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Using Knowledge Building to Support Deep Learning, Collaboration and Innovation in Engineering Education

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Abstract — Knowledge building is a potentially transformative approach to engineering education. In knowledge building students participate in an interactive discourse in which they work together to broaden ideas, reform problems and share knowledge—the result being a deeper level of understanding and the collaborative production of new knowledge. In 2009 we conducted a knowledge building pilot study in the Picker Engineering Program at Smith College. In this study students worked together to formulate a question about the potential for a conscious machine and then engaged in an intensive knowledge building discourse. Assessment data showing the effectiveness of the approach and research questions arising from the study are presented.

Index Terms – deep learning, discourse, knowledge building, narrative, preparation for future learning.

INTRODUCTION

Since the publication of *How People Learn* [1], having students develop deep understanding of what they are learning has been the sine qua non of research and development in education. In the sciences, design and refinement of instruction that supports deep understanding has led to a variety of promising pedagogies [2]. 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 [3]-[5]. A second group of pedagogies falls under the rubric of knowledge building. Knowledge building, knowledge creation, and expansive learning are three examples [6]-[8]. Knowledge building pedagogies place great emphasis on community rather than individual knowledge creation, on the crucial role of discourse, and on the shared goal of idea improvement rather than seeking a final answer. Students are cast as knowledge workers, engaged in the same social, intellectual, and discourse practices as those found in all knowledge producing organizations.

There is a growing consensus that the most important problems facing engineers will require producing new knowledge and that engineers must be educated differently. For example, the National Science Board [9] writes that employers "want engineers with passion, some systems thinking, an ability to innovate, an ability to work in multicultural environments…interdisciplinary skills, communication skills, leadership skills, an ability to adapt to changing conditions, and the eagerness for life long learning." In solving new problems and working out complex designs, engineers will need to be able 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" [6]. Engineering education needs to equip students for this kind of knowledge work.

Knowledge building, as developed by Bereiter and Scardamalia [6], [10]-[13], has been used in elementary through professional post-baccalaureate education [14]–[15]. The body of literature describing implementations of knowledge building, along with the well-articulated theoretical foundations of knowledge building, provides a conceptual and practical foundation from which to build a collaborative knowledge building approach well suited to the education of engineers.

The starting point for collaborative knowledge building is quite often a shared "problem of explanation" [6]. Being able to explain a puzzling or not completely understood phenomenon requires devising a better theory; that is to say, it requires knowledge improvement. As explained by Paavola, et al. [16], "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." Knowledge building theory thus makes a distinction between learning and knowledge building. It is successful when the community has advanced its collective knowledge. The learning achieved by individuals in the community will vary. What is likely is that all participants have deepened their understanding of disciplinary knowledge and acquired the habits of mind, intellectual practices, and skills needed to be active participants in advancing our understanding and improving the world around us. To be successful, it is essential to have both an engaging problem to work on and a teacher capable of negotiating the pedagogical challenges of facilitating collaborative knowledge building.

Seeding Knowledge Building

Devising problems that students care about solving is difficult. Students want to do well in their courses and they often care about solving the academic problems they encounter. However, this concern is far different from caring about (and engaging with) problems in the manner that knowledge building requires. In engineering these problems of understanding must both engage students' imaginations and be grounded in the knowledge of the discipline being studied. We are currently investigating the use of narrative for this purpose. Egan [17] views imagination as a necessary component of learning with understanding and has developed an approach that employs narratives to create engagement in ways that take advantage of how students are thinking. Such an approach may be especially beneficial for the retention of women in engineering programs, since studies have shown that women often leave such programs because coursework fails to engage them [18].

Facilitating Collaborative Knowledge Building

Not only do teachers need to seed knowledge building with problems that students care about, but they also have to create participant structures that support knowledge work. Teachers have to scaffold, share, redirect, and otherwise influence student collaborative discourse. Sustained, progressive discourse requires participants to adopt a set of commitments that distribute "functional aspects of the activity, including agency, authority, accountability, leading and following, initiating, attending, accepting, questioning, challenging, and so on" [19]. Students have to share a set of commitments that bear on the quality of discourse. These include mutual advances in understanding; framing questions and propositions in ways that enable evidence to be brought to bear on them; working from agreement and shared understanding into argument and areas of disagreement; and openness to dissent, challenge, and new ideas [20]. Teachers have to model behavior and thinking that brings these qualities to students' awareness.

Maintaining an on-going record of knowledge building and providing ways for students to contribute to and participate in discourse beyond the temporal and physical confines of the classroom have been shown to be a valuable support for knowledge work. Technology can provide this sort of support. An effective example is CSILE [1], which has been further developed into a program called *Knowledge Forum*.

APPLICATION IN THE CLASSROOM

In 2009 we began a pilot study implementing knowledge building into the Picker Engineering Program at Smith College. The Picker Program, founded in 2000, is the first engineering program established at a women's college in the United States. Students in the program earn an engineering science degree that focuses on developing a broad understanding of engineering principles and integrating them across conventional disciplines—both within engineering and across the liberal arts. Students take a broad array of liberal arts courses and the liberal arts are also brought into the engineering classroom.

The course chosen for the pilot study was Techniques for Modeling Engineering Processes (EGR 389). EGR 389 is a four-credit, semester-long technical elective with an enrollment of 20 engineering students during the pilot study. The intended learning outcomes for the course include developing competence in applying artificial neural networks (ANNs) and auto-regressive integrated moving average (ARIMA) processes within engineering contexts. Consistent with the goals of the Picker Program, the course goes beyond developing technical skills to include an improved understanding of the interdisciplinary nature of AI and an increased capability to participate in knowledge building.

Seeding Knowledge Building

Two narratives based upon Egan's concept of romantic understanding [17] were used to seed knowledge building in EGR 389. Details of both narratives and the underlying theory they are based upon are presented in Ellis et al. [21]. The first narrative was a meta-narrative that was used to frame learning in the entire course and included learning how to distinguish genetically engineered beings from humans. The second narrative was Alan Turing's life story—beginning in his childhood; including his brilliant contributions to the war effort in breaking Nazi Germany's Enigma code; exploring his views on the possibilities for creating conscious machines and the intense debates that followed; and ending with his conviction on charges of homosexuality that resulted in suicide by eating a cyanide-laced apple. For this narrative, a class period early in the course was designated to be a special day for celebrating Alan Turing's life. The goal was to help students intellectually and emotionally put themselves into his place when he wrote, "I propose to consider the question, 'Can machines think?'" [22]. The class included both storytelling and hands-on activities in which students played the part of an interrogator in Turing's gender imitation game and a Turing Test. Almost all of the students found the narrative to be intensely engaging and many made direct connections between Turing's life and their own [21].

Getting Started

The class following Alan Turing day began with discussion of a reading describing knowledge building [12], presentation of guiding principles for knowledge building [23] and a short demonstration of the Knowledge Forum electronic workspace. After the demonstration, students worked in teams to brainstorm questions that interested them from Alan Turing day. Examples included: *What does it mean to be conscious? How closely linked is consciousness to having a body? How do you determine if* *something different from you is conscious?* After some discussion, the class agreed upon the following question: *What is consciousness and can a machine have it?* At this point students brainstormed their initial ideas for answering the question and then worked collaboratively to group them into three 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.

At this point each student chose one of the three theories to focus on and discussed their initial ideas with classmates working on the same theory.

Knowledge Building

With the initial theories now developed, students began a nine-week period of knowledge building in which their discourse was recorded in the Knowledge Forum workspace. Fig. 1 illustrates the structure of a part of the discourse. While the knowledge building largely occurred outside of the classroom and independent of the instructor, there were a number of opportunities in which the instructor continued to guide and support the discourse. These included:

- Providing guidance to help students make greater contributions to the discourse. This often involved encouraging students to go beyond sharing knowledge and focus on refining and transforming knowledge.
- Providing a short lecture on Gödel's Incompleteness Theorem along with the mathematical roots of AI—as requested by the students.
- Initiating the movement toward combining the three different theories into one comprehensive theory.

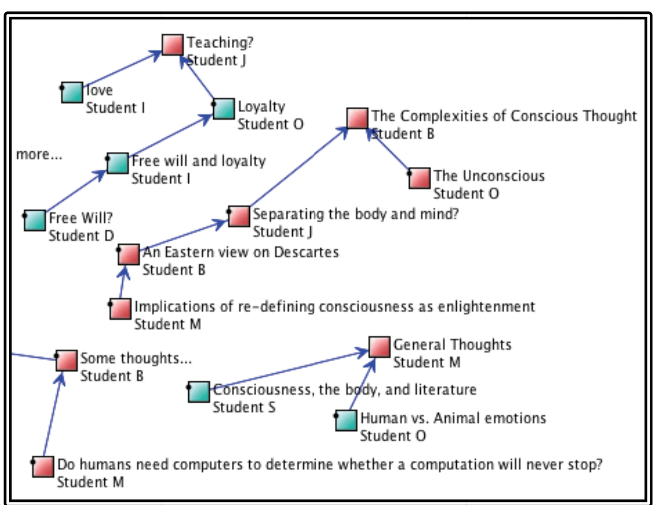

FIGURE 1
PORTION OF THE EGR 389 KNOWLEDGE FORUM WORKSPACE RELATED TO THE THEORY THAT CONSCIOUSNESS ARISES FROM COMPUTATION . BOXES REPRESENT POSTED STUDENT NOTES AND ARROWS SHOW NOTES THAT BUILD UPON OTHER NOTES.

Grading

Doyle [24] writes, "students tend to take seriously only that work for which they are held accountable." Students were evaluated and specifically held accountable for knowledge building in two ways. First, the midterm exam included a question with a hypothetical Knowledge Forum posting describing how a machine's inability to feel limits what it can do (actually a quotation from "The Mind of Mechanical Man" [24]). The question asked students to write two responses to the note—each one illustrating the ideas of an authoritative resource cited regularly in the class discourse. Second, students wrote a self-evaluation in which they reflected upon their attempts at meeting the guiding principles for knowledge building in the class discourse. It was required that their self-evaluation be supported with examples of the notes they posted on Knowledge Forum.

ASSESSMENT

Students were asked to respond to several open-ended questions to gather information about the effectiveness of the knowledge building approach 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 nineteen of twenty students enrolled in EGR 389.

Distinguishing Features

The students in EGR 389 found that knowledge building had features that distinguished it from other classroom experiences. Most (63%) mentioned the collaborative nature of knowledge building. They indicated that this provided a forum for participation of all class members to learn together and allowed students to become teachers. Many respondents (36%) also indicated that the distinguishing feature of knowledge building related to the wide range of ideas that they were exposed to in the discourse.

Effectiveness

Student responses describing the effectiveness of knowledge building included a range of reactions. Many students (42%) were quite positive and indicated that they liked having an opportunity to express and see ideas from their classmates outside of the classroom, having a record of discourse, encountering the diversity of ideas knowledge building generates and being able to think about issues and respond at their leisure. The students who did not find knowledge building to be effective (16%) reported that they were not confident in expressing their thoughts or rebutting arguments. Some students (10%) expressed initial discomfort with sharing their opinions, but felt that they overcame this with time and practice.

Preparation for Working in the Knowledge Age

Most students (84%) felt that knowledge building helped 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. Only one student (5%) disagreed.

Improved Collective Understanding

An analysis of the discourse recorded on Knowledge Forum found that key determinants of successful knowledge building [12] took place. These included exploration of a wide diversity of ideas; regularly bringing numerous authoritative sources into the discourse; and students progressing from merely sharing knowledge to building and improving upon each other's theories. It was also found that the final collective theory reflected the complexity and richness of the topic and showed tremendous advancement from the students' initial naive theories.

DISCUSSION

Although knowledge building is being used increasingly throughout the world to support deep learning and prepare graduates to compete in the knowledge economy, its potential for improving engineering education in the United States remains unexplored. An indication of the importance of preparing engineers to effectively participate in knowledge creating communities and organizations is illustrated by the NAE's Grand Challenges for Engineering [26]—each of which can be considered to be a large-scale knowledge building problem. It is also striking to note that many of the principles and practices of knowledge building are deeply consistent with the ABET Engineering Program Outcomes [A]-[K]. Most obvious is the ability to participate effectively on multidisciplinary teams, communicate effectively, and to engage in life-long learning; in addition, the broad-based inquiry of knowledge building inevitably provides a means to address many of the other outcomes.

The most important result of the pilot study may be identifying some of the questions that must be addressed to support implementing knowledge building broadly, efficiently and effectively in engineering. These include:

1. The pilot study question on machine consciousness successfully generated a class discourse. What types of problems or questions most effectively engage engineering students in discourse?
2. The best actions to take for facilitating knowledge building were not always 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—i.e. to see and conceptualize engineering problems and contexts in new ways; to use what they have learned to advance problem solutions innovatively; and to set new learning goals for themselves and use resources to support that learning?

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. The idea of measuring "preparation for future learning" (PPL) as described by Schwartz, et al. [27] may hold great promise in this area. PPL is a measure of *transfer in* that assesses a student's ability to solve a problem that requires learning something new or seeing a situation from a different perspective. Second, students should develop and improve the competencies needed to participate in a knowledge producing community or organization. The discourse recorded on Knowledge Forum provides a wealth of information in this regard. We also feel that the development of problems designed to measure the ability of students to organize themselves and proceed collaboratively toward a problem solution needs to be investigated. Finally, students need to develop an efficient command of information, procedures, algorithms, formulae, and methodology that represent the "traditional" outcomes of engineering education and are typically measured through exams, projects, reports and other means.

CONCLUSIONS

We have completed a pilot study exploring the use of knowledge building in an engineering course. In this study we found that narrative was an effective tool for seeding discourse and that the discourse met the key determinants of knowledge building. Many students reported that they found knowledge building to be an effective approach to learning and most reported that it helped prepare them to work in the knowledge age. The study also raised questions that need to be addressed to broadly apply knowledge building in engineering education. These include: what types of questions or problems generate discourse; how instructors can best facilitate the discourse; and how a student's ability to use knowledge innovatively can be assessed.

REFERENCES

[1] Bransford, J.D., Brown, A.L., & Cocking, R.R. (Eds.), *How people learn: Brain, mind, experience, and school*, Washington, DC: National Academy Press, 2000.

[2] Sawyer, R.K. (Ed.), *The Cambridge handbook of the learning sciences*, New York, NY: Cambridge University Press, 2006.

[3] Holbrook, J. & Kolodner, J.L., "Scaffolding the development of an inquiry based (science) classroom", *Fourth International Conference of the Learning Sciences*, Mahwah, NJ, 2000.

[4] Marx, R.W., Blumenfeld, P.C., Krajcik, J.S., & Soloway, E., "Enacting project-based science," *Elementary School Journal*, 97, 1997, 341–358.

[5] Hunt, E., & Minstrell, J., "A cognitive approach to the teaching of physics", In K. McGilley (Ed.), *Classroom lessons: Integrating cognitive theory and classroom practice*, Cambridge, MA: MIT Press, 1994.

[6] Bereiter, C., *Education and mind in the knowledge age*, Hillsdale, NJ: Lawrence Erlbaum, 2002.
[7] Nonaka, I., & Takeuchi, H., *The knowledge-creating company: How Japanese companies create the dynamics of innovation*, New York: Oxford University Press, 1995.
[8] Engestrom, Y., "Expansive learning at work: Toward activity-theoretical reconceptualization", *Journal of Education and Work*, 14, 1, 2001, 133-156.
[9] National Science Board (NSB) 07-122, *Moving forward to improve engineering education*, National Science Foundation, National Science Board, 2007.
[10] Bereiter, C. & Scardamalia, M., "Learning to work creatively with knowledge", In E. De Corte, L. Verschaffel, N. Entwistle, & J. van Merriënboer (Eds.), *Powerful learning environments: Unravelling basic components and dimensions,* EARLI Advances in Learning and Instruction Series, Amsterdam; Boston: Pergammon, 2003.
[11] Scardamalia, M. & Bereiter, C., "Knowledge building: theory, pedagogy, and technology", In R. K. Sawyer (Ed.), *The Cambridge handbook of the learning sciences*, New York, NY: Cambridge University Press, 2006.
[12] Scardamalia, M., "Collective cognitive responsibility for the advancement of knowledge", In B. Smith (Ed.), *Liberal education in a knowledge society*, Chicago, IL: Open Court, 2002.
[13] Scardamalia, M. & Bereiter, C., "Knowledge building", In *Encyclopedia of Education (2nd ed.)*, New York, NY: Macmillan, 2003.
[14] Koschmann, T., Glenn, P., & Conlee, M., "Theory presentation and assessment in a problem-based learning group", *Discourse Processes*, 27, 1999, 103-117.
[15] Hmelo-Silver, C.E. & Barrows, H.S. "Facilitating collaborative knowledge building", *Cognition and Instruction*, 26, 1, 2008, 48-94.
[16] Paavola, S., Lipponen, L., & Kakkarainen, K., "Models of innovative knowledge communities and three metaphors of learning", *Review of Educational Research,* 74, 4, 2004, 557-576.
[17] Egan, K., *An imaginative approach to teaching*, San Francisco: Jossey Bass, 2004.
[18] Seymour, E. & Hewitt, N.M., *Talking About Leaving*: *Why undergraduates leave the sciences*, Boulder, CO: Westview Press, 1997.
[19] Greeno, J.G., "Learning in activity", In R.K. Sawyer (Ed.), *The Cambridge handbook of the learning sciences*, New York, NY: Cambridge University Press, 2006.
[20] Bereiter, C., Scardamalia, M., Cassells, C., Hewitt, J., "Postmodernism, knowledge building, and elementary science", *The Elementary School Journal*, 97, 4, 1997.
[21] Ellis, G.W., Rudnitsky, A., & Moriarty, M., "Theoretic stories: Creating deeper learning in introductory engineering courses", *International Journal of Engineering Education*, 2010 (in press).
[22] Turing, A., "Computing machinery and intelligence", *Mind*, 59, 236, 1950, 433-460.
[23] Doyle, W., "Academic Work", *Review of Educational Research*, 53, 2, 1983, 159-199.
[24] Lee, E.Y.C., Chan, C.K.K., van Aalst, J., "Students assessing their own collaborative knowledge building", *Computer-Supported Collaborative Learning,* 1, 1, 2006, 57-87.
[25] Jefferson, G., "The Mind of Mechanical Man", British Medical J., 1, 4616, 1949, 1105–1110.
[26] National Academy of Engineering, *Grand challenges for engineering*, 2008, Retrieved from http://www.engineeringchallenges.org/cms/8996/9221.aspx.
[27] Schwartz, D.L., Bransford, J.D., & Sears, D., "Efficiency and innovation in transfer", In J. Mestre (Ed.), *Transfer of learning: Research and perspectives*, Charlotte, NC: Information Age Publishing, 2005.