# NEW PEDAGOGICAL APPROACHES IN ENGINEERING MECHANICS YIELD INCREASED STUDENT UNDERSTANDING, CONFIDENCE, AND COMMITMENT

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***Abstract* ¾ *The Picker Engineering Program at Smith College has formed a close partnership with Smith's Department of Education and Child Study and Department of Educational Outreach in an effort to fundamentally change the delivery of the engineering curriculum. This paper presents learner-centered educational strategies used in Continuum Mechanics I, a course that includes topics from engineering statics, dynamics, and mechanics of materials. Pedagogical elements used in this course include a variety of active learning strategies in the classroom, conceptual frameworks and narratives, project-based learning, metacognitive approaches, and an explicit effort to make a connection with other subjects in the liberal arts. An assessment of these strategies based upon the responses of 27 women who have taken the course is presented and shows that these strategies are effective in positively influencing student learning and attitudes.*

*Index Terms* ¾ *active learning, assessment, learner-centered, mechanics, metacognitive*

## INTRODUCTION

Drawing upon a broad research base and with strong implications for teaching, the National Research Council (NRC) has recently reported the following points as key to successful learning [1].

1. Students come to the classroom with preconceptions about how the world works. If their initial understanding is not engaged, they won't change or they may learn for the test and revert to preconceptions.
2. To develop competence in an area, students must (a) have a deep foundation of factual knowledge, (b) understand facts and ideas in the context of a conceptual framework, and (c) organize knowledge in ways that facilitate retrieval and applications.
3. A metacognitive approach to instruction can help students learn to take control of their own learning by defining learning goals and monitoring their progress in achieving them.

Based upon these findings, what should the student experience in an engineering classroom look like? Clearly these findings point to a learner-centered approach to teaching—that is, the teacher needs to be aware of and build upon the experiences and knowledge that each student brings to the classroom. Also, teachers must not only help students acquire a deep knowledge of the subject matter, but they also need to help them organize that knowledge in a useful way. Too often in the classroom it is left entirely to the students to put all the pieces together and see the big picture. Finally, teachers must help students to understand, evaluate and take responsibility for their own learning. This description rarely matches what takes place in the typical engineering classroom.

While the research findings on successful learning summarized by the NRC apply to all students, women are particularly at risk in the typical engineering classroom Similar statements can be made for underrepresented minority groups. Goodman, et al. [2] summarize the concern of engineering education reformers as follows: "the interests, socialization, and experiences of women (and other underrepresented groups) are often at odds with traditional engineering structures. These populations tend to flourish, on the other hand, in settings that emphasize hands-on, contextual, and cooperative learning." In their study of thousands of women engineering students in 53 participating institutions, Goodman, et al. [2] found the following:

- Half of all women leaving engineering programs cited dissatisfaction with the programs at their schools, including grades, teaching, workload and pace;
- One-third mentioned negative aspects of their school's climate: competition, lack of support, and discouraging faculty and peers; and
- One-half said they left because they were not interested in engineering.

Each of these reasons is closely related to the pedagogy used in the classroom and illustrates the potential for poor teaching to discourage women careers in engineering.

The Picker Engineering Program, established in 2000, is the first engineering program at an all-women's college in the United States. In addition to educating technically competent engineers, this program also aims to educate socially conscious engineers who will integrate engineering with the sciences and humanities. Indeed, the Picker

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Engineering Program Objectives (i.e., in the context of ABET 2000) include a broad sense of social relevance, with graduates considering the impact of their professional actions on society and applying their engineering education in service to humanity. To deliver the content of this curriuclum most effectively, the Program supports new approaches in the engineering classroom, an effort enhanced by a close partnership with Smith's Department of Education and Child Study and Department of Educational Outreach.

This paper presents educational strategies used in Continuum Mechanics I, EGR 270, a four-credit, semester-long course that is largely populated by sophomore engineering students. The aim of the course is for students to develop a strong conceptual understanding and problem-solving skills in a variety of topics related to the mechanical behavior of a continuum. Topics include 2-d and 3-d rigid body equilibrium, shear and bending moment diagrams, dynamics, vibrations, and an introduction to stress and strain.

## LEARNER-CENTERED APPROACH

Offered for the first time in 2001, EGR 270 was taught with a traditional approach combining three 50-minute lectures and one 180-minute laboratory/problem-solving session per week. In 2002 the course was fundamentally changed to emphasize learner-centered approaches in three 80-minute class per week. These changes are described below.

### Classroom Activities

Classroom activities were based upon the approach that best met the learning objectives of the class. While lectures were used when most effective, every class consisted of a variety of activities, including the following.

*Concept questions* similar to those described by Mazur [3] were used extensively. These questions were designed to reveal preconceptions and encourage small group discussions of concepts. For example, the study of moment of inertia was introduced by having students predict about which axis an angle-shaped column would buckle.

*Investigative case studies* encouraged the development of critical thinking skills as students applied their knowledge to understand real world phenomena. For example, in one case study students needed to apply their understanding of resonance to understand the engineering failures resulting from the 1985 Michoacan Earthquake in Mexico. Students were provided with a variety of evidence including acceleration time series and Fourier spectra of various ground motions and building motions, maps, geological information and a briefing of the damage at various locations. From this information they needed to explain the damage pattern throughout Mexico City and the rest of the country.

*Peer teaching* was used in a variety of ways. Student groups regularly presented solutions to problems worked in class. Student teams also taught their peers about dynamics when they presented an analysis of their own motion studied in one of the course projects. Peer teaching also took place in smaller groups. For example, because of the differing backgrounds of students entering the course, only half of the students had already derived the motion of damped and forced oscillators in a mathematics class. These students were asked to teach the derivations to their classmates who were unfamiliar with the material. Through this activity both sets of students learned and were challenged.

*Hands-on activities* were used regularly in the class to help students develop a feel for concepts. For example, in one activity students pulled various candies apart and compared their deformation behavior.

*Group problem-solving* activities were used in most classes. In these activities students typically worked in small teams to solve a problem that synthesized the content presented earlier in the class. Students benefited from the opportunity to apply what they had learned in the class and assess their learning. By working with their peers and receiving help from the instructor, students left each class with increased understanding and confidence in the new content. This also proved to be a valuable form of regular feedback for the instructor to help inform the teaching in future classes.

*Unstructured time* allowed students to have a say in directing classroom activities to meet their learning needs. They typically used the time to design and solve problems containing elements confusing to them.

### Conceptual Frameworks

Conceptual frameworks were used extensively to help students see the big picture and effectively organize their knowledge. Included were both a succession of increasingly sophisticated concept maps showing the relationship among the major concepts in the course (the final map is shown in Fig. 1) and a Newtonian mechanics micro-framework (see Ellis et al. [4,5]). The course maps were used to place each new topic in context, to illustrate the relationships between topics, as a problem-solving aid, and as a communication tool. The Newtonian mechanics framework was used as a problem-solving tool. Ellis et al. [4] provides a detailed discussion of the development and use of these two frameworks in the course.

In addition to conceptual frameworks, narratives were also used to help students develop and understand the big picture. This began on the first day of class when students were asked to write about (1) how the course fit into their engineering education and (2) their thoughts about the major concepts needed to understand the mechanical behavior of materials. At the end of the course they were asked to write a narrative explaining the important ideas of the course illustrated with examples.

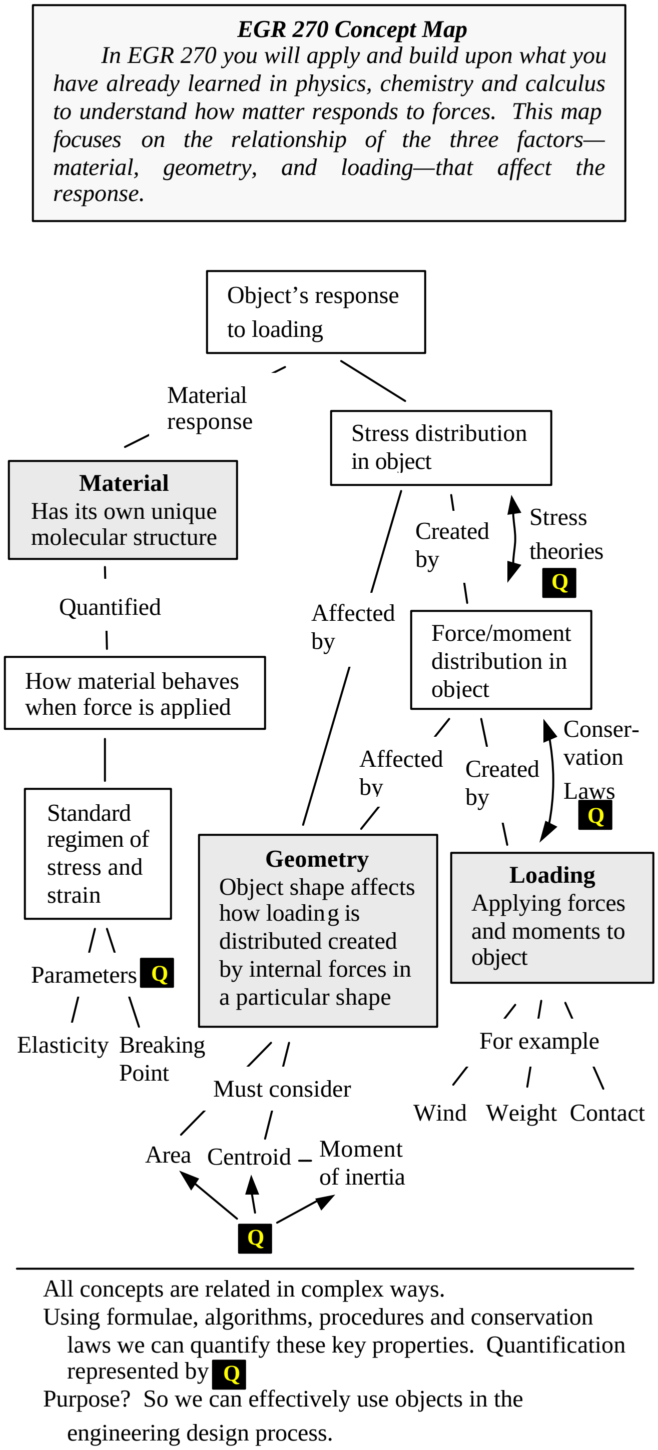


FIGURE 1
CONCEPT MAP USED TO STRUCTURE KNOWLEDGE IN EGR 270

## Project-Based Learning

Three major projects were assigned in the course to help student apply the concepts learned in classroom. In one project students videotaped their own motion in an activity that interested them (often athletic), used VideoPoint software [6] to measure and model the motion, and then gave a presentation of their findings to the class. In the second project students used the West Point Bridge Designer software [7] to design a truss bridge that most efficiently met the constraints of the project. In their final project students calculated the safety of the Washington Monument for various failure modes.

## Metacognition

Throughout the course an effort was made to educate students to become intentional learners, i.e. to use cognitive processes that have learning as a goal, instead of an incidental outcome (see Bereiter and Scardamalia [8]). How to learn effectively in the course and the purpose of each activity in the learning process was made explicit to the students. Rubrics were included with all assignments to focus students toward constructive effort.

Students were also given opportunities to make choices about their learning. For example, students were allowed to choose homework problems from a list that included a range of content and difficulty levels. The students had to decide which problems covered the content they needed to practice and at the difficulty level that was best for their needs. A homework rubric emphasized constructive effort toward learning. In this rubric the level of effort counted for 50%, starting solutions from a conceptual framework and demonstrating conceptual understanding of fundamental ideas counted for 20%, and correctness and presentation each counted for 15%.

An important part of learning is to reflect upon the activities in the learning process. To help students develop this habit, they were asked to write reflections after each of the projects. In these reflections they wrote about what they did well and wanted to continue and what they wanted to improve in future efforts. These ideas were discussed in groups and assembled into a reflection for the entire class. Ideas ranged from time management and group skills to how to include supporting data most effectively or write a sound conclusion. This reflection supported students working together to improve their learning in the course; their efforts will also be used to inform future classes.

## Integrating Engineering in the Liberal Arts

The Picker Program provides opportunities for engineering students to take a substantial number of courses throughout the liberal arts college—and also strives to integrate the liberal arts into the engineering courses. For example, in the study of dynamics students not only learned about the mechanics of the fouetté turn, grande jeté, and arabesque used in ballet, they also were given the chance to experience these moves under the guidance of a dancer. In this activity students applied their understanding of dynamics to understand the technique used in each of these moves. In a homework assignment based upon the classroom activity, students used VideoPoint [6] software to analyze why dancers have the illusion of floating during a grande jeté.

Another example is the 1985 Michoacan earthquake investigation discussed earlier. Following the investigation of the mechanics that led to the tragedy, students were asked to write a paper on the effect that the engineering failures in the earthquake had upon Mexican society.

## COURSE ASSESSMENT

A variety of assessments (pre- and post-course attitude surveys, mid-semester formative assessment, and post-course written surveys and focus groups) were administered to measure the effectiveness of the new approaches introduced into EGR 270 class in the fall of 2002.

At the midpoint in the semester students completed a brief written survey to ascertain, for example, how helpful the use of conceptual frameworks was to their learning. All respondents to this survey were in agreement that the course concept map was helpful to their learning. In focus groups conducted at the conclusion of the course, this was further echoed in student comments such as "He (the professor) makes a point at every new chapter to go through the concept map and say 'so we learned how to do this, which means we can now do this, which relates to this' and it makes everything make sense." Further, in a post-course questionnaire, 92% of respondents in the fall 2002 EGR 270 class agreed with the statement that 'the course goals and objectives were clear' whereas only 60% of EGR 270 students agreed with this statement in fall 2001.

Students responded enthusiastically to the hands-on, project-based learning approaches taken in the fall 2002 EGR 270 course: "It's exciting to be able to apply what we've learned." "People could take anything they do in their life and analyze it very specifically in terms of how it works physically. There's no better way to get outside of the textbook." When asked in post–course focus groups to identify factors critical to their learning in EGR 270, student comments revealed the impact of the metacognitive approaches taken, for example, in the homework assignments: "He (the professor) set up a rubric so that if you do the problem all out and follow each step, you get a certain number of points. He really wants to see you follow the steps and what he taught you, instead of just concentrating on the right answer. The right answer is only worth, like, four points." "He wanted us to learn and he gave us problems that he knew would teach us what we needed to know."

In a post-course survey 63% of respondents in the EGR 270 class in fall 2002 agreed with the statement that "the forms of evaluation in the course were excellent" in comparison to only 25% of EGR 270 students who agreed with this statement in fall 2001. To assess mastery of content knowledge, students in 2001 and 2002 were given a final course examination. Approximately two thirds of the questions on these exams were identical. Based upon an evaluation of student performance on these questions, 86% of students in 2002 demonstrated mastery of the course content knowledge in comparison to 82% in 2001. Furthermore, when asked in post-course surveys to rate their achievement relative to specific learning objectives outlined in the course syllabus, students in the 2002 EGR 270 course agreed strongly that learning objectives were achieved (Table 1).

TABLE I
STUDENT PERCEPTIONS OF LEARNING OBJECTIVES IN EGR 270, FALL 2002 (BASED UPON THE RESPONSES OF 25 OF 27 ENROLLED STUDENTS)

| | LEARNING OBJECTIVE | STUDENTS WHO AGREE OR STRONGLY AGREE |
|---|---|---|
| 1 | I have developed a conceptual understanding of how loading, geometry, and material properties affect the mechanical behavior of a continuum. | 100 % |
| 2 | I have developed problem solving competence based upon fundamental principles in calculating internal and external forces for statically determinate 2D and 3D mechanical systems in static equilibrium. | 96 % |
| 3 | I have developed problem solving competence based upon fundamental principles in calculating internal and external forces for calculating centroids. | 92% |
| 4 | I have developed problem solving competence describing the behavior of damped and forced vibrating systems. | 40 % |
| 5 | I have improved my understanding of calculus and physics through their application. | 88 % |
| 6 | I have improved my skills in oral, written and visual communication. | 64 % |
| 7 | I have improved my ability to work effectively in a team. | 80 % |

*Students responded on a five-point scale ranging from 1 (strongly disagree) to 5 (strongly agree).

In post-course surveys, 83% of students in 2002 reported that their interest in the subject matter was sustained or substantially increased by the instructor's approach as compared to 65% of students in 2001. Most remarkable however, were the results of our affective measures of students' confidence in their skills, abilities and knowledge in math, physics and engineering pre- and post-course. As illustrated in Fig. 2, students felt significantly more confident in all of these fields following their participation in EGR 270. Of particular note is the dramatic increase in confidence in engineering (11% to 81%) accompanied by a rise in commitment to a career in engineering (56% to 69%).

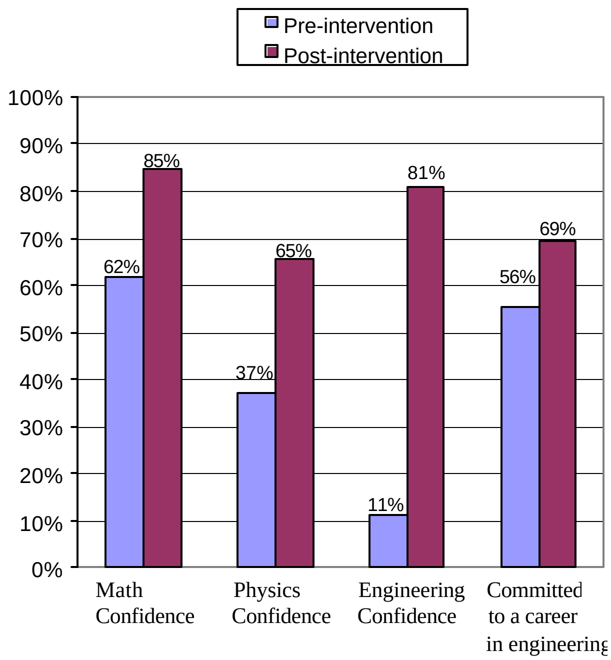


FIGURE 2
PERCENTAGE OF FALL 2002 EGR 270 STUDENTS WHO AGREE OR STRONGLY AGREE WITH THE STATEMENTS "I FEEL CONFIDENT IN MY SKILLS, ABILITIES, AND KNOWLEDGE IN MATH, PHYSICS, ENGINEERING" AND "I AM COMMITTED TO A CAREER IN ENGINEERING.

## DISCUSSION

The rationale for our work in EGR 270 was to employ a learner-centered approach to teaching with the goal of positively impacting students' understanding, confidence and commitment in engineering. Our laboratory for carrying out this work is the Picker Engineering Program, the first engineering program at an all-women's college in the United States. Our assessment data strongly support that the approach used in EGR 270 improves students' learning experiences such that there is enhanced understanding and increased self-confidence in skills, abilities and knowledge. Furthermore, students not only benefited from improved curriculum delivery, but they also developed a better understanding of their own learning. When student focus groups were asked what made the course work for them, they were able to both identify the pedagogical approaches that were used and explain *how* they helped them learn. For example, one student pointed out: "I really liked the grading system…I appreciated that my actual work had more value than the final answer that I would get. It makes me want to work harder at working it out, than just finding the right answer." Another student pointed out that the dynamics framework "helps show how all those formulas and concepts are related which helps me to understand new ones based on old ones I'm already comfortable with."

The course assessment data also indicates that a learner-centered approach supports the retention of women by effectively addressing the critical issues that Goodman et al. [2] identified as cogent to women's attrition in engineering. Following EGR 270, students reported increased interest in engineering along with an enhanced commitment to an engineering career. In focus groups, students identified important factors such as their strong confidence in the forms of evaluation used in the course as well as the improved climate in the classroom that supported the development of positive peer-to-peer and student-teacher relationships.

Currently we are tracking the progress of EGR 270 students as they continue on in EGR 272 (The Science and Mechanics of Materials) where a learner-centered approach is also being employed. In addition, we are beginning a longitudinal study of all students in the Picker Engineering Program in order to better elucidate those factors that positively influence the retention of women in engineering.

The success of EGR 270 suggests the potential effectiveness for using learner-centered approaches throughout engineering programs. Using such an approach will improve individual courses, and its consistent application throughout the curriculum likely will yield additional benefits. Huba and Freed [9] discuss the importance of seeing our classes as part of the entire educational system. "The knowledge, skills, and abilities that students achieve at the end of their programs are affected by how well courses and other experiences in the curriculum fit together and build on each other throughout the undergraduate years." The Picker Engineering Program faculty meets regularly to discuss pedagogy and share best practices. As a result courses in the program are being developed based upon the same learner-centered philosophy and share many common features such as the use of conceptual frameworks, narratives, effective forms of evaluation and an emphasis on metacognition (for example, see Voss and Ellis [10]). Additionally, we are working as a faculty to develop program-wide learning tools such as a conceptual framework for engineering to help students see how their courses fit together in the larger context of the engineering major.

## CONCLUSIONS

A learner-centered approach to teaching introductory engineering mechanics has been shown to be effective for women engineering students. A detailed assessment of the course supports the effectiveness of the approach for increasing understanding, student confidence and commitment to a career in engineering. These results are consistent with research on effective learning and retention of women and underrepresented minority groups in engineering; thus we feel that they are broadly applicable in engineering education.

## ACKNOWLEDGEMENT

This work was partially funded by generous grants from the GE Fund and Ford Motor Company.

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