Interdisciplinary Capstone Projects

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Introduction

Conducting a literature survey in capstone projects via the ASEE conference database alone yields 1000 entries, with each entry to offer something valuable, by either looking at a larger picture such as trends in capstone projects in the US for improving undergraduate education\(^1\) or studying characteristics of similar projects in China\(^2\) or something specific such as integrating externally funded research into capstone experiences\(^3\), utilizing service projects\(^4\), or just working in thermal science in mechanical engineering\(^5\).

A good portion of the capstone courses seen in engineering curricula are focusing on single discipline based activity, such as industrial engineering student teams with a facility layout problem or mechanical engineering students working on a thermal process. In this ABET accredited engineering program, students in their senior year complete a true interdisciplinary capstone project course (Integrated Engineering Design) that involves design, analysis, and development of a product, process/facility, or tooling engaging teams made up from multiple majors. The course is also considered communications intensive due to its reporting requirements by the university. This engineering program houses five different specialties – biomedical, industrial, manufacturing, mechanical, and software allowing great flexibility in the areas of work.

In the recent history, a variety of project types were employed in the course simultaneously including further development and refinement of yet-to-be-commercialized patented products brought in by the inventors, student pitched research and development projects, industry sponsored projects for various industries such as human resources, logistics, biomedical, pharmaceutical, and heavy manufacturing as well as in house research originated by the instructor. Development of open source 3D printers, electrocardiograms, edutainment robotics, composting machines, and rototillers can be given as recent project examples in addition to classical facility design and improvement work.

This paper will depict the structure of the course including the details of different project types, followed by the planning, execution, and control actions. The team structure including team size and the method of working on the same problem with two different teams are included. This approach allows collaboration and competition along the execution of projects. On the contrary, individually student driven projects were by handled the originator of the concept alone and limited number of patent applications or discussions on start-ups were experienced. In addition, the paper will address the benefits of continuing projects over multiple semesters, reporting and documentation requirements including oral and written progress reports as well as final report and its supporting presentation, and peer reviews. The issues arising during the execution of the projects including budgetary limitations and further improvement on Intellectual Property (IP) and entrepreneurship aspects will also be covered in this study.
Integrated Engineering Design

This course is the capstone engineering experience (3 credits) for all engineering majors at the department. Students will participate in interdisciplinary teams to bring a product/system from conceptual design through prototyping if possible. Activities will include detailed design and material selection, cost estimation, process planning, scheduling and material requirements planning, distribution system design, software planning and implementation, and product fabrication, etc. This course becomes an Enterprise Design Experience based on the project type. To register for the course students need to have completed at least 90 credits out of the 126 credit requirement for their degree. Engineering Design Process (ISBN: 9780495668145) by Haik and Shahin is utilized as a reference book since it effectively follows through the stages of the engineering design and development process. The engineering department does not offer many courses on Fridays but this course is placed on a 4 hour block on Friday afternoons starting at 12:00 PM.

Table 1 below depicts the weekly schedule for the Fall course including the requirements. With the syllabus, students are given a sample project list. However, they are not only bound to that list of projects, they can also propose their own. Team formation starts but not completed until the second class along with project selection. The teams are required to have an oral progress report in the seventh class, a written progress report during the tenth class, before they complete their presentations and final reports. Feedback is also given not only after the progress reports but also during the rest of the semester, constantly. Students working on industrially sponsored projects are required to meet with their sponsors to get additional feedback on their progress and to share with the instructor.

<table>
<thead>
<tr>
<th>Weekly Progress Plan:</th>
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<tbody>
<tr>
<td>W1 Course Introduction. Project descriptions and Project teams are initiated.</td>
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<tr>
<td>W2 Project teams are formed and Project scopes/schedules are defined. Operational details are clarified.</td>
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<tr>
<td>W3 Working on projects. More clarifications and team adjustments if necessary</td>
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<td>W4 Working on Projects</td>
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<td>W5 Working on Projects</td>
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<td>W7 <strong>A brief Oral Progress Report from each team</strong></td>
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<tr>
<td>W8 Projects refined and adjusted as necessary continue project work</td>
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<tr>
<td>W9 Working on Projects</td>
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<tr>
<td>W10 <strong>Written Progress Reports are due with Oral Presentations in class from each team</strong></td>
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<td>W11 Grading feedback to teams based on progress reports provided</td>
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<td>W12 Working on Projects</td>
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<td>W13 Working on Projects</td>
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<td>W14 <strong>Thanksgiving</strong></td>
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<td>W15 <strong>Project Presentations with written Final Reports turned in</strong></td>
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<td>W16 <strong>Peer Reviews</strong></td>
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Table 1. Fall semester weekly progress plan

This course is graded based on team performance with instructor’s ability to add bonus points (not to exceed 10 pts) to exceptional work by teams or any member(s) of the team(s) if warranted as decided by the instructor. Team leaders are considered first as candidates for bonus points for themselves and their teams. Total points are calculated as presented in Table 2.:
Table 2. Grading scheme

| Brief Oral Progress Reports | 20 pts |
| Written Progress Report and Oral Presentations | 30 pts |
| Final Reports and Presentations | 40 pts |
| Class Contribution, Leadership, Initiative, Professionalism | 10 pts |
| TOTAL | 100 pts |

Students are required to evaluate other team members’ performance at the end of the semester. However, when some issues arise during the semester (team conflicts and delinquency), team members deal with them swiftly as encouraged by the instructor. Previous instructor followed an approach that each teams had a project manager who will have influence on the allocation of the grade as well as the bonus points if any. In case of continued lack of performance by a team member, the project manager asked for the member to be transferred to another project if the other project manager was willing to accept such a transfer. A student who ended up rejected by all teams was assigned a different individual project with a letter grade reduction in the final grade.

In addition, project reports are graded on three dimensions (Low-High 1-10 scale) based on Team Accomplishment/Technical Merit, Report Quality and Project Feasibility. Students are given additional notes or training including webinars in case of a lack in their background, recently in subjects such as LabView and Robot C programming, sensors and actuators, enterprise structures, product and process development, material handling, supporting systems and services as well as plant design. Subjects of project management, intellectual property, and engineering are also covered in case of a need.

The author proposed the following projects for his Fall 2013 Integrated Engineering Design class:

- **Animatronic Robot Greeter Project (2nd time repeat project):** The objective of the project was to redesign and improve the department’s animatronic greeter. The project required manufacturing processes and mechatronics knowledge, background on Vex Robotics Development System and Robot C programming language skills. It was taken on by 1 mechanical and 3 software majors – a 4 student team (Figure 1).

- **Design and Development of a Digital Light Processing (DLP) 3D Printer (2nd time repeat project):** The objective was to redesign and make the previously built DLP 3D Printer operational. The project required 3D printing, manufacturing processes and mechatronics knowledge, Arduino controllers, Robot C and Creation Workshop background. It was taken on by 1 manufacturing, 1 double mechanical/manufacturing, and 3 mechanical majors – a 5 student team (Figure 2).

- **Design and Development of an Electrocardiogram (ECG) (2nd time repeat project):** A student team of 6 biomedical majors (during Spring 2013) had built and successfully operated based on National Instruments NI 6251 basic data acquisition card and LabView programming environment (Figure 3). The card was to be replaced by Compact sbRIO card and LabView Real-Time programming tool was to be employed in programming. This project required electronics and programming background. However, 5 biomedical majors chose not to take on this project. Since several of them had the Coulter College Award for its annual device development work-shop (associated with the Biomedical
Engineering Society (BMES) Annual Meeting), they come up with their own development project which would be proposed to the Coulter College. The concept involved device development for pregnant woman. This project will not be presented in the paper since students will soon seek a provisional patent.

- **Facilities Improvement Project:** This an industrially sponsored project for a pharmaceutical manufacturer. A third party is involved as well. The project objective was to redesign a new facility acquired by the company and required industrial engineering background, especially in facilities planning and warehousing. It was taken on by 3 industrial and 2 biomedical majors – a team of 5 students. This was a similar project to that of Spring 2013, but not identical. However, it was built further on the previous project (Figure 4).

- **Quality Engineering Project:** This an industrially sponsored project for a manufacturer. The objective was to develop a process and associated machinery for help identifying defects in galvanized sheet metal. The project required background in manufacturing processes and machine design. Two teams took on the project, 8 mechanical and 1 double mechanical/manufacturing major was involved (Figure 5).

Figure 1. Animatronic robot greeter
Figure 2. (top) DLP 3D Printer (bottom) 3D printed parts – during accuracy adjustments

Figure 3. (top) Development of an ECG and (bottom) its software
In addition, remaining group of students in the class, proposed their own project:

- **Stanley Meyer Water Fuel-Cell**: The objective was to investigate how the Stanley Meyer’s hydrolyzer worked by building a working prototype. This was proposed by a team of 6 students consisting 3 industrial, 1 manufacturing, 2 mechanical students. It required chemistry and electrical engineering background.
The proposed projects above and others from previous terms can be categorized as:

- **Industrially sponsored projects**: This type of projects varied by industry and included human resources and training, logistics, biomedical, pharmaceutical, and heavy manufacturing industries.

- **Individuals with patents requesting help on furthering their ideas**: Recently a shower product and multiple composting machines were re-designed and developed based on existing patents belonging to outsiders.

- **In-house**: This category can be further broken into:
  - *Projects proposed by individual students or student groups* as in the case of Biomedical Development for Coulter College work-shop or the myth buster type of project in the Stanley Meyer Water Fuel-Cell. In addition, individual students proposed and successfully completed major product or process development projects. One example is a rototiller designed and built by a single student, who also received a provisional patent. A second example was based on sand blasting of large components which has become a started-up business for the student.
  - *Projects addressing the research needs of faculty members* as in the case of 3D Printer development where students also gain recognition by publishing papers at journals and presenting them in the conferences.

**Student Performance and Assessment**

Enrollment of the course for the three most recent consequent semesters have been 37 (Spring 2013), 29 (Fall 2013), and 33 (Spring 2014). The approach of employing multiple projects and different project types is challenging, but maintains student interest during the course since the students are working on something they are interested in. This is confirmed by the student feedback, and successful project results from most of the projects. Spring 2014 semester is not complete. However, student performance from the previous two semesters can be reported and were excellent. In Spring 2013, Out of the 29 who took the course, 25 students (86%) received the letter grade “A” while the remaining (14%) students earned “A-“ as shown in Figure 6. A similar pattern occurred in Fall 2013 as shown in Figure 7. Out of the 37 who took the course, 31 (82%) students received “A”, 4 students (10%) “A-“, 2 students (5%) “B+”, and 1 (3%) student “D” grade. These grades were earned based on technical merit and successful completion of the projects, quality of documentation and presentation, and individual effort measured by instructor observations and peer review results. Most of the projects were completed according to the

![Figure 6. Spring 2013 grade distribution](image-url)
desired original objective while satisfying thresholds (80% of the students performing at 80% (or “B-“ letter grade) set by the department for all the general ABET Outcomes measured during course assessment.

The previous instructor of this course had evaluated the ABET Course Outcomes A through G and J, K – listed below as Outcomes H and I had not been included in our Faculty Course Assessment Report (FCAR) for this course:

A. An ability to apply knowledge of mathematics, science, and engineering
B. An ability to design and conduct experiments, as well as to analyze and interpret data
C. An ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
D. An ability to function on multi-disciplinary teams
E. An ability to identify, formulate, and solve engineering problems
F. An understanding of professional and ethical responsibility
G. An ability to communicate effectively
H. The broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
I. A recognition of the need for, and an ability to engage in life-long learning
J. A knowledge of contemporary issues, and
K. An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

However, some of the new capstone projects are dealing with subjects like composting and sustainability and will generate the need of revisiting Outcome H. This will be done soon since the department is preparing a new Self-Study for the next reaccreditation cycle. Outcome I is also a strong candidate for outcomes assessment and will be considered.

In terms of the Manufacturing Engineering specific outcomes, the department designated M1 through M5 (shown below) were utilized by the previous instructor:
M1. Graduates have proficiency in materials and manufacturing processes and understand the behavior and properties of materials as they are altered and influenced by processing in manufacturing.

M2. Graduates have proficiency in process, assembly and product engineering and understand the design of products and the equipment, tooling, and environment necessary for their manufacture.

M3. Graduates appreciate the necessity for manufacturing competitiveness and understand how to create competitive advantage through manufacturing planning, strategy and control.

M4. Graduates are able to design manufacturing systems through the analysis, synthesis, and control of manufacturing operations using statistical and calculus based methods, simulation, and information technology.

M5. Graduates have had laboratory experiences which enable them to measure manufacturing process variables and make technical inferences about the process.

However, this will soon need to be changed and other major specific outcomes including Biomedical, Mechanical, Industrial, and Software will need to be added based on the project objectives and content. In the past, most this course enrollment was coming from BS in Manufacturing Engineering Program. Even though some of the Manufacturing Engineering outcomes are still relevant, some other major outcomes need to be added to assessment of this course.

**Conclusions and Future Work**

Within the last few semesters, the course enrollment had grown into thirties, including 33 students enrolled in upcoming Spring 2014 semester, driving team sizes larger than before. It is now more common to have 5 or 6 students in a team even though there may be still teams with 4 students. To avoid the increase in the number of projects, two teams were asked to work on the same project. This happened in Spring 2013, with two teams working on a composting machine project and in Fall 2013 a US manufacturer sponsored two teams to work on the same design problem. Usually these teams start working on the project together during initial phases including problem definition/project scope and data and information gathering, just to be separated to work on the solution by themselves. Collaboration between the teams is still allowed to a certain extent.

As implied earlier, individual students and students groups are allowed to pitch their own project ideas to be evaluated by the instructor. Once the project is accepted, it is treated the same way as the other projects. In the case of an individually driven student projects, they are handled by the originator of the concept alone outside the class in case the student has a patent or is applying for one – as in the case of the rototiller project completed in Spring 2013. The university’s policies on patents are not as strict as major research universities, helping students retain the patents. A local Intellectual Property (IP) lawfirm with ties to the department is also very helpful in working with student projects.

Another method utilized in the course is repeating projects in consequent semesters as in the case of the animatronic robot greeter or the 3D printer project allowing students to build on previous work and carrying the results to a different level. It is interesting see the impact of a different
point of view or approach on a project. Something who was left unsolved or took so long to be resolved is fixed right away by a different group. Similar comment can be made when two teams are working on the same project.

As the regular challenges of the course are handled including budgetary limitations, entrepreneurship content of this experience needs to be increased even though this need may vary from project to project. So far a limited number of projects, such as the recent biomedical device development project and previous shower product project involved enterprise development need. Increase in the entrepreneurship content of the course is necessary due to multiple reasons including helping students (who also earn provisional patents right after the completion of the course) start their own business or some of the projects coming from outside patent holders needing business development plans and start-up help. After completion of the rototiller project, venture capitalists approached the department and asked the students to take part in new formations such as Alpha Lab Gear project – a start-up accelerator 7.

In final words, this paper records the structure of an interdisciplinary capstone course with multiple project types, leading to working prototypes for patent holders, scholarly work in the form of journal and conference papers and possibly start-up companies. Results of projects have been satisfactory from the point of view of students, outside patent holders and industrial project sponsors as well as outcomes assessment of student learning.

References