines and transforms knowledge.
- Assessment is an integral aspect of knowledge work.

A distinctive feature of knowledge building is that it is idea centered, a characteristic essential in a knowledge age pedagogy. By focusing on ideas rather than assignments and tasks, knowledge building supports the intentional, reflective, and metacognitive engagement required for deep learning. The starting point for knowledge building is a shared "problem of explanation" [9]. Being able to explain a puzzling or not completely understood phenomenon requires devising a better theory or explanation; that is to say, it requires knowledge improvement. As explained by Paavola, Lipponen, Kakkarainen [21], "The primary goal of members of an expert community is not to learn something (i.e. to change, or simply add to, their own mental states) but to solve problems, originate new thoughts, and advance communal knowledge."

Effective knowledge building entails students having appropriate learning goals. Therefore an effective learning environment must help students comprehend the nature of deep learning and be able to gauge their own progress as learners. Transfer, the way students are able to use what they have learned, is central to the formation of learning goals. Participating in knowledge building should result in the kind of transfer that Schwartz, Bransford and Sears [22] characterize as innovation. Schwartz, et al. make a distinction between learning in support of efficiency and learning in support of innovation. Efficiency represents the ability to replicate and apply what has been learned. While replication can be rote and narrow, well-learned replication skills can often be applied or transferred more widely—in contexts not exactly like those of instruction. This kind of efficiency is an important and valuable educational outcome. However, Schwartz, et al. argue that efficiency, even in its best sense, needs to be accompanied by innovation. Innovation calls for using knowledge interpretively, seeing things in new ways, asking generative questions, and improving existing knowledge. In other words, innovation requires new learning. Knowledge building, as characterized by Scardamalia's determining characteristics, engages students in solving problems that require going beyond already learned ideas

2.2 Implementing knowledge building pedagogy

Designing a knowledge building learning environment must attend to three major factors. One factor is devising appropriate problems of understanding, problems that require a focus on ideas rather than on the completion of school tasks or activities. A second factor is creating the participant structures and practices that support knowledge building discourse. The third is to develop ways to measure deep learning outcomes. The objective of our research—beginning with the pilot study presented here—is to develop guidelines addressing all three factors.

Devising problems of understanding calls for problems whose solutions build upon students' existing knowledge while at the same time requiring them to learn new things. Beyond being the right kind of problem at the proper level of difficulty, the problem must be engaging enough to summon the motivated effort deep learning requires. The first characteristic of knowledge building is that students have to care about learning and about the problem to be solved. Unfortunately there is neither a sure fire collection of ready-made problems nor a well-defined set of guidelines for producing these problems.

To address this need, we have begun exploring the application of a theory developed by Egan [23]. This approach builds upon students' characteristic ways of thinking to structure engagement with ideas and knowledge. Egan's intent is to engage students' imaginations in their pursuit of understanding and thus engender the kind of caring about learning necessary for successful knowledge building. In Ellis, Rudnitsky and Moriarty [24], we present Egan's approach and how it can be adapted for use in the engineering classroom.

Central to knowledge building and its participant structure is discourse. Teachers have to scaffold, share, redirect, and otherwise influence student collaborative discourse. The three kinds of discourse moves that are especially important in knowledge building are questions, statements that focus on ideas, and regulatory statements directed at collaboration and learning [20]. How to best support students as they become fluent in these moves is currently not well understood.

Providing ways for students to contribute to and participate in discourse beyond the temporal and physical confines of the classroom has been shown to be a valuable support for knowledge work. An effective example of how technology can provide this type of support is Computer-Supported Intentional Learning Environments, CSILE [5]. CSILE has been further developed into a software environment called *Knowledge Forum*. In the pilot study presented in this paper, we use *Knowledge Forum* to support and facilitate collaborative knowledge building.

Developing ways to measure deep learning is an important facet of ongoing work in the learning sciences. Because students take seriously what they are being held accountable for [25], it is essential that course learning assessments hold students accountable for high level outcomes. Schwartz, et al. [22] have made important advances toward the development of tests that measure whether students are able to use what they have learned innovatively. They refer to their tests as PFL assessments (preparation for future learning). We contend that PFL assessments are an important approach for assessing how students think about and approach problems, particularly as they relate to the framing of unfamiliar problems that require new learning.

2.3 Knowledge building in engineering education

In spite of its use in a variety of educational settings around the world, no research has been published that investigates knowledge building pedagogy in an engineering class. Neilsen, Du and Kolmos [26] did publish an empirical study claiming that an online learning community including engineering students interested in satellite operations did meet Scardamalia's determinants for knowledge building. However, knowledge building pedagogy was not used in the community and their only finding was that it is challenging for students with such diverse backgrounds to work together. The absence of research is particularly surprising in light of a growing body of evidence indicating that knowledge building is an effective collaborative approach to learning. Such approaches that create communities of learners, where students take active responsibility for knowledge advancement, are consistent with strategies that have been shown to improve retention in under-represented minority student populations [27–32].

While knowledge building is largely unknown to engineering educators, they are more likely to be familiar with problem-based learning (PBL). In PBL students are confronted with ill-structured, real world problems and work together to determine the information needed to solve the problem and develop their own solutions. (See Prince and Felder [32] for a review of PBL in engineering education.) Bereiter and Scardamalia [33] note a number of similarities between knowledge building and PBL. These include the importance of a problem driving the process, dialog, students identifying what needs to be found out, collaboration, task distribution and a focus on producing a cognitive outcome rather than an artifact or presentation. However, they also note a number of important differences. In knowledge building the problems are normally at the level of principle and are not cases; the focus is on understanding and not reaching a conclusion or practical result; the problems are expected to undergo a transformation through the inquiry resulting not in a problem being solved, but an advancement of the collective state; the teacher serves more as a co-investigator; much of the collaborative work is computer mediated and asynchronous; and the software environment supports and structures the interactions. Bereiter and Scardamalia [16] write that knowledge building is less bound to activity structures than PBL and "is explicitly defined as an approach to knowledge that 'is not confined to particular occasions or subjects but pervades mental life—in and out of school.'"

3. Smith College Pilot Study

As a first step in designing a more comprehensive study of knowledge building in engineering education, in 2009 we began a pilot study in the Picker Engineering Program of its use in one technical elective course. Established in 2000 at Smith College, the Picker Program is the first engineering program at a women's college in the United States and one of only a handful of such programs set within a liberal arts college environment. Students in the program can choose to earn a B.S. in engineering science or a B.A. in engineering arts. The course selected for the pilot study was Techniques for Modeling Engineering Processes (EGR 389) with an enrollment of 20 students. Consistent with the program's vision of emphasizing "the unity of knowledge across engineering subjects in a liberal arts context" [34], the course includes both technical intended learning outcomes (such as applying artificial neural networks and stochastic models in engineering contexts) and nontechnical intended learning outcomes (such as understanding the interdisciplinary nature of artificial intelligence (AI)). Knowledge building was used in the course to help students develop an interdisciplinary understanding of AI by exploring a question that probed the limits of the field.

3.1 Creating student engagement

To be successful, knowledge building requires a level of student engagement that goes well beyond just wanting to do well in the course. As presented earlier, an approach that we are investigating to create this engagement is the use of narrative that engages student imagination. A narrative based upon Egan's concept of romantic understanding [23] was used in EGR 389 to seed the knowledge building process. In this narrative the story of Alan Turing's life—beginning in his childhood; continuing to his contribution in breaking Nazi Germany's Enigma code; exploring his many contributions to the field of computer science; examining his writings on the possibilities for creating sentient machines; and finally ending with his conviction on charges of homosexuality and suicide by eating a cyanide-laced apple—was presented to the class. The narrative accomplished two tasks in the seeding process. First, it introduced students to many of the ideas and background knowledge needed to formulate a meaningful problem of understanding. Second, it created a high level of engagement by helping students put themselves emotionally in Turing's place when he wrote, "I propose to consider the question, 'Can machines think?'" [35].

3.2 Formulating a problem of understanding

With the students now engaged in the topic, a subsequent class session focused on introducing students to the concept of knowledge building and formulating a problem of understanding arising from the Turing narrative. Students were introduced to knowledge building by reading an article by Scardamalia [14], discussing it in class within the context of the changing role of engineers in the knowledge age, learning about five guiding principles for knowledge building [36] and watching a demonstration of the key features of the Knowledge Forum software. Following the demonstration, students were divided into teams to brainstorm a list of questions from the Turing narrative that intrigued them. While a variety of questions were developed, at the heart of most of them was a need to better understand the possibility of machine consciousness. After some discussion, the class agreed upon the following question: What is consciousness and can a machine have it? The class then worked collaboratively to group their initial thoughts into three general theories:

(1) consciousness arises from computation;
(2) consciousness does not arise solely from computation;
(3) consciousness is separate from the physical and cannot be modeled.

Each student chose one of the three theories on which to focus her knowledge building efforts. After an initial face-to-face meeting for each of the theory groups, all of the knowledge building took place in a public discourse on Knowledge Forum.

3.3 Knowledge building

With the problem of understanding formulated and initial theories developed, students began a nine-week period of knowledge building that took place largely outside the classroom in the Knowledge Forum workspace. In the workspace each of the three initial theories was developed in a different *view* (visual space). Although all students worked in the view representing the initial theory they had chosen to focus upon, many students decided to add to or read the discourse in other views. The view for Theory 3 (midway through its development) is shown in Fig. 1. In the figure each box represents a note posted by a student. These notes become the objects of the discourse within the community. Arrows indicate when a note builds upon another note. An example of a posted note is shown in Fig. 2. The notes were typically several paragraphs in length and often included hyperlinks to the authoritative resources being cited. Many students took advantage of the Knowledge Forum scaffolds de-

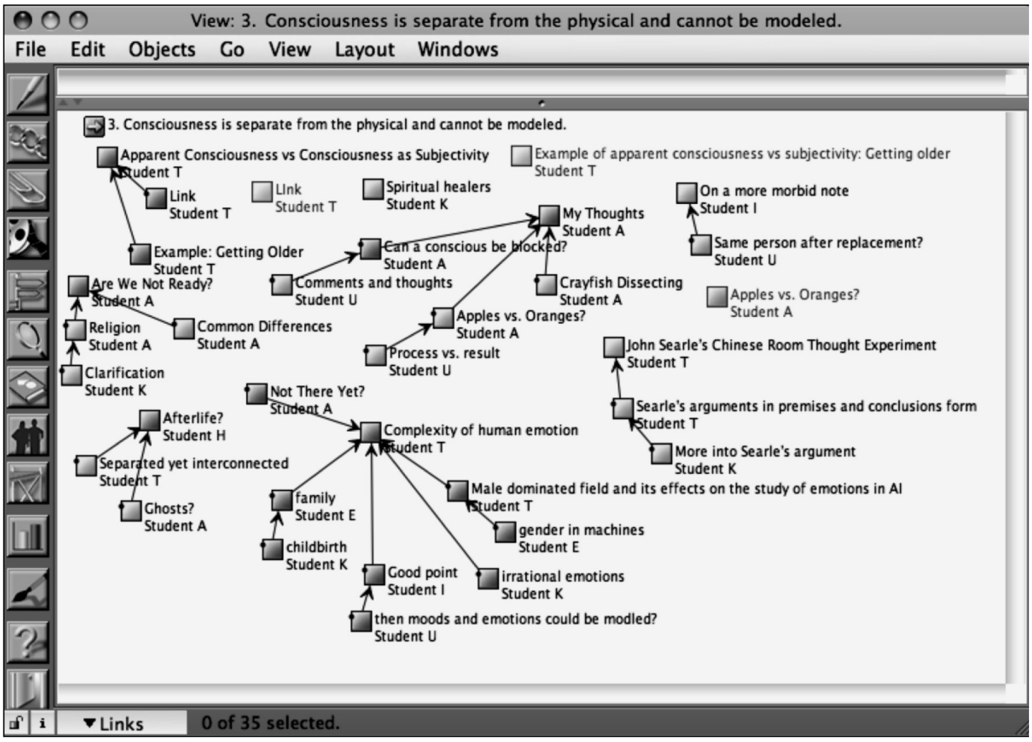


Fig. 1. Portion of EGR 389 Knowledge Forum workspace showing the structure of the discourse in view #3 (consciousness is separate from the physical and cannot be modeled).

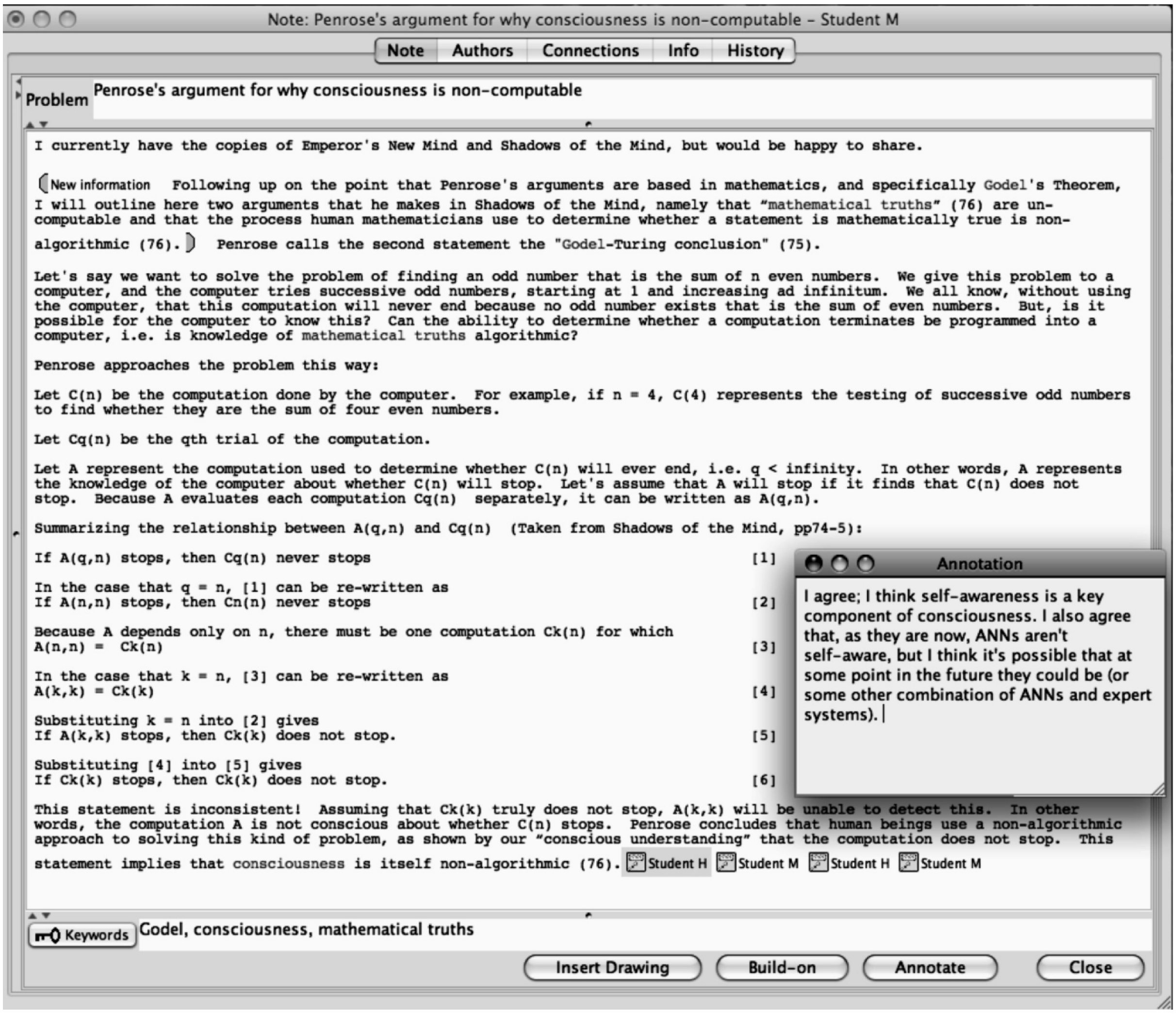


Fig. 2. Detail of student note posted on the EGR 389 Knowledge Forum workspace for view #2 (consciousness is separate from the physical world and cannot be modeled). Note the scaffold used near the beginning identifying the note as posting "New information" and the four annotations at the end added by other students (the first one is opened).

signed to help students frame and present their ideas more constructively. Knowledge Forum allows users to include annotations in their classmates' notes and these were also used regularly. Students typically used the annotations to respond or comment on the details of a note and created a new note when their ideas built upon the original note.

A principle of knowledge building is not only that students engage in a sustained discourse to improve ideas and understanding, but also that the discourse leads to higher-level formulations of the problem [14]. Knowledge Forum supports this higher-level formulation by allowing users to create a note that can rise above the discourse. In the pilot study the students working in each view created a rise above note that summarized and reformulated the discourse in the view. Finally, the entire class worked together to create a final rise above note that integrated the rise aboves of the three views. This final collective rise above showed tremendous advancement from the students' initial naive theories and reflected the complexity and richness of the topic. In it the students:

- Reformulated the initial problem in terms of computability;
- Discussed points of agreement (such as consciousness being linked to physical processes in the brain) and disagreement (the role of emotions and whether they have a non-physical aspect);
- Brought up new questions that arose through the discourse (whether "consciousness should be defined as being human like, or if it should be defined as a separate entity related to higher brain function, abstract thought, or self-reflection");
- Discussed why they felt the problem is so intractable.

3.4 Instructor role

Scardamalia [15] writes about the socio-cognitive dynamics of a successful knowledge building community:

> Participants set forth their ideas and negotiate a fit between personal ideas and ideas of others, using contrasts to spark and sustain knowledge advancement rather than depending on others to chart that course for them. They deal with problems of goals, motivation, evaluation, and long-range planning that are normally left to teachers or managers.

We found that although such a description clearly indicates a reduced and different type of role for the instructor, there were still numerous opportunities for the instructor to support the discourse. In reflecting upon his role in the knowledge building process, the instructor noted that his primary responsibilities were the following:

- introducing the concept of knowledge building to the class;
- creating student engagement;
- guiding the process of developing a generative problem of understanding;
- helping students to decide when to create rise above notes; and
- encouraging students to reflect upon their learning and role in the discourse.

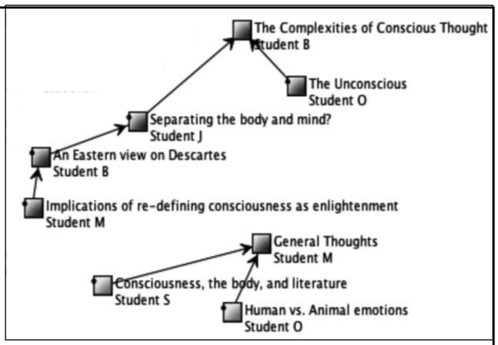
As in most engineering classes, the instructor was also responsible for assessing student learning and assigning grades. Student learning related to knowledge building was assessed in two ways. First, the midterm exam included a hypothetical Knowledge Forum note describing how a machine's inability to feel limits what it can do (after Jefferson [37]). The question asked students to write two responses to the note that illustrated the ideas of two different authoritative resources cited in the class discourse. Second, students wrote a self-evaluation (that referenced supporting evidence from their contributions to the discourse) that reflected upon how their participation addressed the five guiding principles of knowledge building proposed by Lee et al. [36]. This self-evaluation and a review of the student's participation in the discourse were used to assign a grade to each student. Student understanding of technical content in the course was also evaluated through exams, research projects and homework. It was found that the mean student average on technical content in the year of the pilot study was 89.3%. This did not differ significantly from the mean of 88.6% for the previous two years that the course was taught (p-value = 0.74).

4. Examining node from pilot study discourse

Knowledge building takes place when students are working in what Karl Popper has deemed World 3 [38]. In fact, the whole point of knowledge building is to accomplish this. World 3 is the world of ideas and theories and shares Popper's universe with Worlds 1 and 2. World 1 is the world of real things, of events, people, and action. World 2 is the internal representation of World 1 in people's minds. In other words, World 2 represents our personal understanding or mental model of World 1. What is important about World 3 is that ideas are treated as real things: they are what Bereiter calls conceptual artifacts [9], and they exist outside individual minds. Ideas and theories are things that can be examined, tried out, modified, rejected, and most importantly improved. When students are working in World 3, their goals are to advance collective understanding. The discourse is a real conversation that makes conceptual progress.

That is exactly what is found in the Knowledge Forum node illustrated and summarized in Figure 3. Students are clearly working in World 3. Ideas and theories about consciousness, the mind-body split, emotions, unconscious mental activity, and what it means to be human are expressed and are the subject of conversation. The students, some explicitly, acknowledge the tentativeness of their ideas and their openness to improvements. Students are explicit when introducing ideas that may be controversial. Diverse ideas are introduced into the conversation—many from authoritative sources. Students exhibit shared responsibility as conversational roles are distributed among participants. Some initiate discourse, while others raise questions, introduce new ideas, cite authoritative sources, or offer thought experiments. Most important is that the discourse progresses.

A particularly wide range of ideas spanning technical and nontechnical disciplines was brought into the discourse for this node. This is not surprising because knowledge building requires real problems that matter to the participants. It would be difficult to make progress on such problems without exploring the broader context. Student ideas about consciousness, the questions about dualism of mind and body, whether intelligence and consciousness are the same construct, and more are all well represented in the study of the liberal arts. Jackson [39] writes that grounding engineering in the liberal arts makes engineers "more creative by expanding their minds and exercising their imaginations." Similarly the National Academy of Engineering [12] notes that such an education leads to graduates who can meet a critical need by bridging the "two cultures" cited by C.P. Snow [40]. Having engineering students view machine intelligence as being a matter more complex than when they began and raise questions about what it means to be human suggests that knowledge building may be an effec-



***The Complexities of Conscious Thought* (Student B: Note read 62 times x 15 people)** Student B opens with a long note (over 2 pages) explaining why she does not think a sentient machine is possible. She begins her note by signaling her open-mindedness about the theory she was offering. She acknowledges the application of the analogy receiving input from sense organs and a CPU receiving electronic inputs. She believes that some things cannot be modeled and cites insight, gut feelings and intuition as examples. She then presents a theory that brains multitask and only part of what they are doing is conscious. She sees consciousness as the calm clear surface of our mental lives that is amenable to artificial imitation, while below the surface are the roiling crosscurrents of our unconscious. She suggests that all the autonomic and other responses attributable to the nervous system are unconscious, but would have to be modeled because the body and mind cannot be separate and still support consciousness. Student M and B use annotation to have a substantive interchange about thought, logic and the possibility of an illogical consciousness.

***Separating the body and mind?* (J: 37 x 12)** Student J elaborates on the mind-body split by citing Descartes. She wonders whether, as B has suggested, the "body" can be computationally incorporated into the mind. J notes that this would entail a "bodiless mind" which would be unique and then humorously states that we are all well aware of the many "mindless bodies."

***The Unconscious (*O: 19 x 10)** Student O describes how the theories of Carl Jung might add to the conversation about minds, bodies, and consciousness.

***An Eastern view of Descartes* (B: 19 x 10)** Student B contrasts Descartes with Buddhist beliefs about consciousness. She notes that in Buddhism, becoming fully conscious is the same as attaining enlightenment. B wonders whether a fully conscious person is still human. She supports the idea that some human qualities are beyond modeling.

***Implications of redefining consciousness as enlightenment* (M: 20 x 10)** Student M writes an "excited" note acknowledging that the relationship of consciousness and enlightenment represents, for her at least, a new way of thinking about things.

***General Thoughts* (M: 23 x 9)** Student M, in a note entitled "General Thoughts," summarizes her current thinking. She ruminates about the qualities that distinguish humans from other conscious species. She wonders what defines us and separates us. She uses the pig from the film "Babe" to identify some of those human qualities, the ones we employ to humanize Babe.

***Human vs. Animal emotions* (O: 12 x 6)** Student O agrees that there are human qualities, going beyond even emotions, that could not be modeled.

***Consciousness, the body, and literature* (S: 10 x 6)** Student S begins with Walt Whitman's views about the inseparability of the body and soul. She sees how humans are more than the sum of computational parts. S goes on to cite the case of brain-injured people who can function in all ways except they lack emotion. S states that these people could not pass the Turing Test. She wonders what this says about consciousness and what it means to be human.

Fig. 3. Summary of discourse from node from the EGR 389 Knowledge Forum workspace for view #2.

tive means for bringing a more integrated approach to learning into engineering education.

5. Assessing student perceptions in pilot study

In order to assess reactions to the knowledge building approach, at the end of EGR 389 students were asked to respond to the open-ended questions presented in Fig. 4. These questions were designed to gather information about the utility and effectiveness of knowledge building and their impressions about how it impacted their participation, collective learning, development of new knowledge, and preparation for working in the knowledge age. The questions were administered anonymously and completed by 19 of the 20 students enrolled in EGR 389.

5.1 Distinguishing features

Most students indicated that there were features of knowledge building that distinguished it from other teaching and learning activities they have encountered. Many (63%) focused on the communal aspect of knowledge building. They defined knowledge building as being collaborative, providing a forum for participation of all class members, and supporting class members to learn collectively. They often

1. Describe the features of knowledge building that distinguish it from other approaches to teaching and learning that you have encountered. Please indicate whether previous experiences were online or in class.
2. Describe your participation in Knowledge Forum. How effective was Knowledge Forum in helping you to express your ideas, learn from other students, and develop new knowledge? How important to the Knowledge Building approach is the ongoing record of discourse and the "out of class" access to participation in discourse? If you did not participate please describe your reasons for not doing so.
3. How did the use of Knowledge Building in this class help to prepare you for working in the knowledge age?
4. To what degree have students in this class improved their collective (rather than individual) understanding of artificial intelligence?
5. Consider the ideas concerning artificial intelligence that you brought to the class. Describe whether or not your ideas changed over the course of the discussion on Knowledge Forum. Would you still choose the same theory now?

Fig. 4. Open-ended knowledge building survey questions administered at end of EGR 389.

indicated that the type of collaboration in knowledge building differed significantly from their other engineering classes. For example, one student indicated that "we were able to form and shape our own ideas based on the thoughts of our classmates . . . this is different than other approaches to teaching because the knowledge building method allows students to study not only what they can learn from an instructor or book, but what they can learn from each other." In another similar response, one student indicated that knowledge building "allowed the students to actually become the teacher, which is different from most of the learning experiences I have encountered."

The second most commonly cited distinguishing feature mentioned by 36% of respondents was the range of ideas and theories that students were exposed to. One student wrote that knowledge building is "the process of collaborating to come up with an agreed upon theory, taking all possible theories into account." You can "connect ideas," "build ideas," "incorporate outside sources" and "reflect on others' posts." One student wrote, "the feature of grouping together many different theories and seeing what other people have to say has been a better approach to learning" than other methods she had encountered.

5.2 Effectiveness

Student responses regarding effectiveness focused predominantly on their experiences with the Knowledge Forum software and were affected by their frustration with the unstable server on which it ran. While this factor may have had a negative impact on the overall responses, most students were able to articulate their reactions to knowledge building. Many students were very positive (42%) indicating that they liked having an opportunity to express and see ideas from their classmates outside the classroom, a record of discourse, and the ability to think about issues and respond at their leisure. One student indicated that it was a really good way to communicate, that she "began to realize that one mind is so limited . . . it doesn't matter how smart an individual is, there is always something more to know . . . knowledge building really diversifies ideas, like a melting pot." Another two students (10%) reported that knowledge building was a positive experience and improved their ability to express their thoughts. Other responses were varied. Three students (16%) indicated that they found knowledge building challenging because they lacked confidence in expressing their thoughts. In a similar vein, two students (10%) reported a similar initial discomfort with sharing their opinions, but felt that they overcame this with time and practice. Finally, three students (16%) indicated that they prefer to talk in person with peers, though one of the three acknowledged that this might have been due to the Knowledge Forum server being down regularly.

5.3 Preparation for working in the knowledge age

Only one student (5%) felt that knowledge building did not contribute to preparing her for working in the knowledge age; two students (10%) were not sure. The remaining respondents (85%) indicated that knowledge building did help prepare them for working in the knowledge age. They cited that it helped them express ideas and see other viewpoints; broadened their perspective, knowledge, and awareness of outside resources; improved their ability to think creatively and critically; and improved their ability to interact electronically. For example, one student stated:

> Knowledge Building contributes to an ability to think independently and in depth about complex problems, to communicate those independent thoughts with others, and to collaborate and build upon your colleagues' ideas. This is an important skill regardless of

whether it is in the Knowledge Forum context; learning to engage in productive discourse (especially via an electronic medium) is essential to working effectively with others.

5.4 Narrative and framing concepts

All but one student (95%) indicated that the narrative of Alan Turing's life positively impacted their interest in the subject matter. These students reported that learning Turing's story increased their interest, made it more fun to work on knowledge building and influenced their thinking about artificial intelligence. One student wrote that because of the Turing narrative she began to talk with her friends for the first time outside class about what she was learning and that her friends were amazed. Overall, the analysis of student responses clearly indicated that utilizing narrative enhanced engagement and interest in this course.

6. Assessing student participation in pilot study

While we observed that all students participated in the classroom knowledge building activities, we found that the level of student participation recorded in Knowledge Forum workspace was more varied. Fig. 5 illustrates several measures of student participation in the electronic discourse. Figure 5a shows the number of notes read by each participant. The median was 24.5 for all students in the class. Most students read between 10 and 40 notes, but 25% read fewer than 10 notes and 15% read between 60 and 120 notes. Figures 5b–5d show the level of student contribution to the discourse. Most students (80%) contributed at least one note and built on another student's note. The median number of notes contributed was 7.5 with one student contri-

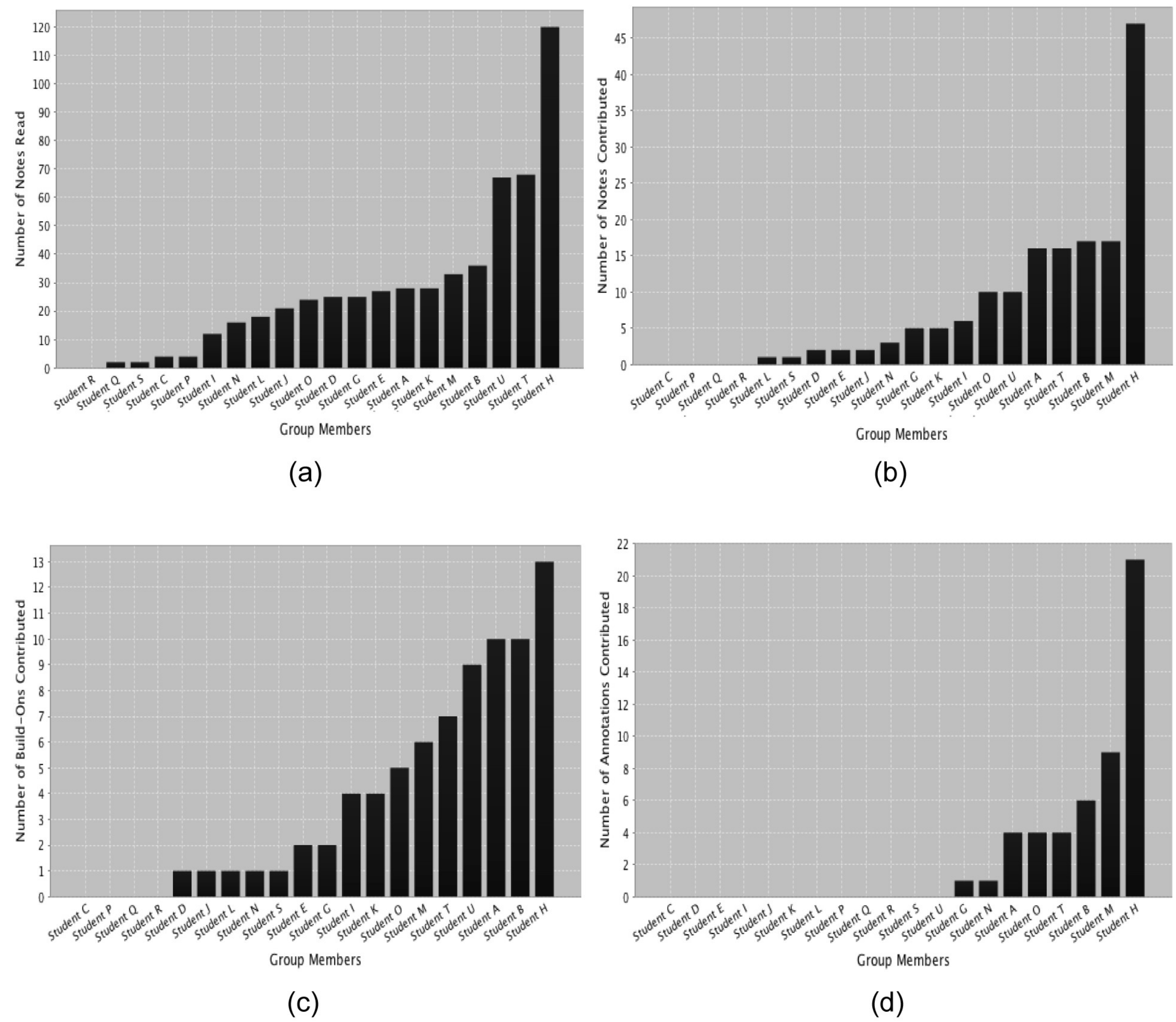


Fig. 5. Student participation recorded in EGR 389 Knowledge Forum workspace showing number of (a) notes read, (b) notes contributed, (c) build-ons contributed and (d) annotations contributed by each student in the class.

buting a maximum of 47 notes. The median number of build-on notes was 1.5 with a maximum of 13. Eight students (40%) also chose to annotate their classmate's notes with a median of 4 annotations.

Reading student notes is the most basic level of participation in the electronic discourse. It was surprising that 25% of the students in the class read only a few notes. These students also posted few notes and annotations. Because of the public nature of the discourse and the diagnostic tools available in Knowledge Forum, these students were identified early in the discourse to encourage their participation. In the instructor intervention they noted several reasons for their low level of participation including: they were frustrated that Knowledge Forum was often inaccessible due to technical problems; they were too intimidated to take the chance of posting their thoughts in a public forum; and they chose not to participate to allow more time to improve low grades in other classes. By comparison, several students became deeply engaged and invested a large amount of time in the discourse. These students chose to read a variety of books that deeply explored the topic by authors including Daniel Dennett, Roger Penrose, Colin McGinn, John Searle and others. It is also interesting to note the role of Student H who became a leader in the discourse. She was not only the most active contributor on Knowledge Forum (see Fig. 5), but she also played an important role in monitoring the progress of the discourse and ensuring its success. However, she never spoke in class other than during knowledge building. In a self-evaluation required for the class, she wrote that "I almost never spoke in class, and was probably not as involved in in-class activities as I could have been; I really could have taken more chances. Most of my participation in this class was through Knowledge Forum."

Not surprisingly there is some evidence to support the idea that students who are more successful in class—as assessed by traditional measures—are also more active in the electronic discourse. In a two-way t-test students with combined midterm and final exam scores in the upper half of the class read a mean of 42.6 notes. By comparison, students in the lower half only read a mean of 15.3 notes. The difference in means is statistically significant (p-value=0.038). However, a comparison of the difference in mean number of notes contributed by the upper student group (11.9) did not show a significant difference (p-value=0.14) from the mean of the lower student group (4.8).

7. Discussion

Knowledge building is a strategy for improving engineering education that both supports deep learning and helps students develop the skills needed to be successful participants in an economy where knowledge and innovation are pervasive. The pilot study is the first step in our plans to integrate knowledge building more broadly in the Picker Engineering Program and systematically investigate its effectiveness and best practices for its use. It raised a variety of questions that remain to be answered, such as:

- EGR 389 is an upper-level technical elective class. Is knowledge building more effective in certain types of engineering classes?
- Students surveyed in EGR 389 focused on knowledge building as a means to improve their professional skills. Is knowledge building more effective at addressing some student learning outcomes than others?
- In EGR 389 the participation in the electronic discourse varied greatly across the students in the class. Does knowledge building work better for some students than others? How can broader participation be achieved?
- Students in EGR 389 participated in an intensive learning experience intended to improve their ability to work effectively with knowledge. As students acquire more experience in knowledge building, how does the role of the instructor change?

While the pilot study raised many questions, we have identified three key questions that will be the initial focus of our future study.

(1) Students in the pilot study engaged in knowledge building in an effort to better understand the nature of consciousness and the limitations of intelligent machines. This problem of understanding created student engagement and resulted in a productive discourse in which ideas and theories were shared, examined and improved. What types of problems most effectively serve as an invitation to and context for knowledge building?
(2) The best actions for scaffolding and facilitating knowledge building were often not clear to the pilot study instructor. What are the best approaches for teachers to establish, adjust and support the participant structures and other determining qualities in knowledge building environments?
(3) Evaluating some aspects of student learning was found to be challenging in the pilot study. What are the best approaches for assessing whether students can use knowledge innovatively?

Ultimately the answers to all of these questions must be based upon assessing student learning that results from participation in knowledge building. We propose that aspects of this learning can be broadly grouped into three categories. First, students need to be able to use knowledge innovatively (that is, to see and conceptualize engineering problems and contexts in new ways). We believe that assessing "preparation for future learning" (PFL) (see Schwartz, et al. [22]) is a promising approach for measuring this aspect of learning. (For example, a PFL assessment may focus on what students notice and identify as important features about a real problem in context or what they would do to learn to solve the problem.) Second, students should develop and improve the competencies needed to participate in a knowledge producing organization. They should be able to ask questions that generate discourse, disagree constructively, focus on idea improvement, set learning goals for themselves and attend to their progress toward those goals. This aspect of learning may be measured by analyzing the Knowledge Forum discourse and through problems designed to measure the ability of students to organize themselves and proceed collaboratively toward a solution. Finally, the ability of students to learn the content and technical components of engineering courses is as critical as their ability to use knowledge innovatively and participate in knowledge building communities. Students clearly need to simultaneously develop an efficient command of the information, procedures, algorithms, formulae, and methodology that represent the "traditional" outcomes of engineering education, typically measured through exams, projects, reports and other means.

8. Conclusions

We have completed a pilot study investigating the application of knowledge building in an engineering course at Smith College. An analysis of the discourse recorded on Knowledge Forum shows that knowledge building clearly took place as indicated by the following evidence:

(1) students worked with ideas as conceptual artifacts;
(2) the community met each of Scardamalia's determinants of knowledge building;
(3) the community greatly improved their initial theories about the potential for developing a conscious machine.

The use of narrative was found to be an effective tool in creating the level of engagement necessary for knowledge building to take place. Student surveys indicated that the majority of students found knowledge building to be an effective approach to learning and prepared them to work in the knowledge economy. While most students participated fully in all phases of the discourse, about one quarter of the class did not participate actively in the electronic discourse. Reasons cited for low participation included a preference for communicating in person; being intimidated by the process; technical problems with accessing the software and choosing to invest more time in other classes to improve a low grade.

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