2006-178: PROFESSIONAL ENGINEERING EDUCATION BEST PRACTICE STUDY FOR FIRST-YEAR, MULTI-DISCIPLINARY COURSES

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Professional Engineering Education Best Practice Study for First-Year, Multi-disciplinary Courses

Abstract

Highly beneficial professional engineering courses are those that include both components of theory and hands-on learning. Hands-on group design projects can be viewed as essential because they tie together all of the theory and force students to start thinking like real engineers. Through the presentation and assessment of design projects, students can recognize their strengths and weaknesses (time management, communication skills, problem solving ability, etc.) early on so that they can develop these skills in future courses. This approach of combining theory and practice is consistent with criteria set forth by Engineers Australia and ABET for engineering degree programs. Both organizations encourage a realistic understanding of professional practice, including project management and ethics, and require students to be able to work in multi-disciplinary groups and communicate effectively. Although universities have the entire duration of the degree program to meet these requirements, students benefit greatly from early exposure. The purpose of this study was to discuss best practices for introductory courses that focus on professional engineering skills and practice. Through internet-based research, information was gathered about 82 courses at universities in Australia, the United States, Canada, and Great Britain. Courses that were multi-disciplinary and mandatory for first-year students were analyzed to determine best practices; the University of Queensland's *Introduction to Professional Engineering* course was used as a case study.

1.0 Introduction

According to feedback from employers, a major weakness of engineering programs continues to be producing graduates with an unrealistic view of the role of professional engineers and inadequate professional skills.[4] Today, universities are actively trying to better prepare students with the communication, teambuilding, business and interpersonal skills to complement their technical engineering knowledge. Many universities are beginning this preparation during the first year with introductory professional engineering courses.

A profession is a learned calling which requires advanced knowledge, understanding, and abilities that are gained from intensive and specialized education, training, and practical experience. More specifically, professional engineering involves the application of a theoretical body of knowledge to solving problems and designing systems. Professional engineers are expected to work as members of teams to develop innovative and creative solutions to problems. They must make judgments about design options based on cost, aesthetics, risk of failure, and environmental impact. In addition, they must be willing to undertake on-going learning to update their knowledge and refine their skills.[2]

According to a survey conducted by the *Engineers Leadership Foundation* and the *Foundation for Professional Practice* of almost two hundred senior engineering managers and leaders, engineering knowledge is essential, but leadership positions can be attained earlier if engineering graduates have been exposed to management, public speaking, and other non-engineering coursework. Respondents highly recommended taking courses in

business management, public speaking, and marketing to improve engineering leadership potential.[3] Success in any career requires life-long learning and application of "people skills," written and oral communication skills, and teambuilding skills in addition to technical skills and theoretical knowledge.

Considering the competitive job market, the obvious question is what are potential employers looking for in candidates. According to the NACE survey, desired characteristics of an ideal candidate have not varied greatly from year to year and generally applicants are well prepared. The qualities and skills considered most important are verbal and written communication skills, honesty, interpersonal and teamwork skills, motivation/initiative and a strong work ethic, and analytical skills. Surveyed employers judged that graduates overall have deficient communication skills (which are considered the important skills), maturity and work ethic, commitment to the organization, and business etiquette. In addition, many graduates display an unrealistic view of the workplace.[4]

Engineers Australia (EA) and the Accreditation Board for Engineering and Technology (ABET) are two organizations that have developed regulations for engineering degree programs, and both require direct preparation for professional engineering practice.

EA has set forth the following criteria for a professional engineering degree[2]:

Program structure and content

(1) math, science, engineering principles, skills and tools for discipline (40%)
(2) engineering design and projects (20%)
(3) discipline specialization (20%)
(4) exposure to professional engineering practice, including management and ethics (10%)
(5) additional electives (10%)
(6) special emphasis on life-long learning, team interaction, and communication

Exposure to Professional Engineering Practice

(1) mandatory lectures on professional ethics and conduct
(2) staff with industry experience
(3) practical experience outside teaching establishments
(4) guest lecturers
(5) industry visits and inspection
(6) industry based final year project
(7) use of journal to record experiences

ABET criteria for program outcomes and assessment requires that students be able to demonstrate[1]:

(1) an ability to apply knowledge of mathematics, science, and engineering
(2) an ability to design and conduct experiments and interpret data
(3) an ability to design a system, component or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
(4) an ability to function on multi-disciplinary teams
(5) an ability to identify, formulate, and solve engineering problems
(6) an understanding of professional and ethical responsibility
(7) an ability to communicate effectively

(8) the broad education necessary to understand the impact of engineering solutions in a global and societal context
(9) a recognition of the need for life-long learning
(10) a knowledge of contemporary issues
(11) an ability to use the techniques, skills, and modern tools necessary for engineering practice

ABET also has general requirements for professional preparation:

(1) one year of a combination of college level mathematics and basic science appropriate to the discipline
(2) one and one-half years of engineering sciences and design appropriate to the student's field of study
(3) a general education component that complements the technical side of the curriculum.

Students must be prepared for engineering practice through the curriculum culminating in a major design experience based on the knowledge and skills acquired in earlier coursework and incorporating appropriate engineering standards and multiple realistic constraints.

2.0 First-Year Professional Engineering Education – Study Background

Universities throughout Australia, the United States, and Canada offer engineering courses designed to introduce students to engineering as a profession and give them a glimpse of what their academic and occupational futures will entail. Some universities offer two-part courses over a two-year period or even a series of related, mandatory courses throughout a student's academic career. Other universities cover professional engineering in discipline specific courses. Beyond coursework, several universities offer optional not-for-credit opportunities to inform students about careers in the engineering profession – guest lecturers from industry, workshops, career fairs, etc. However, this paper will only look at trends in professional engineering courses that are mandatory, available to first-years, and multi-disciplinary in nature. Since this survey was completed through a web search, the data is only as complete as the available websites and in some cases additional information supplied by a course organizer. Courses at 82 universities in Australia, Great Britain, Canada, and the United States were surveyed, but only 34 courses met the initial requirements. Of those 34 courses, 18 are from Australia, 2 are from Canada, and 14 are from the United States. It is important to note that the 34 courses studied do not represent all first-year professional engineering courses. Great care was taken in evaluating the data following judicious reading of online course descriptions; however, available data may have changed since Spring 2005 or may not fully represent the course. In most cases, data in the grid has not been verified by direct communications with the course providers. The authors recognize that aspects of certain courses may have been overlooked, but the purpose of this study was not to compare individual courses but rather to discuss general trends in first-year professional engineering courses. Readers should also note that the principal author is an undergraduate engineering student, and observations presented in this paper are not based solely on the grid data but also on personal experiences and communications in the United States and Australia.

The following is the matrix used to collect data and analyze the courses. The courses shown in the matrix are those that matched the preliminary criteria of being mandatory for first-year students in all engineering disciplines.

University	Course Name	First Year	Mandatory	Multi-disciplinary		Oral Communication	Written Communication	Graphical Communication	Spreadsheets	Research/ Library Resources	Computer Design Programs	Team work	Sustainable Development	Life Cycle Analysis	Project Management	Role/ Responsibilities	Societal Impact	Career Options	Ethics	Design Process	History of Engineering	Discipline Description	Problem Solving	Open-ended Group Project	Industry Sponsorship	Engineering Failures	Role in Organization	Guest Lecturers/ Site Visits	Systems Thinking	Economics	Risk Management	Creativity	Globalisation
Australian National U	Discovering Engineering	X	X	X		X	X					X			X	X	X		X	X			X	X				X					
U of Queensland	Intro to Professional Engineering	X	X	X		X	X	X	X	X		X	X	X	X	X	X	X	X	X	X		X	X	X			X	X		X		
U of Sydney	Professional Engineering	X	X	X		X	X			X		X	X		X	X	X		X	X			X	X							X	X	
U of Western Australia	Intro to Professional Engineering	X	X	X		X	X			X		X	X	X		X	X		X	X						X	X	X			X		
U of Wollongong	Prof Engineers & Mgmt of Tech	1&2	X	X		X	X			X						X	X				X												
Curtin U of Technology	Engineering and Prof Studies	X	X	X												X									X			X					
U of S Queensland	Principles of Prof Eng and Surveying	X	X	X		X	X					X			X	X	X	X															
Deakin U	Engineering and Prof Practice I	X	X	X		X	X					X				X			X										X				
QUT, Gardens Point	Professional Studies I	X	X	X		X	X	X				X	X		X	X	X		X				X	X								X	X
U of Tasmania	Engineering Profession & Industry	X	X	X		X	X		X	X		X	X			X	X		X	X	X			X								X	
Edith Cowan U	Introduction to Engineering	X	X	X			X					X				X				X			X	X									
Charles Darwin U	Design & Innovation: Communicating Tech	X	X	X		X	X		X	X		X								X				X	X			X				X	
Flinders U	Team Project and Communication Skills	X	X	X		X	X		X	X		X						X		X				X					X	X			
U of Ballarat	Engineering Design and Drafting	X	X	X		X	X	X				X	X		X	X			X	X				X		X		X				X	
James Cook U	Engineering 1	X	X	X		X	X	X			X		X		X	X	X		X	X			X	X			X			X	X		
U of South Australia	Engineering Communication & Innovation	X	X	X		X	X		X				X			X	X				X											X	
U of Western Sydney	Intro to Professional Engineering	X	X	X		X	X			X		X	X	X	X		X		X	X						X	X	X			X		
Central Queensland U	Engineering Skills I&II	X	X	X		X	X	X		X		X	X			X	X		X	X	X		X	X									
U of Toronto	Eng Strategies & Practices (new)	X	X	X		X	X	X				X	X		X	X	X		X	X			X	X					X				
U of Queens	Professional Engineerig Skills	X	X	X		X	X			X		X			X		X		X				X		X			X				X	
University of Michigan	Engineering 100	X	X	X		X	X					X	X			X	X		X	X			X							X		X	
Texas A&M University	Foundations of Engineering I and II	X	X	X			X					X							X			X	X										
	Introduction to Engineering	X	X	X		X	X	X	X			X						X		X		X	X									X	
University of Wisconsin-Madison	Contemp Issues in Engineering Profession	1&2	X	X									X			X	X		X	X		X								X	X		
	Introduction to Engineering	X	X	X			X	X	X		X	X			X	X			X	X			X	X								X	
University of Maryland	Introduction to Engineering Design	X	X	X		X	X	X	X		X	X								X		X										X	
Virginia Tech	Intro to Engineering (2 courses)	X	X	X		X	X	X								X	X		X	X			X										
Ohio State University	Intro to Engineering (2 courses)	X	X	X		X	X	X	X		X	X			X					X		X	X										
University of Virginia	Intro to Engineering	X	X	X		X	X	X	X		X	X			X		X		X	X			X	X						X		X	
Columbia University (FU)	The Professional Engineering Elective	X	X	X																													
North Carolina State University	Intro to Engineering & Problem Solving	X	X	X		X				X		X				X				X		X	X	X									
University of Arizona	Intro to Engineering	X	X	X		X	X		X			X				X		X		X		X	X	X									
Lehigh university	Intro to Engineering Practice	X	X	X		X	X					X			X				X	X		X	X									X	
Bucknell University	Exploring Engineering	X	X	X		X	X		X	X		X	X		X	X	X	X	X	X		X	X	X		X			X	X		X	X

The schools considered in this study were all ranked as top engineering schools in their countries. The institutions listed below were considered in the study but do not offer courses that meet all preliminary requirements of being first-year, mandatory, and multi-disciplinary in nature. Data from these schools was used to make general conclusions about professional engineering education, but specific findings discussed later in this paper are based on the schools listed in the matrix. Other schools considered in the study include:

Australia - University of Canterbury, Australia Maritime College, Griffith University, University of Canberra, Victoria University of Technology, University of Newcastle, University of Technology-Sydney, Latrobe University, Swinburne University of Technology, University of Newcastle, RMIT, Murdoch University, University of Melbourne, Monash University, University of New South Wales, University of Adelaide

Canada - University of British Columbia, University of Calgary, University of Waterloo

United Kingdom - Imperial College, University of Birmingham, University of Glasgow, University of Nottingham

United States - California Institute of Technology, Carnegie Mellon University, Cornell University, Duke University, Georgia Institute of Technology, Iowa State University, Johns Hopkins University, Massachusetts Institute of Technology, Michigan State University, Northwestern University, Pennsylvania State University, Princeton University, Purdue University, Rensselaer Polytechnic Institute, Rice University, Stanford University, University of California-Berkeley, University of Florida, University of Illinois at Urbana-Champaign, University of Massachusetts, University of Minnesota, University of Southern California, University of Texas at Austin, University of Washington, Yale University

Other - National University of Singapore, University of Capetown

3.0 Summary of Findings

A majority of the courses emphasized oral and written communications and teamwork. Many courses combined those skills into a group design project, some of which include a build component. Students learn to work cooperatively in multi-disciplinary teams in order to provide deliverables (written report, oral presentation, graphical drawings, cost analysis, etc.). In order to provide a solution, students must learn and apply the engineering design process. Other common attributes include the role and responsibilities of professional engineers, engineering ethics, societal impacts, problem solving, and sustainability. Australian universities in particular focus on the importance of sustainable development in engineering design. The courses involve a variety of approaches to teaching these and other aspects of professional engineering practice, including lectures, individual research or design projects, guest lecturers or site visits, and various types of assessment. Canada's University of Queens requires students in its *Professional Engineering Skills* course to keep a portfolio of experiences during the semester. Courses are designed to give students a realistic understanding of what their lives as professional engineers will be like.

Some schools have developed very creative ways to make students more aware of the engineering profession in the real world. For example, University of Sydney requires students to compose a logbook of newspaper articles about some aspect of engineering

professions. At Bucknell University students in the *Exploring Engineering* course are required to complete a book report about an engineering-related book selection.

4.0 Improving Introductory Professional Engineering Courses

In addition to the attributes cited above, other essential topics should also be considered for an introductory professional engineering course in order to prepare students for future courses and for careers. First, library and research skills along with basic computer skills (word processing, spreadsheets, presentations, graphics programs) are very important for first-year engineering students to learn but are not emphasized in many introductory courses. In our opinion, these skills are vital for completing projects both at the university level and at work, so it is not safe to assume that students have prior experience with them. The University of Queensland's *Introduction to Professional Engineering* provides instruction in these areas through computer workshops and introduction to information management; direct assessment of these skills is part of the course as well.

Group design projects can be viewed as essential in the first year of every engineering program because they give students a realistic impression of engineering projects and force them to start thinking like engineers. Students must use the skills and theoretical knowledge they have acquired to systematically solve a problem and communicate their solution to the client (in this case a professor). Through this process, students recognize areas that they must improve on, helping them take full advantage of future courses. Offering both design-and-build projects and design-analysis projects is very important because both types are encountered after graduation and undoubtedly students have different preferences. Design-and-build projects also help students recognize that what works conceptually may not work in practice. Also, projects should be representative of the engineering programs offered at the university in order to facilitate exploration of different disciplines.

Many entering engineering students are undecided about their choice of engineering discipline, and one of the best ways to help students make a confident decision is to introduce them to each discipline, including the program structure and career opportunities. The most difficult aspect of accomplishing this is making it equally applicable to all majors – it is important to give an impression of what a discipline entails without being too detailed but at the same time satisfying students who are interested in that major. In this area, guest lecturers from industry and site visits are invaluable because students can experience what daily life in each discipline is like. Incorporating industry sponsorship into the group design projects is another way to accomplish this – companies can provide real-world problems for students to work on and offer staff as project supervisors or mentors. Working directly with a real company is exciting for students and can make the project seem more important.

As a business, professional engineering involves selling products, winning bids, and turning a profit. Any introductory course could naturally include an introduction to economic principles like basic costing analysis and feasibility studies which are necessary in completing the business side of engineering. Discussions of business and economics also involve globalization, which touches everyone's life. Students should be made aware of educational and career opportunities in foreign countries, like study abroad and summer internships.

In addition to the above subject areas, professional engineering courses should also try to encourage life-long learning and awareness of engineering outside of the classroom.

5.0 Review of University of Queensland's Introduction to Professional Engineering

University of Queensland's *Introduction to Professional Engineering* course is a mandatory first-year engineering course that uses lectures, workshops, and practicals to teach students the foundations of professional engineering practice. Course lectures cover engineering's links with society, technology, science and management along with engineering responsibilities, professional communication, ethics, and other topics. Workshops are used for graphics and Excel training; however, only the graphics workshops are mandatory (if students did not take high school graphics). During practical meetings, student groups work on a chosen design project that challenges them to solve an engineering problem and then present their solution in a professional manner. Project assessment includes a written report, oral report, team log book, and project implementation plan.

For the first time in several years, a design-and-build project was offered in 2005. The project was based on the Warman Student Design Competition, in which students had to design and build a prototype device. Although the build component was optional (it would require more time than other projects), several teams completed devices that met the competition's criteria. The faculty coordinator was pleased with the creativity and dedication of the teams, and plans to incorporate the build component into future projects. In addition to the course, orientation for first-year engineering students is designed to introduce them to issues in professional engineering. The day-long orientation is sponsored by industry (mining companies in 2005) and includes presentations by industry representatives. The day also involves a design-and-build competition. The 2005 activity, entitled "Sustainability by Design", challenged teams to construct a connection over a strait to allow trade between two islands; supplies included limited amounts of Popsicle sticks, string, and foam cups. In its design, a team had to consider the social, environmental, and economic implications of the transportation system.

Student Feedback and Recommendations

University of Queensland's course offers a great balance between theory and practical experience, but there are some areas for improvement. A handful of second- and third-year civil engineering students were consulted on possible improvements to the course, and the strongest recommendation was to introduce first-year students to the different professions so that they can make a more informed choice of major. One student reported that he had switched engineering majors during his second year because he realized that it was not what he expected – he most likely would have chosen a different major initially if he had received more information during his first year.

Although there are presentations from recent graduates, a more comprehensive overview of the engineering curriculums and careers related to those programs would be helpful. From about 1985 to 2000 the *Dean's Lecture Series* offered students first hand accounts from industry representatives. The guest lecturers represented each discipline that students could choose from at University of Queensland. For several years the optional lecture series was incredibly popular, but due to poor scheduling attendance declined and the series had to be cancelled. Incorporation of more experienced industry lecturers (in addition to recent

graduates) and program overviews directly into the course would be preferable; however, if that is not possible, the *Dean's Lecture Series* could be reinstated in some form. Engineers can follow so many different career paths, so inviting lecturers (both male and female) with different levels and years of experience can be very informative.

Another recommendation from UQ students is to re-evaluate the emphasis on drafting skills because it is not in-depth enough for upper level students in certain majors and may not even be relevant to students in all majors. Also, if students do not have to use those skills until fourth or fifth year, it may not be necessary to teach them during first year. Students also felt that while understanding life cycle analysis was important, completing their own was long, tedious, and unnecessary. Because the students had not completed a life cycle analysis in subsequent courses, they did not feel that so much time should be spent on it. If these subjects are really integral parts of professional engineering, then the students need a better understanding of their importance and a reason for their inclusion in a first-year course.

Based on student response and the amount of time dedicated to sustainable development and life cycle analysis, slightly cutting back those areas is the most obvious way to include more guest lecturers and course overviews. Industry involvement in the course could also be increased by incorporating site visits into the team projects whenever possible. Students want to see what real engineers do day-to-day. In addition, many students choose engineering because they want to make an impact on society, so a media journal may help illustrate the importance of engineering careers. This could be implemented on an individual level (as assessment, students collect journal articles, newspaper articles, accounts of news reports, etc.), or daily lecturers could share engineering news that they come across. Globalization has become a hot topic in all fields, and engineering is no exception – dealing with foreign clients or working in another country. Students should be made aware of internship opportunities outside of their home countries and encouraged to study a foreign language or study abroad. A final recommendation is to offer additional design-and-build projects in the future so that more students have the opportunity to experience it.

6.0 Conclusions

University of Queensland's Introduction to Professional Engineering is a seemingly effective model for a multi-disciplinary first-year introduction to engineering and professional practice. Through lectures, workshops, and group work students learn basic concepts of engineering practice and how to solve engineering problems within a team environment. The components introduced, including communication skills, design process, and teamwork, should be useful throughout the students' academic and professional careers. During the first year, students want to explore different majors and career paths, so the most beneficial courses offer an overview of engineering disciplines and give students a glimpse of what engineers do in the real world. Although this study does not present a detailed analysis of student performance data, it does provide initial information for analyzing how a first professional engineering course affects student performance in later courses and after graduation.

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