Designing Freshman Engineering Experiences

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**Abstract**

*Freshman engineering experiences are critical from the perspective of overall development of students and student retention. These experiences can be particularly challenging to design owing to the differences in student backgrounds, and in levels of prior knowledge/preparation in fundamental scientific concepts. This paper presents an approach for redesigning a freshman engineering design course to introduce students to the fundamentals of the engineering design process through guided and independent scientific inquiry into the problem, and approaches, materials and methods used for solving problem. New course modules draw from current social contexts such as health, sustainability and issues impacting human and social dynamics. Problems are open-ended and creativity and communication are emphasized. Specific examples of redesigned course modules, formal and informal student feedback and plans for future work are offered.*

**Introduction:**

According to a recent National Science Board (NSB 2010) report, the Science and Engineering capacity has grown over the past few years around the world and while it allows greater cross-border collaboration, and a larger pool of researchers, it presents “definite challenges to U.S. competitiveness in high technology areas, and to its position as a world leader in critical S&E fields”. Also, the number of engineering graduates have declined in recent years as is evident from the reported eight percent decline in the proportion of Natural Sciences and Engineering (NS&E) degrees as a share of total degrees conferred between 2002 and 2007 (NSB, 2010). The decline in the natural sciences and engineering degrees conferred can also be attributed to the student attrition from these programs after the students are on campus.

**Reasons for Student Attrition:**

Previous studies have indicated that significant student attrition or “switching” from science and engineering educational programs to other fields occurs during the first one or two years of college in a study (Seymour, 2001), making the first year college experience for students a critical one in the choice of their careers. Several models have been used to describe the attrition of STEM students including a leaky pipeline model, a path model and statistical models based on pre-college characteristics for incoming freshmen as indicators of their future retention in engineering programs (Veenstra et al 2009). However, it should be noted that one of the important findings of Seymour (2001) is that the proportion of students switching (40%) because of “inadequate preparation in high school math and science” is almost equal to the proportion of “non-switchers” (38%) reporting inadequate preparation in those subjects. This suggests that although inadequate preparation in Mathematics and Sciences in the high school is one of the major reasons for switching, it does not mean that the non-switchers who remain in the programs might be more comfortable with their level of preparation and the reasons for their “staying the course” may be different than a perceived lack of preparation. Other reasons for switching cited were related to poor teaching, and difficulty in getting help for academic problems (Seymour, 2001). In an ethnographic study (Seymour and Hewitt, 1997) additional reasons for switching to non-SME disciplines: lack or loss of interest in science; belief that a non-SME major holds
more interest or offers a better education; and feeling overwhelmed pace and load of the curriculum demands, have been noted.

Characteristics of current typical Engineering curricula:

One of the major characteristics of engineering curriculum as it was pointed out in a 2008 Carnegie Mellon report (Shepard et al, 2008) on engineering education, unlike fields such as the Law and Medicine, an undergraduate Engineering degree is the first professional degree for engineers who are expected to work in their profession immediately after graduation thus requiring to have built the set of skills and knowledge required for the profession during their four years within engineering schools. This usually results in a packed curriculum that hopes to prepare students for their profession in the four undergraduate years and in a first year curriculum that is often heavy in technical subjects such as Physics, Chemistry and Calculus in order to prepare them for more of the “engineering” classes in their sophomore year.

A basic analysis of the courses taken at a four-year public institution in Massachusetts showed that Students typically spend eighty percent of the time spent in taking courses in the freshman year in taking courses that are not directly linked to their chosen profession of engineering. It should be noted that this also represents the time the “engineering” students do not get to interact with engineering faculty, or experience engineering laboratories or experience engineering as a profession. In the second year, the ratio of non-engineering courses to engineering courses lowered to about forty percent which would mean that in the sophomore year, the students are required to “immerse” in the engineering curriculum. There are also differences in expectations: the Science, Mathematics and Engineering faculty tend to expect early commitment from the students in order to build their skills and understanding in a linear fashion over time (Seymour and Hewitt, 1997). Research on how people learn warns that “curricula that emphasize breadth of knowledge may prevent effective organization of knowledge because there is not enough time to learn anything in depth”(NRC, 1999). This indicates a need to reevaluate student learning outcomes for courses and mechanisms and paths in which knowledge transfer takes place.

Freshman Engineering Experiences:

While there may be several factors for student attrition from engineering courses, one of the dominant reason appears to be the lack of interest in science and engineering triggered by the near-lack of connections to the field of engineering in their Freshman engineering year. Therefore, Freshman engineering design classes or seminar classes can be utilized to create these connections to engineering faculty and professional world. The engineering design courses provide a platform for building problem solving skills for students and making vital connections to the professional practice of engineering and allow for several design experiences integrated throughout the curriculum during which students build the knowledge base and skills.

Engineering programs in two-year institutions:

Nearly forty percent of engineers who graduated between 1999-2000 attended a community colleges at some point during their studies (NAP, 2005) which explains why the community college pathway to engineering careers must be strengthened and the opportunities for integrating engineering design in the freshman year be explored. In a two-year undergraduate institution, the ABET guidelines of integrating meaningful design experiences throughout the curriculum presents unique difficulties due to
the resources available including manufacturing and research facilities and time constraints. One additional factor is the perceived inadequate preparation of many of the STEM students in the SME subjects in high school by the faculty and the students themselves. Since the transfer takes place in the second year or after the completion of the associates degree, students who attend a community college should also be able to experience first-hand the engineering design process in their freshman or sophomore year at the two-year institution as they would otherwise miss this opportunity after they enter the more rigorous paradigm of the junior level courses.

**Review of the Engineering Design course:**

A review of an existing engineering design course was taken up at MassBay community college in the Spring of 2008 as part of an overall improved curriculum alignment as part of a STEP UP (Science, Technology, Engineering and Mathematics Talent Expansion – University Partnership) grant in collaboration with Northeastern University, Massachusetts and funded by NSF. The engineering design course is a first-semester freshman engineering 4-credit course (Engineering Design with CAD -I) that is based on instruction in Computer Aided Design (CAD), and is transferred to a four-year institution as a 2-credit course in CAD. The course essentially involved teaching students to create 3D models of parts, and assemblies and 2-D drawings using SolidWorks. While Engineering Graphics is a traditional course, it also posed a constraint in that the students did not have time to explore “engineering design” in a meaningful way and tended to spend more time learning the software (more than 80 percent) than in working on projects that simulated the experience of working as an engineer to any extent. This represented an opportunity lost for the engineering students to engage in meaningful design experiences and to build their problem solving skills starting in their freshman year.

**Discussion of approach for redesign of the engineering design course:**

Most four year institutions are now offering an introductory seminar in the broader discipline for the freshmen. Logistics at a two-year institution do not allow for a separate introductory seminar course in the freshman year. Therefore it was observed that the students needed to be exposed to the practice of engineering in this course based on CAD but by making the course relevant to the students by connecting it to the world around them.

The course is taken by freshmen in the engineering programs and also by students of the CAD certificate programs which makes differential instruction a necessity as the goals and learning outcomes for the students are different. Additionally, since the course is taken in the first semester, most engineering students also do not necessarily have developed the background and appreciation for the application of science and mathematics in engineering and hence any course modules or evaluation methods needed to be designed with this constraint. While this appears as a constraint, this approach is consistent with the research on “How People Learn” which suggests that “instruction that enables students to see models of how experts organize and solve problems may be helpful but the level of complexity of the models must be tailored to the learners' current levels of knowledge and skills” (NRC, 1999). Treating these as guidelines, the learning objectives of the course were organized as follows -

1) Developing understanding the process of Engineering Design – understanding the problems, and constraints of design, collecting relevant information about the problem, its scope and resources needed, research and document multiple approaches to the solution of problem and select an appropriate approach for solving the problem

2) Developing proficiency in using the SolidWorks Design Suite - present the design ideas by
creating virtual prototypes (3D parts and assemblies) and by means of clear and industry standard 2D-drawings

3) Gaining an understanding Professional Practices in engineering – developing an understanding of the legal, and social impacts of the problem and being able to work alone or in groups; and communicate the approach to problem solving and solutions concisely and clearly before an audience.

An approach based on the assumption that engineering can be presented as a field that draws knowledge from sciences and mathematics (Engineering Sciences) to address application needs (Engineering Technologies) (Levendis et al, 2007) was also implemented in a course module adopted in the first half of the engineering design course to emphasize the connections of engineering with science and draw from and build on the experiences or existing knowledge of the students.

Integration of Formative Assessment:
In order to understand the preparation or perceived current levels of knowledge and skills of the students a simple survey instrument was created as a part of formative assessment. It was found that this survey instrument yielded important information about the student body that helps in choosing appropriate levels of the learning modules. The responses to the question - “why did you take this class ranged from “I need this class to graduate” to “I previously took a non-credit introductory AutoCAD course and really enjoyed it. I am hoping to pursue an Engineering degree, and I'm really looking forward to further developing my problem solving and design skills”.

Experiences and learning from innovative course modules:
While some existing course modules especially related to CAD were retained and formed the essential tools of assessment, the focus of the course shifted from learning CAD to learning CAD as a tool to express the design ideas. Students were also expected to research how to implement a CAD design, The new course modules are short term projects and in the form of classroom discussions. The course modules drew inspiration from social and legal contexts such as human health, sustainability and social dynamics that are appealing to the students as they can make the connections of the engineering classroom to the solve the problems of global community which they are part of. This is also an important phase for them to “experience” engineering in a guided environment and respond to problems in a way similar to the problems they will be experiencing in their professions.

Some examples of course modules developed and tested include a module based on a prior summer research funded by MassBay foundation (Javdekar, 2007) to study the state of the drinking water related infrastructure in developing countries. In this module, students were given a reading assignment based on the summer research report submitted to the foundation. After the reading, students were asked to report what they thought about the situation. This gave the students a chance to express themselves and present their findings before their peers generating dialogue around the central issue. This course module was tested in an advanced SolidWorks course before adopting it into the freshman engineering design course. Some students have reported that gave them a better understanding of their world that they did not have prior to this experience.

The constraints posed on the design approaches were revised after the initial review of the outcomes – specifically, the problem statement was narrowed down from devising solution to the water filtration, storage and transport to only water transportation systems. Printed materials handed out to students in this case included “Access to water in refugee situations – Survival, Health and Dignity of Refugees” - a document distributed by the United Nations as guidelines. The reading materials are chosen to bring forward the direct impact the engineering designs make on the lives of people and allow students to explore the human and social dynamics of the problems that are expected to make the problems
appealing to work on as they directly impact the lives of people – a message lost in gaining the mastery of technical subjects. Also, for students who found the field of green energy more appealing than the water related issue, students were given a choice to develop a design for a basic solar cooker for a family of five in developing world. The problem statements are narrow, but the problems themselves are open ended. For example, students who created water transportation systems developed variety of solutions – such as a plastic tank that attaches itself on bicycle wheels; or water pumping and distribution systems in a refugee camp that would save several trips and man-hours of effort in transporting water. It is accepted that there might be multiple solutions to solving the same problem and students are encouraged to do so.

The engineering design course used this course module as the final project that students are required to work on for approximately one month (10-12 laboratory hours). The assessment includes assessment of the approaches, the research and effort into the selection of materials, methods and approaches and the communication of the solution which includes developing 3-D virtual prototypes of the parts, assemblies and creating 2-D drawings of the assemblies, and presentation. The grading depended not on the technical accuracy or feasibility of the actual design but on the methods adapted to research about the problem and developing a solution to fit the basic constraints of the problem. Working together on some projects in their first year, many of them get a chance to develop a sense of community and a better sense of themselves as engineers and designers and learn about how they fit in and work with others in a group. Students also learn to provide constructive criticism, ask questions, and offer suggestions for improvement. A mid-term project involved working in groups while students were given a choice to work in groups or individually.

Additional course modules developed included an exploratory activity designed that drew inspiration from another activity that was developed at Northeastern University (NU) for teaching students to make connections between science and engineering. The activity at NU centered on discussion around a low-cost small toy wind-turbine that harnesses wind energy to store in a capacitor that runs a small electric car. The activity was not directly adopted as the formative assessment of student-body revealed inadequate preparation in certain areas of Physics. However, a similar activity of using a paper hang-glider to discuss about the aerodynamics of glider and factors affecting the glider's movement in the air was designed. Some of the responses generated were an indication of students were able to make connections of concepts learned earlier to the current problems before them. As an example, the question “what affects the path of the glider in your opinion?” resulted in several answers some of which are included here -

Answer 1. Factors that affect the glider are the obstacles it hits, air current and the position, velocity, height and angle the glider is thrown.
Answer 2. I think that the main factors that affect the path is the combinations of the wind, the weight and especially the aerodynamics of the glider.
Answer 4. The factors that are affecting the path of the glider are the walls and things in its way.

It was expected that the answers would vary based on the degree of comfort with the terms used in Physics to describe motion however the points were given for participation and effort rather than “right” or “wrong” answers and a set of answers, and introduction to new terms was provided to the students after the discussions. Some resistance was felt during the instruction from students who came from CAD design backgrounds who maintained that they should not be required to answer these questions. Such students were needed to be guided slowly and carefully into reasoning to make inferences and present their inferences in their words.
Conclusions and Future Directions:

Infusing engineering design courses with course modules that bring forth the applications of engineering to solve the problems in world and by creating connections between the science courses and engineering proved to be an overall satisfactory course. For students who are not familiar with the expectations, some additional instruction or guided inquiry into the nature of the problem might become necessary. The revised course received an excellent student evaluation (4.41 on the scale of 0-5) as compared to the prior evaluations (3.7 on the scale of 0-5). Future directions for this course would include adding more hands-on “building” experiences or 3-D printing experiences integrated into the process of freshman engineering design. Also a comprehensive summative assessment will be used in measuring the impact of this course on student learning and outcomes.

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