Using Knowledge Building to Support Deep Learning and the Development of 21st Century Skills

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Ms. Yanning Yu
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I. Introduction

Engineering education needs to change to meet the changing demands on the profession. Engineering graduates must not only 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. 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.

Both the NSB and Sawyer indicate that graduates need to develop what Broudy 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. 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.

Innovation and Efficiency in the Classroom

Significant advances are being made assessing deep understanding. Schwartz, et al. 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).

As do many fields, 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). It is these innovation learning experiences that prepare students for success on PFL assessments. This paper presents the application of an innovation approach called knowledge building in an introductory engineering mechanics class. In knowledge building students participate in an interactive on-line 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. In spite of its strong grounding in the learning sciences and extensive success and research base in K-12 education, this on-line approach to extending discourse beyond the classroom remains largely unexplored in undergraduate engineering education.

**Knowledge Building Theory**

The solutions to many of the most important problems facing future engineers will require the production of new knowledge—i.e. new conceptual artifacts (such as theories) that arise from human thought. 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 and 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 that is needed to solve complex problems. Knowledge building is an instructional approach designed to meet this need.

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 discourse⁶⁻¹¹. Although knowledge building is being used around the world to prepare graduates to succeed 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 that is developed by the participants, such as, Why do we need water to survive? Learners are encouraged 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. Scardamalia¹⁰ provides determinants that define knowledge building discourse including the following:

- Problems are ones that 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.

II. Implementation in the Classroom

*Engineering Mechanics (EGR 270)*

EGR 270 is a four-credit, semester-long introductory mechanics course that is largely populated by sophomore engineering students. Knowledge building was used in EGR 270 in Fall 2011 (44 participants) and Fall 2012 (34 participants). The course met twice a week for 80 minutes and included a weekly 170 minute laboratory. A theoretic course narrative (see the appendix) framed learning within the context of innovation and efficiency and expanded upon the following intended learning outcomes for the course:

• Develop an efficient command of the basic information, procedures and methodology needed to understand the mechanical behavior of an object under loading.
• Develop the ability to use your knowledge in innovative ways.
• Improve your competencies needed to participate in a knowledge organization.

Mechanics concepts covered included an introduction to stress and strain; 2-d and 3-d rigid body equilibrium; analyzing frames and machines; calculating centroids and moment of inertia; and plotting shear and bending moment diagrams.

A variety of strategies were used to balance efficiency and innovation in the classroom. The educational strategies that emphasized efficiency included lecture, discussion, hands-on activities, group problem solving, and parts of the problem sets, case studies and laboratories. The subject of this paper is the innovation classroom practices that focused primarily on knowledge building. 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\(^3\). CSILE has been further developed into a software environment called *Knowledge Forum*. In the study presented in this paper, we use *Knowledge Forum* to support and facilitate collaborative knowledge building.
Knowledge Building

Designing a knowledge building learning environment requires devising appropriate problems of understanding—that is, problems that require a focus on ideas rather than on the completion of schoolwork. It also requires creating participant structures and practices that support knowledge building discourse.

Devising Problems of Understanding

Devising problems of understanding calls for problems whose solutions build on student’s existing knowledge while also 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.

Based upon Egan’s theory of imaginative education, understanding how an EF-3 tornado impacted building in Springfield, Massachusetts and the surrounding communities in June 2011 became the context for knowledge building in EGR 270. Students were introduced to the topic by meeting Springfield residents impacted by the tornado, watching on-line videos of the tornado and taking a field trip to neighborhoods impacted by the tornado (see Figure 1). During the field trip they took pictures of the damage (see Figure 2) and recorded their observations and questions.

After the field trip and a short introduction to knowledge building theory, students spent one week collaboratively developing knowledge building questions on Knowledge Forum. They did this by posting their observations (with pictures from the site and other pictures and videos they found on the Internet), as well as their initial theories and questions about their own and their classmates’ observations. Figure 3 shows part of the Knowledge Forum workspace developed during the first week and shows how students built upon each other’s work. Figure 4 shows three open notes from Figure 4. In the first note a student writes that she wonders about the impact of geometry on the tornado’s impact on a building. In the second note the student states her theory that geometry does play a part, but that the building materials are more important in terms of predicting tornado damage. In the third note the student affirms her interest in the question and expands upon the earlier notes regarding the importance of including socioeconomic factors related to the developing question. Through such a process students developed and improved their questions. They also used the Promising Ideas tool that was recently developed for Knowledge Forum to sort through the many questions they had developed and identify the most promising ones. Using this process in 2012 and a similar process in 2011, 5 or 6 promising knowledge building questions were developed in each class and the students formed teams of 6-9 to work on the question that most interested them. Examples of initial questions—in most cases these questions were significantly improved and refined through the knowledge building process—include:

- What is the safest location in a house during a tornado and why?
- Can an affordable tornado-proof house be designed?
- Why did building codes not protect the buildings and people in the Springfield tornado?
- What do engineers look for when deciding to condemn a building after a tornado?
Figure 1: EGR 270 students surveying damaged houses in Springfield, MA.

Figure 2: Two pictures of tornado damage taken by EGR 270 students.
Figure 3: Screenshot of part of the Knowledge Forum workspace (above) and a blow-up of part of the screenshot (below). Each box represents a note posted by a student that can be open when it is clicked. The arrows indicate when a note builds upon another note and the color of the box indicates if the note has been read or not by the user. Note: in the blowup the student names have been blacked out for privacy.
Figure 4: Open notes for three of the posts shown in Figure 3. Some of the features of Knowledge Forum are highlighted on the figures showing the use of scaffolds to help students engage in theory improvement (as opposed to just sharing ideas), the use of annotations for classmates to add short comments within a note, and embedding/linking other notes within a new note. Note: student names have been blacked out for privacy.
Creating Participant Structures and Practices

Central to knowledge building and its participant structure is discourse. Scardamalia\textsuperscript{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.

KB Talk

With the problem of understanding formulated and initial theories developed, students began a ten-week period of knowledge building that took place largely outside of the classroom in the Knowledge Forum virtual workspace. While most of the discourse took place through posting notes that built upon other student notes, each knowledge building group met bi-weekly with the instructor and a teaching assistant to discuss the group’s progress. Known in the K-12 knowledge building community as “KB Talk,” we found this to be an essential component early in the semester to help students better understand how to productively contribute to knowledge building. One example is the first KB Talk meeting with Group 4 in 2011.

In this meeting students were first asked to reflect upon their progress in improving their collective understanding. After some probing it became clear that were frustrated because they were having trouble making progress on their chosen question. The students were then asked to brainstorm how their discourse could be improved. There was much discussion about what they had learned so far; why they were stuck; what made a good kb question and ways to improve their question; how their initial general questions needed to be more specific; the need for organizing their notes in more productive ways; the need to find new types of authoritative resources; ideas about how they wanted to interact differently to make better progress; etc. They were clearly engaged in a key element of knowledge building—metadiscourse (discourse about the discourse). Also discussed within the context of their own discourse were several other knowledge building elements: rise aboves (creating higher level concepts that rise above the discourse), question refinement and going in new directions, the nature of knowledge building (as opposed to sharing ideas), etc. Because they were already discovering the need for these elements through their initial unproductive discourse, the instructor’s role was to help them clarify and improve their ideas.

A variety of other topics flowed naturally throughout this one-hour meeting: what is deep understanding and what this means for them as learners, the functioning of knowledge organizations such as Apple or IDEO, the future of engineering, the conceptual design of Knowledge Forum, etc. During the meeting it was also clear that students began to take ownership of their knowledge building and began to see knowledge building as a chance to be creative and explore their questions with like-minded individuals. This resulted in a positive attitude towards knowledge building.
The Discourse

Throughout the semester each group developed an increasingly elaborate knowledge building space that included their notes and annotations, rise-abouts and new views (i.e. new spaces to expanded their knowledge building in an organized way. Figure 5 shows two examples and the students use of the drawing features to organize their work. In both 2011 and 2012 each group averaged over 200 notes organized within several to over a dozen different views. Once a question was formulated for each group after the first week, the notes became significantly longer, more sophisticated and often included extensive use of authoritative sources. While these sources were most typically research articles and books, many students also contacted experts in the field, local engineers and city officials. Particularly productive discourse often revolved around creating a list of questions to ask these individuals. Sometimes ideas from the authoritative sources completely transformed a group’s discourse. For example, after discovering the field of biomimicry from an authoritative source, one group completely transformed their discourse to focus on the use of biomimicry for improving building safety in a tornado. Because they could not find research studies in this area, they instead began to focus on biomimicry related to earthquake-proof design and began a substantial discourse comparing how earthquakes and tornados load a building.

Several common themes arose among the various discourse groups. The first is that almost every group had to improve their thinking about what is failure. While initially almost all participants viewed failure as a material rupturing, these naïve views became increasing sophisticated as the discourse progressed. For example, much discussion revolved about the topic of a building being destroyed by a tornado but leaving the inhabitants safe. Is that a failure or success? Another common theme among most of the groups was addressing ethical and socio-economic issues. For example, students investigating the design of a tornado-proof building (or safe rooms within a building) were concerned about the expense of such houses and would they be unaffordable to the poor. Many of the groups also grappled with the ethics and cost-benefit of designing buildings to withstand the unlikely event of a tornado. Finally, all groups engaged in metadiscourse both off-line and on-line. Figure 6 shows two examples of student metadiscourse notes. In the upper note the student is raising the point of revising their knowledge building question and in the lower note the student is summarizing and reflecting upon the group’s recent progress.

Knowledge building theory discourages requiring students to create artifacts such as final reports, posters or presentations because that is antithetical to idea-centered learning and often leads to “reduction to activity.” However, encouraging students to create rise-aboves that occur naturally from their discourse is consistent with knowledge building theory. In EGR 270 students were encouraged to regularly rise above the discourse in ways that fit their discourse. Students often chose to create conceptual artifacts such as group reflections, house designs or policy papers. A number of groups also decided to pull together what they had learned by designing and conducting wind tunnel experiments.
Figure 5: Example of a part of a group’s view late in the semester. The boxes with arrows inside the house indicate links to new views that contain extensive discourse and rise-aboves on that part of the house. Note: student names have been blacked out for privacy.
Figure 6: Excerpts from two student notes showing metadiscourse.
III. Assessment

Although we recognize much more must be done better understand the implementation and effectiveness of knowledge building in the classroom, the following data were collected to assess its effectiveness in EGR 270:

- **Student Survey.** Anonymous student survey focusing on the role of the teacher in the classroom administered on the first and last day of class.
- **Sequestered Problem Solving.** Students received the same final exam that was used in the course before the introduction of knowledge building.
- **Knowledge Forum Diagnostics.** Student participation in posting and reading notes was measured.

**Student Survey**

A key element of knowledge building is transforming the classroom from being teacher-centered to learner-centered. As a first attempt to assess if students viewed this transformation occurring in EGR 270, students were surveyed about the role of the teacher in the classroom. Their answers were then coded and the results are shown in Table 1. The table clearly shows a shift in students’ view of the classroom. Before taking the course, students focused more on the teacher playing the traditional role of being focused on paying attention to individuals, making the material interesting, demonstrating real life examples, providing resources and explaining clearly. After taking the course their answers focused more on the teacher being a facilitator who provides the big ideas for the course and the tools to help students solve complex problems, creates a robust learning environment, challenges students and their ideas, helps students who get stuck, facilitates collaboration and guides student to self-directed learning.

<table>
<thead>
<tr>
<th>Question: What is the role and responsibility of the teacher in advancing knowledge in this class?</th>
<th>Pre-survey</th>
<th>Post-survey</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pay attention to individuals</td>
<td>24%</td>
<td>3%</td>
</tr>
<tr>
<td>Explain clearly</td>
<td>31%</td>
<td>22%</td>
</tr>
<tr>
<td>Motivate students by making material interesting</td>
<td>24%</td>
<td>8%</td>
</tr>
<tr>
<td>Demonstrate real life examples</td>
<td>20%</td>
<td>5%</td>
</tr>
<tr>
<td>Enable students to apply concepts to various situations</td>
<td>9%</td>
<td>22%</td>
</tr>
<tr>
<td>Provide tools for students to solve complex problems</td>
<td>0%</td>
<td>19%</td>
</tr>
<tr>
<td>Provide fundamental (big) ideas</td>
<td>2%</td>
<td>14%</td>
</tr>
<tr>
<td>Provide resources</td>
<td>9%</td>
<td>3%</td>
</tr>
<tr>
<td>Create a robust learning environment</td>
<td>2%</td>
<td>14%</td>
</tr>
<tr>
<td>Guide students to self-directing their own learning</td>
<td>0%</td>
<td>11%</td>
</tr>
<tr>
<td>Challenge students and their ideas</td>
<td>9%</td>
<td>22%</td>
</tr>
<tr>
<td>Help students when they get stuck</td>
<td>0%</td>
<td>14%</td>
</tr>
<tr>
<td>Encourage creative ideas and innovation</td>
<td>7%</td>
<td>11%</td>
</tr>
<tr>
<td>Facilitate student collaboration</td>
<td>7%</td>
<td>14%</td>
</tr>
</tbody>
</table>

**Table 1:** Results of anonymous student survey conducted on the first and last day of class.
Sequestered Problem Solving (SPS)

The same final exam was used in the class from 2009-2012 and was not returned to the students. This provided two years baseline data and two years data with knowledge building. Scores on the final were almost identical and their difference was not significant. The average before knowledge was introduced to the class was found to be 81.9% and the average afterwards was found to be 81.3% (p-value = 0.71 on a two-tailed test). Thus although much time inside and outside of class was redirected towards innovation (i.e. knowledge building) and away from efficiency, the results of a key measure assessing efficiency did not change.

Knowledge Forum Diagnostics

Knowledge Forum includes tools for analyzing student participation and shows that all students in 2011 and 2012 participated significantly in the discourse. Figure 7 shows that the number of notes read by each student in 2011 ranged from 100 to 643 (mean = 202). In 2011 the number of notes post by each student ranged from 13 (one student who only posted 7 times left the class for medical reasons) to 76 (mean = 32). Additionally, many students used the annotations tool and some used Google Docs for creating rise-aboves. Results for 2012 were similar.

Figure 7: Number of Knowledge Forum notes posted and read for each student in 2011.
IV. Discussion

Innovation and Efficiency

EGR 270 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. The SPS final exam assessment provided no evidence that replacing efficiency with innovation negatively impacted student performance on traditional SPS 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. The design of PFL assessments is still a new area of research and we are beginning to design these for use in the 2013 class. Fundamental to these PFL assessments will be asking students to look at new situations and see what they notice, what fundamental principles apply to the situation and what they would need to learn more about. Also encouraging—although nonscientific—were the observations of the strength of materials instructor who teaches many of the EGR 270 students after they complete the class. She noted there was a very significant difference in the students’ ability to make progress on open-ended, complex problems after knowledge building was introduced in EGR 270.

Student participation in the knowledge building discourse is another measure of transfer-in since students must learn in order to improve their collective understanding. The recorded discourse shows that the determinants that define knowledge building¹⁵ 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 own way in order to advance the discourse. Student participation in knowledge building was 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 problems¹⁹.

The research on innovation and efficiency emphasizes the need for a greater emphasis in classrooms on innovation to help students develop deep understanding and to develop the capacity to transfer-in their understanding to a new situation. However, the same research also shows that the two are complimentary in the learning process⁴. For example, in EGR 270 innovation questions that students were exploring in knowledge building became examples used in the efficiency part of the instruction. Examples include calculating if a wind force will overturn a mobile home with and without hurricane straps and finding the wind force on a building. By including the questions that students were working with in knowledge building in the efficiency examples, students were clearly more engaged than when they were solving standard book problems. Another example is the use of material testing laboratories to measure the mechanical properties of building materials that students wanted to learn more about in their knowledge building. The reverse was also true. When new efficiency concepts were introduced, they quickly became a component of the students’ knowledge building discourse and helped it to advance.
Grading

How to grade a student’s participation in knowledge building remains a major challenge and is still being developed. Although Knowledge Forum provides a wealth of data not normally available to the instructor grading collaborative group work (i.e. a detailed record of the entire group discourse), this amount of data rapidly becomes overwhelming to the instructor. Our current practice is to assign a knowledge building grade as follows:

(20 %) Your level of contribution to the discourse on Knowledge Forum. To receive a high grade you will need to be an active and engaged participant throughout the semester.

(40 %) The quality of your contributions to the discourse. To receive a high grade you will need to make important contributions to your group’s discourse. One way to do this is to bring in new ideas, theories, authoritative sources, etc. But don’t forget that asking good questions, critiquing ideas, monitoring your group’s progress, putting ideas together to rise above the general discourse, etc. are equally important ways to contribute. Overall the key here is that you are helping your group improve its collective understanding, theories and designs—not just exchanging opinions.

(40 %) Write a two to five page essay explaining in-depth your understanding of one specific problem/idea that emerged from your group discourse. Below are a few steps to consider:

1. Reflect on how the knowledge related to this problem has advanced:
   • What were your initial thoughts about the problem?
   • What is your current understanding of it?
   • What are some key ideas that led to your understanding progressing and prompted further inquiry of the group?
   • How do they relate to idea improvement in some other knowledge building topics in your group?

2. Identify some current knowledge gaps and challenges around this problem.

3. Based on your response to question 2, formulate some more advanced thoughts and inquiries.

V. Conclusions

We have presented two years of the application of knowledge building into an introductory engineering mechanics class. It was found that all students actively participated and used the Knowledge Forum software. An analysis of the discourse showed that knowledge building took place—both because extensive idea improvement took place and because each of the determinants of knowledge building was met. Student surveys support that such an educational approach changed their perception of the teacher’s role in the classroom (and consequently the student’s role). Comparisons of final exam scores indicate that in spite of the increased emphasis on innovation, student scores on sequestered problem solving assessments (SPS) did not change. While this is a positive result, there is a clear need to develop preparation for future
learning (PFL) assessments to measure changes in the students’ capacity to transfer-in what they have learned to new situations.

VI. References

Appendix: Theoretic Narrative for EGR 270

Why Learn Mechanics in a New Way?

Many of the most interesting professions—such as engineering—are rapidly changing. Globalization and the need to constantly innovate in a knowledge economy are two of the powerful forces behind this change. According to the National Science Board, companies will no longer be looking just for analytic skills when interviewing you for an engineering job. They will also be looking for passion, adaptability and an eagerness to learn. They will want you to be an innovator who can collaborate effectively in interdisciplinary and multicultural environments. EGR 270 is designed to prepare you to do just that.

It is well known that focusing entirely upon solving idealized book problems doesn’t help you develop the deeper understanding needed for interpreting the complex situations that you will face in the real world. Learning how to figure out what information is important, how to frame a problem, what simplifications are needed, and what still needs to be learned are critical to your success in engineering. The good news: research shows that you can develop this deeper understanding through collaborating with peers to better understand and innovate solutions to real-world problems. I hope you take full advantage of this way of learning in EGR 270 to be creative, have fun and expand your mind.

What Will You Learn in EGR 270?

EGR 270 has three intended learning outcomes. The first focuses on learning basic technical procedures and underlying concepts. The second goes beyond a basic understanding and focuses on developing an ability to work creatively with mechanics ideas—i.e., to innovate. Finally, the third outcome focuses on developing the 21st century skills that knowledge organizations are looking for.

Outcome #1 – You will develop an efficient command of the basic information, procedures and methodology needed to understand the mechanical behavior of an object under loading.

The subject of EGR 270 is understanding how an object responds when forces are applied to it. You already have an intuitive sense for the subject, as well as problem-solving skills from your physics and calculus classes. What will be new in EGR 270 is putting all of your current ideas together in a way that makes sense, that helps you to understand new phenomena, and that allows you to calculate numerical values.

Seeing the big picture is extremely important part of learning. In EGR 270, we will use maps to help you connect the concepts. Figure 1 shows a map that connects all the concepts in EGR 270. If you look closely at the horse map, you will see that the mechanical behavior of everything—airplanes, bridges, and even our bodies—is based on how three elements interact. These are the material and shape (i.e., geometry) of an object and the loading acting on it. For example, imagine pulling on a steel wire. Your loading causes internal forces to develop inside the wire; these forces can be calculated. We can account for the shape of the wire by dividing the internal forces by the cross-sectional area of the wire. This results in a new term called stress. Once we know the stress, we can then calculate how the wire deforms by seeing how the material (steel) behaves in laboratory.

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testing with the same amount of stress. There is much more to it, but this is the basic idea to get started. We will learn in EGR 270 about each of these three elements and how they are connected.

![Figure 1: The “Horse Map” showing how all the concepts in EGR 270 are connected.](image)

**Material**

You already know how many materials respond to loading: rubber can be stretched and returned to its original shape, glass is brittle and water can easily flow. By quantifying these responses, we can better understand and predict how a material will behave. Normally we do this by using a machine to apply a load to an object made of the material and then plotting the force and deformation that result. To make the testing results more general and useful we then can plot the stress (force/cross-sectional area) versus strain (deformation/object length). Figure 2 is an example of this curve and a diagram that we will use regularly to organize our thoughts. There is much more that you can learn about material behavior in our advanced mechanics courses and beyond, but no idea is more important to an engineer than stress-strain.

![Figure 2: Stress versus strain curve.](image)

**Loading**

From using Newton’s Laws in physics you already have the basic concepts needed to understand loading. We will be using Newton’s Second Law for translational and rotational motion \((F_{net} = ma)\) and \((\tau_{net} = I\alpha)\) repeatedly to solve for unknown forces and torques (engineers call torques “moments”) acting on an object. Since we will mainly be looking at objects in equilibrium, these equations often simplify to \(F_{net} = 0\) and \(\tau_{net} = 0\). So what is going to be new? Early on we will review and build upon your current understanding of torque to calculate it in a variety of increasingly complex situations. You will then be ready to apply Newton’s 2\(^{nd}\) Law to find unknown forces acting on a single object (like a bone or a beam), to systems of objects (like your skeleton or a building) and in three dimensions. Finally, we will apply Newton’s 2\(^{nd}\) Law to calculate and plot the forces and moments inside an object. Because we can integrate loading to find internal forces and moments, this is a place where calculus will come in handy.
Geometry

One way to increase the strength of a bone or a beam is to increase its cross-sectional area. However, area is not the only factor; you also need to consider the shape of the cross-section. For example, steel members with a cross section shaped like an “I” are common because that shape is better at resisting bending. In EGR 270 you will learn how to calculate two shape parameters: centroid and moment of inertia. This is another topic where we will use calculus.

Outcome #2 – You will be able to use your knowledge in innovative ways.

Innovation is our best hope for solving many of the most important problems facing the world—such as developing sustainable energy sources or feeding the hungry. As an engineer, you will be a key part of a knowledge economy in which success lies in constantly improving ideas. A great deal of evidence indicates that the best way to prepare for such a career is to participate in knowledge building (see sidebar below). In knowledge building the focus will be on creatively working with ideas to improve them through discourse and collaboration. This is exactly what innovation is all about. The focus of knowledge building in EGR 270 will be your questions about a tornado that struck near Northampton last year (see Figure 3). You will investigate damaged neighborhoods, talk to the people affected, and process many sources of information as you collaborate to improve your understanding and create new ideas and designs.

What is knowledge building?
EGR 270 will be based around your participation in an interactive discourse with your classmates to share knowledge, reformulate problems, and continually improve your collective ideas and understanding. You will be working on real world questions, such as Can engineers better protect people from natural disasters such as tornadoes and earthquakes? In this process you will post your ideas using software called Knowledge Forum, organize into working groups that will grow and change based upon your interests; create higher-level concepts that rise above the discourse; and engage in a meta-discourse that assesses community progress in knowledge advancement. I’ll be there to help you every step of the way, but I won’t be the arbiter of knowledge. You and everyone in the class will be counted upon to improve your competencies needed to participate in a knowledge organization.

Figure 3: On June 1, 2011, at least seven tornadoes hit the Pioneer Valley. One of these was a strong EF3 tornado that killed three people, injured hundreds and left many more homeless. The damage was well over $100 million dollars and resulted in about 700 housing units being uninhabitable.
You may have watched the IDEO *Deep Dive* video in EGR 100. Here is what IDEO’s CEO, Tim Brown, looks for when hiring:

Many designers who are skilled technicians, craftsmen, or researchers have struggled to survive in the messy environment required to solve today’s complex problems... A creative organization is constantly on the lookout for people with the capacity—and just as important—the disposition for collaboration across disciplines.²

In EGR 270 you will develop the capacities and disposition that companies like IDEO are looking for through you participation in knowledge building. Some examples include learning how to:

- Participate in discourse that not only shares knowledge, but also refines and transforms knowledge
- Treat all ideas as improvable and improve their diversity
- Negotiate and work toward effective collaboration
- Work toward broader reformulations of a problem
- Participate in a meta-discourse that monitors the progress made by the group

These outcomes are closely related to the EGR 270 course outcomes reported to ABET for accreditation.

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