Teaching Engineers to Compete in the 21st Century- A Multidisciplinary Approach for Honors Students

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Abstract – A recurring challenge for engineering educators is to discover and teach the critical competencies that each generation of engineers must acquire in four short years. As information and communications technology evolve, engineering and technical programs also evolve and refine the roles of analysis, design, systems thinking, creativity and collaborative problem solving. This paper describes a multidisciplinary, process-focused approach that gives technical students experience solving ill-structured, high-level design and development problems. Multidisciplinary in the context of this paper refers to engineering technology and other technical disciplines. In addition, it provides students with an understanding of the principles and body of knowledge of the product design and development process. The vehicle is an honors course, titled "Bringing a New Product to Market from Concept to Launch". The course, which supports the Southern Polytechnic University's Honors Program, asks technical students to integrate the knowledge and perspective from their discipline with others. It provides students experiential learning and teaches them to apply principles of process management for product design and development.

Keywords: Multidisciplinary engineering, product development, honors program

INTRODUCTION

It would be difficult to argue that a scarcity of information technology constrains contemporary education of engineers. The practical challenge is using the plethora of computers, communications and software technology available so that it continues to nurture and support students' intellect and "wetware", facilitates focus and eases their transition to a complex, dynamic and demanding workplace. Ingenious technology provides many answers and enables complex systems with bewildering functionalities. Yet ingenious technology does little to enable students to think critically and deeply about a complex problem. Performance assessment and career progress in the workplace depend on graduates being able to engage in up front planning, risk and logistics analysis, to ask the right questions and to maintain the extended focus needed to execute a practical and timely solution.

The 21st century requires not only more engineers, but engineers who can analyze and manage the complexity that continues to emerge from the ingenious technology of the 20th century, and who can solve workplace-relevant problems.[1] Universities and corporations alike are still learning how to adapt to the creative destruction and disruption wrought by the digital revolution and globalization of the last quarter century.[2] More than ever, the nation needs innovative engineers who can conceive and deliver practical and sustainable solutions that are compatible with the multifaceted constraints and uncertain future of a world in transition. Today's engineering and

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technology students need extended and diverse experiences solving ill-structured problems throughout their education. Unlike the sudden insight and elegant solutions to well-structured physics problems or mathematical puzzles, innovative and practical solutions to real world problems tend to evolve gradually over time and require extended focus and patience [3].

Experiencing the challenges of a complex context and solving problems collaboratively as a member of a multidisciplinary team can help students acquire some of the perspectives, patience, and interpersonal skills needed in the workplace. Ideally, engineering students would have acquired technical depth, intellectual breadth and collaborative experience when they graduate. However, this ideal is very difficult to achieve within a traditional four-year program[4]. Cooperative education programs ease students' transition to the workplace to some degree, but they tend to focus on the more narrow problems of a student's major. Engineering and technology programs can facilitate students' acquiring broader experience by continually challenging them with ill-structured problems whose solutions require diverse teams to collaborate and integrate their knowledge and perspectives[5]. The honors program's product design and development course at Southern Polytechnic State University provides students substantive experience in problem-structuring, collection of relevant data, system level thinking, creativity and iterative problem solving, all within the social context of a diverse team. Preferably, students work on design problems that include the environmental, economic and technological dimensions of sustainability and in addition address a contemporary need of some societal group.

BACKGROUND

The common core of mathematics, science and communications courses have, for very good reason, changed little for engineering and technology majors during the last half-century[6]. Typically, only new auxiliary technical tools such as high-level, office-suite type software and basic computing have made it into the core curriculum. One significant exception in some universities has been the addition of coursework in engineering statistics, data analysis and experimental planning and design. Underpinning the new technical tools for the classroom are the disruptive technologies of the personal computer and the Internet and a mandate for lifelong learning. As we enter the 21st century, along with the ever-higher storage densities, two new potentially disruptive technologies have emerged, broadband mobile communications and global connectivity. Their impact on individuals, corporations, and the university will be far reaching and will create new models of efficiency and effectiveness and perhaps even a "flatter world" [7, 8, 9]. These technologies will continue to change how we work, learn, entertain ourselves and manage life. For example, the Ipod™, I-phone™ and the Tablet PC have the potential to change university life[10].

There have been some classroom experimentation with cornerstone design courses to address the experiential aspects of problem solving, but unfortunately, freshmen design projects can be problematic because students can become frustrated when they have not yet acquired the tools needed to perform[6]. Capstone design courses have been used for several years but these focus more on the design of a specific component related to the students' major. Neither cornerstone nor capstone courses typically emphasize concurrent, collaborative problem solving in the multidisciplinary context that is common in current practice. Companies and educators have long recognized the importance of the multidisciplinary knowledge present in cross-functional teams for successful and efficient product design and development [11].

Discipline specific engineering analysis, design and textbook problem solving will no doubt continue to be a fundamental, necessary and dominant part of the engineering curriculum. Indeed, engineering educators in America continue to do an admirable job in teaching the fundamentals of engineering science. There is some evidence however, that attention to integration of knowledge is needed for addressing the complex spectrum of issues of the 21st century [5, 12, 13]. For example, engineers cannot address problems such as resource scarcity, homeland security and economic and environmental sustainability in isolation because these issues involve complex systemic interactions among several technical disciplines. These issues, along with ubiquitous information technology and global connectivity, have compounded the contextual complexity of 21st century product design and development. Engineers who can learn to integrate innovative solutions into the new context will create the most successful products and services and become future engineering leaders[14].

Asking the right questions requires that students understand and frame problems from multiple perspectives and to collaborate and integrate their collective knowledge and skills. Moreover, it requires the use of process analysis and systems engineering management methods similar to those developed by corporations, systems engineers, industrial engineers and quality professionals [15,16,17,18]. Providing students with several weeks of guided experience in structuring and solving multidimensional design-type problems can help them form the habit of asking the questions needed to validate a solution before they design and develop it.

COURSE DESIGN AND DESCRIPTION

The SPSU honors course on bringing new products to market consists of students from traditional engineering and technology programs and include students from such diverse disciplines as technical communications, architecture and management. The students have typically completed their core curriculum. The ideal class size is about 8-12 students and will support two or three student design teams. Independent teams work on the same problem. At this stage of course development, the small class of honor students helps us to identify, minimize and learn from challenges. The small class size also supports active student engagement, and provides faculty the opportunity for individual mentoring. Honor students tend to exercise a higher level of self-management and organizational skills and are often better prepared for the systems level thinking needed to attack loosely structured problems. However, honor students may tend initially to discount the value of systems thinking as so much "common sense" because it does not directly involve solving the systematically defined analytical problems at which they excel. Ironically, this subset of technical students seems to include both those best prepared and those who can benefit most from more experience solving the type problems encountered frequently in the workplace[1, 19].

We attempt to balance the composition of a student design team across technical disciplines, gender and national origin. Team composition thus represents contemporary cross-functional product development teams. We give students extended experience planning, organizing, communicating, collaborating, integrating and coordinating their work because these are such important navigation and competitive skills for students newly entering the workforce. Two things that many graduates experience in a new job are that they alone represent their discipline or function on a project and that the data they need are not always found in the library but may reside in the heads of others inside and outside their organization.

Faculty *assigns* the student teams a real world virtual product, process or service design problem, typically by the second week into the course. Students do not get to select their problem because in the workplace employees do not have the luxury of choosing what they work on. Both careful problem selection and the active interest of faculty in the problem are crucial for continued active engagement of the students. The assigned problem may be one aspect of a problem that the university or community faces or expects to face, or it may involve both technology and intergenerational issues.

The professor has three roles in the course: a teaching professor, a supervisor and a mentor. Project updates, a team journal, a final presentation and written report, and peer evaluations count about 65 percent of the grade. Traditional exams, homework assignments and class contributions count about 35 percent. Homework assignments are used to elaborate textbook principles and are designed to relate directly to students' virtual design project.

The first half of the course is devoted primarily to intensive formal lectures on general principles and the standard body of knowledge associated with product and service design and development. The second half focuses on application of these principles and uses an actual industrial problem as a case study. Students collaborate with faculty to discover how they might apply the principles and body of knowledge to their specific project. Students get copies of the lecture slides at the start of class to take notes and take one or more short exams to assure that they learn the relevant body of knowledge. Requiring interim progress reports with specific deliverables help to avoid surprises and to lessen the opportunity for the "student syndrome" to develop. Team updates involve about an hour of discussion and feedback designed to simulate what might happen at work. We try to give students multiple exposures to writing short progress reports to sensitize them to how their management might perceive the substance, style and tone of expression. Experience in both the workplace and classroom demonstrates that it is important to provide continual structure and guidance during product development and to require periodic updates and deliverables to review progress, however little.

Lack of responsible risk taking among engineers and managers is a continuing concern of corporate executives. Because a level of safety is important for responsible risk taking and for promoting creativity, we allow students to learn by making and correcting mistakes. The iterative problem solving process simulates actual product development where modification of proposed solutions can be common because of change, new information or organizational sensitivities.

At the end of the semester, each student gives a brief presentation to explain their role, results and contribution and evaluates their team members' work. Faculty with career experience in designing and developing systems products and services evaluate each team's solution and the individual presentations. The students evaluate the course and instruction methodology and their team members' contribution.

THE VIRTUAL DESIGN PROJECTS

Key to student engagement in the course is careful attention to the selection of a virtual design topic and discussion of relevant industrial case studies. We use a virtual design project to accommodate time and money constraints. In addition, the instructor can better tailor a virtual design to the academic maturity and experience of the students. A virtual design enables the selection of topics that require students to consider a diversity of design, development and customer use dimensions, including those potentially impacting society. The design may just require students to evaluate and select the best among many commercially available products and to defend their decision. In the workplace, especially in manufacturing and some service industries, one frequently does not have the time to create "greenfield" designs, but must select commercially available products. The evaluation and selection of products for a given application can be a challenging assignment for new engineers and can require them to go through much of the virtual design process.

We try to select topics that are contemporary, technologically intensive and ones that undergraduates can readily identify with. In addition, these are useful for helping students to learn about a variety of contemporary technologies to which they might not otherwise be exposed. The virtual design topics our students have worked on include a mobile phone for senior citizens, the redesign and renovation of the university student center for the 21st century, and a Tablet PC for use by a university's engineering and technology students. Students typically get two topics from which to choose.

SCHEDULE FOR A ONE-SEMESTER COURSE

We have used a single three-hour class per week with a twenty-minute break and two shorter classes. Either schedule is suitable but each has advantages and disadvantages. The three-hour format can be challenging for some students' attention, especially if scheduled later in the day. On the other hand, the three-hour format provides an immediate, pre-scheduled opportunity for student teams to meet and discuss how the lecture principles apply to their specific design and to organize their work.

OBSERVATIONS AND DISCUSSION

It can take several weeks of active persistence and encouragement to get students performing as a team just as it does for product development teams in industry. Part of this time no doubt represents the usual storming phase for teams. This situation occurs for non-team based courses too, but it seems to require more instructor attention in a product design and development course. This is especially true for those undergraduates with no work professional experience who may be a little lost initially and need help getting started. The instructor can shorten the time needed to get the student teams performing by actively working to engage the students' interest with the variety of new technologies and economic possibilities present in their assigned design. Assigning students contemporary articles that are both technology oriented and highly readable provides an excellent vehicle for class discussions. Short stories that can relate and link technical and nontechnical principles to actual product failures and successes experienced in the workplace as well as customer interactions are very popular with the students.

A possible disadvantage is that the smaller classes are less efficient compared to a more mass-produced courses having relatively constant content. However, it has been recognized that junior and senior students need more contact with faculty [20, 21]. In addition, we believe that the importance of helping students acquire skills that the National Academy of Engineering has identified as critical for 21st century justifies investment in somewhat smaller class sizes for select courses[5]. Although principles and concepts change little with each offering, instructors may need to invest slightly more time in researching and learning about contemporary products and associated technologies that will be interesting and engaging. It is important to integrate real workplace examples into the lecture and to provide hints that demonstrate how body of knowledge principles might relate to a specific virtual design.

The course has been evaluated by sixteen students. Each filled out a course evaluation sheet that asked them to rate how well they thought the course was taught. Students scored the course at a 4.2/5, which indicates that students as a group "agreed" that the course was taught well. This is especially important given that the students represented several disciplines and that they were required to do extended work on a single unstructured problem. Honors students at our university tend to prefer well-structured problems with few fuzzy details so that they can assess exactly what is needed to do to earn the grade. We interpret the course rating as very positive.

Some students indicated they would prefer that more structured and explicit criteria be used to assign individual grades such as the same exam or essay for everyone. A few asked more than once how exactly their grade would be determined even though the syllabus provided that information. The majority of the grade being determined from the student's individual contribution to the team's final report, and their individual presentation at the end of the course was likely sources of concern.

One might infer from the foregoing that the usual, highly structured, problem based exams or assignments continue to represent students' skill comfort zone. This was somewhat surprising for honor students, who might be expected to have enough confidence not to be overly concerned with their ability to do well in less structured situations. It may also reflect, as mentioned previously, that honor students not only represent those best prepared technically but may also include those who can benefit most from experience solving ill-structured problems that take several weeks of integrated effort. This is consistent with Herbert Simon's conclusion that 20th century engineering education since World War II suffered a systemic bias towards analysis and this worked to the detriment of the design and synthesis skills needed for creative solutions to real world problems[22]. Although in recent years there have been some movement to correct this bias, many students still expect problems to have quick solutions like those on timed exams. They expect the solutions to be unique, logically neat, well organized, linearly developed and final. Unfortunately, most design problems, regardless of ones' profession, have never had these attributes. Students can experience some discomfort and impatience when they experience a sustained situation with no immediate or clear-cut solution. Instructors can effectively counteract student concern associated with their inexperience solving ill-structured problems by providing empathy, encouragement and adaptive guidance to keep them making progress. In addition, it is helpful to reinforce with examples how some technical problems may only have more or less satisfactory solutions that are provisional and evolving.

CONCLUSIONS & FUTURE DEVELOPMENT DIRECTIONS

The multidisciplinary honors product design and development course at Southern Polytechnic State University's provides the students with experience in systems thinking, process analysis, applied creativity and multidisciplinary, real world problem solving. The course focuses on high-level design and systems engineering and can help students acquire some of the skills the National Academy of Engineering has identified as critical for competiveness in the 21st century. The sixteen-week semester time constraint will continue to limit the degree to which design integration skills can be developed. Notwithstanding the time constraint, the course provides students experiential learning and concurrently teaches them important elements of the body of knowledge of product design and development and the associated process management skills. Student feedback on the course has been generally very positive although we recognize that feedback from any new approach includes the Hawthorne effect to some degree. We expect the course, which is still being "prototyped" and refined, to be a valuable addition to our curriculum for engineering and technology honors students. Future development work needed includes detailed documentation of actual industrial case studies to facilitate active engagement of students in learning the principles as applied in specific contexts. The use of such case studies may enable a similar course to extended to include non honors students as well.

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