AC 2010-1055: DEVELOPMENT OF ENGINEERING-RELATED MINORS FOR NON-ENGINEERING STUDENTS

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Development of Engineering-Related Minors for Non-Engineering Students

Abstract

Many Americans lack even a rudimentary understanding of the principles underlying the technology essential for daily life. Engineering concepts are pervasive in decision making within industry, government, education, and health care, yet most decisions in these sectors are made by people with little or no formal engineering education. This research will develop minors to be offered by engineering units as an approach to developing technological competence in non-engineers. A collaboration between Iowa State University, Ohio State University, Hope College, and Rice University is building on the promising results achieved in the Minor in Engineering Studies Program at Iowa State. The project goal is to develop the concepts and resources to support model minors which can be adopted efficiently and widely within American higher education. To facilitate adoption by other institutions, flexibility is a key objective of the intended guidelines. Since the appropriateness of using the name engineering in the context of a minor is subject to debate, the specific name of minor should be part of that flexibility. These degrees do not focus on teaching specific engineering technical content but on teaching students how to think like an engineer. The minor aims to develop the broad understanding and practical technological competence outlined by the National Academy of Engineering in reports such as *Technically Speaking*. Thus decoupled from the engineering major, the Minor in Engineering Studies at Iowa has attracted students majoring in business, communications, journalism, and design. Minors provide a recognized credential deemed attractive by many students. This work will develop a set of Technological Literacy Objectives and Outcomes for such a minor. These outcomes will be similar to the ABET a-k outcomes that are used for engineering degrees, but will be focused on developing technologically literate citizens. The anticipated use of a standard set of outcomes rather than a standard series of courses, will allow flexibility for each institution to develop a minor or minors that is best suited to its local conditions, similar to the way engineering departments meet the ABET a-k requirements for engineering degrees.

Background

The quality of life and economic prosperity of the over 300 million residents of the United States is dependent on the development and use of technology. This includes issues ranging from formulation and implementation of energy policies to telecommunications. Educating the public with essential information about technology and technological literacy requires a fresh look at our efforts in undergraduate education. Engineering programs at all levels must acknowledge responsibility for educating non-engineers about technology [1–11]. Engineering concepts are pervasive in decision making within industry, government, education, and health care, yet most decisions in these sectors are made by persons with little or no formal engineering education. It is apparent that engineering programs have not been successful in meeting the technological literacy needs of the non-engineering population.

The structure of our institutions of higher education has made it difficult for non-engineers to develop any depth of understanding about engineering and technology. The engineering major has an elaborate curriculum, requires substantial prerequisite courses, and is a difficult pursuit to combine with another field of study. Science courses emphasize knowledge of the natural world but provide little practical understanding of our complex human-built technological infrastructure. Non-engineers who complete a university natural science distribution requirement are hardly prepared to lead the world's largest economy through its present turmoil and to make informed decisions about topics such as supporting the automotive industry, developing fossil fuel alternatives, or appropriate regulation of nanotechnology.

Minors can provide an efficient and credible way for non-engineering majors to obtain a practical and meaningful degree of technological literacy. These minors will not be intended to develop design-level engineering knowledge, but rather are based on the general competencies advocated by the National Academy of Engineering in such documents as *Technically Speaking*[12] and *Tech Tally* [13]. As an example, the Iowa State University Minor in Engineering Studies combines several courses, achieving a balance of depth and breadth that is not possible in a one- or two-course distribution requirement. A minor also provides a formal credential that students can use when entering the job market—a strong incentive and motivating factor for many students.

Project Overview

This work intends to establish a detailed understanding of the value of minors offered by engineering for non-engineering students. In addition, a general structure for such a minor will be developed. This effort builds on the promising results and related experience from four different institutions.

Determination of the Value of a Minor from Engineering

To help establish a clear idea of the value of a minor, work will be done to determine gains in technological knowledge and skills for students participating in minor programs. This will include assessment of those skills. Since the minor students are not engineering majors, it is expected that assessment methods normally employed with engineering majors may not be appropriate and new assessment tools specific to the non-engineering student may be required.

In promoting minors for non-engineers it will be important to determine the perceived value of the minor by students. This will be done through focus groups, surveys, and interviews with students participating in minor programs. Also surveyed will be potential minor students from majors such as business, public policy, and fine arts.

For a minor offered by an engineering unit to gain popularity among non-engineering students an important element will be the extent to which potential employers view the minor as a valued set of knowledge or skills. In this work, an attempt will be made to establish the perceived value of the minor by employers. Efforts will focus on obtaining information from current and potential employers of students completing the minors. In addition, representatives from both technical and non-technical industries will be polled.

Structure of the Minor

A potential structure for the minor programs will be developed. This will identify critical stakeholders including students, faculty, administration, and employers. A means will be established to include stakeholder's views in determining the structure of a minor program in general and on a specific campus.

In developing the structure of minors, it will be necessary to establish common goals and potential measures of those goals. A critical determination is whether the minor should focus on student knowledge and skills or specific courses.

It is currently anticipated that the structure for a minor will be based on objectives and outcomes rather than a prescribed set of courses. These outcomes will be similar to the ABET a-k outcomes that are used for engineering degrees but will be focused on developing technologically literate citizens. The use of a standard set of outcomes rather than a standard series of courses will allow flexibility for each institution to develop a minor or minors that is best suited to its local conditions, similar to the way engineering departments meet the ABET a-k requirements for engineering degrees.

As a starting point the development of the outcomes and objectives will be the broad dimensions of technological literacy as outlined in *Technically Speaking*[12]. The dimensions are defined as knowledge, capabilities, and ways of thinking and acting. Here ways of thinking and acting is considered synonymous to what is also termed habits of mind.

In elaborating on the specific aspects of a minor, some general outlines currently seem appropriate. An emphasis on engineering problem analysis and problem solving skills is expected. Such skills are useful in many arenas but initial development is seen as specific to engineering practice. The extent to which the non-engineering students will embrace the need to develop skills in systematic problem solving remains an open question.

A significant familiarity and even competence in application of the engineering design process may also be expected. This is characteristic of engineering and a widely applicable skill. It is possible to envision that students with such a minor would be able to be on, or even lead, an engineering design team with people possessing specialized technical skills. This would require familiarity with the engineering process, its terminology, methods, and limitations, and how it is managed.

Knowledge of issues arising in engineering practice is seen as an appropriate outcome. This would include ethics and the conflicts that can occur between engineering decisions and business decisions. Related topics might include intellectual property, and the issue of what can be learned from engineering failures and why they can occur.

Some capability relating to technical content is also anticipated. In most institutions some of the courses in the minor probably will be introductory courses in particular engineering disciplines. Clearly some level of specific technical competence is an appropriate outcome.

The overarching goal of the minor is to support the technological literacy of non-engineers. Care must be exercised in structuring the minor to not give the impression that students are partially trained engineers. While such a minor is not necessarily the study of engineering, it may be something engineering schools are uniquely qualified to offer.

Work Completed in Support of Minor Development

While the development of a minor entails a considerable scope of effort, initial results for some of the elements of a minor have been completed by the collaborating institutions. Iowa State University has established one possible model for an engineering minor and has already graduated non-engineering students who have completed an engineering studies minor. Ohio State University has completed a university-wide review of its general education requirements and has identified technological literacy as an insight area within general education targeted for future development. Hope College has established a survey of modern technology course for non-engineers taught by engineering faculty. Rice University has established an Introduction to Engineering Design course focusing on the construction of robots, which is taken by both engineers and non-engineers. Rice also anticipates that its minor in engineering studies will serve pre-service teachers seeking certification to teach K-12 engineering.

Minor in Engineering Studies (MES) at Iowa State University

The MES Program at Iowa State University has been successfully implemented and has graduated eight students with the minor degree and is engaging over thirty students in their second and fourth years in the program.[14-16] These graduates have been successfully employed or are seeking graduate degrees. Three of the graduates are working in technically oriented companies in a supervising capacity, and one is enrolled in a graduate degree program in aerospace engineering. This particular student was a student in meteorology, and after taking the MES classes became interested in engineering. Currently, the students choosing to participate in the MES Program are from business (management, marketing, financing), economics, design (architecture, graphic design), journalism and communication, and political science.

All of the MES courses at Iowa State are designed with no prerequisites. In general, the program assumes that students have no other background than a high school degree. The program requires twenty-one credits for each student. There are three introductory classes (nine total credits): ES 260, Introduction to Engineering: From Thoughts to Things; ES 265, Survey of the Impacts of Engineering Activities; and ES 270, Survey of How Things Work. In addition, each student must take six credits of junior- or senior-level classes from an approved course list. These classes are offered by different faculty and are all related to understanding technology, technological development, and social, ethical, and environmental aspects of technology. The rest of the total of twenty-one credits can be filled from the approved class list.

The Iowa State MES program mixes engineering and non-engineering students in classes that were previously only populated by engineering majors. Some engineering classes have been modified by the faculty to also include non-engineering students in the class. This idea is based on the fact that the college and MES Program believe that interaction between engineering and non-engineering students who would be the future policymakers and managers is essential. There are four engineering classes approved by the MES Program that include both engineering and non-engineering students. It should be mentioned that in such classes students are evaluated according to a separate set of standards. This means that the non-engineering students are not required to do the advanced engineering, physics, and mathematical parts of assignments. Non-engineers in these classes complete specifically designed homework intended to emphasize concepts and applications over detailed technical rigor.

Engineering Minors at Ohio State University

Two substantial university-level reviews of general education at Ohio State over the past decade have brought forth the need for technological literacy as an insight area within general education. However, it was determined that while technical literacy was an appropriate goal of general education, no satisfactory program of courses existed for this insight area at the university. Subsequently the College of Engineering developed two proposed minors in the general domain of technological literacy directed to meet this need. The minors were informed by the existing Iowa State MES program but configured to meet local conditions. The minors have been approved at the College of Engineering level and it is anticipated will be approved at the university level. The earliest implementation will begin in the 2010-2011 academic year.

Model Curriculum Structure for Two Minors

OSU has established two minors each with a different emphasis.[17] These are an Engineering Sciences Minor and a Technology Studies Minor. Table 1 summarizes and differentiates the two minors. In each case the learning goals are defined in a manner appropriate to the intended audience and the curriculum is structured appropriately to the background and needs of the audience.

Administration and Advising

The two minors offered by the College of Engineering will be administratively supported by the Engineering Education Innovation Center (EEIC). The EEIC director will chair the Minors Oversight Committee and assure the advising of students, certification of completion, and review of courses as well as be responsible for on-going development of the minor. This oversight committee will report to the Core Curriculum and College Services Committee of the college (acting as curriculum committee for both minors). Although difficult to anticipate, demand for the two minors is initially projected at 50 to 75 students per year for each minor. Staffing of the core courses will be accomplished through the close collaboration with the First-Year Engineering Program (FEP). FEP will be responsible for staffing, space, and equipment needs for the courses. FEP currently uses regular faculty, adjunct faculty supported by professional staff, and graduate and undergraduate teaching associates.

Table 1. Construct for Engineering Science and Technological Studies Minors at Ohio State.

	Engineering Sciences Minor	Technological Studies Minor
Key Audience	Students who have an interest in working with technology experts/engineers and in technology based industry/environments. *Examples:* Business, Economics, Science, and Math majors *Assumptions:* Competence in mathematics through beginning concepts of calculus	Students who have an interest in understanding technology at a level that will help them become more informed citizens and perhaps more attractive to employers. *Examples:* Humanities and Arts majors *Assumption:* No particular prerequisites
Learning Goals—At the completion of the minor, students will be able to:	1—demonstrate a basic understanding of the engineering design process	1—appreciate the importance of methods and underlying assumptions used in cost-benefit analysis and risk-benefit analysis by engineers
	2—perform simple analysis and estimation using engineering methodology	2—achieve a survey-level understanding of why particular materials and processes are used to produce simple engineering devices and systems
	3—understand the capabilities and limitations of basic manufacturing processes and engineered systems	3—better understand the role of technology (engineering) in society and the interactions of technology (engineering) with their major field
	4—make informed decisions about the desirability of engineering activities by weighing the benefits of those activities against the risks	4—understand how to access and interpret reliable information to make informed decisions regarding technological issues
	5—work effectively as a member of a team including technological experts	
Key curriculum components—Model Curriculum	Understand fundamentals of engineering science and design (beginning calculus prerequisite)	"How it works" (minimal level of prerequisites)

	• Introduction to Engineering
	  ○ Design process
	  ○ Communication with graphics tools
	  ○ Numerical approaches to problem solving
	• Science base and complimentary engineering science base
	• Computational technology competence
	• Appreciation of interaction of technology and society
	• Capstone interdisciplinary teamwork experience
		• Introduction to Engineering
		  ○ Design process
		  ○ Communication with graphics tools
		  ○ Quantitative approaches to problem solving
		• Science base
		• Computational technology competence
		• Appreciation of interaction of technology and society

Student Learning Outcome Assessment Plan

The Minors Oversight Committee is charged with assuring the assessment of student learning outcomes. The EEIC will administer a minor completion survey and work collaboratively to support the qualitative and quantitative evaluation proposed. The survey will explore student perceptions of (1) the attainment of the learning goals indicated for the minor, and (2) structure, availability, and appropriateness of courses in the minor. This data, along with enrollment data, will be reviewed annually by the oversight committee.

Engineering in the General Education Program at Hope College

"Science and Technology of Everyday Life" at Hope College

It is expected that a necessary course for a minor in engineering will be an overview course summarizing a wide range of engineering principles and technological systems. The engineering department at Hope College has established such a course entitled "The Science and Technology of Everyday Life." This is offered to students from non-technical majors and includes students from business, history, fine arts, and pre-service education students. The course is taken by approximately 150 undergraduates each year.[18]

The objective of the course is to develop both a familiarity with the engineering aspects of how various technological devices work and an understanding of the basic scientific principles underlying their operations. To better engage students, the course topics were selected to represent the technologies most frequently encountered in everyday life and were based partly on the results of surveys of student interests.

Evaluation using the Motivated Strategies for Learning Questionnaire (MSLQ)

At Hope, results on changes in student attitudes and motivation to understand technological topics in this course have been assessed using the Motivated Strategies for Learning Questionnaire (MSLQ). Items from this instrument are self-report items on a seven-point scale.[19] These measures are designed to be task-specific, that is, they measure motivation in a particular area of study. The MSLQ has been shown to be a reliable and valid measure of student motivation in higher education samples[20] as well as middle and high school samples[21]. The components of the MSLQ that are used to evaluate interest and attitudes about engineering and technology include: intrinsic motivation, extrinsic motivation, task value, self-efficacy, and test anxiety.

Promising results are summarized in Figure 1. The pre- and post-MSLQ data were analyzed using paired t-tests. After completing just one engineering course for non-engineering majors, these students demonstrated increased intrinsic motivation, increased task value, and improved self-efficacy about science and technology. Self-efficacy increased by more than 10% and test anxiety about technological topics decreased by almost 15% in one semester. All results are statistically significant ($p<0.05$). These results are encouraging for the prospect of attracting non-engineering students to pursue an engineering minor.

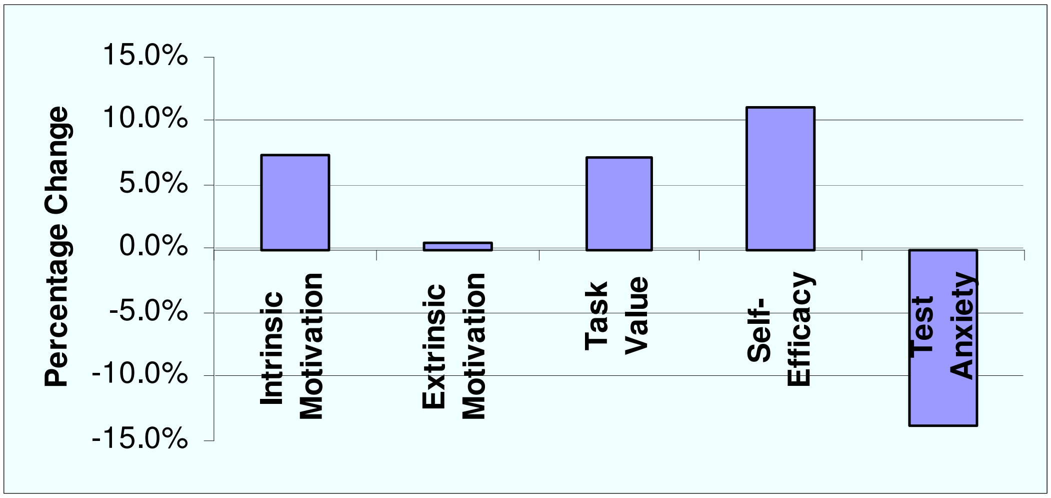

Figure 1: MSLQ Results Hope College—48 Students, Spring 08.

Rice University: Introduction to Engineering Design and New Minor Program

Minors have only been established in recent years at Rice University. However, Rice has a well-established Introduction to Engineering Design course that is taken by both engineers and non-engineers. Besides appealing to science majors and other non-engineering students, the intended engineering minor at Rice will be structured so that it will qualify students for the Texas teaching certificate in engineering. The Rice program will also investigate the possibility of allowing students to complete elements of the minor using non-course relevant experiences, such as internships, study abroad, participation in engineering design project teams, and some other appropriate extracurricular experiences.

Rice University: ELEC201—Introduction to Engineering Design

A desirable feature of an engineering minor would include having some courses in the minor enroll both engineering students and non-engineering majors. At Rice University a model for such a course has been developed. The ELEC201 Introduction to Engineering Design Course is taken by both engineering and non-engineering students. This hands-on course immerses students in an engineering design and problem-solving team experience that exposes them to the challenges and rewards experienced by practicing engineers.[22,23] Teams of three students design, construct, and program a small autonomous robot to engage in a competition at the end of the semester. The engineering challenge for each team is to devise a game strategy and to design and build the mechanics and software to implement their strategy within the rules of the game and the available materials. The humanities faculty at Rice has praised the course for its content, breadth, and accessibility. It became the most popular course at Rice with enrollment having to be determined by lottery. Figure 2 shows students working in the class.

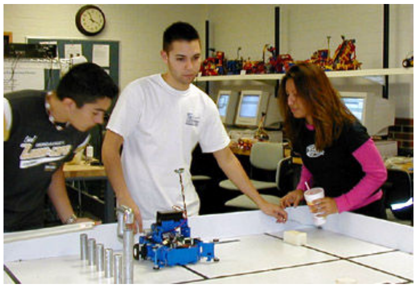

Figure 2: Engineers and Non-engineers Collaborate in Introduction to Engineering at Rice.

The Rice Minor in Engineering Studies Program

The unique character of Rice University presents both opportunities and challenges in implementing technological literacy courses and a minor. Minors are new to Rice, having been approved only in the past two years. Thus, although there are presently fewer than five minors, there is an interest in their creation, and each proposal generates significant publicity among students and faculty. Many Rice undergraduates arrive with a solid background in high school mathematics and science, many with AP credit—even those who do not plan to major in engineering or science. It is expected that such students will be open to the idea that technological understanding and engineering problem solving and analysis will help them make more effective and meaningful changes in a world that is dominated by technological opportunities and challenges.

Rice expects to develop and implement its MES using two primary strategies. First, the intended minor will have a dual use to appeal to two student constituencies. The primary constituency is non-engineering majors who appreciate that technology pervades today's economy, business, and society. Rice does not have an education department or school, but it does have an education certification program to qualify students to teach K-12. The Rice MES will be structured so that it will qualify students for the Texas teaching certificate in engineering. The MES offering will also be coordinated with Rice's existing masters in science teaching degree taken by many working teachers.

The second strategy is to design the minor so students have multiple reasons to explore the early courses and develop motivation to pursue the entire program. Rice requires all undergraduates to satisfy a breadth requirement of 12 semester hours in each of three areas: humanities, social science, and science, engineering, and mathematics. Only specified courses can be used to satisfy the breadth requirement, and presently there are only a few courses in engineering accessible to non-engineering majors. Rice will design at least the initial courses in the MES to meet the breadth requirement, giving students a reason to take them and to sample the minor. To encourage retention in the MES, Rice will structure it to allow students to satisfy some requirements using non-course relevant experiences, such as technically related summer internships and foreign experience, participation in engineering senior design project teams, and some extracurricular experiences, such as Engineers Without Borders projects.

Summary

This work will advance the development of a minor offered by engineering units applicable for students who are not engineering majors. The minor is intended to be widely applicable to a range of institutions throughout U.S. higher education. Under investigation is the possibility that the credential of such a an engineering studies minor may provide an incentive for some non-engineers to develop a broad understanding of the technology upon which our economy depends.

To facilitate wide adoption a focus of the current work is the establishment of a set of Technological Literacy Objectives and Outcomes for a minor. These outcomes will be similar to the ABET a-k outcomes that are used for engineering degrees but will be focused on developing technologically literate citizens. The use of a standard set of outcomes rather than a standard series of courses will allow flexibility for each institution to develop a minor that is best suited to its local conditions, similar to the way engineering departments meet the ABET a-k requirements for engineering majors.

To help in promoting the minor to non-engineers, survey work is being conducted with students currently enrolled in programs at collaborating institutions. Surveys are also being conducted with students who are potential constituents of such a minor program. This will provide critical insight into the interests and motivations of non-engineering students. Work is also underway to determine the value that potential employers might place on such a minor.

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Bibliography

1. Augustine, N. (Chair), National Academies Committee on Prospering in the Global Economy of the 21st Century. 2005. *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future*. Washington, D.C.: National Academies Press.
2. Duderstadt, J. J. (Chair), National Academy of Engineering Committee to Assess the Capacity of the United States Engineering Research Enterprise. 2005. *Engineering Research and America's Future: Meeting the Challenges of Global Economy*. Washington, D.C.: National Academies Press.
3. Duderstadt, J. J. 2007. *Engineering for a Changing World: A Roadmap to the Future of Engineering Practice, Research, and Education*. Ann Arbor, Michigan: University of Michigan Press.
4. Flanagan, J. L. 2006. U.S. competitiveness and the profession of engineering. *The Bent of Tau Beta Pi*, 16–22.
5. Galloway, P. D. 2007. *The 21st Century Engineer: A Proposal for Engineering Education Reform*. Reston, Virginia: American Society of Civil Engineering.
6. Boyer, E. 1998, 2001. *Reinventing Undergraduate Education (The Boyer Commission Report)*. New York: Carnegie Foundation.

7. Clough, G. W. (Chair). 2004. *The Engineer of 2020: Visions of Engineering in the New Century*. National Academy of Engineering. Washington, D.C.: National Press.
8. Clough, G. W. (Chair). 2005. *Educating the Engineer of 2020: Adapting Engineering Education to the New Century*. National Academy of Engineering. Washington, D.C.: National Press.
9. Clough, G. W. 2006. Reforming engineering education. *The Bridge*. Washington, D.C.: National Academy of Engineering.
10. Vest, C. M. 2006. Educating engineers for 2020 and beyond. *The Bridge* 36(2, Summer).
11. Council on Competitiveness. 2004. *Innovate America: Thriving in a World of Challenge and Change*. Washington, D.C.
12. Pearson G., and A. T. Young, eds. 2002. Technically Speaking: Why All Americans Need to Know More about Technology. National Academies Press.
13. Pearson G., and E. Garmire, eds. 2006. *Tech Tally: Approaches to Assessing Technological Literacy*. National Academies Press.
14. Mina, M. "Work in Progress – Minor in Engineering Studies: Teaching Engineering Concepts to Non-Engineering Students, *Proceedings of the 37th ASEE/IEEE Frontiers in Education Conference*, October 10 – 13, 2007, Milwaukee, WI
15. Mina, M. "Work in Progress – Minor in Engineering Studies: The Role of Engineering Colleges in Providing Technological Literacy, *Proceedings of the 38th ASEE/IEEE Frontiers in Education Conference*, October 22 – 25, 2008, Saratoga Springs, NY
16. Mina, M. "Minors in Engineering Studies: Teaching Technology to Non-Engineers - First Results," *Proceedings of the American Society for Engineering Education Annual Conference*, June 22 - 25, 2008, Pittsburgh, PA.
17. Gustafson, R. J. and B. C. Trott. 2009. Two Minors in Technological Literacy for Non-Engineers, *Proceedings of the American Society for Engineering Education Annual Conference*, June 15-17, Austin, TX.
18. Krupczak, J. J., S. VanderStoep, L. Wessman, N. Makowski, C. Otto, and K. Van Dyk. 2005. " Work in progress: Case study of a technological literacy and non-majors engineering course," *Proceeding of the 35th ASEE/IEEE Frontiers in Education Conference*, October 19-22, Indianapolis, IN.
19. Pintrich, P. R., D. Smith, T. Garcia, and W. McKeachie. 1991. *A Manual for the Use of the Motivated Strategies for Learning Questionnaire.* Technical Report No. 91B-004. National Center for the Improvement of Postsecondary Teaching and Learning, University of Michigan.
20. Pintrich, P. R., D. A. Smith, T. Garcia, and W. J. Mckeachie. 1993. Reliability and predictive validity of the motivated strategies for learning questionnaire (MSLQ). *Educational and Psychological Measurement* 53: 801–13.
21. VanderStoep, S. W., P. R. Pintrich, and A. Fagerlin. 1996. Disciplinary differences in self-regulated learning in college students. *Contemporary Educational Psychology* 21: 345–62.
22. Hanford, B. 2004. *Engineering for Everyone*. American Society for Engineering Education, *PRISM*. Available online at: http://www.prism-magazine.org/dec04/feature_engineering.cfm. (accessed 10 March 2010).
23. ELEC201. Introduction to Engineering Design. Rice University. Available online at: http://www.owlnet.rice.edu/legolab. (accessed 10 March 2010).