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Finding Meaning in the Classroom: Learner-Centered Approaches that Engage Students in Engineering*

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The Smith College Picker Engineering Program has partnered with the college's Department of Education and Child Study and Office of Educational Outreach to develop a learner-centered approach to engineering education, central to which is the integration of engineering and the liberal arts in the service of humanity. This paper presents the results of applying these educational strategies to Continuum Mechanics I, a sophomore-level engineering course including topics from engineering statics, dynamics, and mechanics of materials. Pedagogical elements used in this course include a variety of strategies designed to help learners engage their preconceptions, construct knowledge meaningfully, and take control of their learning. Assessment data demonstrate that the implementation of these strategies leads to increases in student satisfaction, confidence and commitment towards engineering, while also achieving the technical learning objectives of the course. The significance of these strategies for effectively engaging students, particularly women and other underrepresented groups, in the field of engineering is discussed.

INTRODUCTION

THE SMITH COLLEGE Picker Engineering Program, founded in 2000, is the first engineering program established at a women's college in the United States. The rationale behind the program is to view engineering as 'the application of basic scientific and mathematical principles in the service of humanity'. Thus imagined, engineering finds itself well situated at a liberal arts college. The program's goals are to educate engineers who are adaptable to the rapidly changing demands of society and to prepare them to lead society toward an equitable and sustainable future [1]. To accomplish these goals, students are expected to take a broad array of liberal arts courses—and the liberal arts are also brought into the engineering classroom. The Program supports the use of educational strategies that are based upon the research on how people learn. This effort is enhanced by a close partnership with Smith's Department of Education and Child Study and Office of Educational Outreach.

The pedagogical approach that we are trying to develop and refine is based in both cognitive and social cognitive theories about learning. These theories view learning as extremely complex and influenced by many frame factors that include learner motivation, prior knowledge, instructor knowledge and experience, size of class, and many more. A cognitive view of learning sees humans as consummate learners who are always in the business of building a mental representation or cognitive structure that model their world. Schools deal in bodies of organized knowledge that focus on particular aspects of the world. The teacher's goal is for students to have access to this knowledge in ways that help them better understand, solve problems, and act in the world. Cognitive theory posits that learners must build this understanding, acquire this knowledge, through their own efforts and activity. Students need to engage with the content in ways that build on what they already know and create a 'space of learning' [2]. Cognitive theory suggests that a transmission model of teaching and learning is not likely to encourage any but the most highly motivated learners to engage in meaning building behavior. The theory also suggests that learning proceeds better when it is intentional. That is to say, when students have a conception of the learning goals they are seeking. Having clear learning goals enable students to employ metacognitive skills of self-monitoring and self-regulation. Thus good pedagogy helps students grasp the structure of the subject matter. Social cognitive theory suggests that appropriate engagement often happens in a context in which students encounter the thinking of others. In this view learners construct knowledge only after they encounter and use the knowledge in a social context and with the help of scaffolding provided by more knowledgeable individuals.

These theories place students at the center of the learning process. The pedagogical devices, structure and techniques need to be aimed at:

- helping students grasp what and how they are being asked to learn;

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- seeing ways that students can manage their own thinking and learning;
- creating the kind of social context that supports collaboration, shared thinking, and risk taking;
- facilitating various kinds of engagement with the content in ways likely to build understanding.

Guided by this underlying theory our efforts have been to locate and adopt promising pedagogical strategies.

Drawing upon a broad research base, the National Research Council (NRC) recently reported the following points as key to successful learning [3]:

- 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.
- 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.
- A metacognitive approach (involving the learners' knowledge of their own thought process) to instruction can help students learn to take control of their own learning by defining learning goals and monitoring their progress in achieving them.

These points carry strong implications for effective teaching that are often at odds with the typical engineering classroom. The pedagogy traditionally practiced in engineering courses takes a 'bottom-up' approach, adding incremental bits and pieces as students tackle increasingly difficult problems. The hope is that students will eventually get the big picture and be able to integrate and apply all the procedures. The all-too-frequent reality, however, is that students cannot apply their knowledge to new situations. This becomes evident when they are unable to solve problems even slightly different from those used for practice and instruction. This becomes even more apparent across courses.

The need for a different approach—one that focuses on meaningful learning—in the engineering classroom is eloquently expressed by Schneck [4]:

> The exponential surge of material that must now be covered in engineering curricula, its rapid obsolescence, and the general trend toward more holistic attitudes in 21st century education all require that the engineer of the future be a product of a program of integrated learning—one that teaches students to use unified, deductive approaches to the creative formulation and solution to engineering problems. Moreover, successful engineering programs in the 21st-century university will be those that address the current void between product-oriented skills training and process-oriented holistic training.

Novak [5] summarizes the requisites for such meaningful learning as follows:

- *Relevant prior knowledge:* That is, the learner must know some information that relates to the new information to be learned in some nontrivial way.
- *Meaningful material:* That is, the knowledge to be learned must be relevant to other knowledge and must contain significant concepts and propositions.
- *The learner must choose to learn meaningfully.* That is, the learner must consciously and deliberately choose to relate new knowledge to knowledge the learner already possesses in some nontrivial way.

Learner-centered pedagogy focuses on ways learners must be engaged in order to learn meaningfully. Our goal is to focus on the metacognitive aspects of learning. In this way we hope to provide learners with a set of learning skills and attitudes that enable them to become more autonomous. Learners need to know how to process information in ways that enable them to construct meaningful knowledge. Mayer describes three processes in which the learner must engage for meaningful learning to take place [6]. These are: select, organize, and integrate. Learners must recognize and pay attention to the relevant and important content, they must organize the content in a structure that is faithful to the disciplinary structure of the content, and they must integrate the content into their existing cognitive structure (i.e., knowledge).

Theory directs us to believe that the best way to teach metacognitive strategies is to first model their use explicitly and then, in a variety of ways, encourage students to internalize the strategies. Achieving self-monitoring and self-regulation requires not only learner intention, but also a repertoire of learning skills that can be brought to bear appropriately and effectively in a learning situation. Mayer identifies two classes of strategies that learners can use to facilitate meaningful learning [6]. One he calls **structure strategies**. These strategies help learners think about the structure of the content they are learning. They acquire an organized and interrelated set of ideas, a set that they can continue to build upon rather than a hodge-podge of unconnected facts and formulae. The second class of strategy Mayer calls **generative strategies**. Generative strategies help learners link new knowledge with existing knowledge. These strategies focus on productive ways of processing information, ways that involve the sort of intentions and consciousness necessary for meaningful learning.

What then should the student experience in an engineering classroom look like? Clearly the findings described here 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. Teachers must help students acquire a deep knowledge of the subject matter, *and* they need to help students 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 understand, evaluate and take responsibility for their own learning.

While the research findings on successful learning summarized above apply to all students, women are particularly at risk in the typical engineering classroom. This is evidenced by the fact that only 8.5% of the engineers in the United States are women [7]. Similar statements can be made for underrepresented minority groups and are summarized by Chubin *et al.* [8]. Goodman *et al.* [7], 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 from 53 institutions, Goodman *et al.* [7], 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.
- One-half said they left because they were not interested in engineering.

Each of these reasons is related to the pedagogy used in the classroom and illustrates the potential for poor teaching to discourage women from careers in engineering. The integration of engineering and the liberal arts, which is the hallmark of the Picker Engineering Program, has important implications for attracting and retaining women in engineering. Grasso [9] illustrates this point by comparing the fields of medicine and engineering. He states that if a physician is asked why she selected a career in medicine, she is more likely to say 'I like helping people' than 'I liked biology'. On the other hand, an engineer's most common response to the same question is, 'I liked math and science'. Grasso points out it is not surprising that most college-bound students, especially women, are unwilling to sign on for educational programs that promise such a narrow role in society. This is particularly tragic because of the flawed reasoning. Engineers don't just design and create things: they also need to consider the societal, economic, environmental and ethical issues involved as part of the design process. Based upon their study of women in engineering, Goodman *et al.* [7], support Grasso's illustration with the following suggestions for improving engineering education:

- [Recognize] that a major reason many women choose engineering is because of an altruistic bent (and the knowledge that engineering does, in fact, help society and people).
- [Nourish] students' interest by using examples in class that highlight application and problem solving and that demonstrate how engineering has led to improvements in society and the quality of people's lives.

This paper illustrates educational strategies used in the Picker Engineering Program by presenting examples from the introductory core class in engineering mechanics (EGR 270). EGR 270 is a four-credit, semester-long course that is largely populated by sophomore engineering students. Topics include 2-d and 3-d rigid body equilibrium, shear and bending moment diagrams, dynamics, vibrations, and an introduction to stress and strain. The primary aim of the course is the development of conceptual understanding and problem-solving ability in engineering mechanics. Alongside that aim, other important objectives are the development of communication skills, the ability to work effectively in a team, and an increased understanding of professional responsibility. The paper pulls these strategies apart in order to describe them more clearly. Topics include integrating engineering and the liberal arts, engaging learners, helping students organize their learning and helping students take control of their learning. It is important for the reader to realize that in practice this content and the instructional practices are much more an integrated whole.

INTEGRATING ENGINEERING WITH THE LIBERAL ARTS

Froyd and Ohland [10] have reported that integrated programs can improve retention, improve learning of interdisciplinary content and improve acquisition of non-disciplinary skills. As in all of the courses in the Picker Program, the liberal arts are integrated regularly into EGR 270. For example, dance is one of the approaches used to teach dynamics in context. In classroom activities students learn about the mechanics of the fouetté turn, grande jeté, and arabesque used in ballet—and under the guidance of a dance instructor they also experience the movement. This allows them to directly *feel* the concepts that they are learning. (Research has shown the importance of kinesthetic experience for learning mechanics [11].) By examining the proper technique in the movements, students see how the artistry is achieved within the constraints of the laws of mechanics. In a follow-up to the classroom activity, students use VideoPoint [12] software to discover the mechanics of why a dancer gives the illusion of floating during a grande jeté (the kicking motion changes the center of mass and results in the head following a flatter trajectory than the center of mass).

Another example of integrating the liberal arts is that ethics is taught across the engineering core at Smith. Riley *et al.* [13], notes that this approach has several benefits. These include allowing students time to develop their sense of morality and mature in their ability to analyze and reflect on ethical problems, encouraging students to see ethics as a practice of thought and exchange of ideas that must be exercised over a lifetime, and helping students see ethical decision-making as part of the core skill set of an engineer. The approach is a particularly good fit in the Picker Program because other topics related to social responsibility, notably sustainability, are also distributed across the curriculum. In EGR 270 ethical considerations are integrated with the technical content through two case studies.

In the first case study, students examine the 1976 Hyatt Regency Hotel collapse in Kansas City. The unit includes assigned readings on professionalism, a multi-media presentation by the instructor laying out the chronology and facts of the case, a group problem-solving activity to identify the technical cause of the failure, and group discussions of the issues of professionalism involved in the failure. These issues include assigning responsibility for the design flaw, understanding the responsibilities of licensed professional engineers, assessing the communications among the parties, and discussing the discipline actions that were taken. Experience has shown that these discussions are an important opportunity for students to share and work through their personal concerns about taking on the ethical and legal responsibilities of the profession.

In the second case study, students investigate both the mechanics and societal effects of the 1985 Michoacan earthquake. This class activity also begins with the instructor presenting the facts of the case in a multimedia presentation. This presentation includes not only the technical aspects of the case—such as the geology, acceleration–time histories and their Fourier spectra, and pictures of various structural failures—but also attempts to make students aware of the human dimensions of the tragedy. Based upon this information, students work in groups to explain the damage pattern of the earthquake throughout Mexico. Once the technical analysis is completed, students research and write a paper on the effect that the tragedy (and the engineer's role in it) had on Mexican society. Topics arising in these papers include discussions of political unrest, unification of a divided lower class, government re-organization, tourism and other economic effects, exposure of corruption, the response of citizens to the president's actions after the quake, and the tremendous suffering of the victims.

ENGAGING THE LEARNER

There is a growing literature base about the need to engage the learner to promote meaningful learning in the classroom. Recently Smith *et al.* [14], summarized the history, theory, and research base of this movement and 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. They also cited a variety of references to guide the implementation of these techniques in the classroom [15–17].

A variety of approaches are used in the EGR 270 classroom to engage the learner. Mazur [18] has shown the effectiveness of using concept questions to increase student engagement and promote deeper understanding of concepts in physics. In EGR 270 concept questions are used regularly to help students identify the preconceptions they bring to the classroom and then help them challenge or build upon those preconceptions as appropriate. For example, in the beginning of the unit on moment of inertia students are asked to identify about which axis an angle-shaped column will buckle under axial loading. After reasoning through the question on their own, students work in groups to discuss and reconcile differences among their answers. The activity concludes with students testing their answers experimentally using cardboard folded in the shape of an angle column. Using this question as a starting point, the theories involved in the unit can be developed and related back to a common experience. Later in the unit, similar questions on the same content will help both the student and instructor assess the learning that has taken place and help inform the direction and pace of the class.

Another strategy used on a daily basis is group problem solving. In this activity students work in small teams to solve problems that synthesize the content presented during the class. While the students are solving the problem, the instructor works with each group to answer questions and identify common issues that may need to be addressed with the entire class. After completing the problem, a student team presents its solution to the rest of the class. Many students participate in this process by asking questions, sharing alternate solutions or providing additional insights. As in the use of concept questions, it is not just the students who gain directly from the immediate feedback and opportunity to improve their understanding. The instructor also gains a better understanding of the students' needs and can adjust the class accordingly.

Project-based learning is another strategy for engaging students that is an integral part of the EGR 270 class. Throughout the semester students work in teams to produce a video for teaching dynamics concepts, design a bridge and analyze the structural safety of the Washington Monument. Through these projects students develop a deeper understanding of mechanics and practice applying their knowledge to situations beyond those idealized in the textbook. It also provides an ideal way for students to learn skills that go beyond the technical content of the course. The following is a description of the video production project that illustrates this approach. A more detailed description of the project can be found in Ellis *et al.* [19].

Despite the fact that video is a primary communication medium in our society, engineering students typically receive little or no preparation in its use. This represents a missed opportunity not only for preparing students to be effective communicators, but also for using the medium to engage them in the learning process. For example, Reynold and Barba [20] report that the use of video can help empower the learner by allowing them to control time and study phenomena that are difficult to observe; by bringing sense to verbal descriptions of scientific phenomena through visual and auditory representations; and by helping students make immediate and direct connections to the concrete world. In EGR 270 students develop and demonstrate a basic proficiency in the use of the medium by producing a two- to three-minute instructional video on combined translational and rotational motion. This requires students to analyze, synthesize and evaluate information gathered from a variety of resources—a strategy reported by Briedis [21] for developing lifelong learning skills. Smith's Media Services supports this effort by providing equipment and offering workshops in video production. Consistent with Smith's philosophy of integrating engineering and the liberal arts, these workshops give equal emphasis to the technical and artistic aspects of production. Students are also instructed in management and team production skills.

Examples of screenshots from two different videos are shown in Fig. 1. It has been our experience that students produce videos that exhibit creativity and originality, both in content choice and presentation style. They often tape motion based upon the personal interests and experiences of the team members to illustrate the concepts in their videos. These have included shooting billiards, bicycling, diving and playing basketball. Students express their creativity by choosing the production approach (voice-over, interview, vignette, combination, etc.), storylines, musical effects and shot composition.

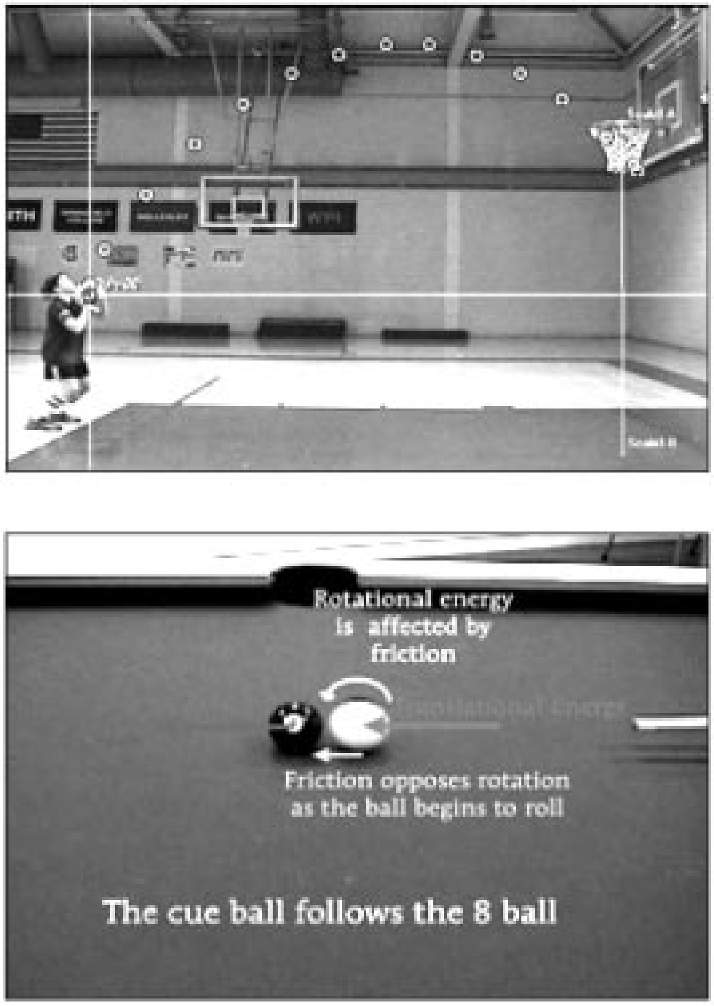

Fig. 1. Screenshots from student videos that explore the mechanics of a foul shot (upper) and the mechanics of spin in billiards (lower) [19].

HELPING STUDENTS ORGANIZE THEIR LEARNING

One approach to helping students organize their knowledge is the use of concept maps. Concept maps are not a new phenomenon in education. Their use is based on the theory that meaningful learning is an effortful process involving the construction of relationships between the learner's existing knowledge and new knowledge. They have been used in a wide variety of ways including for assessment [22–25], as planning tools [26, 27], and for problem solving [28]. Ellis *et al*. [29], discuss the use of concept maps that help engineering students more effectively organize their knowledge for developing a more meaningful understanding of engineering mechanics. Guidelines for using concept maps [29] are give below:

1. *Develop initial map(s).* Decide on the scope of the concept map(s) needed. These can be course level or program level maps that include all the major ideas and their relationships, and/or they can be more focused maps depicting, for example, problem solving strategies, unit or chapter ideas, or student's prior knowledge.
2. *Introduce maps to students.* Introduce maps after an initial activity in which students identify and articulate related existing knowledge.
3. *Use maps.* Refer to maps whenever new ideas are introduced to point out how the new ideas are related to ideas already learned by students. Refer to maps whenever course material is reviewed in order to make explicit and emphasize the ways the reviewed material relates to the overall course structure. Refer to maps when analyzing phenomenon of interest to show how the ideas provide a 'template' or frame of reference for thinking about the phenomenon. When teaching or reviewing problems and their solutions, refer to maps in order to focus on and include strategic knowledge in classroom discourse. Show how the maps can be a useful engineering tool by using them regularly in analysis and design applications.
4. *Revise maps.* Initial maps are necessarily approximations. By engaging students with the beginning maps, they become familiar with the concept map as a tool for thought and they become participants in reshaping and refining the map to better serve their growing understanding. Refinement often adds detail,

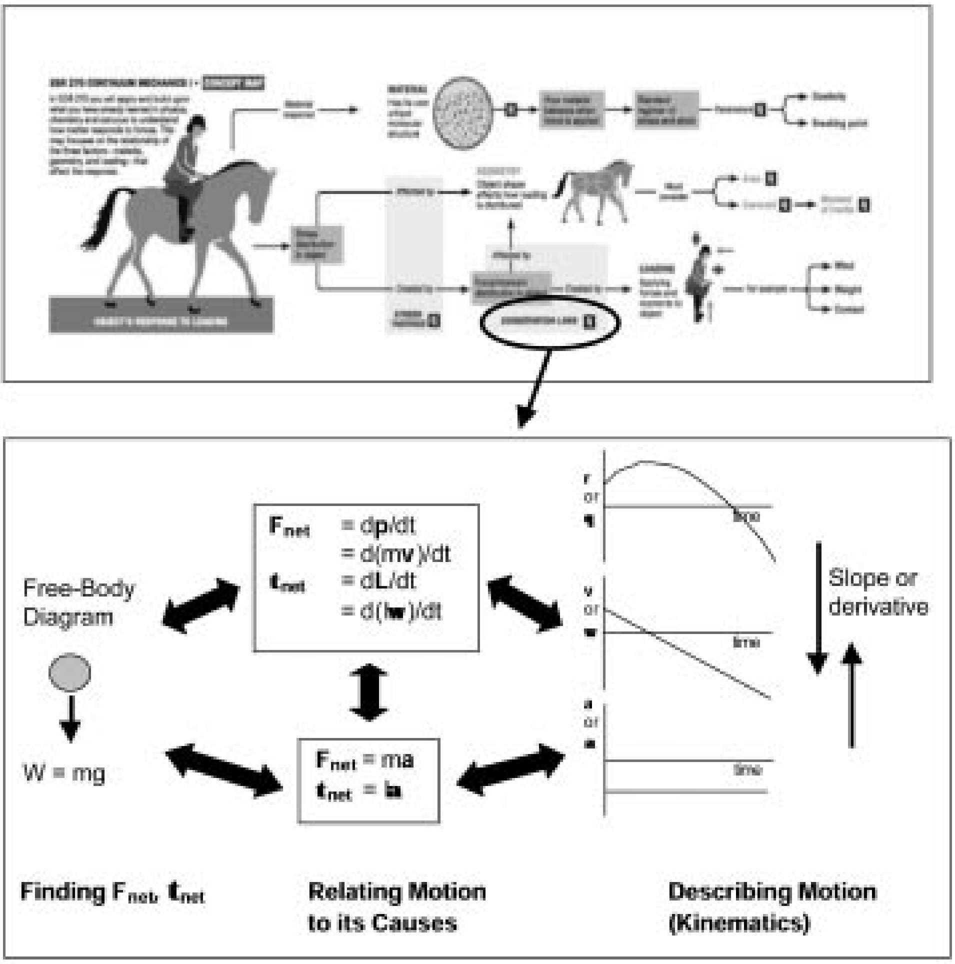

Fig. 2. Concept maps used in EGR 270. The upper map shows the relationships among topics in the course. The lower map shows the relationship between motion and its causes [29].

but can also result in a 'master' map that is lean and shows the major relationships among ideas.
5. *Repeat steps 3 & 4.*

Two sets of interrelated instructor-generated maps are used in EGR 270. These include a succession of increasingly sophisticated course concept maps showing the relationship among the major concepts in the class (the final map is shown in the top of Fig. 2) and a second dynamics map illustrating the relationship between motion and its cause (bottom of Fig. 2).

The course map is introduced on the first day of class as part of a group activity in which students articulate their current knowledge of continuum mechanics (such as the importance of shape or material for resisting bending) and then explore how this knowledge is represented on the concept map. Through this activity the students are made aware of the knowledge they already possess and the nature of the learning that needs to take place, i.e., representing and organizing their knowledge in a meaningful way and developing the quantitative skills needed for its application. Following this activity the concept map is revisited regularly throughout the course to help students understand why they are learning each new topic, how new concepts fit in with the concepts already learned, where assumptions and idealizations are made and where, conceptually speaking, they are headed in the future. Finally, the map is used to help students organize data, equations, and concepts for solving problems.

The dynamics map first is used in EGR 270 as an organizing device for reviewing Newtonian mechanics and then later as a tool for solving rigid body dynamics problems. To solve problems, the students identify on the map the location of the variables that are given in the problem statement and the variables that need to be calculated. The pathway connecting these locations is then identified as the solution procedure. Through this approach the structure of the dynamics concepts is reinforced each time students solve problems. Further discussion of this map for teaching physics can be found in Ellis and Turner [28].

HELPING STUDENTS TAKE CONTROL OF THEIR LEARNING

Felder and Brent [30] discuss the importance of meeting the needs of engineering students with different learning styles, approaches to learning and intellectual development levels. They describe how the 'one-size-fits-all approach to teaching' that has been typical in engineering education 'violates virtually every principle of effective instruction established by modern cognitive science and educational psychology.' Throughout EGR 270 students are given opportunities to make choices about their learning. For example, students are allowed to choose homework problems from a list that includes a range of content and difficulty levels. This requires the students to identify which problems cover the needed content at the right difficulty level to meet their learning needs. The homework is then graded using a rubric designed to encourage constructive effort toward learning and useful feedback to the student. In the EGR 270 rubric the level of effort counts for 50%, starting solutions from a conceptual framework and demonstrating conceptual understanding of fundamental ideas counts for 20%, and correctness and presentation each count for 15%. This approach is meant to discourage students from becoming adept at mimicking a process that is in the textbook or demonstrated by the instructor—an approach that results in a short lived and limited ability to solve engineering problems [31].

Another example in EGR 270 is the use of student narratives to encourage reflection upon the learning process. After completing each of the three projects, students write narratives reflecting on what they have learned through the experience, including what they did well and want to continue, and what they want to improve upon in future efforts. Individual ideas are discussed in groups and assembled into a reflection for the entire class that will be shared with students taking the class in the future. Our experience is that students discuss a wide range of issues, from time management and group skills to how to include supporting data most effectively or write a sound conclusion. Below are several excerpts of student reflections on the video production project.

One group, recognizing the delicate balance between education and entertainment, wrote:

> Our group has learned that a good video must grab the audience's attention in the introduction and maintain its interest throughout the production. Though our introduction and theme helped maintain interest, the use of background music would have made our explanation more exciting. Also, while our diagrams and equations were helpful aids, they could have been presented more slowly, so that they would be easier to understand. The video should have a steady flow, with numerous clips and transitions that lead into one another and do not interrupt the movie's pace.

Many groups wrote about the growth of their team skills. One example is the following:

> The group learned how to accommodate each member's individual schedule, cooperating during meeting times to be most productive, and accepting diverse opinions in a mature fashion. All these skills will be applicable in future professional settings during internships and eventual careers.

ASSESSING EGR 270

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 the

EGR 270 class in the fall of 2002. These data, when possible, were also compared to the 2001 class that was taught by the same instructor in a more traditional lecture format.

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 it was found that the percentage of students that agreed with the statement, 'the course goals and objectives were clear' showed a statistically significant difference ($p = 0.009$) when the instructional approach was changed from lecture to learner-centered pedagogy. In the Fall 2001 class, only 60% of respondents agreed with the statement; whereas in the Fall of 2002, 92% agreed.

In the mid-semester survey students were also asked if the video project was helpful for their learning. A positive response was indicated by 83% of the respondents, 15% did not respond or indicated no preference, and 2% indicated a negative response. The following were cited multiple times as positive factors in the experience:

- the satisfaction of learning the skills needed to communicate through a new medium;
- the opportunity for creative expression in an engineering course;
- the intellectual challenge of communicating ideas;
- the chance to learn on their own; and
- the experience of working in a group.

Students responded enthusiastically to the hands-on, project-based learning approaches taken in the fall 2002 EGR 270 course: One student wrote, '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.'

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 (statistically significant difference, $p = 0.003$). To assess mastery of content knowledge, students in 2001 and 2002 were given a final course examination that included standard engineering mechanics problems and as well as questions designed to measure conceptual understanding. Approximately two thirds of the questions on these exams were identical. Based upon an evaluation of student performance on the identical questions, students answered 86% of the questions correctly in 2002 compared to 82% in 2001. Although this increase in mean test scores was not statistically significant ($p = 0.176$), it clearly does not show a decrease in the mastery of content knowledge as measured through a traditional evaluation instrument. (The changes made to the exam in 2002 were designed to measure student learning of the higher-level skills introduced in the revised course—such as using concept maps to help frame and develop solution strategies for ill-defined problems. In future studies we recommend including such questions in comparative studies.) Finally, 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).

In post-course surveys, 83% of students in 2002

Table 1. Student perceptions of learning objectives in EGR 270, Fall 2002 [19]

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%

* 25 out of 27 students responded on a five-point scale ranging from 1 (strongly disagree) to 5 (strongly agree).

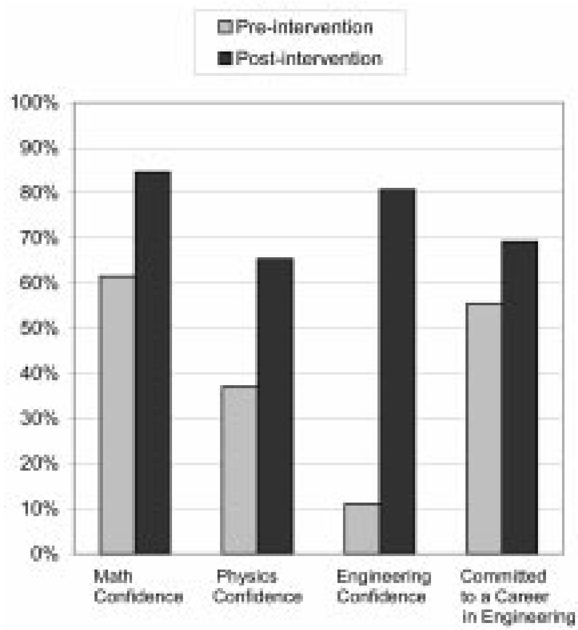

Fig. 3. Percentage of fall 2002 EGR 270 students who agree or strongly agree with the statements 'I feel confident in my skills, abilities, and knowledge in math, physics, engineering' and 'I am committed to a career in engineering' [32].

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 (not statistically significant, $p = 0.24$). 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. 3, students felt 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%).

DISCUSSION

In Fall 2002 we transformed EGR 270 from a traditional lecture format to a format centered more on the needs of the learner. Through this process it was our goal to positively impact the students' understanding, confidence and commitment to pursue a career in engineering. The assessment data for EGR 270 support that the learner-centered approach enhanced understanding and increased self-confidence in skills, abilities and knowledge. Student focus groups also indicated that the course helped students become more aware of their own learning. For example, when the 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* these approaches helped them learn. 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.* [7], identified as cogent to women's attrition in engineering. Students were clearly satisfied with the pedagogy used in the course and in focus groups cited their confidence in the evaluation system. Students also emphasized in focus groups that the positive climate in the classroom supported the development of peer-to-peer and student-teacher relationships. This is consistent with the reform principles presented in Building Engineering and Science Talent (BEST) study [33] of 'exemplary' or 'promising' higher education intervention programs aimed at increasing diversity in science and engineering education. They reported that 'student interaction opportunities that build support across cohorts and allegiance to institution, discipline, and profession' was evidence of peer support—one of the eight principles for reform. Finally, as noted in the previous section, student interest in the course content was very high. Research has also shown that the retention of women in engineering is related to confidence in one's ability. Seymour and Hewitt [34] found that women who persist in engineering tend to be confident and can 'brush off' negative comments that they receive. The increased mathematics, physics and particularly engineering confidence levels measured in EGR 270 supports the use of learner-centered approaches for increasing the retention of women.

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 [35] discuss the importance of seeing individual classes as part of the entire educational system that students encounter: '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. This results in a more consistent approach to teaching with an emphasis on the learner throughout the entire program. Concept maps, reflective narratives, effective forms of evaluation and an emphasis on metacognition have become common elements of many classes. Early indications support the effectiveness of these approaches with a retention rate of 87% for the first graduating class (out of 23 students) and 92% of the following class (out of 28 students) remaining in the program in their senior year. Also encouraging is a 100% retention for under-represented minority students in the graduating and senior class (out of 11). In an attempt to better understand these numbers graduating students were asked in an exit survey what encouraged them to stay in the program at Smith. Common answers included the emphasis on the liberal arts and the satisfaction of succeeding in a challenging program. However, the development of supportive relationships that the program fosters was the most prevalent answer. One student wrote:

> Smith is an excellent learning environment not only because of the rigor of the program, but also because of the sense of community that exists here. Professors are able to challenge us constantly by pushing the limits of our education. They are able to do so successfully because there is an excellent support system amongst the students and faculty.

CONCLUSION

A learner-centered approach to teaching introductory engineering mechanics has been shown to be effective for women engineering students. An assessment of the course supports the effectiveness of the approach for increasing student satisfaction, confidence and commitment towards engineering, while also achieving the technical learning objectives of the course. 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.

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