Designing the Engineering Classroom for Women

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In May 2004, Smith College became the first college in the United States to graduate a class of all-female engineers. This marked a milestone in engineering education because of the disproportionately low numbers of women in the profession. Although women make up 56.8% of the United States workforce, only 8.5% of the country's engineers are women (1). This is not the case for other professions. A recent study by *U.S. News and World Report* showed that in the highest-ranked professional schools in the United States, the proportions of female graduates were 45% in medicine, 44% in law, and 30% in business. By comparison, only 15% of graduating engineers were female (2). An Engineering and Workforce Commission report also shows that in 2003, females comprised 16.2% of all freshmen engineering students, having steadily declined from the 19.9% peak reached in 1996 (3). What can be done to make engineering education more attractive to women? This chapter will address this issue and present solutions that can be implemented in the classroom. It should be noted that even though the focus is on curriculum change to help women in the engineering classroom, the ideas presented are effective for all learners.

Engineering and the Liberal Arts

The Smith College Picker Engineering Program was founded in 1999 as the first engineering program at a women's college in the United States. The rationale for the program conceives of engineering as connecting basic scientific and mathematical principles in the service of humanity. Thus imagined, engineering finds itself well situated at a liberal arts college. Moreover, women have not been adequately represented in the field of engineering, and the program at Smith College will help remedy this. The engineering program's goal is to educate engineers who are adaptable to the rapidly changing demands of society and prepare them to lead society toward an equitable and sustainable future (4). To accomplish these goals, not only are students expected to take a broad array of liberal arts courses, but also the liberal arts are brought into each of the engineering courses.

One example is the introductory course in circuit theory. In this class, Picker engineering students investigate the political public debate on "DC" versus "AC" electricity delivery at the end of the 19th century and the roles played in this debate by Thomas Edison (5) and Nikola Tesla (6). Through discussions, students increased their physical understanding of the two systems by applying their knowledge to a real-world context. Additionally, the students engaged in enthusiastic discussion about the political atmosphere surrounding the debate and the questionable ethics in the approaches of specific individuals to convince the public of a particular point of view (7). Many other examples exist in the program, including the use of dance to learn dynamics and the political and societal effects of engineering failures in the 1985 Michoacan earthquake.

In addition to better educating women to bridge the traditional boundaries between the sciences and humanities and take on leadership roles, the integrating of engineering and the liberal arts also has important implications for attracting and retaining women in engineering programs. Grasso illustrates this point by comparing the fields of medicine and engineering (8). 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 that 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, economical, environmental, and ethical issues involved as part of the design process.

Pedagogy and the Female Learner

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 (9).

- 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 1) have a deep foundation of factual knowledge, 2) understand facts and ideas in the context of a conceptual framework, and 3) organize knowledge in ways that facilitate retrieval and applications.
- 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 on 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 on the experiences and knowledge that each student brings to the classroom. Teachers must help students acquire a deep knowledge of the subject matter—but they also 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 to understand, evaluate, and take responsibility for their own learning. Unfortunately, this rarely describes the 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. The Goodman Research Group (1) summarizes 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, the Goodman Research Group (1) 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 closely related to the pedagogy used in the classroom and illustrates the potential for poor teaching to discourage women from careers in engineering. The following sections illustrate several of the learner-centered strategies used in the Picker program to encourage meaningful learning and student retention.

Concept Maps

One problem common to many students is seeing the "big picture" in their courses. Students tend to get lost concentrating on a particular topic at hand and do not immediately link related concepts. This problem becomes particularly obvious when students have difficulty transferring knowledge between courses or to real-world applications. The use of concept maps to identify key concepts and show the relationship between them is one approach for helping students gain and maintain an understanding of the overall conceptual structure of a course.

Concept maps are not a new phenomenon in education and have been applied in a variety of ways, including assessment, planning, and problem-solving. The theory underlying their use stems largely from the work of Ausubel (10) and subsequent work by Novak (11,12) and Novak and Gowin (13). The theory stresses that meaningful learning is an effortful process involving the construction of relationships between the learner's existing knowledge and new knowl-

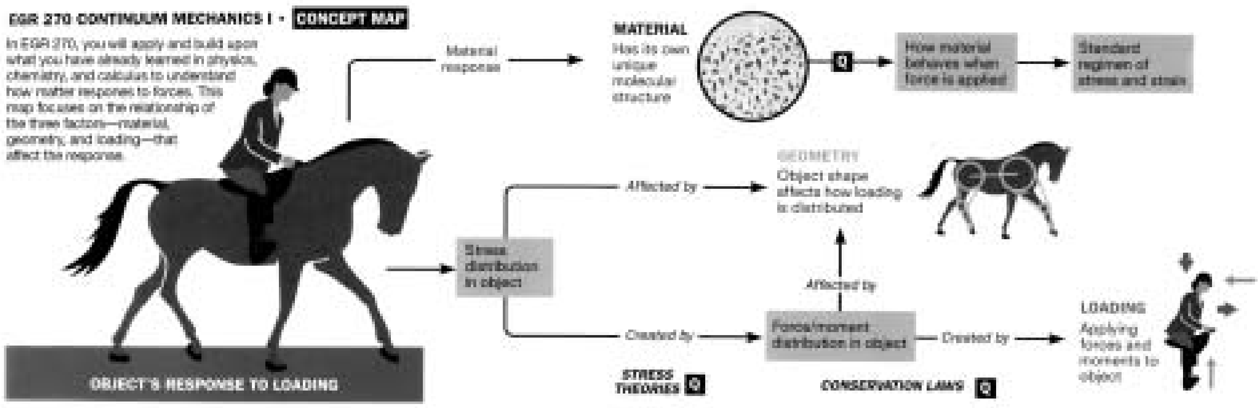

Figure 1. Concept map for an introductory mechanics course.

edge. Unfortunately, in the classroom, not all learning efforts of students are equally productive. This is mainly because the preexisting knowledge of students is often rooted in misconceptions that make new learning difficult. Concept maps can help identify these student misconceptions and can be a means of correcting them.

In the Picker Engineering Program, students use instructor-generated concept maps and also construct their own. One example is the introductory course in solid mechanics reported by Ellis et al. (14). In this course, a succession of increasingly sophisticated concept maps showed the relationships among the major concepts in the course (the final map is shown in Figure 1). The maps are used to place each new topic in context, to illustrate the relationships between topics, and to solve problems. After taking the course, one student reported:

> *"…In this course, you always know what you're doing…he makes a point at every new chapter to go through the concept map and [says] 'so we learned how to do this, which means we can now do this, which relates to this,' and it makes everything make sense."*

Students who have taken the course reported a dramatic increase in their confidence to solve engineering problems and an increased commitment to a career in engineering. They related this in part to the use of conceptual frameworks for helping them develop confidence in their ability to learn engineering topics.

Reflective Narratives

Reflective narratives are another approach for helping students process new knowledge. In the process of writing narratives, students must put concepts together into a form that makes sense and that can communicate their understanding. This requires students to relate the new ideas presented in the course to their existing knowledge. Their use is best illustrated through an example.

Introduction to Engineering is a Picker engineering course intended for first-year students interested in engineering. The course aims for students to develop a sound understanding of the engineering design process through a semester-long team-based design project, to develop communication skills, to understand engineering in a global and societal context, and to develop their own views on the nature of engineering. To help students assimilate the information in the course, they are required to write a reflective narrative three times during the semester. In all three cases, students are given the same assignment: to write about their views on engineering and how they see themselves in relation to the field (Figure 2). In particular, students are encouraged to articulate their "big picture" educational and life goals and how they believe engineering might be an appropriate vehicle for achieving these goals. Used partly as an assessment tool, the intended learning outcomes of the assignment were to 1) help students draw connections between the curriculum, engineering, and their goals and values and 2) encourage students to self-identify as engineers (15).

EGR100 Engineering Narrative

A 1998 HARRIS poll found that 61% of adults in the United States are not well informed about engineering. One goal of this class is for each student to develop an understanding of the nature of the engineering profession. Your perspective on this will naturally evolve during this semester, over the next four years, and beyond. In this assignment, you will write a thoughtful narrative that expresses your current views on the nature of engineering and how you see yourself in relation to this field.

Why a narrative? Narrative communication (i.e., storytelling) is a powerful tool that people of all cultures use to communicate their understanding of the world around them. By developing a narrative about the nature of engineering, you will be engaged in a creative act that will help you to organize your thoughts about the subject of this course (and, perhaps, your major and your future career). This narrative assignment is about telling a two-part story. The first part is about the question: What is engineering? The second part addresses how you see yourself fitting into that story. What are the central themes of this discipline, and how are they relevant to your own personal values and goals? Such a story will help you make sense of this vast area and, more importantly, provide a framework within which you can begin to piece together the ways in which different components of your education fit together as part of a greater whole.

Figure 2. Instructions for reflective narrative assignment in Introduction to Engineering (after Ellis et al. [15]).

Student 1

First version: *"The Webster dictionary defines engineering as the application of mathematics and science by which the properties of matter and the sources of energy in nature are made useful to people."*

Final version: *"The stated definition [of engineering] is very general and through my experience in Introduction to Engineering I was able to form my own definition. Engineering is applying scientific and mathematical principles that are appropriate for the community [for which] the design is being created in the hopes of making a useful tool for [that] community."*

Student 2

First version: *"Engineering is applying math and science to situations. It could also be more product-oriented."*

Final version: *"Since I have come to Smith, I have continued learning about engineering in general, but I have also started to learn about the societal context of engineering and to examine how my own goals and values might relate to a career in engineering...While the engineering culture certainly falls within the scientific culture, I believe that in engineering there is much overlap into the humanities culture. It is important for engineers to know about the world for which they are designing products."*

Figure 3. Excerpts from student reflective narratives in Introduction to Engineering (after Ellis et al. [15]).

Sample extracts from student narratives are shown in Figure 3. These responses portray how the objectives of the assignment were achieved by the end of the semester. For example, in the first version written by Student 1, she uses a dictionary definition to describe engineering. However, in the final version, she modifies the same definition into a more specific and personal one using the knowledge and experience she gained in the course over the semester.

Reflective narratives help students observe and assess their learning process. In a post-course survey, many students commented on the strong metacognitive nature of the assignment. For example, one student writes, "I enjoyed writing the narrative in sections throughout this course. I thought that in doing so, I could tacitly view how my perceptions on engineering had changed and developed." By drawing out these sorts of reflections, reflective narratives are one way to help students—particularly women—increase meaningful learning and in this way promote a continued interest in engineering.

Active Learning

Many engineering classes are still taught using a lecture format in which the professor delivers the information to students, who are expected to assimilate the information passively. Unfortunately, this teaching model is contrary to a learner-centered teaching approach and the key findings on learning presented earlier in the chapter. A better approach for using time in the classroom is active-learning strategies. In these strategies, students become active participants in the learning process. Felder and Brent (16) provide an introduction to active-learning strategies and tips for their use in the classroom. Active learning is clearly in agreement with the research on effective learning. It also is part of the answer for engaging the large numbers of women who leave engineering because of lack of interest in the subject.

Active learning can take many forms. In the Picker program's Continuum Mechanics 1 course, lecture is only one of a number of learning strategies used in the classroom. Other learning strategies are described in Ellis et al. (17) and include the use of concept questions, peer teaching, investigative case studies, group problem-solving, and team project activities. All of these strategies have in common the active engagement of students in the learning process and involve a substantial amount of student interaction within a group. It is interesting to note that in focus groups conducted after the course and in other student feedback, students consistently mentioned the classroom environment that promotes the building of relationships as the most important reason for their success in the course. Both the relationships formed between students and their peers and the relationships developed between students and faculty were cited as being equally important. This result is not surprising. The Goodman Research Group (1) showed that female engineering students are more likely to stay in engineering when they feel they are a part of a larger community in engineering.

The Results

The number of women in the Picker Engineering Program is small but increasing. The combined retention rate of the first graduating class and the current senior class is 90% (46 of 51 students) overall and 100% (11 of 11 students) for underrepresented minorities. These rates are significantly higher than the current national retention rate for minorities, which is 39% (3). In an exit survey, the graduating class was asked to list the factors that encouraged them to stay in the engineering program at Smith. Common answers were the emphasis on the liberal arts and the satisfaction of succeeding in a challenging program. However, the overwhelming answer was the supportive relationships that the program fosters. 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

This chapter presents strategies for teaching engineering through a learner-centered approach that is consistent with the research on effective learning and retention of women in engineering. An assessment of the women enrolled in the Picker Engineering Program indicates that learner-centered strategies successfully increase understanding, confidence, and commitment to a career in engineering. These strategies are based on research that supports their effectiveness for educating all learners (9); therefore, we feel this approach is broadly applicable in engineering education.

REFERENCES

1. Goodman Research Group, Inc. 2002. Final Report of the Women's Experiences in College Engineering (WECE) Project. Funded as "A Comprehensive Evaluation of Women in Engineering Programs." National Science Foundation Grant REC 9725521, Alfred P. Sloan Foundation Grant 96-10-16. Cambridge, MA.

2. *U.S. News and World Report*. 2002. Retrieved 1 June 2004 from http://womensissues.about.com/library/blwomeneducationstats.htm

3. Engineering Workforce Commission of the American Association of Engineering Societies. 2003. Engineering and Technology Enrollments. Washington, DC.

4. The proposal to offer a degree in engineering science at Smith College, Picker Engineering Program, Smith College, November 2001.

5. Flatow, I. 1993. *The War of the Currents, or Let's 'Westinghouse' Him, They All Laughed*. Harper. New York

6. Metzger, T. 1996. *Blood and Volts*. Autonomedia. New York

7. Voss, S. E., and G. W. Ellis. 2002. Applying Learner-Centered Pedagogy to an Engineering Circuit-Theory Class at Smith College. American Society for Engineering Education/Institute of Electrical and Electronics Engineers Frontiers in Education Conference.

8. Grasso, D. 2002 Engineering a liberal education. *American Society of Engineering Education Prism* magazine. Volume 12, Number 2: 76.

9. National Research Council Commission on Behavioral and Social Sciences and Education. 2000. *How People Learn: Brain, Mind, Experience, and School*. Washington, DC: National Academies Press.

10. Ausubel, D. P. 1968. *Educational Psychology: A Cognitive View*. New York: Holt, Rinehart and Winston.

11. Novak, J. D. 1977. *A Theory of Education*. Ithaca, NY: Cornell University.

12. Novak, J. D. 1998. *Learning, Creating, and Using Knowledge: Concept Maps as Facilitative Tools in Schools and Corporations*. Mahwah, NJ: L. Erlbaum Associates.

13. Novak, J. D., and D. B. Gowin. 1985. *Learning How to Learn*. Cambridge, U.K.: Cambridge University Press.

14. Ellis, G. W., A. N. Rudnitsky, and B. Silverstein. Using conceptual maps to enhance understanding in engineering education. *International Journal for Engineering Education*. In press

15. Ellis, G. W., B. Mikic, and A. N. Rudnitsky. 2003. Getting the "Big Picture" in Engineering: Using Narratives and Conceptual Maps. American Society for Engineering Education Annual Conference and Exposition.

16. Felder, R. M., and R. Brent. 2003. Learning by doing. *Chemical Engineering Education* 37: 282-283.

17. Ellis, G. W., G. E. Scordilis, and C. M. Cooke. 2003. New pedagogical approaches in engineering mechanics yield increased student understanding, confidence and commitment. American Society for Engineering Education/ Institute of Electrical and Electronics Engineers Frontiers in Education Conference.