New Directions in Freshman Engineering Design at the University of Maryland

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Abstract - The University of Maryland has a well established, project-based “Introduction to Engineering Design” (ENES 100) course which is taken by approximately 750 freshman engineering students each year. This paper explores the formation of this course through the NSF sponsored ECSEL program, with an emphasis placed on the evolution of this course over the past two decades. While the ECSEL program revolutionized how the introductory course was taught, the long-term implementation suffered from several shortcomings related to the challenges of teaching to such a large student cohort. In 2006, ENES 100 became the first “Keystone Course” offered by the newly formed Keystone program. Since its inception, the Keystone program has revitalized ENES 100 by making three major changes. The first change was to switch the focus of the course from simple design-build construction projects to the design-build of complex systems. The second change emphasized the product development theme of the course. The final change was to unify the course among each of the 20 sections taught each year. Initial results indicate that students are responding favorably to the changes made by the Keystone program.

Index Terms – Freshman programs, Keystone program, Multidisciplinary design, Product development.

INTRODUCTION

The rapid advancements in technology and economic globalization place demands on educational organizations to focus more on students’ active learning and on the development of problem-solving skills. These demands are challenging the educational community to set higher expectations and standards for all students, and to develop the fullest potential of every student in the process of higher education. At the University of Maryland at College Park, the freshman engineering design course is an important example of the effort made to address these issues.

Introduction to Engineering Design (“ENES 100”) is a required course for all freshmen engineering students. This project-based course was initiated in 1991 and developed through the NSF sponsored ECSEL (“Engineering Coalition of Schools for Excellence in Education and Leadership”) program. As one of the seven participating schools of engineering under the ECSEL program, the mission of ENES 100 was clearly defined: to foster creativity, critical thought, and excitement about being an engineer, and to develop leadership skills through teamwork [1]. Between 1992 and 2002 a significant percentage of the faculty members, including two deans and seven departmental chairs, joined the innovative teaching/learning activities.

More than 100 students worked for the ECSEL program as undergraduate teaching fellows and graduate teaching assistants. They were tasked with helping the freshmen with the implementation of their design projects, and they made great contributions to the success of teaching engineering design to the students.

The main effort made under the ECSEL program was centered on creating a project-driven approach to teaching engineering design to incoming students. In 1992, seventeen students participated in the pilot section of ENES 100, which was anchored around the design and construction of a swing set. Afterwards, five design projects were developed to form a design project cycle. Those projects were based on the development of a wind mill, a solar desalination still, a weighing machine, a postal scale, and a human-powered water pump [2].

After the highly successful ECSEL program ended in 2002, the leadership role and responsibility of teaching ENES 100 was assumed by the Dean’s Office. Several new design projects were developed in an attempt to introduce microprocessor controls using the LEGO RCX brick. The first few years following ECSEL support brought mixed reviews of the course, both from the students enrolled and the instructors tasked with developing projects and teaching the course. As a response to these less-than-enthusiastic evaluations, the Dean’s office conducted a comprehensive review of ENES 100 in 2005 to identify areas where continuous improvement and significant changes were needed. Although the feedback from the students who took the design course seemed acceptable in terms of learning outcomes and student satisfaction, there was a pressing need to enhance the teaching/learning process for the course. The areas identified for improvement were in the development of new design projects with system integration requirements, applications of new technologies, and enhanced communication skills through teamwork.

At the beginning of 2006, the Dean’s office established the Clark School Keystone Academy of Distinguished Professors to recognize those educators who have made significant contributions to the undergraduate education in engineering, and to provide these faculty members with the support necessary to continue to make contributions to the
undergraduate curriculum. The mission was clear: to revive the infrastructure of freshman and sophomore engineering courses with a focus on engineering design. To ensure the success of this new initiative, the Keystone program encouraged the school's best faculty members to teach the most fundamental courses in the engineering curriculum. Faculty members are selected from throughout the college and given renewable three-year appointments with financial incentives. Resources are provided to the group to enhance Keystone courses via infrastructure improvements and the addition of technical support staff.

In Fall 2006, ENES 100 became the first “Keystone Course” and the newly appointed Keystone professors were tasked with developing a new approach to revitalize the teaching and learning process. In collaboration with the other instructors of ENES 100, the Keystone professors work as a team and search for innovative, flexible, and responsive approaches to meet the needs of students in engineering education. The current annual enrollment is approximately 750 students. As a result, the entire teaching process requires the offering of 20 sections each year, with the support of 2 full-time graduate teaching assistants and 20 undergraduate teaching fellows each academic year [3].

During the past two years, several surveys have been created to measure the effectiveness of learning, student satisfaction, and faculty participation. The two year development experience and data obtained from those formative assessments strongly indicate that the participating students are responding favorably to the new approach made by the Keystone program. The participating faculty felt strongly that the innovation in teaching has brought meaningful changes to improve the educational value to the students in class. More importantly is the fact that the innovation has been integrated into the participating faculty members’ daily teaching duties.

At the same time, the Keystone program has obtained a significant amount of financial support to start a process of renovating the classrooms, computer facilities, and fabrication/assembly areas. Two full-time technicians have been added to the Keystone staff to develop new lab equipment, demonstrations, and to provide technical support to the students and instructors in the process of completing the design project.

In the next section, the current structure of ENES 100 is described and the three major thrusts that have been made under the Keystone leadership to reenergize the course have been highlighted. The third section describes the survey that was developed and administered to assess the importance of the course objectives and the perceived success of achieving those goals. The initial results of this survey are then presented and discussed. In the final section, conclusions are drawn regarding the impact the Keystone program has had in attempting to revitalize the Introduction to Engineering Design course offered at the University of Maryland.

Seven key outcomes have been identified for the freshman design course. In no particular order, these outcomes can be briefly listed as: to foster creativity, to generate excitement about the engineering profession, to introduce the product development process and to provide students with an appreciation for analytic and computational tools, to develop a student’s communication skills, to get students thinking about the key roles of ethics and professionalism in the engineering discipline, and to expose students to modern trends in engineering. The key features of the new format for the freshman engineering design course, designed to meet these course objectives, are explained below. These features are presented in three sections that emphasize the changes that have been made as compared to the pre-Keystone ENES 100 course offering.

I. Complex Project

The project given to the students is formulated to be sufficiently complex so that groups of 9-10 students working cooperatively are required in order to design and build the project on time. These groups are typically further divided into subgroups of 2-4 people to focus on specific aspects of the project. Slight variations on the project can allow it to be used for several consecutive semesters without getting stale or predictable, and this allows time for the instructors to refine the project and enhance the learning experience for students. Figure 1 provides a sample of a product designed and built by a team of students. The product shown is an autonomous, model-scale hovercraft that must be able to meet a set of product specifications which requires the successful design and integration of structural, levitation, propulsion, power, sensors, and controls sub-systems.

Developing a new product with system integration requires the use of analytical tools coupled with hands-on...
The project that has been used for the past four semesters involves the design, fabrication, and testing of autonomous model hovercraft. This project requires knowledge from aerospace, mechanical, electrical and materials engineering. In order to achieve this design objective, students need to learn fluid mechanics principles at an introductory level, so that they can calculate lift and thrust. They need to learn about basic circuit theory and components, such as batteries, transistors and relays. They need to understand something about fan operation, the strength and weight of materials, control theory, computer programming and 3D modeling. They also need to conduct design tradeoff studies in which they must, for example, balance the need for lifting the hovercraft against the total weight of the system designed. Additionally, students must balance the cost of the designed sub-systems with the limited budget provided for the project [4].

The hovercraft project has been carefully selected so as to be sufficiently complex for students to have difficulty completing on-time and on-budget, but not so difficult that it is impossible to meet the product specifications. Historically, about 15-25% of the design teams that start the project will succeed in meeting all of the product specifications. The remaining hovercraft are never looked at as failures, but are instead measured in terms of their degree of success in meeting the product specifications and the product development timeline. The technological challenges overcome by a design team are always highlighted and encouraged, and student teams are rarely discouraged from making educated design choices that may contain major technological risk (e.g., unproven technologies). Of course, relaxing the product specifications could drive the overall success rate up, but this would be a disservice to the students enrolled who will soon enter a profession in which complex and multidisciplinary design problems are the norm.

The complex design project forces students to work as teams to overcome difficulties and challenges. The teams typically form three subgroups: structure and levitation, sensors and controls, and power and propulsion. Other divisions are possible, but subgroups are always required. The interaction of these subgroups provides an important dynamic to the design process that is missing in simpler projects.

II. Product Development Emphasis

During the first day of class each semester, a unique set of product specifications are handed out, common to all sections, and are considered to be “cast in stone.” These specifications describe the requirements for the device in terms of physical characteristics, the performance requirements, the cost requirements, reporting requirements and overall schedule. They also describe the test conditions that will be used at the end of the semester for the final design competition.

The overall schedule includes a number of milestones that must be achieved during the semester. The milestones can either be in terms of performance or reporting. There are three different milestones for oral presentation reviews: the product development plan, the preliminary design review, and the final performance analysis. The product development plan presentation occurs early and requires a Gantt chart to map the planned schedule for the completion of the project, as well as an organizational chart to show the team’s structure. The preliminary design review requires a complete set of drawings and a bill of materials. The final review requires a self-analysis of the team with respect to the milestone process, product specifications and their own project plan. Written reports follow the second two oral presentations in which all of the details of the team’s design are expected to be documented and reported.

For the hovercraft project, performance milestones include mid-point demonstrations of hovering, propulsion, and control (sensors and programming). A final performance milestone requires the successful navigation of the course provided. Technical requirements in the product specification always include safety requirements, and may define limitations on the hovercraft size and weight, restrictions on power sources (e.g. no gas-powered motors), time requirements for levitation, completing the course, etc., definitions of “hovering” (e.g. Can your device “hop”? Can your device drag anything?), and limitations on what parts, if any, can be reused from commercial devices.

Currently, students are required to use the LEGO NXT brick as the core microprocessor for their control system. While the ENES 100 faculty only supports Robolab in terms of teaching students to program the bricks, students are not discouraged from using other programming languages if they want more sophistication in their control algorithms. In fact, out-of-class tutorials have been held by undergraduate Teaching Fellows to help students familiar with C-programming to learn BrixC and RobotC.

The current product specifications require students to design an autonomous hovercraft capable of navigating a “J” shaped test-track with one long straightaway and four 45-degree bends. The sides of the test-track are defined by 2"x4" wood studs (with the narrow side contacting the floor). A four-inch strip of black tape defines the centerline of the course. All sensors are allowed, either home-made, LEGO or third-party sensors, with the exception of touch sensors, as contact with the 2x4 boundaries is considered a violation of the product specifications. The specifications have been fine-tuned over the past two years and there are plenty of alternative formulations available to keep the hovercraft project challenging to students for many years to come.

At the end of the semester, all students are expected to have gained a comprehensive understanding of the product development process through their hands-on learning experiences and the project’s requirement for teamwork. These learning objectives are enhanced through the use of the milestone process outlined above.
III. Course Unification

One objective of the Keystone program is to provide a maximum uniformity of technical content required for development of the project, without stifling important individual faculty creativity to the process. Each semester, there is a group of six to ten instructors engaged in course instruction. The material delivered to the students in class could vary significantly if the organization of the teaching material and the control of the delivery process in class are not exercised at the upper level of the course management. The Keystone program takes the leadership role in this critical link between the instructors and the participating students.

The educational experience over the past two years has strongly demonstrated the importance of having central leadership in the teaching/learning process. All sections are required to share the same course objectives, syllabus, course schedule, project requirements and assessment methods. The technical subjects are divided into 4 or 5 areas. For each of the subject areas, an instructor is appointed, and that person is responsible for outlining the necessary material for that topic.

The freshman design course meets three times per week for a total of 5-hours. Twice the class meets in small sections of 36-40 students for two 2-hour periods. Every Friday, all students from each section are required to attend a 50-minute common lecture with several other sections. The first half of the semester, these common lectures—presented by the appointed instructor on the topic—provides information on themes that are essential for the design project. Thus, all students see identical introductory lectures for all key technical components of the course, spanning topics such as fluid mechanics of hovering and propulsion, batteries and circuits, programming the NXT, simple dynamics and control strategies, and technical graphics. Each week, the delivered material is posted on a website and is accessible to all instructors and enrolled students. Individual instructors take the responsibly during the following week to further detail the information on those concepts discussed in the Friday lectures to ensure each student has a basic understanding of the subject and that the individual learning needs of students are taken into account.

During the second half of the semester, students attend common lectures on themes related to modern engineering trends and issues. In order to provide a broad view of the variety of engineering disciplines and the real-life experience of engineering, speakers are invited from both the campus community and industry to present seminars to the freshman students. The invited speakers have included the University President, Chairs of engineering departments, and CEOs/VPs of industrial corporations.

Standardized lab demonstrations (fan testing demonstration, circuit soldering demonstration, sensors demonstration) are held during the individual course meeting times. Additionally, there are several lectures on computer tools (Robolab, Pro/Engineer) that are also standardized in terms of the presentation material and exercises.

The common Friday meeting times allow for common midterm exams. Due to space restrictions, there are 2-3 different versions of these exams for the different Friday sections, but all problems on the same topic are written by the same instructor. Each problem is graded across the sections to aid with the uniformity of the assessment.

Another part of the assessment comes from oral presentations that each team makes at various stages in the development of their project. There are always four evaluators at each of these presentations: the course instructor, the undergraduate Teaching Fellow, and two reviewers who have a connection to the course but are external to the particular section. To further help with uniformity and continuity, the same external reviewers attend all presentations for a given section. There are unified formats and standards for the student teams to submit their project progress and final reports. All homework assignments are also common to all sections. The due dates of all homework, in-class oral presentations and all written report submissions are synchronized between the sections.

Regular meetings throughout the semester are held with the instructors from each section of ENES 100 in order to make group decisions on issues that arise and to insure that the coordination of the class continues to run smoothly.

The project ends in a course-wide competition, where all sections get to compete against each other to see who’s project best met the specifications and to cement the idea with the students that they are truly receiving a unified introduction to engineering design. Figure 2 provides a snapshot of the first hovercraft competition in which students, faculty and staff all gathered to marvel at the accomplishments of the freshman engineering students who designed, built, and tested an autonomous hovercraft to meet a very difficult set of product specifications in just one semester.

FIGURE 2

COURSE-WIDE COMPETITION AT THE UNIVERSITY OF MARYLAND
RESULTS AND DISCUSSION

I. Description of Survey

A survey was generated to poll both the current and prior students on how effectively the seven thematic goals of the course were met. The questionnaire was developed as a 5-point Likert scale questionnaire, with selections covering "completely successful" to "not at all successful" over a range of 5 discrete steps. The seven statements that were evaluated are summarized in Table I. Results are presented as the mean value of the sample responses, assigned a numerical value of 4 for "completely successful" down to 0 for "not at all successful."

<table>
<thead>
<tr>
<th>Topic</th>
<th>Question</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foster Creativity</td>
<td>Fostering your creativity, innovation and critical thought</td>
</tr>
<tr>
<td>Generate Excitement</td>
<td>Generating excitement about being an engineer</td>
</tr>
<tr>
<td>Appreciation of Analytic Tools</td>
<td>Giving you an appreciation of analytic and computational tools that you will need to acquire in your academic journey towards becoming a practicing engineer</td>
</tr>
<tr>
<td>Product development process</td>
<td>Introducing you to the product development process and instilling within you the importance of a system (big picture / teamwork) approach to the development of modern technological devices</td>
</tr>
<tr>
<td>Communication skills</td>
<td>Impress upon you the importance of good communication skills in the engineering discipline</td>
</tr>
<tr>
<td>Ethics and professional development</td>
<td>Impress upon you the key roles of ethics and professionalism in the engineering discipline</td>
</tr>
<tr>
<td>Modern trends in engineering</td>
<td>Exposing you to a sample of the current efforts, challenges and opportunities in the engineering community</td>
</tr>
</tbody>
</table>

Student responses were collected from: all sections of ENES 100 conducted in the Fall of 2007 (406 responses from 482 enrolled), all sections of a sophomore Dynamics course that consisted largely of student who enrolled in the first Keystone ENES 100 course taught in the Fall of 2006 (70 responses), and a junior level Fluid Mechanics course which consisted of students who took ENES 100 before the Keystone revisions (86 responses) and transfer students who completed an equivalent ENES 100 course at their prior institution (39 students). The majority of the latter students completed their first two years at one of several community colleges, which in agreement with the University of Maryland, had created courses within their program modeled after the original ECSEL course. It should also be noted that upper-level students surveyed do not necessarily represent a complete cross-section of the student population, as the two courses used to complete the survey are not required throughout the college (strongly biased towards Mechanical, Civil and Bioengineering).

The comparison of survey means between groups were then analyzed for statistical significance using the statistical analysis tools available in Microsoft Excel. Specifically, a two-tailed t-test was performed (using the TTEST function), specifying a test for two samples with unequal variance. The critical threshold for a statistically significant difference in the means was taken to be P<0.05.

II. Results

Based on the results of the survey (Table II), an improving trend is clearly noted in the majority of the surveyed areas with the implementation of the Keystone modifications. Most notable are the relative increases (current Keystone – Pre-Keystone) in the categories of ethics and professionalism (+0.64, P<0.001), modern trends (+0.63, P<0.001), appreciation of analytic tools (+0.48, P<0.001), product development process (+0.36, P<0.001), communication skills (+0.36, P<0.001) and generating excitement for the discipline of engineering (+0.25, P<0.033). The variation in fostering creativity (-0.02, P<0.84) remained nominally the same.

<table>
<thead>
<tr>
<th>Topic</th>
<th>Current Keystone</th>
<th>Early Keystone</th>
<th>Pre-Keystone</th>
<th>Outside UMD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foster Creativity</td>
<td>2.92</td>
<td>2.66</td>
<td>2.94</td>
<td>2.53</td>
</tr>
<tr>
<td>Generate Excitement</td>
<td>2.54</td>
<td>2.63</td>
<td>2.29</td>
<td>2.72</td>
</tr>
<tr>
<td>Appreciation of Analytic Tools</td>
<td>2.60</td>
<td>2.44</td>
<td>2.12</td>
<td>2.50</td>
</tr>
<tr>
<td>Product Development Process</td>
<td>2.97</td>
<td>2.77</td>
<td>2.61</td>
<td>2.48</td>
</tr>
<tr>
<td>Communication skills</td>
<td>3.05</td>
<td>2.83</td>
<td>2.69</td>
<td>2.60</td>
</tr>
<tr>
<td>Ethics and professional development</td>
<td>2.42</td>
<td>2.04</td>
<td>1.78</td>
<td>2.37</td>
</tr>
<tr>
<td>Modern Trends in Engineering</td>
<td>2.51</td>
<td>2.06</td>
<td>1.88</td>
<td>2.21</td>
</tr>
</tbody>
</table>

Considering the changes made between the pre-Keystone and current Keystone course offerings, it is believed that the improved areas are largely due to the three major changes made in the course:

- Providing a high-level project which requires the use of several analytical developments for successful completion of performance targets. As an example for the current hovercraft project, a brief introduction to fluid mechanics principles was needed to properly size the hovercraft plenum, blower assembly and power source for the hovercraft, and use of these equations were required (and tested) by the students during their design process. This was instituted to reduce the all-too-common “cut-and-try” approach that was often observed in the earlier implementation of the course.
- Requiring consistent deliverables from the student groups based on the product development process and formal grading of several written and oral reports. This provided a clear message to the students on the importance of the process in completing the design and production of complex products.

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• Giving consistency to a substantial portion of required material throughout the course by providing a weekly “anchor lecture” to all classes, given by the same expert on the topic. Thus, an electrical engineer was used to provide a discussion about batteries and power systems, an expert in CAD systems led instruction on use of software design tools, and a product liability specialist was recruited to discuss the role of ethics in engineering practice. This helped to ensure that all sections received the same minimal technical content and topical emphasis, which could then be supplemented by the individual section instructors.

It should also be noted that there may be unintended psychological bias in the data, which has not been taken into account. For example, it is not known how a student’s perception of a given class changes over time, and some of the trends might reflect a changing opinion as they increase their experiences and mature as a student. However, while this possibility is acknowledged, the authors are confident that the major source of the trend is a result of the changes made to the class, as anecdotal feedback prior to the Keystone program had registered a notable dissatisfaction in several of the key areas discussed above.

Several interesting comparisons can also be made to those students who completed a similar course prior to entering the University of Maryland. Their responses indicated a much more favorable experience in several categories in comparison to the pre-Keystone course (ethics, +0.59, P<0.001; and generate excitement for the profession, +0.43, P<0.03), which speaks highly to the effort and resources dedicated to teaching the course at their prior institution. In comparison to the external course offering, the current Keystone revised course appeared to be demonstrably better in its emphasis on the product development process (+0.49, P<0.006) and communication skills (+0.45, P<0.02)).

CONCLUSION

The Keystone program was established in 2006 to reexamine and revitalize the freshman and sophomore programs in engineering education offered at the University of Maryland. The initial focus of the Keystone faculty and staff has been centered on the freshman engineering design course—ENES 100. This course is a design-build, product development course which was launched in 1991 through the NSF sponsored ECSEL Program.

Initial survey results indicate that the changes made by the Keystone program are allowing faculty to better meet the seven thematic goals of ENES 100 and that students are responding favorably to these improvements. Anecdotally, one student’s evaluation of this course at the end of the semester revealed, “This class went beyond textbooks and conventional thinking, forcing kids to get to know one another quickly and work as a team. I thoroughly enjoyed this class and believe that it is a great introduction to engineering as a whole.”

Session T2D

While the major changes made to ENES 100 by the Keystone program have resulted in clear improving trends, minor course modifications, such as improvements to the common lectures, demonstrations and reading materials, as well as refinements to the specifications and the timeline for the product development process and other course milestones, are continually under consideration in an effort to enhance student satisfaction and to provide incoming engineering students with an outstanding first impression of the engineering discipline. The authors plan to continue to track the effectiveness of the modifications made in meeting the goals of the course, as well as to begin to look at the value students place on these goals. Future work will also include the inspection of 1-year retention rates and the examination of graduation rates for engineering students enrolled before and after the Keystone program’s implementation of an improved Introduction to Engineering Design. The feedback obtained will be used to continually improve the ENES 100 freshman engineering design course.

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