Project-Based Learning in First Year Engineering Curricula: Course Development and Student Experiences in Two New Classes at MIT

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Abstract - **The October 2006 report by the Massachusetts Institute of Technology (MIT) Task Force on the Undergraduate Educational Commons highlighted the importance of project-based first-year experiences. Over the 2006 - 2007 academic year six new project-based science and engineering courses were offered at MIT. This paper examines two of these six introduction to engineering classes, delivered by the Mechanical Engineering and Aeronautics and Astronautics departments. Each course is centered around a semester-long design-and-build team project. Both classes require a strong web presence by the students through online documentation of the design process. One class is developed around a service learning model with teams of students working with underserved community-based partners to design products for use in these communities. The second class has students working in teams to design underwater remote operated vehicles (ROVs). Two different learning philosophies were used in designing course content; with the underwater ROV course focused on exploration of technology for student-centric design, while the service learning class focused on problem solving methods and meeting design needs of a community. This paper discusses the curriculum design and development for each class and the differing experiences of the 35 students between these two classes.**

Index Terms – Design and Build, Engineering Curricula, First-Year Experience, Project-Based Learning

INTRODUCTION

Project-based learning is growing in importance as part of undergraduate engineering education at the Massachusetts Institute of Technology (MIT). Endorsed by the Dean for Undergraduate Education [1] and funded largely by the d'Arbeloff Fund for Excellence in Education [2], project-based course offerings targeted towards freshman have increased significantly in the last year, with six new courses beginning during the 2006 – 2007 academic year.

The Mechanical Engineering and the Aeronautics and Astronautics Departments at MIT offered two new courses to expose freshmen to engineering design: *Solving Real Problems* and *Explore Sea, Space and Earth: Fundamentals of Engineering Design*. Both courses were proposed in Spring 2006, planning and publicity occurred during September 2006 – January 2007 and were offered for the first time in February - May 2007.

Freshmen at MIT take general preparation courses as required by the Institute before declaring their majors at the end of their first year. These general preparation courses include single and multivariate calculus, biology, chemistry, mechanics and electromagnetism/electrostatics. Freshmen must take one "Communication Intensive" subject by the end of their first year to satisfy MIT's communication requirement[3]. The two courses discussed within both fulfill the communications requirement.

Freshmen are also subject to a 57 unit credit limit, which typically amounts to four twelve unit classes and a nine unit seminar. The number of units represent the number of hours students are expected to spend on the course each week, both in and out of class. The nine unit seminars provide freshmen the opportunity to gain subject-specific knowledge before declaration of their major field of study. The six new project-based courses, including the two discussed here, were each offered for nine units.

Learning technologies are incorporated in most classes at MIT, mainly through the Stellar online course management system and documentation on MIT's Open Course Ware. This is no different for the two classes profiled in this paper. *Solving Real Problems* used a custom built website to enhance student-teacher and student-student communication. Student were also expected to contribute to team blog and wiki sites. *Explore Sea, Space and Earth* used the Stellar course management system and had students build online design portfolios over the semester. Prior research has shown that increased communication and e-portfolios have enhanced learning experiences in project-based courses[4, 5, 6].

The remaining sections discuss each course's curriculum and project design, student experiences and the recommendations and lessons learned. Included within each section is a discussion of the learning technologies used in the teaching of each course.

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COURSE DESIGN

The *Solving Real Problems* course and the *Explore* course invoked two different methodologies in terms of curriculum design and concept presentation as outlined in this section. Both courses were taught by professors who are experienced in teaching project-based courses. The lead instructor of the senior level Mechanical Engineering course *Product Engineering Processes* [7] and the lead instructor for graduate level *Elements of Mechanical Design* are the professors of *Solving Real Problems*. Professors of *Explore Sea, Space and Earth: Fundamentals of Engineering Design* have also taught *Introduction to Aerospace and Design* [8, 9], *Introduction to Ocean Science and Engineering*, and *Introduction to Design and Manufacturing* [10]. This previous experience is reflected in each course's design as the methodologies and curriculum used in each course are similar to those of the courses taught previously by the professors.

I. Solving Real Problems

Solving Real Problems used a top down approach to teach students about design and engineering. In the first lecture of the semester students were presented with several projects to choose between for their semester-long design experience. After specific projects were selected by the students, lectures were tailored to the contextual engineering issues needed for work on the chosen projects.

Projects were conceived by community partners and then selected through an application process screened by the professors and the MIT Public Service Center. These projects are summarized in Table I below. Three of the nine projects were selected by students for further development over the semester.

TABLE I
PROJECTS AVAILABLE FOR SELECTION IN SOLVING REAL PROBLEMS

Project	Community Partner	Selected (Y/N)
Robotic Water Shark	Super Duck Tours	N
Pedal-powered Concrete Mixer	Maya Pedal	Y
Golfer Prosthesis	Therapeutic Recreation Systems	N
Pedal-powered Water Pump	Maya Pedal	N
Vegetable Waste Composter	The Food Project	Y
Reading Device for the Vision Impaired	Partnership for Older Adults	Y
Hands-free Twin Stroller	Vision Impaired Individual	N
Universal Mailbox	Partnership for Older Adults	N
Assistive Swimming Device	Cardinal Cushing School	N

The course schedule and curriculum modules are summarized in Table II below. Students had 5 hours of class time per week: a two-hour lecture and a three-hour lab each week. Lecture time was focused on teamwork and general design skills: brainstorming/ideation, sketching for design, materials selection, presentation skills.

TABLE II
SYLLABUS FOR SOLVING REAL PROBLEMS

Week	Lecture Topic	Lab Topic
1	No lecture – 1st week of class	No lab – 1st week of class
2	Introduction, User-centric design	Design & Build Cardboard Chairs
3	Customer needs, Brainstorming	Ideation, Meet the client, Needs assessment
4	Sketching, Drawing for Design	Project ideas compilation
5	Student presentations of project ideas	Machining, Lab safety
6	Teamwork, Ethics, Scheduling	Project work
7	Estimation, Prototyping	Mockup fabrication
8	Presentations to Clients	Part Sourcing, Prototypes
9	Materials selection, Batteries	Prototype fabrication
10	No lecture – Holiday	Prototype fabrication
11	Design detail finalization	Prototype fabrication
12	Effective presentations	Prototype fabrication
13	Presentation Practice	Prototype fabrication
14	Prototype presentation to clients	No lab

Specific engineering concepts such as power transmission elements, part selection, fabrication and design details were taught in laboratory sections by the teaching assistants and professors working with each team. These modules were specific to each team's project, but could be useful for future design projects as well. Client meetings occurred at multiple points during the semester, and students were encouraged to contact their clients whenever they had questions.

Web-based technology was incorporated throughout the *Solving Real Problems* class. A detailed website was used to communicate information about the lectures prior to class meetings, post lecture materials and post the course syllabus. Also, online blogs and wiki-pages were provided to each team. Teams used the blogs to communicate information about the progress of the project to the clients and teaching team, who could then offer suggestions through comments posted to the blog. The wiki-pages were used to disseminate information within teams and were supplemented by team e-mail lists. The web pages, in addition to two mid-semester presentations, were meant to teach students communication skills to fulfill MIT's communications requirement.

At the end of the semester, each team was expected to have developed a full and working mockup of their project to be given to their client. Grading for the semester was as follows:

TABLE III
GRADING RUBRIC FOR SOLVING REAL PROBLEMS

Milestone	Percent
Ideation/Brainstorming	10%
Project Ideas	10%
Project Mockup	15%
Progress Report	5%
Presentation Practice	5%
Project Prototypes	25%
Design Journal	20%
Instructor Leverage	10%

Certain project milestones did not factor into the grading rubric, namely peer reviews and the initial project ranking assignment to indicate project preference.

II. Explore Sea, Space and Earth: Fundamentals of Engineering Design

The *Explore* class used a bottom-up, or "fundamentals-to-big picture," approach to design engineering to design the course schedule. Students were introduced to the design project in the first meeting of the course, but lectures focused on general engineering concepts that were not specific to their projects.

This course was aimed at freshmen still undecided in their choice of major as of spring semester. As such, engineering topics were presented in a manner that could be applied to Mechanical Engineering, Ocean Engineering and Aerospace and Astronautical Engineering in order to help \students decide between these three majors. The course was offered under two departments: the Mechanical Engineering Department and The Aeronautics and Astronautics Department.

The teaching team outlined learning objectives during the course development. These learning objectives were as follows:

- Actively participate in reading and discussing the Exploration and Engineering Fundamentals materials
- Introduce, use, and calculate engineering fundamental principles
- Propose and evaluate engineering designs for human-operated robotic designs and understand societal implications.
- Effectively communicate, research and document engineering analysis and the design process for an operational system.
- Frame and resolve ill-defined problems, and design and operate a robotic vehicle for exploration.
- Participate as a contributing member of an engineering team comprised of 4-6 students.

The project was chosen by the teaching team to best suit freshmen and to have elements that were applicable to exploring sea, space and earth. Students worked in teams of three to four in order to design and build underwater remote operated vehicles. At the end of the semester, the ROVs participated in a competition to gather materials at a depth of 15 feet. Each team was allowed a total of 6 motors, one specifically meant for use as a back up incase of failure. The competition setup can be seen in Figure 1, where the object depicted will be submerged at the bottom of a 16 ft. pool.

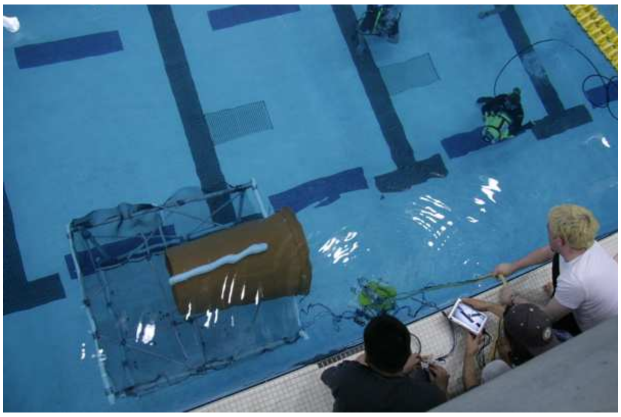

FIGURE 1
UNDERWATER LOCATION OF MATERIALS FOR RETRIEVAL FOR ROVS

The lectures for the *Explore* class focused on breadth over depth of exposure to several engineering concepts. The syllabus for the *Explore* class is detailed below in Table III. At the end of the semester, lecture times were left unscheduled in order to give students more time in lab to build their projects. End-of-semester lectures were also planned to give students wider exposure to engineering; guest lecturers spoke about their research and experience in ocean and space exploration, as well as the ethical and societal implications of engineering decisions. Two 1.5 hour lectures were held each week, as well as a 3 hour lab section. In addition to the six hours of class time, students were expected to spend about three hours each week on homework.

TABLE III
SYLLABUS FOR EXPLORE SEA, SPACE AND EARTH

Week	Lecture 1 Topic	Lecture 2 Topic
1	Course Introduction	Intro to ME/OE & Aero/Astro, Sketching
2	Equations of Motion	Momentum, Energy & Power
3	No Lecture - Holiday	Structures I
4	Lift, Drag & Propulsion I	Structures II
5	Linkages & Bearings	Lift, Drag & Propulsion II
6	Mechanical Elements - Gears	Mechatronic Elements: Motors
7	Systems Engineering	Team Progress Reports
8	No Lecture – Lab Time	No Lecture – Lab Time
9	No Lecture – Lab Time	Ethics, Societal Impact of Engineering
10	No lecture – Holiday	Space Exploration Guest Lecture
11	Ocean Exploration Guest Lecture	No Lecture – Lab Time
12	No Lecture – Lab Time	No Lecture – Lab Time
13	Final Design Competition	No Lecture – Presentation Practice
14	Final Team Presentations	End of Semester

Labs provided students work time for their projects with a teaching assistant and also were a weekly opportunity to receive feedback from peers and instructors on project design. Software tutorials on website design and solid modeling were also provided during lab time. Lab topics are summarized in Table IV.

TABLE IV
WEEKLY LAB TOPICS FOR EXPLORE SEA, SPACE AND EARTH

Week	Lab Topic
1	Lab Safety, Writing & Communications
2	Solidworks & Website Building
3	Machining Exercises & Practice, Brainstorming
4	Machining Processes, Play with Materials in Kits
5	Machining, Peer Review
6	Peer Review on Solid Model of Concepts
7	Continue Machining
8	Project Work Time, Design Notebook Review
9	Project Work Time
10	Project Work Time
11	Project Work Time
12	Wet Test Week
13	Build, Test, Build
14	No Lab

Web-based technology was used to disseminate information in the *Explore* class. A course webpage hosted on MIT's standard course management system was used to post the syllabus, lecture materials and readings. In addition, each student was expected to prepare a web-based portfolio of their design process chronicling the design process by the end of the semester.

Rather than using the web-based technology to fulfill the communications requirement, the *Explore* class requires a design paper of the students midway through the semester. This design paper was on a topic of the student's choosing, and factored into the semester grades. Grading for the course is summarized in Table V.

TABLE V
GRADING RUBRIC FOR EXPLORE SEA, SPACE AND EARTH

Peer Review	5%	Project – breakdown as follows:	
Participation	5%	Does it Work	15%
Weekly Design Notebook Review	15%	Design Review #1	10%
Research Paper	10%	Design Review #2	10%
Final Design Notebook	15%	Final Design Portfolio	15%
Total	50%	Total	50%

STUDENT EXPERIENCE

This section qualitatively describes student involvement in *Solving Real Problems* and *Explore Sea, Space and Earth* over the course of the semester.

I. Solving Real Problems

Thirty students pre-registered to participate in *Solving Real Problems* before the start of the semester; fourteen students showed up to the first lecture and signed up to collaborate on the projects; thirteen students remained in the course at the end of the semester. Though the initial drop of thirty pre-registered students to fourteen attending the first lecture, this is not atypical of MIT's course registration system where students often oversubscribe to too many courses and then unsubscribe in the first week of class. Of these thirteen students, six were male, and seven were female. Two professors, four teaching assistants, two instructors from the Writing and Humanistic Studies Program and a coordinator from the Public Service Center worked with the students on this course, creating a 1.4 : 1 student-instructor ratio.

Professors and teaching assistants attended all lecture and lab meetings. In addition in class time, students were expected to spend about four hours on average outside of lecture preparing for class and working on their projects. At the student teams' request, teaching assistants or professors would be present for these meetings.

Project selection and work began in the second week of classes. After the presentations of each design project option in the first lecture, each student listed three projects that they would like to work on during the semester. Students were assigned projects based on preference. Thirteen of the fourteen were assigned one of their top three selections. The three projects selected were a composting system for the Boston Food Project, a concrete mixer for Maya Pedal, and a reading device for the Partnership for Older Adults.

Teams for each project varied in number and years of experience of student members. The compost team and the concrete team consisted of six and five students respectively. The reading device consisted of three students initially, but only two students by the end of the semester. All students in this class were in their first year of studies except two, who were in their third year. Both third year students were on the compost team. Scenes from the compost team's semester are shown in Figure 2.

FIGURE 2
SCENES FROM SOLVING REAL PROBLEMS - COMPOST TEAM

We found that all teams made use of the web-based blog sites, averaging between one and two posts a week. These posts ranged in length and quality, but overall communicated the status of their design projects well. The team wiki-pages were used much less, with only one team posting to their wiki-page during the semester. However, e-mail lists were very active and integral to team communication, as well as student-instructor communication.

II. Explore Sea, Space and Earth: Fundamentals of Engineering Design

Twenty seven students pre-registered to take *Explore Sea, Space and Earth* before the beginning of the semester, twenty one showed up for the first lecture and seventeen students stayed enrolled throughout the semester. Again, the initial drop of twenty seven pre-registered students to twenty one attending the first lecture is not atypical of MIT's course registration system. Eight of the seventeen students that remained throughout the semester were female and nine were male. Every student that completed the *Explore* class was in their first year. Most listed their prospective majors as either Mechanical Engineering or Aeronautics and Astronautics, with a few interested in Ocean Engineering. Four professors, three teaching assistants, an instructor from the Writing and Humanistic Studies worked with student in the *Explore* class, creating a student-teacher ratio of 2.1 : 1.

Teaching assistants were responsible for overseeing and leading lab sections, while professors shared responsibility for lectures. The total number of lectures each professor taught ranged from two to five. Given that the teaching assistants saw students consistently each week during lab section, they may have been the most continuous part of the course for the students. Professors would often but not always attend each other's lectures giving the benefit of additional face-to-face time with the students.

Midway through the semester lecture times were mostly left unscheduled in order to offer more working time to students in the lab to work on the physical build of their projects. The three lectures after this break were also considerably less technical than those before the break and intended to broaden student's consideration of engineering. Guest lecturers and panelists were the center of these three lectures, students were encouraged to ask questions about their experience and opinions. We found that student's consideration of the issues at hand in these lectures was thoughtful and insightful.

Students' experiences on the project were largely positive. Students worked in teams of three or four in order to design their underwater ROVs, collaborating both on design, building and presentations throughout the semester. A solid model of a preliminary design and the corresponding physical build are shown in Figure 3.

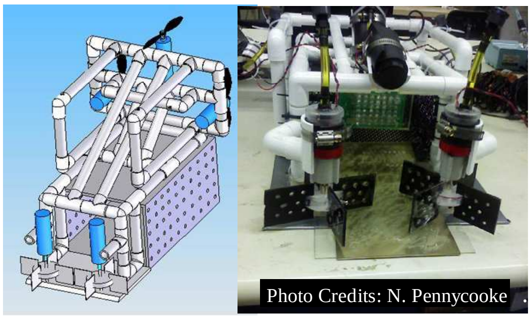

FIGURE 3
ONE TEAM'S DESIGN AND IMPLEMENTATION OF THE UNDERWATER ROV

Teams were mixed in gender and machining experience level. Students kept individual design notebooks that were used to keep notes and ideas for designs for their ROVs. Each week, teaching assistants reviewed the notebooks and wrote feedback in the notebooks for the students. These notebooks were valuable to the compilation each student's design portfolio at the end of the semester.

RECOMMENDATIONS AND LESSONS LEARNED

Over the semester, we have collected lessons from our experiences offering these courses. One common lesson from both classes is that the small course sizes and low student-teacher ratios may make it difficult to offer this course in a sustainable manner. Given that the curriculum for these courses were originally developed for up to 40 students, it may be possible to offer them on a larger scale. Otherwise, the professors have discussed offering selected lectures conjoint with the other new project-based classes. This would create a larger community of freshmen participating in the project-based courses. Efforts towards this are already happening this year; a festival celebrating and showcasing the projects developed by freshmen over the course of this year happened at the end of the spring semester.

I. Solving Real Problems

Through the evaluation of *Solving Real Problems* we noticed three key lessons.

First, when professors and students are working on teams together it is important that students continue to feel ownership of the project. In this sense, we made efforts to have instructors fill a mentor role and act as another team member, rather than purely as an instructor. This proved to be particularly true for freshmen in comparison to working with older and more experienced students.

Second, it is important that students participating in service learning have direct contact with the clients in order to see the real benefit of their work. The compost team and the lighting device team had this and thus could envision and plan for their work's use in the real world. The concrete team's direct contact with their client was limited; they instead worked with a mentor experienced in designing a project similar to their own. This impacted the observed motivation level of the concrete team during the semester.

Third, we noticed that the team that included the two upperclassmen was more productive and better organized than the other two teams. Though this may be a result of the combination of personalities on the team, we believe that having older students on each team would result in a better learning experience for the freshmen. These older students helped the team feel more confident in their decision making and also offered solutions in the building process with which the freshmen were not familiar.

II. Explore Sea, Space and Earth

As for the evaluation of *Explore Sea, Space and Earth*, we have been able to pull a few observations from preliminary reviews of student's reflections on the course in their online portfolios. For one, students seemed startled by the amount of material covered and the speed of coverage in the first few weeks of the semester. However, as the students became more involved with their design project and gained experience applying the theoretical material to practical design problems, reservations about the lecture material lessened.

It is likely that in the second year of the *Explore* class, the Systems Engineering lecture would be removed, as the abstraction of the conceptual material covered in this lecture made it less informative and less useful than the other engineering lectures. Also related to course content, the general engineering lectures at the end of the semester also enabled students to become more familiar with other areas of engineering that they may not be interested in studying full-time but still have an interest in. We found that the end of semester lectures were highly valued by the students. These lectures came in the two weeks before students had to declare their majors, and many cited this course as helping them make decisions about choice of major in their online portfolios.

SUMMARY

Solving Real Problems and *Explore Sea, Space and Earth: Fundamental of Engineering Design* courses provided students with the opportunity to learn and apply subject-specific knowledge before in depth study of the material that would follow declaration of a major. We found these experiences to be crucial to freshmen at MIT to help their decision of undergraduate field of study.

Furthermore, the projects developed by students showed that freshmen are capable of building useful and functional products despite their limited experience with design engineering. These projects inspired students to take an active role in their learning through research, ideation, design and implementation. We hope that these projects and experiences in the application of engineering theory provide a context for students when continuing with their engineering studies. We also believe that the application of engineering theory helps ignite a passion in the students that can continue through the theoretical classes taken during their sophomore through senior years. Though the initial enrollment numbers are low, we hope to see growth in student enrollment as these classes become well established and better known throughout campus.

Solving Real Problems and *Explore Sea, Space and Earth: Fundamentals of Engineering Design* required a large amount of resources, both in instructor time as well as finances to support material costs and machine time. We hope that there are economies of scale when offering these and similar courses to larger numbers of students. Regardless, we believe that the student experiences seen in these two classes are worth the inputs necessary.

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