2006-1574: TEACHING INTRO TO ENGINEERING IN CONTEXT – UVA ENGINEERING'S NEW CORNERSTONE

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Teaching Intro to Engineering *in context* – UVA Engineering's New Cornerstone

Abstract

As anyone who has been there can tell you, there is probably no 'thornier' engineering design problem than that of the introductory course in engineering. Along with the traditional requirements that it provide students with a diverse set of fundamental understandings and skills, introduce them to engineering design and to the profession, and illustrate the role of science and analysis, this humble course is now burdened with a host of newly recognized needs. These include the ability to excite a wide range of students about engineering, motivating them to its study, and aiding in the retention of non-traditional engineering students. This paper discusses our efforts to redesign the University of Virginia's Intro to Engineering to better meet all of these requirements, using the *Engineering In Context* approach. The EIC approach seeks to improve retention and the quality of learning through integration of context. Here, the critical contextual learning component is a semester-long, hands-on project (theme) emphasizing application of the engineering problem-solving method to a current challenge or opportunity, coupled with more focused consideration of problem identification and definition, and the potential impact of a successful solution.

In addition to being better able to meet the needs of students, this new cornerstone course is now more attractive to faculty, who are encouraged to draw on their own research and experience in selecting a theme for their students. Although the EIC approach, like problem-based learning, design integration and other techniques for linking theory and practice, is intended to counter the abstraction of technical knowledge and skills advocated by the 'engineering science' model of engineering education, context integration is seen as a potentially more comprehensive and unifying approach.

Introduction

In response to dramatic changes in the demographics of entering engineering students, the intro to engineering course of today has become much more complex than it was even a decade ago, with a host of new requirements. Traditionally, the introduction to engineering course taken by entering first-year undergraduates has played a fairly modest role in the overall context of the undergraduate engineering curriculum, with primary attention given to developing the student's general skills at setting up and solving technical problems, emphasizing the importance of a methodical approach, application of appropriate theory, consistent handling of units and proper interpretation and presentation of results. However, dramatic changes have brought new forces to bear, which are reshaping this traditional component of the curriculum. These changes include increasing numbers of women and minorities in engineering (and the need to increase them further), better preparedness of high school graduates for college-level study, and heightened competition among institutions and fields for the best students. Entering engineering students are therefore more diverse, more demanding, and more 'consumer-conscious' and sophisticated in the evaluation of career alternatives than ever. So in addition to providing students with the fundamentals of technical problem solving, the intro to engineering course must now provide an effective learning experience for a much more diverse group, and actively motivate students to the study and practice of engineering, thereby improving retention.

The introduction to engineering offered to students in the School of Engineering and Applied Science at the University of Virginia (affectionately known as ENGR 162) has traditionally comprised three projects, each requiring roughly a third of the (Fall) semester: these included a paper design study, a technical problem, typically requiring some optimization, and a design-build-test activity[i]. The principal drawbacks of this course plan is that the time available for each project is too short to allow consideration of realistic problems (or of real problems in a realistic way) and that the projects had little relation to one another, and thus did not form a coherent learning experience. As a consequence, students looking to make connections between their interests and the world of engineering were often disappointed. Also, the early stages of open-ended problem solving, in which a problem or opportunity is identified and defined, were of necessity left out entirely.

In response to these shortcomings, an experimental section of ENGR 162 was developed for testing in Fall 2002. Only one of thirteen sections would be taught using the new design, which was developed on the basis of an emerging educational reform initiative at UVA, known as Engineering In Context (EIC)[1]. The fundamental basis for the EIC approach is that the absence of realistic context in engineering education is a common feature among the sources of (1) a disconnect between engineering education and engineering practice; (2) an over-reliance on the engineering science model of engineering education[2]; (3) students who require considerable on-the-job training before they become productive for their employers; and (4) a lack of awareness of the wide range of factors that shape the modern practice of engineering.[3] The success of the context-based design for ENGR 162 led to its adoption for two sections in 2003, six in 2004 and ten in 2005 (cf. Tbl. 1).

This paper describes the EIC model for our intro to engineering course at UVA and presents and discusses our experiences with it thus far.

Engineering In Context Approach to ENGR 162

The engineering science model, which emphasizes the extraction of technical knowledge and skills out of the context (social, political, cultural, environmental, etc.) in which they are applied, and subsequent presentation in the classroom, has become the predominant model of engineering education in the US since the second World War. While some reduction in the level of detail surrounding a problem is essential for presentation in the classroom, the process carried too far, leads to a level of isolation which renders the problem a mere test of analytical engineering science skills. A metaphor for this abstraction process is that of freeze-drying coffee; starting with the freshly harvested coffee beans (the 'context'), the freeze-drying process reduces the coffee to a compacted residue of solids. And just as it is claimed that later, the addition of hot water leads to a rich, satisfying coffee experience, it is implied that students will absorb all of the missing context upon graduating into the real world of practicing engineers ('add water') and make all the necessary connections to their technical extract.

Unfortunately, the lack of context has several short and long range negative effects: 1) the student's ability to appreciate the need for the knowledge and skills presented in the classroom, i.e. to clearly see their usefulness, is diminished, thus missing an opportunity to motivate learning[4], 2) the student's ability to appreciate the connectivity between technological solutions and their influence on social, cultural, economic and other contexts is lessened, and 3) the manner in which the problems arise, to which the tools are to be applied for solution, is not available to the student.[3] This latter effect leads to graduates who can solve problems when the problem is given to them clearly defined, but who are unable to resolve problems out of a realistic context. In fact, the really important skill that every engineering student should have learned is the very process by which a technical problem is resolved out of the complex of contextual layers, and reduced to the essential needed to achieve a useful solution in harmony with the context into which it is introduced.

The contextual approach recognizes that success in contemporary engineering practice requires a combination of traditional technical understandings and skills plus a range of what might be called contextual skills, *understandings* of the contexts and constraints of engineering practice and *abilities* that allow engineers to function more effectively in these contexts.[2] For the most part, these contextual skills, sometimes also called "professional" skills[5], fall outside of the traditional engineering disciplines. Although they require significant input from the humanities, social sciences, and business management, traditional courses in these areas will not help students develop contextual skills *unless the students have integrative experiences* that help them understand how all the elements of engineering practice should come together.[2,6]

The re-design of ENGR 162, which will be referred to as '162X', consists of a semester-long design and development project (EIC case study), lecture topics on various technical aspects, lifelong learning exercises, and project reporting and documentation assignments. The EIC case study, or 'theme', provides a conceptual framework in which lecture topics, such as design methodology, engineering analysis, estimation, economic analysis, engineering ethics, and so on, are integrated. Figure 1 below, illustrates the theme-based structure of 162X; the design problem is introduced almost at the outset of the course and is developed (in teams) through well-defined stages, including problem identification and definition, concept generation, concept selection, preliminary design and proof-of-concept or prototype demonstration. In addition to lecture topics, which familiarize students with engineering and design, the essential tools needed to manage their time and projects effectively are also covered. Ancillary topics, such as technical drawing, materials and manufacturing, etc. may be introduced, or substituted by other topics at the discretion of the instructor. Assignments follow the development of the EIC case problem and include both oral and written reports. A separate, but important, component is the 'Way It Works' team presentation, intended to cultivate lifelong learning skills. Student teams identify and research a specific technology, and then educate their peers in a 20-30 minute presentation as to the 'way it works', prior art, impact, and applications. Teams rotate this assignment such that any given team may present two or three times during the semester.

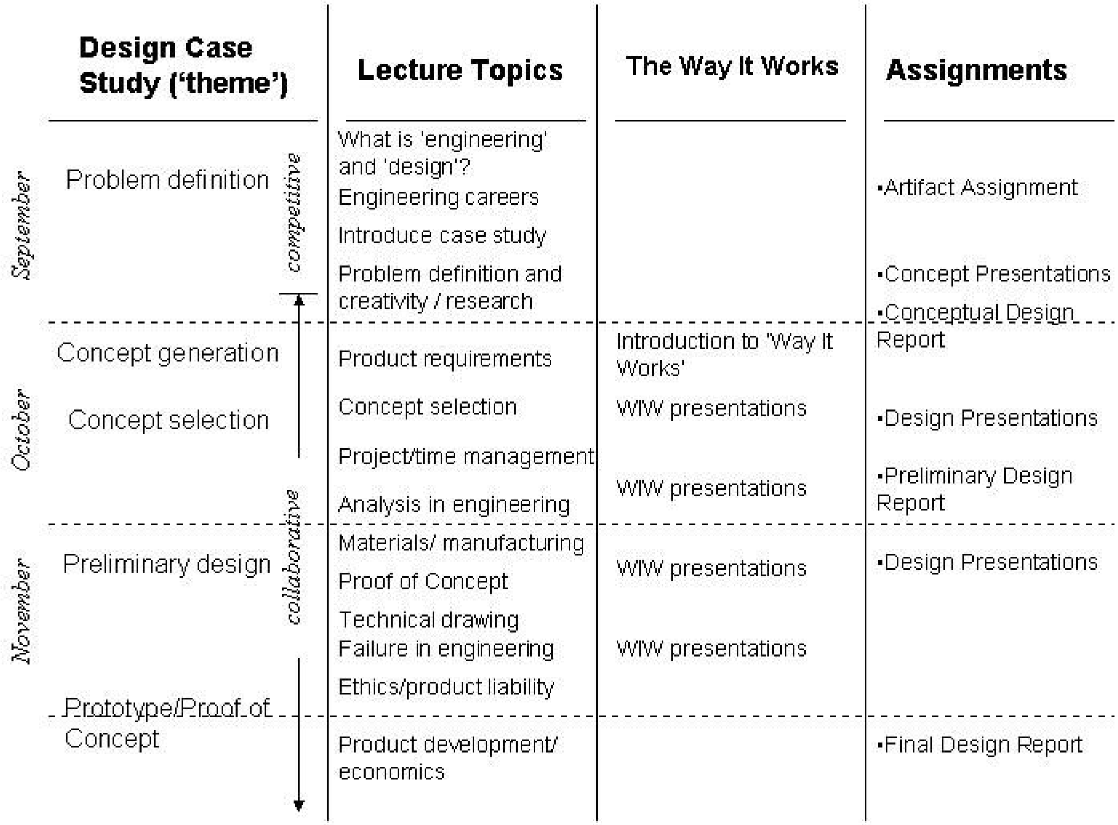

Figure 1. A design case study, or theme, supported by lecture topics, provides the framework for introducing students to engineering and design. The theme is chosen by the instructor and may be different for every section of ENGR 162X.

An important emphasis in 162X is placed on the identification and definition of the problem to be solved – resolving technical problems out of a realistic context. Rather than provide students with a well-defined problem at the outset, the students are required to work in small teams to carry out research and define the problem as they see it. For example, the instructor may state that a certain number of people die each year as a result of freezing (hypothermia) in downtown Chicago. The causes for these deaths must be researched and, through analysis and discussion, the team must come to a consensus as to what the 'real problem' is. After about the first three weeks, teams present their view of the problem to their peers as persuasively as they can, and provide an initial solution concept. The class then comes to a consensus as to the best problem identification and solution concept.

During the subsequent phase, in which teams collaborate (see Fig. 1), new teams are formed to address various aspects of the selected problem/concept. For example, if the freezing problem were identified as a lack of emergency shelter for homeless persons and the suggested solution concept was some sort of rapidly deployable, temporary shelter, then a decomposition of the problem might suggest engineering design teams with a focus on structure, thermal insulation, safety and public acceptance, power generation, materials and manufacturing, management, etc. Students are then allowed to choose the team whose focus best matches their interests, or intended choice of engineering major. Of course, not every problem will result in such a multidisciplinary solution, and few will include all engineering disciplines offered at a given institution, but judicious selection of the initial problem statement can go far in ensuring a relevant experience for the majority of students in the class.

In addition to teams whose focus lies within a particular engineering discipline, some teams may be chosen to have a functional role, e.g. management or ensuring that liability and public health issues are properly addressed by the project. Typically, a different case study problem is addressed by each section of 162X, though it is quite possible that two or three instructors (being perhaps members of the same engineering department) will share development and use of the same theme. Although students currently select sections of 162X based primarily on schedule preferences, it is planned to list the theme for each section in the course offering directory, along with time and location information for the upcoming academic year.

Results and Discussion

An important measure of the success of an intro to engineering course is the willingness of faculty to teach it. The School of Engineering & Applied Science at UVA does not have a general engineering department and so, faculty from among the various departments, mechanical, electrical, chemical and so on, are called on to teach ENGR 162. It has not traditionally enjoyed very great popularity as a teaching assignment. Faculty whose primary interests are research and teaching confined to their area of expertise, find an intro to engineering a subject which is disturbingly diffuse and broad, and too far removed from their specific interests. They question how to relate what they know well to what is common to all engineering and, in addition, often have the perception that introductory engineering deals with too many non-technical issues. Therefore, in addition to meeting the needs of students, faculty requirements must also be considered in the design of the course.

The contextual model for ENGR 162 addresses these needs by allowing faculty to choose a problem area related to their own field. For example, when Bob Davis and Mark Aronson, both in the Chemical Engineering department at UVA, recently taught ENGR 162, they chose biodiesel fuel generation as the subject for their EIC case study[7]. This particular topic is one that is relevant to the research interests of both Davis and Aronson. Secondly, the course now has a well-defined structure and canon of engineering knowledge and skills, which are described in an instructor's guide manual, in addition to course syllabus, etc. Finally, variation of the theme from year to year serves to provide renewed vitality and attraction for the instructor, and allows for topical themes, such as the recent Hurricane Katrina levee failure, to impress upon students the relevance of the engineering profession.

Examples of other themes used for ENGR 162X include, the design of handicap access to historically significant buildings, safe and efficient movement into and out of stadiums for large-scale public events, the loss of lives and property due to wildfires, child deaths due to smoke inhalation, the design and development of special effects for productions of the University's Drama Department, and the design of a public pedestrian 'greenway' near the University's location in Charlottesville.

The modified, context-based version of ENGR 162 was taught for the first time in Fall 2002 as a single pilot section. The model was expanded to two sections, with two different instructors, in 2003, and further expanded in 2004 and 2005. Table 1 below, shows the number of context-based sections (as a fraction of the total number of sections) for 2001 – 2005, and the mean overall rating for the course, as obtained from student evaluation responses[8], for both the conventional and context-based approaches. Each section of ENGR 162 has, on average, 34 students, (corresponding roughly to a freshman class size of approximately 510 students).

Table 1. Overall Course Rating as a Function of the Number of Theme-based Sections[6]

Year	*Overall Course Rating (Std Dev)*		*No. Context-based Sections/ Total No. Sections*
	Conventional	*Context-based*	
2001	3.27 (0.28)	NA	0/18
2002	3.23 (0.41)	3.50	1/13
2003	3.13 (0.26)	3.33(0.06)	2/15
2004	3.39 (0.41)	3.60 (0.30)	6/15
2005	3.37 (0.27)	3.41 (0.33)	10/15

The data, though preliminary, appear to indicate a substantial improvement in overall student satisfaction with the course. The data also seem to indicate an improvement in satisfaction with the conventional approach, arguably due to the increased attention given to course quality since introducing the context-based design. Perhaps a still more interesting metric is that of the percentage of students retained in engineering. Students from the first year for which the new course was offered, 2002, are just now approaching graduation. The rate of retention for the students in the 2002 pilot section, who will be graduating in Spring 2006, is 76%, slightly above the 70% retention rate observed school-wide. However, while promising, this is an observation for only a single section and is therefore obviously not a statistically significant result.

Synergy between engineering and humanities and social sciences is strengthened through coordination of the course's objectives and thematic content with those of STS 101 (Language, Communication and the Technical Society). STS 101 is an existing course, which serves to introduce students to engineering professionalism, the key concepts of technology and society interaction, and the distinctive aspects of professional communication in engineering. A modest degree of coordination between STS 101 and the intro to engineering cornerstone course is sufficient to give students a much clearer sense of the multidimensional nature of engineering practice.

Conclusion

The introductory engineering course students encounter during the first semester of their engineering education is arguably the most important of their undergraduate experience; it is here that most students taking a 'wait and see' attitude towards an engineering career are either won or lost. The Engineering In Context-based cornerstone course is intended to motivate students to the study of engineering by connecting them, not to the things engineers must know, but using context-based learning, to a sense of *what it means to be an engineer*. The design of the cornerstone course relies on use of a contextual theme[ii] as a framework for teaching and exercising engineering fundamentals, and broadens context through links to humanities and social sciences instruction and professional practice. Also innovative is the emphasis on problem identification and definition, the earliest, and often most critical, stage of analytical and open-ended problem solving. Themes chosen for the cornerstone are multidisciplinary and contextual; they require different types of expertise to solve (across disciplines and possibly functions as well) and multiple perspectives to analyze and understand. UVA's EIC pilot program has clearly demonstrated the feasibility and potential for a contextual learning approach to teaching introductory engineering from both faculty and student perspectives.

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[i] A separate computer lab portion of the course introduces students to computer applications, such as spreadsheet analysis, mathematical problem solving and CAD.
[ii] The contextual theme can be thought of as an 'enveloping' case study, which not only provides motivation for learning, but serves as a framework in which new knowledge is assimilated and applied.