Preeminence in First-Year Engineering Programs

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Abstract

The Department of Freshman Engineering (FrE) at Purdue University is currently celebrating its 50th Anniversary. For five decades the Department has slowly evolved, reacting to nationwide trends and advances by incorporating new pedagogical approaches to engineering education, and adopting engineering technologies appropriate to the time. The Department is now looking towards taking a leadership role in engineering education reform. Such a step will create opportunities to reform the first-year engineering program, long the centerpiece of FrE.

FrE serves as the gateway to the Schools of Engineering with all students completing the FrE core curriculum being admissible as sophomores to the professional engineering degree programs at Purdue. In this role, FrE works closely with the Engineering Professional Schools, the School of Science, and the School of Liberal Arts, as well as industry, alumni and parents to recruit, retain, and reinforce outstanding engineering students.

Transformation of the first-year program needs to find balance between a number of opposing forces. A minimum of fundamentals in science and math are required to prepare students for their sophomore engineering coursework, and exposure to the nature of engineering and its opportunities is needed to enable students to identify an appropriate career path. However, the academic rigor of the first year in engineering is overly challenging and even shocking for many students. Still, calls for engineering education reform speak of educating students in areas of communication, ethics and professionalism, design, working in teams, leadership, entrepreneurship, and global understanding (to name a few), all of which vie for curriculum time. As we seek to transform the first year we also need to keep an eye to current engineering education research, and to those issues touching on matters of diversity and social responsibility.

This paper will share the struggle and the insight gained by its authors in transforming a high-quality first year program into one seeking recognition as "preeminent." Planning activities, reactions to opportunities and threats, overcoming resource constraints, showcasing and exploiting of strengths, shoring up of weaknesses, and the overall process of transforming the first-year program will be discussed.

Background

To successfully compete and to be leaders in the future work place, our graduates must have a world-class engineering education, be equipped with the latest technical knowledge and tools, and have adequate understanding of the social, economic, and even political issues that affect their work. Engineering graduates need to be significantly better prepared to deal with information retrieval, integrating knowledge, and synthesis than has heretofore been possible. They must be able to take a holistic approach to problems involving complex and ambiguous systems and scenarios and to employ creative and critical thinking skills.

In an increasingly global marketplace, our graduates are expected to work on multinational teams, to have global perspective, and to be culturally and linguistically literate. They must possess communication skills to interact effectively in the community and within the professional and political arenas. Today's ethical issues will assume global proportions and our graduates must have the strong ethical foundation they will need to deal with issues involving equitable distribution of resources, byproducts of design and production, proprietary information, sustainable development, environmental conservation, genetic engineering, and human cloning. They must be familiar with legal and business aspects of engineering solutions and their social impact and have a foundation in best business practices and the fundamentals of entrepreneurship.

Reform in the first-year needs to find balance between a number of seemingly opposing forces. A minimum of fundamentals in science and math are required to prepare students for their sophomore engineering coursework. Students and the engineering disciplines wish to have exposure to the nature of engineering and its opportunities to enable students to select an appropriate career path. The more we try to fit into the first-year curriculum, the greater seems to be the outcry from students struggling to avoid changes to other majors, academic failure, and outright transfer to other institutions.

The academic rigor of the first year in engineering is overly challenging and even shocking for many students. Still, calls for engineering education reform speak of educating students in areas of communication, ethics and professionalism, design, working in teams, entrepreneurship, leadership, and global understanding (to name a few), all vying for curriculum time. As we squeeze more of these into our existing courses, the fairness of the course workload becomes increasingly an issue for the students therein. Telling them that it is good for them, much like a nutritious diet, provides little comfort. Those topics too large for existing courses go begging for a champion to find them a place in the curriculum, and curriculum committee meetings use great amounts of time and debate trying to find a balance of these competing forces that can be made to work effectively for our students.

Transformation of Freshman Engineering

As we seek to transform the first year we also need to keep an eye to current engineering education research, and to those issues touching on matters of diversity and social responsibility. Certainly we attempt to recruit the most diverse classes of students that we possibly can. Some of our seminars include diversity and social responsibility as central issues to be learned about and discussed. Recruiting of faculty and staff is another matter, however, where the cold realities of the marketplace dictate whether we can or cannot make suitable progress. In the classroom, current engineering education research is being utilized to the extent possible in pedagogy and technology utilization. Issues external to the classroom, such as class size and course structure, are being addressed to the extent possible, but run into constraints such as faculty size, classroom availability, and the inertia inherent in committee-made decisions.

To continue to meet the needs of Purdue's Schools of Engineering and the greater engineering community, we envision a new framework for reform in engineering education[1] that entails the development of academic and research programs devoted to growing the engineering education research base in general, and implementing research-informed changes to the first-year engineering program. The following material includes some potential directions for change, with a particular focus on curriculum and advising, based on current first-year experience research findings.

Since 1953, Purdue University's Department of Freshman Engineering (FrE) has pursued a wide variety of educational and research programs that have focused on beginning students. With about 1600 entering students yearly, the gateway role played by FrE has always been of considerable importance, particularly with regard to the core curriculum that must be completed by all these students prior to their movement, as sophomores, into Purdue's professional engineering degree programs.

As the students in FrE complete the requirements of the first-year curriculum and move, as sophomores, into their chosen professional degree programs, they are largely unaware of the enormity of the effort put forth by FrE, the Engineering Professional Schools, the School of Science, and the School of Liberal Arts, as well as industry, alumni and parents to recruit, retain, and reinforce these outstanding young people in their academic pursuits. Reinforcement comes through a curriculum under constant review and through academic advising services supplied by faculty, professional staff, and student peers.

FrE's assessment of beginning engineering students and the first-year engineering program is, and has always been, fairly comprehensive. The FrE assessment strategy is to collect and analyze data from a number of sources and of a variety of types and use triangulation of that data to develop an understanding of the program's strengths and weaknesses. These data include programmatic data such as retention data as well as initiative or program specific data. These data are collected in recurring efforts as part of longitudinal assessment and periodic evaluation of unique programs. More resource intensive data collection means such as interviews are used to calibrate and validate the less resource intensive efforts that are carried out every year. The success of the FrE program can be attributed to the blending of the scholarship of teaching and the scholarship of discovery in engineering education. The FrE program has long benefited from faculty efforts to adapt, apply, and forward the best of engineering education practice.

Recent Advances and Lessons Learned – The vision articulated above "to educate future engineering leaders who are ready for the[se] challenges of the 21st century, and who will take leadership for shaping events and creating the future" does not, in and of itself, imply that the program we currently believe to be excellent is mired in shortcomings. Over the past several years we have made substantive efforts to improve three programmatic areas:

- *Engineering Problem Solving and Computer Tools* - is a required course for first-year students. It has successfully migrated from a tools (e.g. syntax) course to a problem-solving course that addresses a broader array of understandings, abilities, and skills students need to be successful engineers (ABET EC2000 Criteria a-k) and gives students an appreciation for what the pursuit of an engineering degree entails. Faculty are implementing the best of, assessing, and contributing to the body of research on student teams, active learning, open-ended problem solving and higher-level learning, and teaching assistant training.

- *First-Year Seminars* - required course for first-year students. The faculty have worked with various constituents to develop two models for small group seminars, faculty led (ENGR 103) and peer mentor led (ENGR 104) seminars. These courses have been the test bed for implementing first-year experiences that have stood the test of time elsewhere and tailoring them to meet the needs of Purdue engineering students. In the case of ENGR 103, this work has provided students with more intimate exposure to the engineering opportunities available in the participating Schools of Engineering. In the case of ENGR 104, this work has allowed us to look at the impact of various peer led models on student retention, overall first-year academic performance, and program satisfaction. Models under investigation include learning communities, dedicated international student divisions, and alumni mentoring. This work has also resulted in the creation of *ENGR 404 - Instruction, Mentorship, and Leadership*, a course designed to educate upper-division engineering students on being effective peer mentors and instructors to first-year students. Thus, first year students choosing to take ENGR 104 will be exposed to effective peer mentoring, much as are the Honors students in the Peer Mentoring program described below.

- *The Freshman Engineering Honors Program* - is designed to provide the highly motivated and academically successful student with a broader and more enriched educational experience during his or her freshman year through a variety of academic challenges. The program is intended to cultivate the inquisitive nature of its participants by allowing them to explore, expand and excel in a curriculum that promotes both scholastic achievement and breadth of knowledge. Students are admitted to the Honors program based upon a combination of their SAT/ACT test scores (1360 SAT or equivalent ACT), high school GPA (3.8 on a 4 point scale), and class rank (top 10%) or by being the recipient of one of Purdue's merit-based scholarships. Participation in the program is optional, but students choosing to join are required to enroll in a minimum of 7 credit hours of Honors or Honors designated courses per semester, as well as maintain a 3.4 GPA in order to earn recognition for Honors program completion. Overall, the Honors Program provides a small school environment, while utilizing the resources of one of the nation's top engineering programs. Many of its participants are not only valedictorians and National Merit Scholars, but are also proven leaders in their communities and high schools.

  More recently, the program has established an Honors Residential Learning Community (HRLC) and currently has a membership of approximately 100 students. HRLC participants are all housed in a common residence hall (dormitory), attend common engineering classes and actively participate in co-curricular activities, which highlight engineering accomplishments. The Honors program has also established a Peer Mentor Program. This program connects new Freshman Engineering Honors students with students who have successfully completed the Honors Program in previous years. The

Peer Mentor Program is being implemented within the ENGR 100H lecture series, which incorporates small group sessions led by upper-class peer mentors. The goal for the program is to provide a student support/learning atmosphere for Freshman Engineering Honors students to gain a better student perspective of college life, the Honors Program, the Schools of Engineering, and Purdue University.

Several threads of commonality exist between these various efforts. They all required a great deal of planning to successfully execute, as should be expected. They all involved reaction by faculty to a perceived need, to improve content, to showcase or exploit a strength, or to shore up a weakness. In some cases, they exploited opportunities that arose suddenly or unexpectedly, while there were also constraints and outright roadblocks to overcome in some cases. While not all needed first-year reform measures have been implemented, or maybe even thought of, insight regarding the "change process" has been gained that are worth considering.

Opposition can often be thwarted, or even eliminated, through the process of generating "buy-in" from affected parties, converting them to supporters by soliciting their feedback early and incorporating it into the proposed changes. Resource shortfalls defy elimination through simple planning, and usually require more than a little hard work to overcome. For many situations, internal funding may be meager to nonexistent. In these cases, various external grant programs may be tapped for needed funding. Creativity is absolutely essential in this, often providing the insight necessary to substitute one source for another in overcoming resource constraints. When opportunities are correctly anticipated, these become the needed resources for implementation of change. This seldom happens without a great deal of hard work and preparation.

Focusing on the Future

As the academic programs of the new framework for engineering education at Purdue University take shape, we expect that the transformation of the first year program will include improvements in curriculum, pedagogy, use of technology, and recruiting and retention. These are discussed individually in the following sub-sections.

Curricular Improvements
Curricular improvements include the work previously described herein on the core courses and seminar courses in FrE. In addition, we envision developing and deploying a different introductory engineering course. This new course represents a significant departure from previous offerings in so far as it will have, as its core teaching objectives, an introduction to teaming and the teaching of engineering fundamentals, problem solving strategies, and design concepts in contrast to teaching computer tools with a specific focus on logic development and algorithmic design.

The purpose of the course will be to introduce students to fundamental engineering concepts and problem solving strategies that provide a framework from which students can make key interdisciplinary connections to math and science. Course materials will be presented in a learner-centered environment and will focus on processes (how to pose questions, how to acquire information to address those questions, and how to assess the quality of information) in order for the students to gain a more complete understanding of the role of an engineer in problem solving and design.

Use of computer tools will not be abandoned. To the contrary, it is envisioned that students will simply have a more “introductory” exposure to computer tools, like Excel and MATLAB. It is still our objective to have students develop a basic understanding of computer tools and the advantages and disadvantages for implementing various solution strategies. In addition, we expect the students to gain insight with regard to selecting the most appropriate tool to facilitate solving an engineering problem.

It is anticipated that specific course outcomes will include enabling a student to:

1. Understand engineering fundamentals and basic engineering science concepts so he/she can synthesize said concepts to create higher quality engineering solutions and designs;
2. Translate a written problem statement into a mathematical model;
3. Implement simple algorithmic solutions to engineering problems/designs using the most appropriate computer tool;
4. Perform basic file management tasks using an appropriate computer tool;
5. Work effectively and ethically as a member of a technical team; and
6. Develop a work ethic appropriate for the engineering profession.

As part of the transformation of the freshman year courses, we propose the development of a new C programming course taught by the Computer Science department in order to provide the students with a rigorous development of programming logic using the context of engineering problems. As part of this new course, we propose that it include pedagogical practices that have been shown to be effective toward the retention of women and underrepresented minorities, such as active/collaborative learning experiences and the inclusion of contextual, real-word engineering problems that explicitly benefit society. Furthermore, this new course will include strategies to help students develop their ancillary skills (i.e., communication skills, teamwork, etc.) by incorporating “formal teaming” as an explicit component of the course. Overall, we envision a course that develops a student’s sense of logic and algorithmic design (within a contextual engineering setting) and less emphasis on a student’s low-level cognitive ability to simply memorize syntactical constructs.

The purpose of the course, as we suggest, should be to introduce students to structured problem solving and top-down programming techniques using C in the context of solving engineering problems. In addition, students should learn how to transform typical engineering problems into their algorithmic equivalent and subsequently into an appropriate programming language. In addition, by the end of the course the students should be able make the connection of logic, algorithmic design and programming syntax to working in a MATLAB environment. Lastly, students should have knowledge and experience in working as effective members of a *technical learning team*.

It is anticipated that specific course outcomes will include enabling a student to:

1. Apply knowledge of logic, algorithmic design and programming syntax to the solution of engineering problems;

2. Translate a written problem statement into a mathematical model that is suitable for algorithmic development;
3. Use a logical problem solving process for software development, which includes sequential structures, conditional structures, and repetition structures;
4. Use a logical software development process, which includes developing, systematically debugging, and executing programs written in C;
5. Have a working knowledge of the syntactical structures for C;
6. Make the connection of logic, algorithmic design and programming syntax to working in a MATLAB environment; and
7. Work effectively and ethically as a member of a technical team.

Pedagogical Improvements
Guided by the successes and failures of others[2], we are poised to make major improvements in our students' first year experience. We are undergoing a major restructuring of our department[1], which will allow us to vastly improve our implementation of the methods and measures proven successful by engineering education researchers at Purdue and throughout the country in promoting student learning. In addition, we will be implementing these methods on a scale much larger than most engineering programs, with about 1500 first-year students taking our mainstream courses annually. Our restructuring will also allow us to keep abreast of pedagogical changes on a continuous basis.

Further, this restructuring will result in an environment wherein the researcher and the practitioner will be one and the same. A new building with teaching lab facilities specifically tailored to first-year engineering courses will open its doors to us in less than three years, assuring our ability to adopt methods developed elsewhere as well as those developed here. We will thus be enabled to consistently use the best pedagogy available in our courses, which will help to establish us as the preeminent Freshman Engineering Program in the country and allow us to serve as a model to other institutions.

Some of the pedagogical improvements that we initially envision are[2]:

- incorporating new knowledge into lower level courses more rapidly and more thoroughly;
- introducing engineering concepts by examining current issues for which most students have some personal context;
- organizing courses, or often course *modules*, to address real-world problems;
- developing curricula that expose students to key interdisciplinary connections, and multi-disciplinary perspectives stressing concepts as much as facts;
- focusing on *processes* (how to pose questions, how to acquire information to address those questions, assessing the quality of information);
- using the vast computational power of modern personal computers and mathematics to explore engineering concepts and illustrate those concepts in ways that entice students;
- ensuring that students have frequent access to active learning experiences, in class (such as in peer groups or in laboratory classes) and outside of class (as in study teams, using interactive class bulletin boards, and/or in faculty research projects);
- developing a freshman curriculum that embodies some or most of the above features, and that takes full advantage of modern technology, particularly personal computers,

multimedia materials, digital libraries, hypertext documents, and access to vast networked resources, including databases and activities on other campuses;
- improving ancillary skills (communication skills, teamwork, respect for ideas of others, cognitive skills, etc.) as a critical byproduct of modern approaches to teaching and learning;
- ensuring that students have ready access to people who can provide them with reasonable assistance (faculty, teaching assistants, graduate students, advanced undergraduate students, and able peers);
- demonstrating respect for students' genuine efforts to learn, understanding that many learn through initial failures, and encouraging further efforts to learn;
- mentoring students, and
- devoting more energy to advising students about course selections and career options.

Our goal will be to "provide a curriculum that engages and motivates the broadest spectrum of students, enabling every student to learn and providing reasonable flexibility for students to move onto or off of various career-preparation paths without undue penalty"[2] that is based upon sound pedagogical practices and a solid foundation of educational research. Courses (or modules) will be designed to allow students to develop engineering skills above and beyond the "normal" first-year requirements, and will offer hands-on components, as well as an introduction to the engineering profession. Such courses have been shown to better inform students about engineering disciplines and improve student satisfaction and retention[3-8]. Problem-solving, design, and logic will provide the framework by which students will develop a firm foundation of engineering fundamentals, while at the same time expose them to key interdisciplinary connections, and multi-disciplinary perspectives which stress conceptual understanding as much as the learning of facts. Ancillary skills, such as oral and written communication skills, teamwork and respect for ideas of others will be threaded throughout the students' first year experience in order raise their awareness of the importance of developing such skills for their future success. Finally, we envision actively engaging students in service learning projects. Such projects have been shown to make students keenly aware that giving back to one's community is the norm as an engineer, rather than the exception.

Greater Use of Technology

FrE faculty are currently involved in research involving use of technology in the lecture classroom. Emphasis is on such use to support active and collaborative learning efforts to supplement the traditional lecture class format. Work has been done using laptop computers, and is under way on use of PDA devices.

Recruiting and Retention Improvements

The engineering education literature continues to draw attention to the fact that shrinking engineering enrollments pose a potentially serious problem for American industry and society[9,10] The annual graduation rate in engineering has decreased by roughly 20 percent in the last decade. Most engineering schools have undertaken major recruitment efforts in order to correct this problem, many of them directed at women and minorities. However, since freshman enrollment is heavily influenced by factors out of the university's control (for example, fluctuations in the job market and starting salary levels in engineering relative to other fields[10], engineering schools seeking to improve their graduation rates are turning to retention as an effective strategy[11].

Considering the strong academic records of most students who choose to go into engineering, the observed rates of attrition are dramatic. In his massive study of nearly 25,000 students at over 300 institutions, Astin[12-14] found that only 43% of the first-year engineering students in his population went on to graduate in engineering. Moller-Wong and Eide[15] obtained similar results for a cohort of 1,151 engineering enrollees at Iowa State University. They found that after five years, 32% of their subjects graduated in engineering and 13% were still enrolled, for a potential graduation rate between 40% and 45%. In this regard, Purdue stands at or above the national norm, graduating in excess of 60% of the engineering students that begin in engineering.

Does having an above average graduation rate imply that we already have a preeminent first year engineering program? Probably not; when comparing attrition rates after the freshman year, we are at (or are slightly below) average. Our typical attrition is approximately 25 to 28%, compared to other peer-institutions whose attrition rates average 20 to 25%. A common, but incorrect, explanation of the attrition rates is that most of those who leave engineering lack the academic ability to cope with the rigors of the discipline. In fact, studies have shown little difference in academic credentials between students staying in engineering and students leaving[16-18]. The true explanation appears to involve a complex set of factors including students' attitudes toward engineering, their self-confidence levels, and the quality of their interactions with instructors and peers[11-16] along with their aptitude for engineering.

Therefore, in order to move the Freshman Engineering Program to a level of preeminence, we must simultaneously address *recruiting* and *retention* issues (i.e., improve our capture rate of a diverse population of high achieving students and then retain them), as well as improve course content, integration of content, and pedagogy. Pedagogical improvements in engineering education have been facilitated by a large infusion of funding from NSF during the 1990's, particularly for undergraduate programs.

Conclusion

It is evident that there are significant and complex challenges to recruiting, retaining, educating, and preparing a highly diverse student population for not only future careers in engineering but also life-long learning. The nature and culture of engineering is such that these challenges can only be addressed by the engineering community. Transformation of the first-year engineering program at Purdue University will be tightly linked to a new vision for the Department of Freshman Engineering[1]. Through this new vision, we seek to create programs with the capacity to develop a research base to significantly impact engineering education reform, particularly in the first year.

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