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Theoretic Stories: Creating Deeper Learning in Introductory Engineering Courses*

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Used properly, narrative can be an effective approach to communicate meaning in a way that engages the imagination of a student. The kind of narrative structure that is most appropriate for college students, especially in subject areas such as engineering and science, involves theoretic thinking, a sense of abstract reality, and meta-narrative. In this paper, we describe the application of theoretic story in two engineering classes. In a sophomore-level introductory course in mechanics, a program-level story and a course-level story were used to frame how the mechanics concepts fit together and how the course fit into an engineering education. In an upper-level elective course in modeling, a narrative about Alan Turing was used to seed Knowledge Building and the course objects were restructured to help frame learning. An assessment of the two courses showed increased student performance, high levels of engagement, transfer in and transfer out of subject areas, and other indications of deep learning.

Keywords: story; narrative; engagement; artificial intelligence; mechanics

1. INTRODUCTION

THERE IS a general consensus among economists and organizational theorists that we are living in an economy built upon knowledge work [1, 2]. However, traditional instructional practice has failed to prepare students to participate in this new type of society [3]. Knowledge building is particularly important in engineering education. The ability to be an effective participant in a community or organization dedicated to the creation of new knowledge is critical for engineers who will encounter multiple global challenges in the 21st century [4]. In this paper we present the application of theoretic story in two courses in the Smith College Engineering Program as an attempt to help address these failings. The Picker Engineering Program, founded in 2000, is the first engineering program established at a women's college in the United States. Students in the Picker Program earn an engineering science degree that focuses on developing a broad understanding of engineering principles and integrating them across conventional disciplines.

Within this context, Engineering Mechanics (EGR 270) focuses not only on helping students learn how to solve problems traditionally emphasized in introductory engineering mechanics courses, but also on the development of deep conceptual understanding and the organization of knowledge in a way that supports application and future learning. In Techniques for Modeling Engineering Processes (EGR 389), students learn to model engineering processes using artificial intelligence (AI) and statistical approaches. As in EGR 270, the goals for the course go beyond developing technical skills to include developing a level of conceptual understanding that allows them to apply their knowledge adaptively, an understanding of the interdisciplinary nature of AI, and an improved capability to participate in Knowledge Building. To meet the learning goals of each course, instructional strategies beyond traditional practice are clearly required. The use of theoretic story for increasing engagement and encouraging deep learning is one of these strategies.

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2. THEORY

Good teachers have always undertaken the challenge of helping their students achieve deep learning or learning for understanding. The publication in 2000, by the National Research Council, of *How People Learn* [5] placed paramount importance on deep learning or understanding as the quality of educational objective likely to have the greatest long-term benefit to students. Sawyer [1] notes that learners 'retain material better, and are able to generalize it to a broader range of contexts, when they learn deep knowledge rather than surface knowledge, and when they learn how to use that knowledge in real-world social and practical settings.' Deep learning means that students are able to use their knowledge interpretively; that is, use knowledge in new ways, in new contexts, and in ways that support future learning [6].

A great deal of research and development in learning science investigates how people develop understanding and how educational environments can be designed to best support this kind of learning. There is a growing consensus that the most important problems facing students, as they emerge into today's knowledge age, will require intense collaboration around the creation of new knowledge. Engineers will need to be able to participate in what Bereiter [3] describes as a 'demanding sort of discourse, which presents problems in keeping things moving forward without shutting out objections and divergent ideas and in taking into account relevant facts without getting overwhelmed by complications.' For demanding and extended discourse to take place in classrooms, it is critical that the instructor creates a learning environment in which students are consciously and purposefully engaged in knowledge work. In other words, successful knowledge work requires students to *care* about the problem. While students want to do well in their courses and they do care about solving the academic problems they encounter in order to do well, this type of engagement is far different from the intentional engagement that knowledge work requires. Purposeful engagement depends on students having learning goals; these goals are the purpose. Setting and making use of learning goals calls for students to employ sophisticated metacognitive skills. (See Bereiter [3]; Bereiter & Scardamalia [7, 8]; Scardamalia and Bereiter [9, 10]; Scardamalia [11] for more information on knowledge building pedagogy.)

Bereiter and Scardamalia [12] use the term 'intentional learning' to distinguish students who have learning as their goal from students who have task completion or performance as their goal. When students have a task completion or performance orientation, learning in school is incidental rather than intentional. Students want to achieve good grades and focusing their actions and efforts on getting their schoolwork accomplished is often the best way to do this. There is nothing inherently wrong with incidental learning; we are constantly learning without consciously intending to do so. If doing well in school required innovation, far transfer, and deep thinking, students might (and sometimes do) achieve understanding-type outcomes as an incidental consequence of those requirements. However, school assessments tend to emphasize repetition and routine application of knowledge rather than interpretive (i.e., deep) uses of knowledge. When one views learning as schoolwork, emphasis is placed on efficiency rather than innovation [6]. School tasks not only lead away from deep learning, research indicates that students seek ways to accomplish school tasks that do not involve any (emphasis ours) kind of learning [13]. Shifting educational outcomes from routine, memory-oriented, and incidental learning will require students to set goals that go beyond doing well or achieving in a narrow or shallow sense.

Helping students become intentional about learning for understanding is challenging beyond having to overcome their routine ways of approaching learning. Helping students set new learning goals is difficult because describing what understanding or deep learning means, with any precision, is difficult. While we use the term almost every day, understanding is not readily defined. People may believe that they know understanding when they see or experience it, but most people have a very hard time putting a particular understanding into words. Learning scientists recognize that rather than being a singular quality, understanding has varying levels or depths. Most current approaches to stating educational objectives avoid the use of understanding altogether and instead use or substitute skill-oriented or performance language to describe learning goals. Many educational approaches to understanding first ask 'what learners will be able to DO, if they understand.' The problem is that understanding does not reduce to skills in any neat way; said conversely— no collection of skills necessarily add up to understanding. Using the terminology and epistemology of skills encourages students (and teachers) to cling to performance goals and does not provide students with the framework they need to become intentional, reflective, and deep learners.

Becoming an intentional learner is an achievement rather than an ordinary or expected development on the part of learners [12]. This paper focuses on two essential components that support intentional learning in the context of engineering education. One component is the motivation necessary for students to want to go beyond the requirements of schoolwork. The other component is having a conception of learning (an epistemology) useful for setting learning goals that includes understanding.

Typically the sequence of instruction in science and engineering courses begins with discrete bits of content with the hopeful intent that these bits will accumulate, meld, and make sense at the course's conclusion. Unfortunately without a framework or organizer that provides a bigger picture, students cannot formulate deep learning goals, nor can they reflect on their developing knowledge and progress toward understanding. Rather than focusing on the big conceptual picture, student goals are focused on acquiring these discrete outcomes on, almost, a week-to-week basis. Helping students, who are essentially novices when it comes to a course's content, to adopt a 'big picture' perspective for their learning is a tall order.

Schwartz et al. [6] make a distinction between transfer out and transfer in. People bring knowledge into learning situations and this knowledge has a very consequential impact on what and how people learn. Knowledge brought into a learning situation is what they call 'transfer in'. The knowledge transferred in guides learner thinking as they decide what is important and what to attend to in a new learning situation. Transfer in also shapes the learning goals students create for themselves.

'Transfer in cannot always rely on access to previously acquired knowledge schemas, skill sets, or replicative facts that can easily be brought to bear on a new learning situation. To deal with this phenomenon, effective teachers often help students assemble new 'platforms for subsequent learning.' [6] Conceptual maps have been shown to be effective tools for scaffolding the creation of an interpretive framework that students can use to focus on the big picture of a course [14]. Another tool that can help students transfer in, one mentioned explicitly by Schwartz, et al. [6] and Bereiter [3], involves the use of the imaginative framework developed by Egan [15]. Egan sees teaching as storytelling; however his stories are not intended to teach new content but to set the stage for learning.

Story is not new. It has long been applied as a tool for communicating understanding to students [16]. Stories are powerful culture-shaping communications that address questions without compromising their complexity. They ground complicated concepts in concrete terms and connect abstract ideas with emotions and events [17]. Bruner [18] notes that the narrative mode, the telling of stories, is how human beings express their understanding of the world. Schank [19] urges the use of story in teaching and describes all communication as story exchange. He views story as central to human learning and the primary means learners have of relating their existing knowledge to the new ideas they are learning. Teaching often involves the use of many examples, experiences, and demonstrations and they need to be tied together in a coherent way for them to have educational value. Students cannot be expected to impose coherence. Teachers—who know what the examples are supposed to teach—need to draw out the implications and reveal the conceptual thread or story that ties them together [3]. E. O. Wilson [20] writes about the power of story for understanding science and notes that we all live by narrative, every day and every minute of our lives. He describes narrative as the human way of working through a chaotic and unforgiving world. Storytelling is not something we just happen to do. It is something we have to do, if we want to remember anything at all. Researchers (in cognitive psychology) have learned that stories—both the ones stored in our memories and those we generate as we interact with the world—are essential to all aspects of learning

Egan [15] equates teaching with storytelling and views the engagement stories afford as an essential element of learning for understanding. According to Egan, used well, narrative not only conveys a coherent view of understanding but also can engage students' imaginations. Imagination is a way to address student motivation. Egan describes different kinds of stories and accompanying conceptual tools that are particularly suited for learners at different ages. Student thinking develops and progresses through stages of oral language, literacy, theoretic thinking, and ironic thinking [21]. The tools associated with earlier stages are supplemented by more sophisticated tools. Tools of theoretic thinking—such as a sense of abstract reality and a sense of personal agency in understanding—become part of a student's conceptual toolkit, joining tools of literacy, such as metaphor, imagery, and humor. Students use the growing toolkit as they encounter more complex narrative structures. The kind of story or narrative structure that is most appropriate for college students, especially in subject areas such as engineering and science, involves theoretic thinking, a sense of abstract reality, and meta-narrative.

> Theoretic thinking is the development of this new world of abstract ideas and the growing ability to think in terms of these abstractions, and then connect the results of abstract thinking back to the concrete world. [21]

The work reported in this paper employs narrative and conceptual tools in the manner of Egan, along with visual representations of ideas (i.e., conceptual maps) in order to convey the big picture in engineering mechanics and modeling courses. Students are encouraged to use the big ideas to set learning goals and to reflect on their progress toward understanding throughout the course.

3. APPLICATION IN THE CLASSROOM

3.1 EGR 270 engineering mechanics

EGR 270 is a four-credit, semester-long course that is largely populated by sophomore engineering students. Twenty-one students were enrolled in the course in Fall 2008. Learning goals for the course include:

- Achieving a conceptual understanding of how loading, geometry and materials properties affect the behavior of a continuum
- Calculating internal and external forces for 2D and 3D mechanical systems in static equilibrium; centroids and moments of inertia; and normal and shear stress and strain
- Developing professional skills including report writing, video production, engineering ethics, and teamwork

In an introductory mechanics courses like EGR 270, it can be all too easy for students to learn problem-solving procedures while losing sight of how these procedures relate to fundamental concepts, how the concepts fit together or how the concepts can be applied in a modern engineering context. Students may then be unable to apply their knowledge outside of a limited domain of idealized situations, which can inhibit future learning [14]. Two theoretic stories were used to frame the learning in the course, with the goal of helping students (1) see how the theories, laws and concepts that constitute engineering mechanics fit together, (2) see how engineering mechanics fits into each student's engineering education, and (3) scaffold metacognitive activity by helping students formulate learning goals for themselves. These theoretic stories can be summarized as:

- Program-Level Story: To be globally competitive in the knowledge age, engineers must provide high value. They need to develop an integrated understanding of a variety of complex subjects, be able to apply this knowledge in innovative ways, communicate effectively through a variety of media, provide leadership and engage in life-long learning.
- Course-Level Story: The mechanical behavior of solids is governed by the complex interplay of loading, geometry and material properties. Fundamental principles from science and mathematics underlie this relationship, and engineering approximations and simplifications are used in its application. A deep understanding of this relationship allows engineers to recognize how to apply it correctly in a variety of situations.

Together these stories framed the learning throughout the course.

3.1.1 Program-level story

The program level story is introduced to students on the first day of class through a discussion of the report *Moving Forward to Improve Engineering Education* by the National Science Board [22]. Students discuss the changing nature of engineering and engineering education, how their program fits into that change and how this impacts their education and future. After the first class the themes in the program level story are revisited often; these themes impact and frame much of the learning that takes place throughout the class. Examples include discussions on meaningful learning and how experts approach problem solving in mechanics; an emphasis on relating mechanics concepts to conservation laws for greater generalization; the production of an educational mechanics video that integrated communication, technology, and learning; laboratories and homework assignments that required defining, scoping and framing open-ended problems; and an ethics case study. Also, collaboration is encouraged throughout the course and student portfolios encourage reflection.

3.1.2 Course-level story

One strategy for helping students see the big picture of how concepts fit together is a concept map. Figure 1 shows a map created for EGR 270 that illustrates how the mechanical behavior of an object is related to the loading, material, and geometry of the object. Ellis et al. [14] reported on the effectiveness of this map for helping students communicate ideas, see the relationships among concepts, solve problems, and support project work. Using the map allowed students to see the big picture from the beginning of the course. By contrast, students are typically introduced to engineering mechanics through an engineering statics course and must wait for subsequent courses to eventually bring meaning to their current course. Bereiter [3] writes, 'From an instructional standpoint, it is always unfortunate when students have to learn things first before they can appreciate their value. Motivation becomes difficult.'

In EGR 270 this 'bottom-up' approach is replaced by students learning about the big picture from the first day through the course-level story. The class begins with students working in teams to decide upon the safety of walking across a simple plank bridge set up in the classroom and to brainstorm the concepts involved in making their decision. While students can often list the major factors affecting the bridge performance, they have much more difficulty seeing how the concepts fit together or how they can be quantified. This leads to the introduction of the course-level story. Following the first class, students develop an increasingly sophisticated understanding of the story that includes how the concepts fit together and how they are quantified. They explore the course-level story through a variety of approaches throughout the class that include:

- Using the concept map that illustrated the story

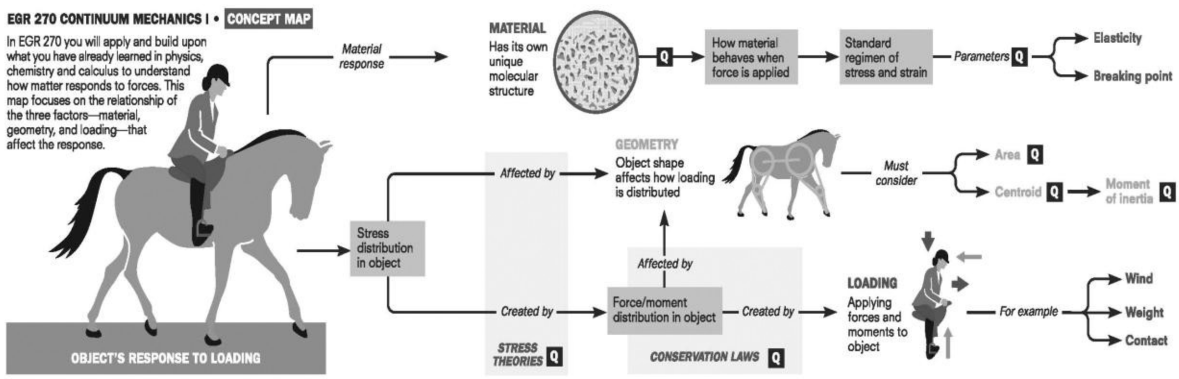

Fig. 1. Course concept map used in EGR 270 [23].

to introduce and connect concepts and to solve problems

- Beginning the course by investigating simple stress/strain problems that integrate all elements of the course level story (material properties, geometry and loading)
- Participating in classroom and laboratory activities in which students apply the story to increasingly sophisticated applications designed to promote discourse.
- Producing a short educational video about some aspect of the story for K-12 educators
- Completing a semester-long structural analysis of the Washington Monument in which all of the elements of the story are synthesized
- Completing homework assignments that require using the story to explain material behavior they observe in their daily life

3.2 EGR 389 techniques for modeling engineering processes

EGR 389 is a four-credit, semester-long course that is largely populated by junior and senior engineering students. The intended learning outcomes for the course include the following:

- Achieving a conceptual understanding of backpropagation, feed-forward artificial neural networks (ANNs), autocorrelation and autoregressive integrated moving average (ARIMA) models.
- Developing competence in constructing, training, testing and applying ANNs
- Developing competence in fitting ARIMA models to time series data and applying them for simulation and forecasting
- Developing professional skills including technical writing and Knowledge Building

Twenty students were enrolled in the course in Spring 2009. The following describes two applications of story used in EGR 389 to increase student engagement and frame learning.

3.2.1 Seeding knowledge building

Alan Turing is generally recognized to be the founder of artificial intelligence. The instructor used the story of his life to create the level of emotional and imaginative engagement required for Knowledge Building. A class period early in the semester was designated to be a special day to explore and celebrate Turing's life—beginning with his childhood, education and early signs of his genius; leading to his code-breaking and its impact on history; exploring his views on machine consciousness and the intense debates that followed; and concluding with his conviction on charges of homosexuality that led to his suicide by eating part of a cyanide-laced apple. The storytelling was interactive throughout and included two hands-on activities:

- Students played the gender imitation game presented in Turing's article 'Computing Machinery and Intelligence' [24] to help them better understand the Turing Test.[1]
- Students applied their understanding of the Turing Test in conversations with several chatterbots.[2]

Alan Turing lived an extraordinary life—he was not only a quirky genius whose work in computer science helped transform the way humans live, but also a tragic hero who was betrayed by the country that he helped protect in a time of crisis. Every effort was made to maximize the dramatic impact of his story and to help students put themselves emotionally in Turing's place when he wrote, 'I propose to consider the question, 'Can machines think?'' [24] As Bereiter [3] writes, 'Power 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 . . .' Now engaged, the students began a discourse in the next class in which they formulated their question for Knowledge Building. They chose to consider the question, 'What is machine consciousness and can a machine have it?'

3.2.2 Framing THE CONCEPTS

As is the practice in courses offered by the Picker Engineering Program, the intended learning outcomes for EGR 389 were formally presented in the course syllabus. Although the outcomes were expressed in language designed to be accessible to students, there was certainly no reason why they should have been engaging or comprehensible to a novice. To engage the imagination and help students see the big picture of where the class was headed, the outcomes related to technical content were recast in a way that engaged romantic understanding [21]. In this approach the students were cast as superheroes taking the class to develop four superpowers:

1. Seeing into the future
2. Creating alternative realities
3. Creating and teaching powerful artificial brains
4. Exposing robots that are visually indistinguishable from adult humans

These superpowers refer to the following:

1. Using ARIMA models to forecast future values of a stochastic process
2. Using ARIMA models to generate multiple realizations of a stochastic process
3. Finding the optimal ANN architecture and

[1] In the Turing Test a human interrogator engages in a text conversation with a human and a computer. If the judge cannot reliably tell which is which, then the machine passes the test. In the gender imitation game, a male and female try to convince the interrogator that they are female (or male).

[2] A chatterbot is an application of AI that attempts to simulate intelligent conversation and pass the Turing Test.

syntax weights through a regimen of training and testing
4. Developing an understanding of the Turing Test that includes a sophisticated questioning strategy (such as asking questions with ambiguous syntax that requires semantics to understand)

Various strategies were used to introduce each superpower on the first day of class. For example, to introduce superpower #1, students were shown a time series graph of monthly unemployment rates and asked to devise a strategy to predict future rates. Students compared their strategies in pairs and reported out to the class. For superpower #4, a video clip from the movie *Blade Runner* was shown. In this clip a replicant (a biologically-engineered humanoid that is visually indistinguishable from humans) was interrogated by a blade runner (a special police officer who hunts replicants). After watching the clip students were asked to place themselves into the role of the blade runner and consider what questions they would ask to expose the replicant as being non-human.

The superpowers had their greatest impact on the first day of class as a means of creating engagement and helping students see the big picture of what the course was going to be about. In fact the level of excitement generated on the first day was palpable. After their introduction the superpowers continued to be referred to throughout the course by both the instructor and students. They were used to help students see how the pieces of the class (such as learning about autocorrelation) related to the big concepts (forecasting and simulation) and gave students a language and context to express their thoughts. As students learned the concepts behind the powers and developed a more sophisticated language to describe the concepts, it is interesting to note that they stopped using the original language of the superpowers. They had simply outgrown their need to use the simpler terminology and way of thinking.

4. ASSESSMENT OF STUDENT LEARNING

Both quantitative and qualitative methods were used to assess how student learning was impacted by the teaching methods used in the two courses. Traditional quantitative measures such as exams, lab reports, and assigned homework were used to assess content learning. In addition a pre-post open-ended questionnaire, an engineering ePortfolio, a video production project, and a structural analysis project were used to assess student capacity to apply new concepts, communicate complex concepts to diverse audiences, and reflect and participate in their own learning process. Overall, the assessment process was used to gain an understanding of the extent to which students were able to 1) master course material, 2) engage in the learning process, and 3) develop a deep level of understanding. Although comparison data is limited for this pilot study, the student data collected and the experiences of the classroom instructor both suggest a strong potential for the approach and a need for further study.

The assessment data is reported separately for the two courses since somewhat different measures were used in each. The analysis includes an assessment of overall achievement as well as an assessment of engagement and deep learning. Achievement data provides an overall measure of competency. Such data is useful for drawing conclusions based on skill objectives, but it lacks depth. To obtain a more in-depth picture of student learning, we collected achievement data and analyzed student portfolios, reflections, projects, and responses to questionnaires. The information collected from these sources represents an undeniably complex set of qualitative data. Reduction techniques, as defined by Miles and Huberman [25], were used to organize and meaningfully reconfigure data. Qualitative data were then analyzed and coded based on general categories utilizing techniques outlined by Rossman and Rallis [26]. These methods allowed us to draw conclusions and verify findings across different data sets about the impact of narrative on student learning.

4.1 EGR 270 engineering mechanics

4.1.1 Course grades

An examination of quantitative measures showed that overall students did very well in Engineering Mechanics during the one semester that theoretic story was included in the course. As in previous offerings of the course, final grades were calculated based on student performance on tests, a video project, a structural analysis project and portfolio submissions. As the data in Table 1 indicates, the majority of students received grades of A or B and the GPA was 3.28. By comparison, in the previous seven times the course was offered (all but one with the same instructor), the GPA was 2.96. A two-sample t-test did not show the difference in GPA to be significant at the 95% confidence level ($p = 0.072$).

4.1.2 Engagement

The two primary methods of assessing engagement were (1) an analysis of student artifacts and reflections in their electronic portfolios and (2) student responses to course evaluations. Seventy percent of student portfolios referred to the impor-

Table 1. Final EGR 270 Course Grades

	Grade				
Course	A	B	C	D	F
EGR 270	10	7	3	1	0

tance of real world experiences in helping to understand the concepts learned. For example, one student indicated that she:

> found conceptual analysis questions extremely challenging. However, the more I practiced I become more observant of the physical phenomena happening around me and got better at applying concepts learned in class to day-to-day life . . . A strong conceptual understanding was required in analyzing the Washington Monument. I believe that the ability to apply concepts to real world problems [is] a stronger indication of learning than the ability to solve text book problems.

Excerpts from other student reflections were similar, for example:

1. I was very proud and knew that I really understand the concepts and was much less likely to forget or misunderstand them now.
2. I haven't just memorized procedures, but understand why we solve problems the way we do.

The real-world experiences that students refer to were generated from and understood with the context of the course-level story.

Projects exploring and applying the course-level story captured student interest in different ways. Some students expressed excitement about the concept maps or video projects, others the Washington Monument project, and still others about applying concepts to ideas they generated from their everyday lives. It should also be noted that not all students were reflective about the impact of course narrative. While seventy percent showed high levels of engagement in their portfolios, approximately thirty percent of the students provided little analysis or in-depth reflection, making it difficult to assess their level of engagement. However, end-of-course evaluations showed an overall high level of engagement. Seventeen of the twenty students who responded indicated the class almost always resulted in their leaving with new thoughts and /or new ways of looking at things. Two students indicated that this often occurred, while only one student indicated that this seldom occurred. Nine students indicated that their interest in the subject matter was high to begin with and sustained, while seven students indicated that their interest substantially increased and was sustained. Only two students indicated that their interest was somewhat or substantially diminished. Overall, course evaluations indicate that the majority of students were interested and engaged in course content both within and outside of the classroom.

4.1.3 Deep learning

Deep learning was assessed by examining the students' ability to 1) critically analyze new ideas, 2) link those ideas to existing knowledge, and 3) utilize them in problem solving in unfamiliar contexts—all of which are indicative of deep learning [27]. The following pre-post essay questions were used:

1. Describe the knowledge and skills that you think are important in order for you as an engineer to compete in the global marketplace.
2. You are given the task of reporting on the structural safety of Ford Hall (the building being constructed on Green Street). What are the 4 most important things that you need to consider in putting together the report? Explain each of these things in, at most, a paragraph.
3. A gymnast stands on a balance beam. Explain in your own words (but referring to the picture above [a gymnast on a balance beam]) how the beam responds to the loading depicted in the illustration (i.e. the gymnast is the loading).

Nineteen of the twenty-one students in EGR 270 filled out both the pre- and post- questionnaires. Pre-post responses to questions were analyzed based on categories including range of factors considered, level of analysis, use of technical language, and overall ability to utilize material learned in unfamiliar contexts. Responses to question one showed very little change between pre and post-tests. Both pre- and post-test responses mentioned the use of social and communication skills and technical analytic skills most frequently, with other factors such as leadership, ethical considerations, and changes in the world marketplace mentioned by fewer respondents. Overall, students demonstrated that they had considerable knowledge about the skills needed to compete in the global marketplace in both the pre- and post-tests. Post-test responses showed a slight increase in emphasis on understanding the environmental, cultural, and human factors involved in engineering problems. High levels of demonstrated knowledge and lack of change over the semester are not surprising giving the program's emphasis of the subject in all classes.

Responses to question two showed considerably more change between pre- and post-tests. The level of analysis and use of appropriate technical language increased for all but one of the nineteen respondents. Students demonstrated that they were able to utilize the technical concepts and terms learned in class and apply them to a new situation. In the pre-test the student responses were typically lists of unconnected ideas, while in the post-test the ideas were more likely to have structure—typically related to the course-level story. The level of sophistication in the post-test answers also increased. For example one respondent indicated in the pre-test that 'the foundation of the building needs to be examined to ensure that it is strong enough . . . the buildings wear and tear should also be taken into consideration.' While in the post-test she indicated that she would 'consider the factor of safety due to compression failure and bending failure. The factor of safety against compression failure tells us the maximum amount of compression the building can withstand. The tensile failure tells us the maximum amount of tensile loading the structure can withstand . . .' She goes on to discuss safety, force, and materials, clearly demonstrating an ability to coherently apply the concepts learned in the course.

The response pattern was similar for question three. The level of analysis, use of technical language, and ability to apply content learned in class to new situations improved considerably for eighteen of the nineteen respondents. For example, initial responses typically referred to the weight of the gymnast pressing down on the beam, the force of gravity, the support from end columns, and downward force. In contrast post responses referred to loading, reactions and internal shear force, bending moments, point loads, and net force. By effectively applying the technical concepts and language learned to this unfamiliar situation, students demonstrated understanding and the ability to transfer their knowledge. As in question two, students were much more likely to organize their responses in a structure resembling the course-level story in the post-test.

4.2 EGR 389 techniques for modeling engineering processes

4.2.1 Course grades

An examination of quantitative measures showed that overall students did very well in Techniques for Modeling Engineering Processes during the one semester that story was used in the course. Final grades were based on exams, homework, participation, Knowledge Building, and projects. As indicated in Table 2 the majority of students received an A for their course work. The GPA of 3.44 was found to be significantly higher than the combined 2.95 GPA of the four previous offerings of the course ($p = 0.032$) that were taught by the same instructor.

4.2.2 Engagement

As previously indicated two primary narratives were used in EGR 389 in order to create engagement, help students see the big picture, frame the concepts in language the students understood, and foster a deep level of learning. In order to assess these factors students were asked to respond to the following two questions:

1. The 4 superpowers were used to illustrate key concepts in this course. Describe the superpowers and indicate how they impacted your learning in this course.

Table 2. Final EGR 389 Course Grades

	Grade				
Course	A	B	C	D	F
EGR 389	12	5	3	0	0

2. Describe your thoughts about Alan Turing. How did learning about his life impact your interest in Artificial Intelligence?

Nineteen of the twenty students enrolled in EGR 389 responded to the questions—their responses clearly indicating that the majority thought that these two narratives positively impacted their learning. Fourteen students reported feeling more engaged as a result of the use of the concept of the superpowers. Twelve of the students reported that Alan Turing's story impacted their interest in learning about artificial intelligence in a positive way. Students indicated that the superpowers 'made it easier to enjoy the course, inspired me to test limits and learn more, and were useful in helping put what we learn in context . . . which can be lacking in other engineering classes.' Students thought that Alan Turing's story ' made us question the philosophical ideas and ethics surrounding our societal constructions about our perception/ understanding of the world, learning about him was one of the ways I learned to believe in the power of artificial intelligence, made it more fun, and fostered talking about artificial intelligence to friends outside of class.'

In addition, sixteen of the nineteen students who responded to the course evaluation indicated that the material covered in class almost always resulted in their leaving with new thoughts and/ or new ways of looking at things. Two students indicated that this often occurred, while one student indicated that it occasionally occurred. Twelve of the nineteen students reported that their interest in the subject matter was high and sustained and four students reported that their interest was increased and consistently sustained. Three students indicated that interest increased and was usually sustained and no students reported diminished interest. Overall, course evaluations indicate that the majority of students were interested and engaged in course material both within and outside of the classroom.

4.2.3 Deep learning

As discussed earlier, the use of storytelling and the imaginative framework is intended to promote 'transfer in' and set the stage for deep learning. There are several indications suggesting that deep learning resulted. First, all of the students who fully responded to the first question successfully named the four superpowers (several students only responded to how it impacted their learning). This is critical because student understanding of learning goals enables students to self-monitor and self-regulate their learning. It is interesting that thirteen out of nineteen students responded to the question using the concepts and technical language learned in the course instead of the original language provided by the instructor. Some students made direct links. For example, one student wrote, '1) see into the future—ARIMA forecasts . . . 2) create alternative realities—ARIMA simulations . . .'

Others bypassed the original language and explained the concepts in more sophisticated terms, '[I] learned to use ARIMA to model time series data, and using those models, make forecasts of future data.' About fifty percent of the students were able to critically analyze and reflect on their learning. It was clear from responses such as: 'I am better equipped to express my point of view, I am surprised at how far my thoughts and opinions have developed, and I am continually reshaping and restructuring my views to fit my new understanding' that students thought their learning had progressed beyond content skill development.

Evidence also suggests that the Turing narrative was successful in promoting deep learning by creating the emotional connection needed for Knowledge Building. Not only did almost all respondents use words such as 'fascinating,' 'interesting' and 'remarkable' when describing their thoughts on Alan Turing, but many also wrote about a more personal emotional engagement. One student wrote, 'I thought his story was very interesting and sad at the same time. It made me want to look further into AI.' Another wondered 'what makes them [geniuses] so special.' Several students made direct connections between Turing and their own lives—'his life gave me a greater appreciation for what a single person can do' and 'hopefully [I will] not be persecuted by my government for my personal life.' Assessing the deep learning that took place during the Knowledge Building is beyond the scope of this paper, however there are strong indications supporting that it occurred including: a record of collective theory revision that progressed from naive to sophisticated and nuanced; a record of intensive involvement by most members of the class in the theory development; a record of extensive student-guided research that integrated relevant outside sources into theory development; and student reflections and survey responses describing the progression of their learning.

5. DISCUSSION

The use of theoretic story involves a search for a 'bedrock of knowledge and beliefs' [21]. Such an approach can hold a great appeal in that it appears to completely explain how everything fits together. For example, in EGR 270, the course-level theoretic story attempts to explain how the interplay of loading, material and geometry determines the mechanical behavior of an object. But no matter how useful these narratives can be, they tend to run into limitations. Egan [21] writes: 'The aim of the educational process is recognition that metanarratives are always inadequate, always hopelessly less rich and complex than the reality they try to represent.' To illustrate his point, the EGR 270 course-level narrative includes approximations in the application of stress theories, treating the material as a continuum, some use of point loads, etc. Understanding where these theoretic limitations occur and their impact is a major component in the progression of novice to expert understanding of engineering mechanics. Thus it is the intention of the EGR 270 narrative not only to bring order to theory, but also to help students see its limitations (referred to as ironic understanding by Egan). It is interesting to note that when students answered the three pre-post questions for EGR 270, it was only in the post-test that students considered theory limitations. For example, in the post-test several students compared treating the gymnast as a point load versus a distributed load and discussed the implications. Narrative helps students to identify limitations, progresses understanding, and engages students in meaningful ways.

There is a growing recognition of the need to increase student engagement in the engineering education literature. As Smith et al. [28] write, there is a need for faculty to 'consider not only the content and topics that make up an engineering degree, but also how students engage with these materials.' They summarize the literature on a variety of classroom strategies for engaging the learner (such as active and cooperative learning, learning communities, service learning, cooperative education, inquiry and problem-based learning, and team project learning). Given that everything we teach has theoretic dimensions, the use of theoretic narrative is another strategy should be considered for increasing engagement. Adams et al. [29] provide a good example to the engineering education community of the potential of storytelling by presenting their personal journeys into engineering education research. They write that, 'By bringing the reader into our stories we seek to make visible and shared what we are collectively learning and to invite the reader to reflect on their own stories.' It is interesting that one of the co-authors, Karl Smith, writes that it was his Academic Bookshelf column entitled 'That reminds me of a story: The role of narrative in engineering education' [30] that received the most responses.

Engaging students is a key factor in meaningful learning and plays an important role in retention. Ohland et al. [31] found that the level of disengagement of all engineering undergraduates increased during their education and that this increase in disengagement happened more quickly for students who did not persist in engineering. This increasing level of disengagement is of particular concern in the retention of women engineers because studies have shown that lack of engagement is a more important factor for retaining women than it is for men [32]. In fact, Goodman et al. [33] found that half of the women in their study who left engineering said they left because they were not interested in engineering. In this article, Goodman et al. also raise a concern about reductionist engineering courses that omit intellectual and sociopolitical histories. They cite the work of Adelman [34] and Bleier [35] who showed that reductionist instructional approaches help discourage women from scientific fields. By contrast, it is exactly this richness of context that theoretic story brings into the classroom.

6. CONCLUSIONS

The use of theoretic narrative has been shown to be effective for increasing engagement and supporting deep learning in engineering. An assessment of its application in two different courses showed:

1. Increased student performance in terms of course grades
2. High levels of engagement and 'transfer in' that supported application, theoretic thinking and Knowledge Building
3. Indications of deep learning including 'transfer out' to new situations, self-reflection, successful goal-setting and self-monitoring in Knowledge Building

These results are consistent with research on the use of narrative in various educational settings; thus we feel that they are broadly applicable in engineering education.

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