# AC 2012-4267: CREATING A LEARNING ENVIRONMENT THAT SUPPORTS INNOVATION AND DEEP LEARNING IN GEOTECHNICAL ENGINEERING

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# Creating a Learning Environment that Supports Innovation and Deep Learning in Geotechnical Engineering

## I. Introduction

There is a growing consensus that engineering education needs to change to meet the changing demands on the profession. Not only must engineering graduates be knowledgeable in traditional content areas and competent in applying standard problem-solving procedures, but they must also have passion, adaptability and an eagerness to learn. Successful graduates need to be innovators, effective collaborators in interdisciplinary and multicultural environments, excellent communicators, leaders, and lifelong learners[1]. Engineering education is not alone in needing to rethink the educational strategies that best prepare students for success. Based upon research emerging from the learning sciences, Sawyer's description of a successful college graduate (in any field) has much in common with the National Science Board (NSB) report. Sawyer writes that to be successful in the knowledge age, graduates will need to develop a deep and integrated understanding of complex subjects; possess excellent communication skills; be able to participate in demanding discourse in multicultural environments; possess a capacity for lifelong learning; and most importantly, have the capability to work creatively with ideas to generate new theories, products and knowledge[2].

Both the NSB and Sawyer indicate that graduates need to develop what Broudy[3] terms as *replicative* knowing (recalling previously learned facts) and *applicative* knowing (applying knowledge to solve new problems). But to be most successful, graduates also need to develop *interpretative* knowing. In this type of knowing people categorize, classify, predict and infer. It includes what one notices about new situations and how one frames problems. Interpretive knowing has an important effect on subsequent thinking and cognitive processing[4]. The need to help students develop deeper understanding—such as interpretive knowing—is well recognized and since the publication of *How People Learn* (HPL) has become the major focus of the learning sciences. HPL places great emphasis on deep understanding because the evidence points to the central role of understanding in determining whether knowledge is usable, transferable, can be employed to advance one's knowledge, and can be used in the creation of new knowledge. HPL notes that by introducing students to traditional subjects in new ways, it is possible "for a majority of individuals to develop a deep understanding of important subject matter"[5].

***Innovation and Efficiency***

Measuring deep learning is a major educational challenge; however, significant advances are being made. Schwartz, et al.[4] describe most assessments of learning as being focused on *transfer out*, which typically attempts to measure replicative or applicative knowing. The authors characterize these kinds of measures as "sequestered problem solving" (SPS) where one cannot learn from one's mistakes and there are no contaminating sources of information. Schwartz, et al. contrast this with assessing *transfer in*, which focuses on measuring interpretative understanding by asking students to solve a problem that requires learning something new or seeing a situation from a different perspective. The authors characterize measures of *transfer in* as "preparation for future learning" (PFL).

Engineering education emphasizes SPS measures in assessing student learning as well as the development of *efficiency* (rapid retrieval and application of knowledge to solve problems) needed for success in SPS assessments. Schwartz, et al.[4] emphasize the need to balance learning experiences designed to support efficiency with learning experiences designed to support *innovation* (opportunities for experimentation and deep learning). These innovation learning experiences prepare students for success in PFL assessments. This paper presents the application of innovation approaches to learning in a geotechnical engineering class. In spite of their strong grounding in the learning sciences and extensive research base in K-12 education, these approaches remain largely unexplored in undergraduate engineering education. The first approach is Imaginative Education (IE) as developed by Kieran Egan[6,7,8]. In IE cognitive tools associated with the development of understanding are used to engage students' imaginations and frame learning more productively. The second approach is knowledge building. In knowledge building students participate in an interactive discourse in which they work together to broaden ideas, reformulate problems and share knowledge—the result being a deeper level of understanding and the collaborative production of new knowledge.

***Imaginative Education***

The overall design of the learning environment described in this paper was based upon IE theory. IE builds on learners' characteristic ways of thinking to structure their engagement with ideas and knowledge. Egan's intent is to engage learners' imaginations in their pursuit of understanding and thus engender the kind of caring about learning necessary for developing deep understanding. In the IE approach, instruction is designed to support a developmental sequence of five different types of understanding that enable learners to make sense of the world in different ways. As shown in Table 1, each of these five understandings is associated with specific cognitive tools. The tools are mental devices that have been developed by our ancestors to help them make sense of the world and to operate more effectively in it. The five types of understanding do not develop inevitably on their own, but instead occur through engaging a learner's imagination in learning about the world and applying this array of cognitive tools. Although undergraduates will normally have passed the stage when earlier understandings are dominant, it is important to note that they are not left behind when students become literate. Rather they are transformed and become a permanent element of later understanding and work particularly well when combined with other types of understanding.

All students can learn to use the cognitive tools to increase their ability to think and understand. For example, a well-crafted story is a tool that can convey a coherent view of understanding in a memorable form while at the same time helping the learner engage emotionally with the information being communicated. Bereiter[9] writes "narratives…create in the reader the experience of significant conditions and events. When in the grip of a story, people don't think, 'How is this relevant to me and my problems?' They experience events through the protagonists…" While instructors may recognize the utility of many of these cognitive tools, it may be less clear how to use them effectively in the classroom. It is the goal of IE to guide their usage in a way that makes learning more engaging and meaningful, while also helping students develop new types of understanding.

**Table 1:** Five Kinds of Understanding that Imaginative Education is Based Upon and the Cognitive Tools Associated with Each (after Imaginative Education Research Group[8])

| Type of Understanding | Cognitive Tools |
|---|---|
| Somatic (Pre-linguistic) | Bodily senses; emotional responses and attachments; rhythm and musicality; gesture and communication; referencing; intentionality |
| Mythic (Oral Language) | Story; metaphor; abstract binary opposites; rhyme, meter and pattern; joking and humor; forming images; sense of mystery; fantasy; games, drama and play |
| Romantic (Written Language) | Sense of reality; extremes and limits of reality; association with heroes; wonder; humanizing of meaning; collections and hobbies; revolt and idealism; context change |
| Philosophic (Theoretic use of Language) | Drive for generality; processes; lure of certainty; general schemes and anomalies; flexibility of theory; search for authority and truth |
| Ironic (Reflexive use of Language) | Limits of theory; reflexivity and identity; coalescence; particularity; radical epistemic doubt |

***Knowledge Building***

There is a growing consensus that solutions to the most important problems facing future engineers will require the production of new knowledge. Examples include developing new sources of energy and reverse-engineering the brain. Future engineers will need to be able to combine their technical expertise with an ability to collaborate with colleagues in order to produce innovative solutions to complex problems. Introducing learners to these types of knowledge age problems is a significant departure from the traditional approaches to engineering education and requires engaging learners in the kind of collaborative knowledge work needed to solve complex problems. To address this need, knowledge building is the second educational approach used in the instructional design of EGR 340.

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[9-14]. Although knowledge building is being used increasingly around the world to support deep learning and prepare graduates to compete in the knowledge economy, its potential for reforming engineering education in the United States remains largely unexplored.

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 schoolwork and tasks, knowledge building supports the intentional, reflective, and metacognitive engagement required for deep learning. In a knowledge-building environment the focus of the learning community is on continually improving ideas. It begins with a question of understanding, such as, *Could a computer ever have feelings?* The next step is to encourage learners to generate and post their ideas about the topic (typically in an asynchronous, online group workspace such as provided by *Knowledge Forum* software). In the process the community organizes itself into working groups that grow and change in response to the interests of learners. The workspace preserves the discussions so that the learners can return to them for comment and reflection. Scardamalia[13] provides twelve determinants that define knowledge building discourse, such as exploring real ideas and authentic problems, "rising above" the discourse to create higher level concepts, taking collective cognitive responsibility and using authoritative resources.

## II. Implementation in the Classroom

### *Geotechnical Engineering (EGR 340)*

Although the concepts in this paper are presented within the context of an introductory geotechnical engineering class, the approach is general and can be applied throughout engineering education. The course described is Geotechnical Engineering (EGR 340), a technical elective offered by the Picker Engineering Program at Smith College. The course met twice a week for two hours with labs integrated into the class time. The prerequisite for the course was EGR 270 (Engineering Mechanics). The intended learning outcomes for the course are:

- Develop a conceptual understanding of the properties of soil, water flow through soil, volume changes in soil and soil strength.
- Develop problem solving competence in the following areas: soil phase diagrams, engineering classification of soils, 1-d water flow in soils, flow nets and 2-d seepage, effective stress in soil for hydrostatic, 1-d flow, 2-d flow and capillary rise, stress distributions caused by various loading shapes, amount and rate of consolidation, shear strength of soil, and soil compaction.
- Become familiar with: laboratory soil tests and field sampling and improvement techniques.
- Improve your communication and group skills by participating in a discourse in knowledge building.

Established in 2000, the Picker Program is the first engineering program at a women's college in the United States and one of only a small number of engineering programs set within a liberal arts college environment. The 2010 enrollment of the EGR 340 was 12 women (three seniors, five juniors and four sophomores) and included ten engineering and two geology majors. EGR 340 introduces students to the engineering behavior of soil within the context of a variety of real-world applications such as constructing dams, roads and buildings; protecting structures from settlement and other damage; and preventing groundwater contamination. The topics covered in the class include soil classification, permeability and seepage, volume changes, effective stress, strength and compaction.

### *Innovation and Efficiency*

In EGR 340 a variety of strategies were used to balance efficiency and innovation in the classroom. The educational strategies that emphasized efficiency included lecture, discussion, soil testing laboratories following standard procedures, peer teaching, problem sets, case studies and other standard practices in engineering education. The classroom practices focusing on innovation and deep learning included a variety of experimental activities and field trips, Imaginative Education and knowledge building.

An example of balancing innovation and efficiency is how students learned about Atterberg Limits (the moisture contents of fine-grained soils that indicate the boundaries between different types of engineering behavior). As in most introductory geotechnical courses, students performed the standard ASTM laboratory procedures to determine the liquid limit and the plastic limit of a soil. Through this efficiency activity students learned the procedural knowledge associated with the topic. However, innovation was also integrated into the experiment to help students develop a deeper understanding of the concepts by requiring students to design their own liquid limit or plastic limit test and explain the principles behind their design. For example, one student design for the plastic limit was to roll the soil into a ball and see if it stuck or marked a white or glass surface—the plastic limit being the moisture content when no mark is left or the ball slightly crumbles. The student explained her design as follows:

> I think this process could work because it uses what I learned about texture of soil during the plastic limit test we performed in class. When the soil was plastic, it was almost sticky and would come off on my hands and often didn't hold its shape very well because it was deforming too much. When the soil was semisolid, I couldn't roll it as much without it falling apart. The trick was to find that optimal level when the soil wasn't too sticky but wasn't too dry, and could hold its shape without deforming too much under pressure. This test uses the 'stickiness' of the soil as a way to define its plasticity.

The student was clearly engaged in deep learning. She learned the procedures related to the plasticity and also showed that she was able to work innovatively with the concepts.

***Imaginative Education***

<u>Mythic Understanding</u>

Egan writes that a place to start when using an imaginative approach to education is to ask the question, "What is emotionally engaging about the topic?"[6] Referring to the challenges geotechnical engineers face in dealing with such a complex, ever-changing, three-phase material (and with only limited knowledge of the material due to sampling difficulties and expenses), geotechnical engineering is sometimes referred to as being the "dark arts of engineering." With this in mind, EGR 340 used the dark arts as a mythic cognitive tool (fantasy) to engage students and support the development of Ironic understanding. It began on the first day of class when students were welcomed to the "dark arts" class as if they were witches and wizards learning their craft at Hogwarts (the fictional boarding school for wizardry in the popular Harry Potter books and the dominant popular fiction of their youth) and included a short video from one of the Harry Potter movies to set the mood. At this point students began working in teams to brainstorm the meaning of the dark arts reference. The resulting discourse on why soil is such a complicated engineering material led to the students coming up on their own with the need to cover most of the course topics. The dark arts reference was revisited throughout the semester to frame other classroom activities in engaging ways (see Ellis and Thornton[15] for more details).

Romantic Understanding

Although largely absent from formal education, the use of Romantic understanding is a powerful cognitive tool that is ubiquitous in our media and popular culture. Focusing on what is emotionally engaging about the topic, EGR 340 used the Romantic cognitive tools of association with heroes and fascination with the extremes of reality. The emotional connection in geotechnical engineering to the "heroes" of the field is unusually strong and EGR 340 focused on two of them: Karl Terzaghi (1883-1963) whose book, *Erdbaumechanik*, revolutionized the field and Arthur Casagrande (1902-1981) who became known as the "right hand" of Terzaghi. Numerous pictures, anecdotes and quotes exist for both individuals and provide ample material about their personal lives and professional lives (such as Terzaghi being invited to MIT in part to evaluate the embarrassing settlement problems that plagued the new Cambridge campus in 1916[16]. New topics were often introduced through a historical context that included the contributions of Terzaghi and Casagrande. These narratives were presented in a way to help students identify with the heroes; to put themselves in the heroes' place as they developed the field; and to see how their ideas developed.

At the heart of soil mechanics is the effective stress principle developed by Terzaghi. Predicting the development of quick conditions is often included in geotechnical courses as an application of the effective stress principle. However, in EGR 340 student fascination with understanding the mystery of quicksand (an extreme of reality) was used as a unit-level narrative to engage students in learning about effective stress. The unit began with a liquefaction demonstration (presented as part of the dark arts story). Students then worked in teams to develop initial theories to explain why tapping a beaker would cause soil to change from a solid to a liquid. With students now engaged in an unsolved mystery and some of their preconceptions revealed, the unit went on to explore effective stress and seepage. This included learning about local quicksand sites and earthquake liquefaction and participating on a virtual safari based upon recorded encounters with quicksand. On the safari students applied their collective understanding of geology, soil mechanics and fluid dynamics to explain the behavior of students who fell into quicksand under different scenarios and rescue them. The safari also included a lab with quicksand tanks for students to see and feel different seepage conditions, measure hydraulic heads and calculate pore water pressures and soil stresses under various seepage conditions.

Philosophic (Theoretic) Understanding

Most college age students have noticed that there are theories, methodologies, and schema that underlie patterns of seemingly disconnected details and experiences. EGR 340 engages and develops Philosophic understanding by using theoretic narratives and concept maps. By bringing order to concepts and helping students see the big picture from the beginning, these tools help students develop learning goals, organize their learning within a conceptual framework and reflect on their progress toward understanding.

Concept maps were used in a variety of ways in EGR 340, including helping students see relationships among concepts, solve problems and assess learning. The instructor created concepts maps at the unit level (Figure 1) and at the course level (Figure 2). The course-level map was discussed on the first day of class and revisited regularly. Unit-level concept maps were used to help students see the big picture at the beginning of each unit and were referred to regularly throughout the unit. After modeling the use of concepts maps in the first two units of the class, students were then asked to design a concept map for the third unit on volume changes

(Figure 3). Finally, in Unit 4 students explored another tool that supported theoretic thinking by writing a unit-level theoretic narrative (see Figure 4).

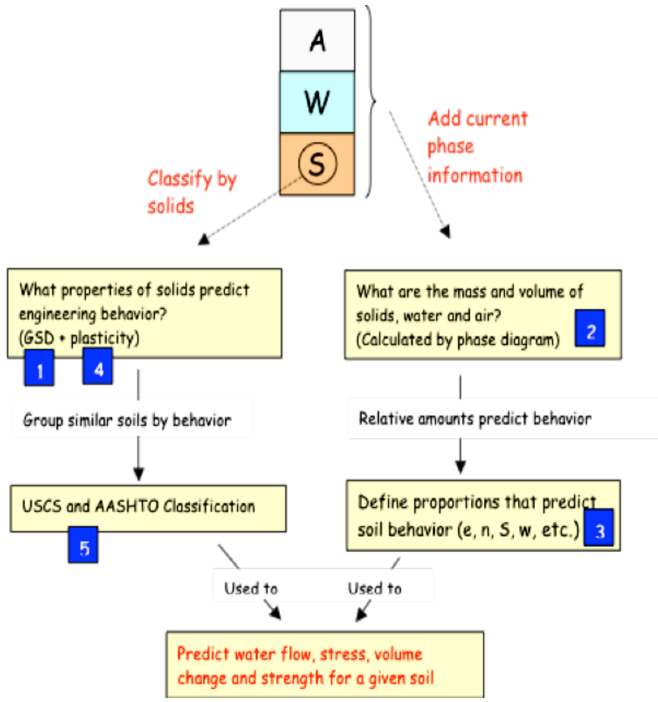


**Figure 1:** Instructor-generated unit-level concept maps for Unit. The numbers in the blue boxes indicate the order of topic coverage (after Ellis and Thornton[15]).

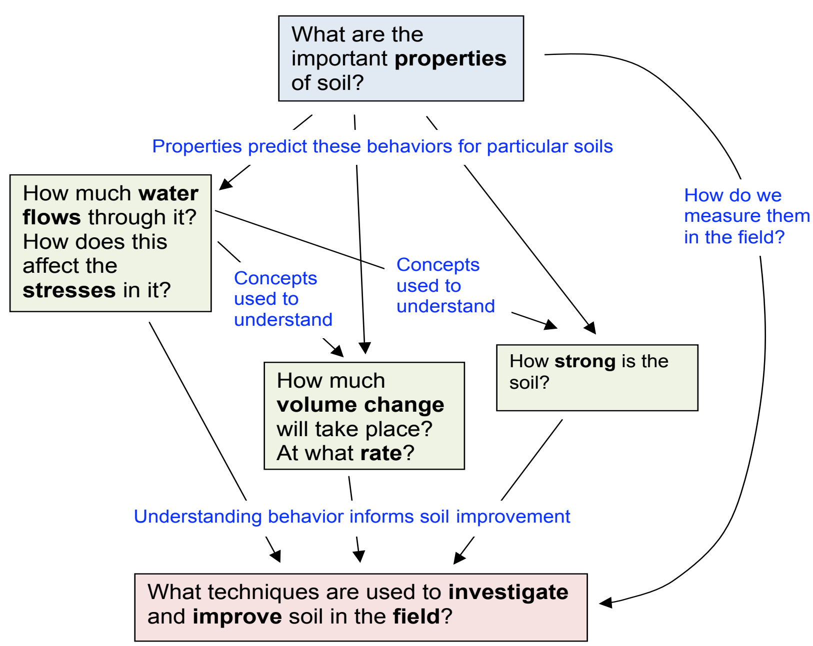


**Figure 2:** Instructor-generated course-level concept map for the topics covered in EGR 340 (after Ellis and Thornton[15]).

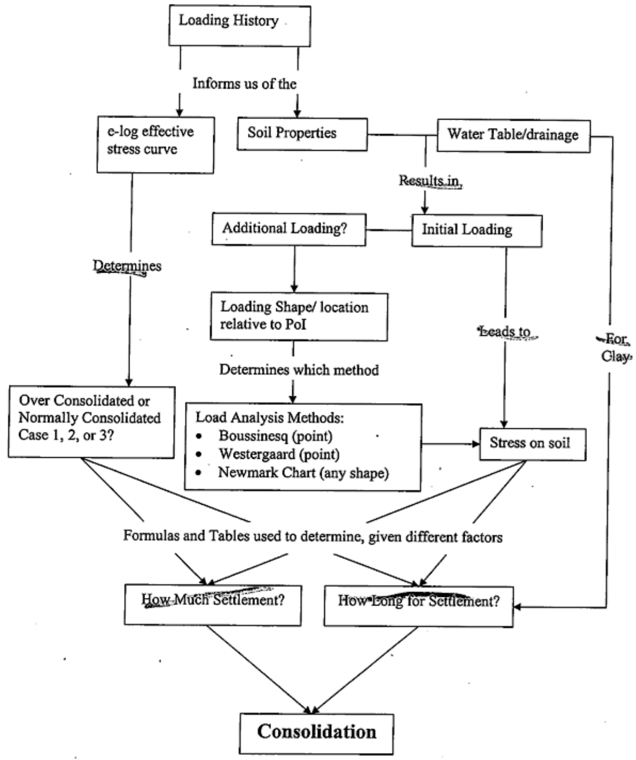


**Figure 3:** Student-generated concept map for Unit 3.

The strength of a soil is its ability to withstand applied stresses. Since individual soil particles are very strong but the connections between them are not, soils fail due to shearing (not compression or tension). The trick is determining which plane within the soil is the weakest and will lead to shear failure.

A sample of soil in the ground has a stress on the top and bottom (horizontal planes) and smaller stress pushing on its sides (vertical planes). These are the principal stresses and they are used to determine the angle of the failure plane using Mohr's Circle. The Mohr's Circle diagram for soils has some tricks that depend on the soil properties and drainage characteristics.

Every soil has a failure envelope, or a line through the plot that is the limit of stress that leads to failure. The failure envelope is determined by the loading history of the soil (pre-consolidated, normally-consolidated), the soil properties (grain size distribution, void ratios, etc.) and the drainage and consolidation. Drainage is an important criteria because the pore water is the first thing that holds the stress, so sometimes you want to drain the soil and or consolidate it depending on the available equipment, time and money.

The y-intercept of the failure line is at the cohesion factor. The cohesion factor is represented along the y-axis (shear stress), generally zero except for clays. Cohesion is related to the amount that the soil would naturally hold itself together if you compressed a clump and released it. Similar to a snowball, the soil that retains a little more water naturally will be more cohesive than the powdery stuff. The angle this line makes with the horizontal is the friction angle.

Taking all of these components into consideration will lead to a complete Mohr's circle diagram. If the semi-circle drawn between the principal stresses is below the failure envelope, the specimen is safe. Where the semi-circle of nominal stresses touches the failure envelope, the shear and normal stress can be determined that lead to the determination of the angle of the plane relative to one of the principal stresses that the soil will fail along.

Examples of soil not being strong enough to withstand a load are mudslides and coastal erosion.

**Figure 4:** Student-generated theoretic narrative for Unit 4.

Ironic Understanding
Students are engaged in Ironic understanding when they come to recognize the inadequacy of Philosophic theories and methodologies to fully explain the complex behavior of the world and instead begin to think in terms of practices, approaches, viewpoints and community. Ironic understanding began with the dark arts Mythic narrative that was grounded in the inadequacy of theories and methodologies learned in the course to fully explain soil behavior. Through the use of Terzaghi and Casagrande narratives, students saw the human context in which they were developed. Finally, students developed Ironic understanding as they regularly explored the inadequacies of the Philosophic concept maps—such as Atterberg limits not fully capturing soil plasticity.

***Knowledge Building***
Designing a knowledge building learning environment requires attention to three major factors. The first is devising appropriate problems of understanding—that is, problems that require a focus on ideas rather than on the completion of schoolwork. The second is creating the participant structures and practices that support knowledge building discourse. The third is to develop ways to measure deep learning outcomes[17].

Devising Problems of Understanding
Devising problems of understanding calls for problems whose solutions build on student's existing knowledge while requiring them to learn new things. Beyond being the right kind of problem at the proper level of difficulty, the problem or project must be engaging enough to summon the motivated effort deep learning requires. 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.

After an introduction on knowledge building, the instructor presented examples of possible geotechnical knowledge building problems (such as understanding the levee failure in Hurricane Katrina or the consequences of a major earthquake striking the eastern United States). The students then worked together to generate their own knowledge problems and voted to select the problem they would all work on. These included:

- What are the geotechnical effects of climate change on coastal areas? (9 votes)
- How did ancient societies create long lasting structures before our modern understanding of geotech? (5 votes)
- What is the future of mining? Its impacts, development of new mines and fate of old mines? (5 votes)
- How long after a landfill is capped can it be built on? (2 votes)
- How are new technologies helping geotechnical engineers realize their role in sustainability? (1 votes)

Creating Participant Structures and Practices
Central to knowledge building and its participant structure is discourse. Scardamalia[13] 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 scaffold, share, redirect, and otherwise influence student collaborative discourse.

With the problem of understanding formulated and initial theories developed, students began a five-week period of knowledge building that took place largely outside of the classroom in the Knowledge Forum electronic workspace. Students were encouraged to begin their participation by posting a note with their initial theories and also building on at least one other students note. An early view of part of the workspace is shown in Figure 5. The posted 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 designed to help them frame and present their ideas more constructively. While most of the discourse took place through posting notes that built upon other student notes, Knowledge Forum also allows users to include annotations in their classmates' notes and these were also used regularly to respond to or comment on the details of a note.

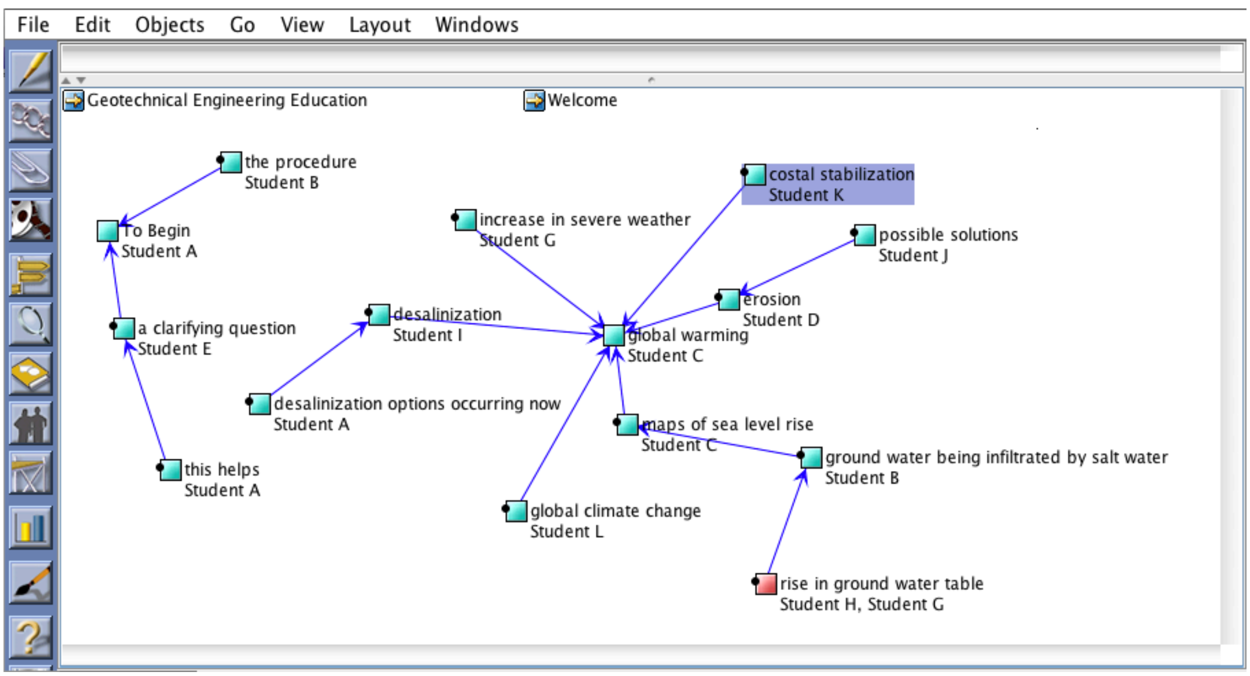


**Figure 5:** Portion of the Knowledge Forum workspace early in the discourse. Each box represents a note posted by a student. These notes become the objects of the discourse within the community. Arrows indicate when a note builds upon another note.

A principle of knowledge building is that students engage in a sustained discourse to improve ideas and understanding, and also that the discourse leads to higher-level formulations of the problem[13]. Knowledge Forum supports this higher-level formulation by allowing users to create a note that can *rise above* the discourse. In EGR 340 the students worked together to create a rise above note that summarized the discourse (see Appendix). This final collective rise above showed much advancement from the students' initial naive theories and reflected the complexity of the topic

Grading
Student participation in knowledge building was assessed in two ways. The first was the instructor's evaluation of the quantity and quality of notes posted by the student. One advantage of using the Knowledge Forum software is that the entire discourse is available to the instructor and changes in students can be observed. The second assessment measure was a student self-evaluation. In this evaluation the students used specific examples to reflect upon how their participation in the discourse addressed the five guiding principles of knowledge building proposed by Lee et al.[18]. These include working at the cutting edge, progressive problem solving, collaborative effort, monitoring one's own understanding and using authoritative resources constructively.

## III. Assessment

The following data were collected to assess the effectiveness of the pedagogical approaches used in EGR 340:

- *Smith College Course Critique System*. Standard instrument used to assess all classes at Smith College; it is administered anonymously on-line during the final week of class.
- *Student Survey*. Anonymous student survey administered by an assessment research scientist on the last day of class.
- *Preparation for Future Learning (PFL) Question.* Students submitted written answers to a PFL question on the first and last day of class.
- *Sequestered Problem Solving.* Students received the same midterm, dam analysis project and final exam as the previous course offering.
- *Knowledge Forum Diagnostics.* Student participation in posting notes, posting annotations and reading notes was measured.
- *Knowledge Building Self-Reflections. S*tudent self-reflections of their participation in knowledge building were coded and analyzed.

***Smith College Course Critique System***
Table 2 summarizes results from the college's course critique system. The students clearly had a positive opinion of the course and their mean responses ranked significantly above the department mean on four of the five questions.

**Table 2:** EGR 340 Student Responses Recorded Anonymously in the Smith College Course Critique System.

| Question | EGR 340 Student Response | | | | EGR 340 Mean | Engrg Dept. Mean | p-value* |
|---|---|---|---|---|---|---|---|
| | Value = 4 | Value = 3 | Value = 2 | Value = 1 | | | |
| 1. Were the course goals clear? | Extremely clear | Somewhat clear | Somewhat unclear | Very unclear | 3.92 | 3.51 | **0.033** |
| | 11 | 1 | 0 | 0 | | | |
| 2. Did the assignments and other work help you learn? | Almost all | Some | Very few | Almost none | 3.83 | 3.60 | 0.18 |
| | 11 | 0 | 1 | 0 | | | |
| 3. How often did class leave you with new thoughts and/or ways of looking at things? | Almost always | Often | Occasionally | Seldom | 4.00 | 3.27 | **0.003** |
| | 12 | 0 | 0 | 0 | | | |
| 4. Did the instructor present ideas in a clear and comprehensive way? | Almost always | Generally | Seldom | Almost never | 4.00 | 3.38 | **0.003** |
| | 12 | 0 | 0 | 0 | | | |
| 5. How much did the instructor engage you with the material? | High to begin with & sustained | Somewhat increased & usually sustained | Somewhat diminished | Substantially diminished | 4.00 | 3.46 | **0.017** |
| | 6 | 0 | 0 | 0 | | | |
| | Substantially increased & sustained | | | | | | |
| | 6 | | | | | | |

*Included are p-values comparing the EGR 340 mean with the mean for all Picker Engineering Program classes (except EGR 340) using two-tailed, unpaired tests (after Ellis and Thornton[15]).

***Student Survey***

Likert Scale Questions

Student responses to the Likert Scale student survey questions are presented in Table 3. The table indicates that the students found the course to be different from their other courses; that they felt they learned deeply; that the Mythic and Romantic narratives were engaging; that the use of concept maps was useful in the learning process; and that they were able to build upon each other's ideas in knowledge building.

**Table 3:** Anonymous EGR 340 Student Responses to Post-Course Survey Questions

| Topic | Question | Strongly Agree | Agree | Neutral | Disagree | Strongly Disagree |
|---|---|---|---|---|---|---|
| General | This course was different than other engineering courses I have taken. | 8 | 3 | 0 | 0 | 0 |
| | I think I have a deep understanding of material covered in this class. | 7 | 4 | 0 | 0 | 0 |
| Related to Imaginative Education | Framing the course in terms of the dark arts made me engage more with the content material in this course. | 8 | 3 | 0 | 0 | 0 |
| | The use of narrative (Karl Terzaghi & Casagrande) in this class helped me to get more interested in course material. | 6 | 5 | 0 | 0 | 0 |
| | The quicksand lab helped me to deeply learn the concepts related to effective stress. | 10 | 1 | 0 | 0 | 0 |
| | Concept maps used by the professor provided a useful tool for framing course content. | 8 | 3 | 0 | 0 | 0 |
| | Creating my own concept map helped me to begin to learn how to organize my understanding of course material. | 5 | 5 | 1 | 0 | 0 |
| Related to Knowledge Building | Using Knowledge Forum helped me to learn from other students. | 4 | 5 | 2 | 0 | 0 |
| | I think in this course we were able to effectively build on each other's ideas to create new knowledge. | 7 | 3 | 1 | 0 | 0 |
| | I think students in this class effectively used referenced sources to support their ideas in Knowledge Forum. | 3 | 7 | 0 | 1 | 0 |
| | I believe that Knowledge Forum is an important skill to learn. | 6 | 5 | 0 | 0 | 0 |

Open-Ended Questions

Students were also asked to respond to two open-ended questions. One was about how the Mythic (Dark Arts) and Romantic (Terzaghi-Casagrande) narratives impacted learning. All responses are shown in Table 4 and indicate the narratives increased their engagement. The second question was about how knowledge building impacted their learning. Responses were positive—noting increased confidence, learning in greater depth, and enjoying learning from peers; made suggestions for improvement—such as using knowledge building throughout the semester and creating self-selected groups to work on multiple topics; and negative—usually frustrations with the software.

***Preparation for Future Learning (PFL) Question***

Box 1 shows the PFL question that students answered on the first and last days of class. Table 5 shows a coded analysis of student responses that showed greatest gains were made in the use of technical language and applying geotechnical concepts. For example, one student's answer for question b changed from "the properties of the soil in the area, and how much having the station will affect the whole soil cycle" to "what kind of soil they used to make the land, how high is the ground water table, how much weight the gas station is going to exert on top of the soil, is there flow in the soil or not, and was there anything sitting on the soil before (pre-consolidation)."

***Sequestered Problem Solving (PFL)***

Students received the same midterm, dam analysis project and final exam used when the class was last offered (two years earlier with eight students and the same professor). Scores on all assessments increased compared to the previous course offering: dam analysis project—87.2% to 91.5% (p-value = .29), midterm exam—82.6% to 84.6% (p-value = 0.32), and final exam—84.5% to 88.2% (p-value = 0.23). However, the small class sizes make the results inconclusive.

***Knowledge Forum Diagnostics***

Knowledge Forum includes tools for analyzing student participation and shows that all students participated significantly in the discourse. Figure 6 shows that the number of notes read by each student ranged from 42 to 90 (mean = 66). Figure 7 shows student contributions in the form of notes and annotations. Note contributions ranged from 7 to 24 (mean = 15) and annotation contributions ranged from 2 to 11 (mean = 6).

***Knowledge Building Self-Reflections***

As presented earlier, students submitted a self-reflection examining their participation in knowledge building. While meeting all five of the guiding principles is not necessary to be an effective member of a knowledge building team, each student was asked to reflect upon her success at using each one. Our analysis showed that eight of the twelve students in the class presented sufficient evidence supporting their effective use of all five principles. The remaining students provided evidence of effectively using either three or four principles. Student reflections on the overall progress of the class were largely positive. One wrote:

> Once someone in the class started posing something in the forum, we started responding and building up ideas about what the answer should be. Then, we finally came to the conclusion; we got the answers for what we were looking for. Importantly, our answers were not just a phrase or a sentence; they are engineering concepts with clear explanations. I really think we achieved a lot from this project and I am proud of my class.

**Table 4:** Anonymous EGR 340 Student Responses to Post-Course Survey Questions

| Question: Practicing the dark arts and the personalities of Karl Terzaghi and Arthur Casagrande were used to frame this course. Describe how their use impacted your learning in this course. |
|---|
| They are the innovators of this field, so I feel motivated and excited to know more about the materials so that I can make sense of geotechnical engineering. |
| I feel special learning geotech because I feel like I kind of get to "talk" to Kerzaghi and Casagrande during the learning of this course. They inspire my study at some point. |
| This method of framing the course gave it more context, and hence made it more memorable. I think it will make the learning of the course content more durable over time. |
| It made it a lot more enjoyable and interesting! It hooked me into paying attention even if I was really exhausted and tired from something else. |
| My attention was always kept. I loved starting each class with some sort of Harry Potter anecdote and finding the hidden KVT [Terzaghi] references in our handouts. I think, though it was kind of silly, it helped make me relate to the topic better. |
| My interest in this course was greatly increased by Prof. Ellis' excitement and implementation of these frames. The background material gave the course more depth and the dark arts analogy gave me a more real life understanding of why geotech is so different from other engineering disciplines. |
| I LOVE THE DARK ARTS. The framing of this class was fantastic. I loved coming to class because of the framing. It was completely ridiculous, but I loved every minute of it. |
| It made this course really fun and entertaining. It really gave us something tangible to hold on to. |
| They greatly impacted my enthusiasm for this course. I was pleased to see in-class humor and the ways in which these storylines carried through the semester. I would have loved the subject anyways, but Professor Ellis really pulled off adding these components in to class in a way that was fun and amusing. We may be college students, but we still love to have some imagination time. |
| Question: Describe how knowledge building impacted your learning and participation in this class. |
| When I feel like I am learning more and becoming well equipped, I have more confidence and answer in class more often. |
| Knowledge building helps me to keep track of my project every day instead of spending 10 hours on the day before the due day. |
| Knowledge building has allowed me to explore topics of interest to me to a greater depth and surrounded by a supportive network of classmates. |
| It made me realize how much I could learn from my peers and they could learn from me. It made me realize the importance of having peers with different educational backgrounds and strengths in different academic areas. |
| I enjoyed the knowledge building tool. Sometimes though, I felt like I didn't have time to keep up with it consistently. I think it may have been interesting to start this at the beginning of the class and have it grow as our understanding of geotechnical engineering grew. |
| It was fun and interesting to have an open ended problem and a group research and discussion section for class. |
| Knowledge building was a little intimidating at first, but once I get into it I really like it. Even though it may have been a little more complicated/confusing at first, I think it might be cool to try to pick a question and work through it throughout the semester b/c then you could apply specifics from class learning. |
| I found the knowledge building exercise interesting. I think it helped me learn how to learn from other people better and use the conversation to get somewhere. |
| Maybe not so much. I don't know, the software really isn't the easiest to use and therefore I'm much less excited to go and participate than I would be in a larger class discussion. |
| I was involved in the process but not head over heals about the question. It would have been nicer if groups had been formed concerning people's interests. |
| Knowledge building was my least favorite part of the course. I did learn a lot of new ideas, but I found the online software difficult and too separate from the rest of the class. |

Bradford Miller wrote an article in *Geotimes* discussing the "Big Dig". In this article he writes the following about the soil in Boston.

> Many Bostonians know that the city's shoreline footprint has grown through history. The waterfront expanded outward into Boston Harbor and the city grew onto land "reclaimed" along the Charles River estuary, perhaps most famously in the Back Bay and South End areas. However, not all of the residents give much thought to how much area actually was created, and where the filling material originated. Nor do they consider how this unique soil profile affects construction and underground engineering.

Suppose that you are a geotechnical engineer (i.e. an engineer that deals with soil-related issues) and you are asked to report on the feasibility of building a gas station in the Back Bay near the Charles River. Please answer the following:

a. What are the important features that you notice about the proposed project and site?
b. What would you need to learn more about to write the report?
c. What major ideas or theories frame the way you think about the project report?

**Box 1:** EGR 340 Preparation for Future Learning (PFL) Question administered on the first and last day of class.

**Table 5:** Coding Student Responses to a PFL Question Related to Building a Gas Station Near the Charles River

| | Beginning of Course | | | End of Course | | |
|---|---|---|---|---|---|---|
| | **No** | **Developing** | **Yes** | **No** | **Developing** | **Yes** |
| Technical Language | 92% | 8% | 0% | 0% | 8% | 92% |
| Insight and Communication | 0% | 25% | 75% | 0% | 0% | 100% |
| Geotechnical Concepts | 43% | 16% | 41% | 0% | 0% | 100% |

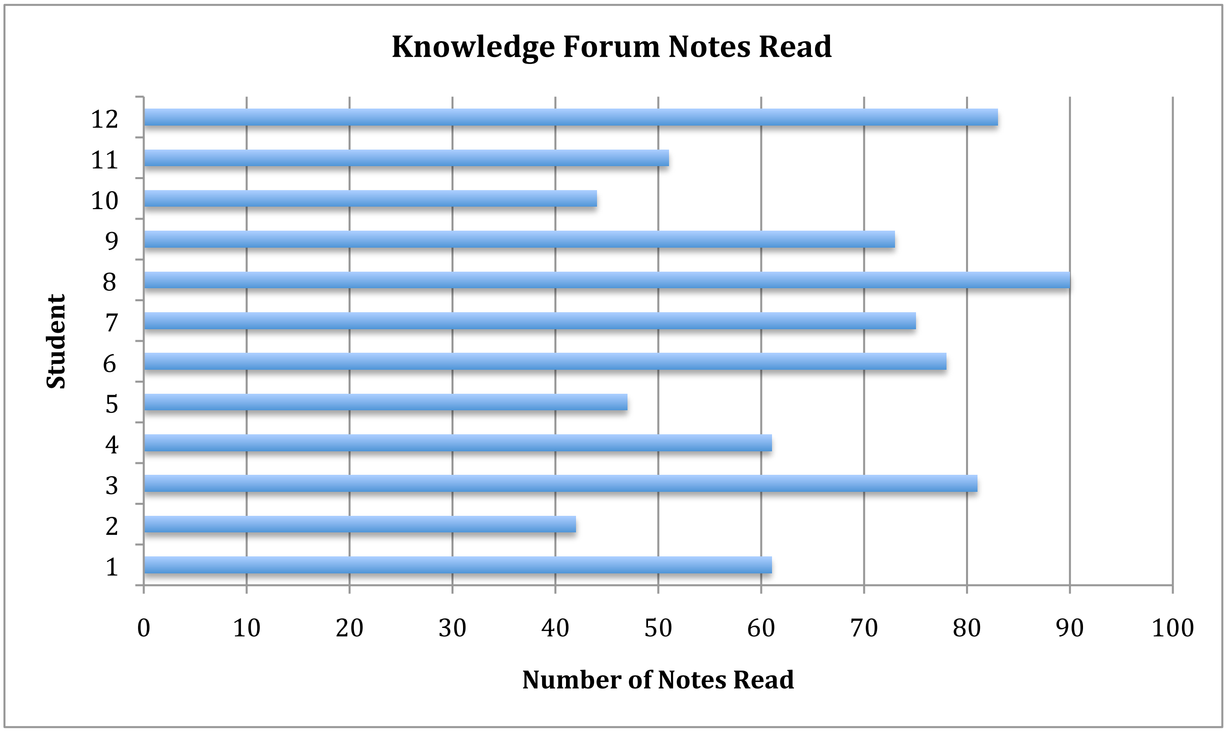


**Figure 6:** Number of Knowledge Forum notes read by each EGR 340 student.

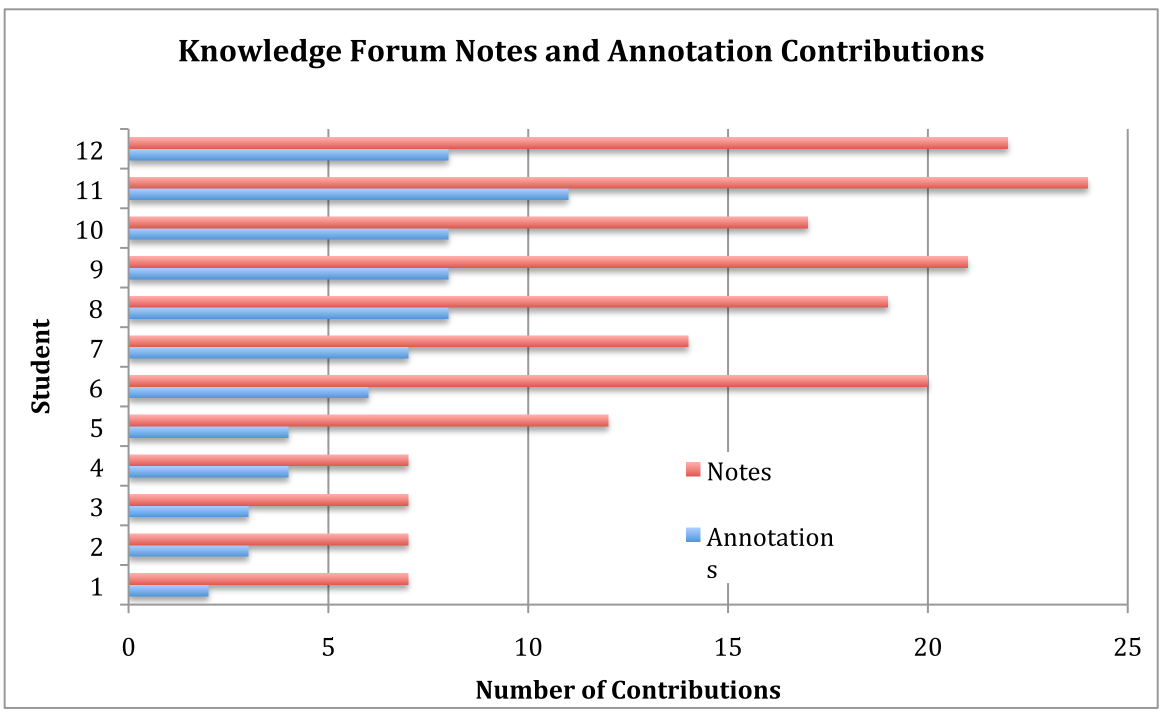


**Figure 7:** Number of Knowledge Forum notes and annotations contributed by each EGR 340 student.

## IV. Discussion

***Innovation and Efficiency***

EGR 340 was designed to better support transfer of the concepts learned in the class—including *transfer in* and *transfer out*—by including both innovation and efficiency in the design of the learning environment. This is a departure from standard practices in engineering that often focus largely on efficiency. Student learning was measured both by sequestered problem solving approaches (SPS) designed to measure transfer out and by preparation for future learning approaches (PFL) that were designed to measure transfer in. While the class sizes were not large enough to show a statistically significant improvement in the SPS assessments, they provided no evidence that replacing efficiency with innovation approaches negatively impacted student performance on traditional assessments. As noted by Schwartz, et al.[4], the benefits of innovation for developing interpretive knowing are often not uncovered with SPS assessments and require the use of PFL assessments that measure transfer in. While the design of PFL assessments is still a new area of research, an attempt was made in EGR 340 to design such a measure for geotechnical engineering (Box 1) and analyze the results (Table 5). While this assessment did show gains in student understanding that would not have been measured by SPS testing, further research is necessary to better understand the student responses and improve the assessment tool. Student participation in the knowledge building discourse is also a measure of transfer in since students must learn in order to improve their collective understanding. Again, evidence from analyzing the discourse and student self-reflections is encouraging and supports further investigation.

***Imaginative Education***

Assessment data indicates that the use of cognitive tools was effective in generating student engagement. Undergraduate students are typically in the process of developing philosophic/theoretic understanding and perhaps working toward developing ironic understanding. Thus it is not surprising that they found the use of concept maps and other theoretic tools to be useful. What is particularly interesting is the strong student response to cognitive tools associated with levels of understanding that undergraduates have typically gone beyond. As IE theory predicts, these earlier tools become transformed as students integrate them into their new level of understanding. For example, all of the students surveyed agreed that the Dark Arts narrative associated with Mythic understanding impacted their engagement. There is also some evidence possibly indicating that the Mythic narrative supported student development of Ironic understanding. One student reported, "…the dark arts analogy gave me a more real life understanding of why geotech is so different from other engineering disciplines."

***Knowledge Building***

Knowledge building is an approach for improving engineering education that supports deep learning and helps students develop the skills needed to be successful participants in an economy where knowledge and innovation are pervasive. This paper presents one of its first applications in an engineering course and the results were positive. Figures 6 and 7 show broad student participation in posting notes and reading notes posted by classmates. An analysis of the discourse and the final rise above show that the determinants that define knowledge building[13] were met. Ideas were improved, questioned were redefined, authoritative sources were used constructively, diverse ideas were raised, higher level concepts were created and students found their way in order to advance the discourse. Finally, as shown in Tables 3 and 4, student surveys indicated that knowledge building supported their learning. Student responses to knowledge building were particularly positive considering that research has shown that approaches to teaching and learning "which involve understanding and higher level cognitive processes [such as knowledge building] are difficult for teachers and students to accomplish in classrooms". Doyle notes that this is due to students facing ambiguity and risk in the accountability system and teachers facing complex management problems[19].

While this study indicates that knowledge building may have the potential to play an important role in engineering education, there is still much to be learned before it can be used on a larger scale. We have identified three key questions that will frame our future research in this area:

1. Students in EGR 340 worked together to create their own knowledge building problem. 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 instructor. *What are the best approaches for instructors to establish adjust and support the participant structures and other determining qualities in knowledge building environments?*
3. Theory indicates that knowledge building supports the development of interpretive knowing and deep understanding; however, creating PFL assessments to measure these often unmeasured aspects of student learning was found to be challenging. *What are the best approaches for assessing whether students can use knowledge innovatively?*

## V. Conclusions

We have presented the application of two educational approaches designed to support deep learning in an introductory geotechnical engineering course. Student surveys support the use of imaginative education for successfully engaging students. An analysis of the discourse recorded on Knowledge Forum shows that knowledge building clearly took place, as indicated by the community meeting each of Scardamalia's determinants of knowledge building. 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.

## VI. References


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**Appendix: Final Knowledge Building Rise Above**

As a class, we decided to join our efforts to build knowledge around the question of global climate change impacts on geotechnical issues at our coasts. As broad as this issue may have seemed, we were excited to have the opportunity to explore a range of coastal issues including desalination, saltwater intrusion, coastal stabilization and erosion, groundwater table rise, and increased severe weather (which threaten infrastructure and foundations). Before we could really begin to think critically about these geotechnical issues, we began by considering climate change and how we perceive this change.

There is still much controversy today around the terms used to describe anthropogenic impacts on our changing world. As a class, we decided that the term “global climate change” was most appropriate since it captures both the broad range of impacts as well as the scale of these changes. The use of the term “global warming” seems limited and is often misunderstood since some regions will experience definite global cooling with increased changes. We also realized the necessity to define what we included as “global climate change” impacts since as-to-date, societal classification of these impacts seems to be widely subjective [1].

As a class, we agreed to define climate change as the changes wrought in global climate due to human exploitation of natural resources. The broadest factor contributing to climate change is the global increase in concentrations of atmospheric $CO_2$ due to combustion, which is widely used to power human industry. Carbon dioxide acts as a greenhouse gas, trapping energy from the sun inside the earth's atmosphere. This increase in energy in the biosphere causes more severe weather, melting of ice caps, and hence rise in sea level [2]. Higher concentrations of $CO_2$ are also acidifying the oceans, changing the chemistry of our planet's very lifeblood. These changes are taking place at a rate that will trend to threatening the biota of the planet.

One way of looking at climate change is within the metaphor of a snowball, which was created by human exploitation. Perhaps dating to the industrial revolutions of Europe and then America, this snowball began rolling down the hill -- gaining momentum. Now, not only is there more $CO_2$ in the atmosphere, but there is also an increased ability to hold water vapor, another greenhouse gas. Many natural systems can act as positive feedback loops, so essentially things may continue to get much worse since the system is now unstable and exponentially increasing.

Due to climate change impacts on severe weather and changes in sea level and water chemistry, global climate change has particular significance to geotechnical issues in coastal regions. The consequences of global climate change that we have been focusing on so far are the rise in sea water level, more frequent rainfalls in some area of the globe, changes in salinity in the soil and changes in water content. The rise in sea level allows sea waves to reach more land in the coastal areas and wash away the sediments. This results in beach erosion and a decrease in land area [3]. The increase in the frequency of rainfall and melting of glaciers leads to the rise in ground water level. As we had learned in class, the increase in ground water level results in a higher pore water pressure in the soil and a decrease in effective stress. We’ve learned this semester about the importance of soil effective stress to strength and support of structures. Therefore, a decrease in effective stress could lead to catastrophic collapse of structures. Global warming also leads to changes in soil salinity and an increase in sodium contamination in soils. Salinity results in deaths of plants on the surface of the soil. The death of organics leads to a higher amount of void space in the soil (as roots or animal corpses decompose). This increased void space may increase the likelihood of failure in surface structure [4]. Sodium contamination in soils (excess sodicity) also can lead to excessive swelling in clays, soil dispersion, and collapse of soil structure including void space and macropores. As a result, soil becomes more dense with decreased hydraulic conductivity, leading to problems with irrigation that interfere with plant fertility [5].

Humans have been adapting to live along coastlines for centuries. Many countries have developed ways of dealing with rising ocean tides and severe weather occurrences. For instance, in the Netherlands dikes and levees have held back the sea for years. Levees were even built in ancient Egypt along the Nile River [6]. People have also developed artificial coastal barriers to protect populated mainlands from the full force of tidal waves and storm surges. These traditional structures are a mode of flood control. Another way people have affected the coastline in the past is land reclamation. This is done by filling in coastal areas, making the land extend farther into the sea. Examples of this include Boston's Back Bay area where fill was brought in and the area was reclaimed for urban expansion. The role of a geotechnical engineer is quite apparent in these practices, as soil and soil behavior plays an essential role in these processes.

Today, as the sea begins rising and invading coastal areas people find new adaptations. Already the issue of salt-water intrusion has become widespread, leaving many island and coastal peoples without fresh water. Some of the ways of dealing with this include fresh water injection and other ground water management techniques [7]. However, this leads one to question whether a geotechnical engineer, who would be essential in these operations, should actively change the environment. This may be seen as an ethical issue. Some engineering consulting firms actively manage ground water sources and aquifers to monitor and control salt water intrusion.

These leads us to the question of the future; if the sea continues to rise and global climate change causes irreversible changes to our environment, particularly in coastal areas which will be most affected, how should we proceed? Multiple sources have split the possibilities in three different categories: retreat, accommodation, and protection. Retreat is fairly self-explanatory; people would abandon the coastlines to the ocean and retreat inward. Accommodation is an intriguing option in which the areas remain populated but the sea is allowed to intrude. Melody's book describes floating cities, houses on stilts, and great sea walls [8]. Some other innovative ideas proposed by architects and design groups include 'porous' streets and recycled reefs [9]. No matter what happens, the role of geotechnical and civil engineers along coastlines will be a dynamic one, adapting to our changing environment.

Though as a whole we could have strived to dig deeper into these subjects to gain a more detailed knowledge, this project provided an opportunity for our class to work together in a free-form manner. We worked to bounce ideas off another and collaborate in productive ways. We each gained knowledge in areas that we hadn't had any previous contact with. This project gave our class the opportunity to realize how much more there is to learn about climate change and its incredibly far-reaching impacts. We now have a few more tools to use to better understand future learning experiences we have surrounding the idea of climate change and hopefully will be able to inform others around us about the significance of these impacts on geotechnical issues.

[1] http://www.nasa.gov/topics/earth/features/climate_by_any_other_name.html

[2] http://www.buildingfutures.org.uk/assets/downloads/Facing_Up_To_Rising_Sea_Levels.pdf
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