Improved Student Engagement through Project-Based Learning in Freshman Engineering Design

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Logan Micher was born in Southary, England, in 1996. He earned an IB Diploma in May 2012, and is currently working towards his Bachelor of Engineering degree. Logan recently developed a low-cost, programmable robot designed for intermediary robotics instruction, and held classes in which he walked students through design, prototyping, revision, manufacturing, and assembly processes. Since 2010, Logan has worked as a private tutor; most recently he has moved from small in-person tutoring into electronic classroom learning as a consultant for an online tutoring service. In previous semesters, he has aided the teaching of introductory design and modeling classes at Florida Polytechnic University. As the operator of the Florida Polytechnic University Robotics Laboratory, he trains students to use fabrication machinery, 2D and 3D design software, and analytic methods to aid in student and research projects. Logan also provides 3D modeling, prototyping, and 2D design services to various local companies, and hopes to earn certifications for 3D design in the coming months.

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POSTER: Improved Student Engagement through Project-Based Learning in Freshman Engineering Design

Abstract

The implementation and assessment of Project Based Learning (PBL) in a one credit hour freshman undergraduate course on Engineering Design is described. The project selected consisted of a magnetically levitated, wirelessly powered desk lamp. The overall objective of the instructional modality selected was to improve student engagement and retention at the freshman level by exposing students to a hands-on engineering design experience. In contrast to design courses taken in the final year of study, this course was taken prior to the accumulation of detailed technical knowledge in the student’s engineering discipline. Instructional scaffolding was implemented in course delivery, and included: 1) creating a safe, respectful, collaborative environment for instructor and students; 2) crafting learning goals with the flexibility to ensure they overlapped with the variegated “zones of proximal development” of the freshman student cohort; and 3) gradually tapering instructor involvement from lecturer and frequent collaborator to infrequent guide and troubleshooter as students mastered and applied the skills needed to complete their projects.

To minimize “social loafing,” inter-student collaborations were encouraged through ad-hoc rather than formal groups, and a unique prototype desk lamp was required of every student. Access to an in-house 3D printer facility to print the prototype hardware was provided in order to give students exposure to mechanical design software, acclimate students to 3D printed product quality, and to facilitate the timely delivery of components at a reasonable cost. Access to a 3D printer facility enabled the completion of approximately 100 unique student projects at the end of the 15-week semester; although use of the 3D printers was not mandatory, almost half of the finished prototypes incorporated 3D printed components.

The instructor’s selection of the project was guided by the need to stimulate the interest of students pursuing a variety of engineering disciplines, provide design constraints while encouraging individual creative content in the completed prototype, enable students to complete
hardware component designs with easily learned design tools, and allow successful hardware demonstration against a set of design requirements within the time, space, and resource constraints of a one credit hour class.

The course deliverables included: submission of a quad chart containing design objectives, design details, bill of materials and a Gantt chart; completion and demonstration of a working prototype; and an original data sheet describing the features of each unique design. The deliverables were assessed based on completed prototype quality (including an end-of-semester contest to select the top designs by an independent panel of judges), compliance with a subset of the design specifications, total number of prototypes completed, and course evaluations provided by enrolled students. Surprisingly, many students invested considerable time outside of class to complete what were arguably very ambitious lamp designs. The level of personal pride in student prototypes led to a friendly competition to achieve the highest value for one performance metric, with one prototype exceeding the design target by more than a factor of 300. The conditions that led to the students’ self-imposed workload and the exceptional overall student engagement will be presented.

Introduction

Dym et al.¹ states that “design is the central or distinguishing activity of engineering,” and provided one definition of engineering design as “a systematic, intelligent process in which designers generate, evaluate, and specify concepts for devices, systems or processes whose form and function achieve clients’ objectives or user’s needs while satisfying a specified set of constraints.” From a technology perspective, Hyman², in his operational definition of design as “a proposed solution to a problem,” identifies the engineer’s ubiquitous constraint that “the design itself is a value-added proposition, meaning there is a business value in the solution, or else why bother designing it?”

Emphasis on design in undergraduate engineering programs has evolved over the past century. In the 1800’s, engineering promoted “the application of sciences to the common purposes of life.”³
Engineering programs provided specialized training so students could become immediately useful in the growing economy.

The 1930 *Wickenden Report* recommended design projects for second and third year students, and the 1955 *L. E. Grinler Report* recommended twin goals for engineering education of technical (including analysis and creative design) and general (ethics, humanities, social sciences, math and basic sciences), with engineering content limited to upper division classes. Constrained by institutional credit-hour caps, courses on engineering design or laboratory experiences that supported design activities, such as shop or manufacturing technology, were gradually eliminated from the engineering curriculum.

This approach started to reverse in the early 1990’s as employers identified the paucity of real-world content, engineering design and creative content as important shortcomings of engineering programs. As summarized by Jerry Jenkins, CEO of Texas Instruments; “Most engineering jobs involve design and practice, not theory and research.” A 1997 National Science Foundation report called for engineering programs to place more emphasis on teamwork, project-based learning and close interaction with industry. With the Accreditation Board for Engineering and Technology (ABET) explicitly requiring engineering design content in the curriculum, senior year capstone design classes, freshman cornerstone design classes and in some cases, design courses throughout the curriculum, were introduced into engineering programs. Interestingly, the cornerstone design course was introduced in part to improve student retention in engineering programs by exposing freshmen to engineering faculty and an engineering learning experience.

A variety of teaching frameworks for engineering courses have been described including Project-Based Learning (PBL), Inquiry-Based Learning, Design Competitions, Case Study modules, Reverse Engineering and Design-Based Learning. Project-Based Learning (PBL) was identified as the most effective teaching framework for engineering design. Provided the project has been carefully selected to involve a nontrivial component of design or creativity, PBL forces students to adopt both divergent thinking (open-ended questions with multiple solutions that may not hold any truth) and convergent thinking (questions whose answers hold truth, typically found in the engineering curriculum).
Divergent thinking can be uncomfortable for both student and instructor, but it often leads to substantial creative content in a project. As noted in Sheppard et al (1997) in describing the freshman engineering design and product design program at Stanford, one of the instructors (Faste) noted: “some of the best ideas were initially labeled ‘stupid’. “ There is a clear need to create a classroom environment that encourages divergent thinking and permits new ideas to be explored.

There are numerous examples of cornerstone (freshman/sophomore) design classes in engineering programs. Three examples highlight some of the characteristics needed to provide an engaging engineering experience for freshman students. As part of a curriculum overhaul, MIT implemented CDIO (Conceive-Design-Implement-Operate) in a variety of courses. In particular, the Electric Go-Kart project was implemented in the freshman/sophomore class Introduction to Design and Manufacturing. Notable student outcomes of this 6 hours/week class (3 hours lecture, 3 hours lab) included a strong student interest in continuing to modify and use their prototypes; and providing a student (who may have no prior design or fabrication experiences) with a set of practical skills that have utility throughout the remainder of their school and career.

Arizona State University implemented a design component in their Introduction to Engineering course to increase student retention. With a 1-hour lecture and 3-hour lab each week, the first 7 weeks were used to introduce skills, tools, and some engineering basics, followed by 8 weeks for student teams to design, build and demonstrate a prototype device. The authors noted that the choice of project had a pivotal role in the student experience, with overly challenging or unconstrained projects having a negative impact on student interest in engineering.

In an effort to acquaint freshmen with the various areas of mechanical engineering at The Citadel, Rabb et al. modified an Introduction to Mechanical Engineering course to combine individual and teamwork projects and assignments, many of which were small, hands-on activities. Following the opinion of Vogt that “student self-efficacy had very strong effects on effort and critical thinking where academic confidence had insignificant effect,” the course activities were designed to be open-ended and fun. According to Rabb et al.-
“What everyone wants is a little excitement each day about going to class, a little reminder of why they chose mechanical engineering, through fun and challenging experiences that prepare them for their future.”

Student response was overwhelmingly positive, with four instructors receiving ratings of 4.85/5 and numerous students requesting more hands-on activities throughout the course.

Approach

Project Based Learning (PBL) was implemented in the inaugural semester of a one credit hour freshman undergraduate course Introduction to Engineering Design. The objectives included:

1) improve student engagement and retention;
2) minimize social loafing (the tendency for people to make less effort in a group versus working alone);
3) equalize the hands-on skills of the freshman students;
4) create an immersive engineering design experience.

Achievement of these objectives was assessed using completed prototype quality (including an end-of-semester contest to select the top designs by an independent panel of judges), design diversity as an indicator of significant divergent thinking employed by the students, compliance with a subset of the design specifications, the total number of prototypes completed, and course evaluations (in particular responses to open-ended questions) provided by enrolled students.

A ‘clean slate’ approach began with an instructional scaffold that included the following:

1) a safe, respectful, collaborative environment for instructor and students;
2) flexible learning goals to ensure they overlapped with the “zones of proximal development” or knowledge frontier of the freshman student cohort;
3) gradual tapering of instructor involvement from lecturer and frequent collaborator to infrequent guide and troubleshooter as students mastered and applied the skills needed to complete their projects.

Project selection was guided by the need to pre-select sub-assemblies and components that students could combine in endless ways to achieve a defined set of technical specifications. The project needed to hold the interest of a range of engineering concentrations. Strict avoidance of pre-designed kits forced students to experience the frustrations and rewards of creating unique design content. The project selected consisted of a magnetically levitated, wirelessly powered desk lamp.

A key initial assumption was that students enrolled in the class would have a wide range of different hardware and software skill sets. The assumption (which turned out to be correct) necessitated the selection of assemblies that could be integrated into a unique design with minimal prior knowledge or experience. This applied to both hardware and software tools. It also made the project choice more difficult, since there needed to be sufficient flexibility to give advanced students an interesting challenge while simultaneously making project completion a realistic goal for novices. As Rabb et al\textsuperscript{12} commented; “A students’ view that they could accomplish the work in a class was a greater factor in a students’ effort and in the critical thinking that they did in a class, than was their general academic skill.”

Rather than an inflexible project that targeted the average student’s ability (and left frustrated students on both ends of the incoming-skills distribution curve), the project was chosen to have sufficient flexibility that each successful prototype would have its technical sophistication selected by each student. \textit{In effect, the students were entrusted with the personal responsibility of defining how much they wished to expand their knowledge frontier.} The positive impact of this assumption on student engagement and prototype uniqueness is discussed later in the paper.

Project

The project chosen was a desk lamp. To introduce nontrivial electrical, optical, materials and mechanical engineering concepts, the lamp was composed of four main components, as shown in
Figure 1. The lamp base was a commercial magnetic levitator that used active feedback to levitate a 1-inch diameter permanent magnet disk approximately 0.5 inch above the base. A mechanical structure attached to the levitating magnet held one or more LED’s (Light Emitting Diodes) that provided the light at the table surface. To power the LED’s, a wireless magnetic power coupling assembly was provided and consisted of two circuit boards (one transmitter and one receiver) with air coils attached to each. By affixing the receiver circuit and coil to the levitated structure, electrical power could be coupled from the fixed lamp base to the levitated assembly without intervening wires by positioning the transmitter coil in close proximity to the receiver coil, forming an air-core transformer. The transmitter circuit was energized from the levitating electronics.

Figure 1: Schematic drawing of desk lamp project showing major components. The LED’s, printed circuit board, support structure and location of the wireless power coil are design elements for the student. COTS = Commercial Off The Shelf; LED = Light Emitting Diode; PCB = Printed Circuit Board.
Each student was required to complete the following tasks:

1) design a mechanical structure to hold the LED’s;
2) select quantities and type(s) of LED’s for the lamp;
3) design a printed circuit board (PCB) to hold the LED’s or electronics associated with the LED’s;
4) design a mounting arrangement for the receiver coil and PCB;
5) design a mounting arrangement for the transmitter coil and PCB; and
6) assemble, test and demonstrate a completed prototype.

A number of coupled constraints are apparent with this project, as shown in Figure 2. If the student design resembled the layout shown in Figure 1 (in fact many prototypes were surprisingly different from this design), then the elevation of the LED’s altered the optical Lux at the table surface. The heavier and/or taller the support structure, the more unstable the levitation mechanism became. As the support structure weight increased, the levitated gap decreased, which affected the air-core transformer coupling efficiency.

Figure 2: Flow diagram showing dependencies between main aspects of the prototype. The levitation feature introduces dependencies between support structure weight, levitation stability, LED elevation, optical Lux at the table surface, and coupling distance of the air core transformer. HW= Homework.
Because the levitation assembly was symmetric about the vertical axis through the permanent magnet, the support structure could freely rotate, perhaps requiring a mechanical stop or other means to inhibit motion of the LED’s. The choice of materials used for the support structure was important since ferromagnetic or electrically conductive surfaces placed near the air core transformer impacted power coupling efficiency.

The design specifications included an illuminance of at least 250 Lux at the table surface. In addition, the assembled lamp had to remain upright while being slid horizontally along the table surface at a rate of 1 inch per second for 4 seconds. The lamp also required a custom designed printed circuit board, to give all students experience with at least one CAD tool.

Apart from these requirements and general safety guidelines, the students were free to construct the support structure using any materials of their choosing, including ABS construction blocks, custom designed or web-sourced shapes printed using an on-campus 3D printer facility, CNC fabricated metallic or polymer parts, wood, free-form stiff wire, construction foam, recycled plastic bottles, board game pieces, and etc.)

Logistics

The class was scheduled to meet for one 50-minute period each week for 15 weeks. Since the course included a laboratory component, up to 2 hours per week of additional time was made available to the students in the latter half of the semester in suitably equipped fabrication rooms. Cordless power tools, soldering stations, hand tools, a drill press, scroll saw and a solder reflow oven supported 12 workstations in each of two rooms. Approximately 100 students were enrolled in six separate sections, with class section size varying from 6 to 24 students.

Weekly milestones were set in order to encourage steady progress on student designs. As shown in Figure 2, weekly assignments in the first five weeks reinforced Just-In-Time lecture material specifically tailored to provide engineering basics that were immediately applicable to the project. Software tools for mechanical CAD and electrical CAD (printed circuit board layout)
with shallow learning curves and free access off campus enabled students to make rapid progress on their designs. To avoid technically advanced engineering design content that was beyond the scope of the class and the ability of the students, empirical design equations and curves were provided (for example, the levitation gap versus structure weight, or power coupling efficiency versus coil gap) to guide the lamp design.

Prior to finalizing designs, the students learned basic hand tool skills by populating a printed circuit board with surface mount and through-hole components, and modifying a plastic support plate for mounting said circuit board. Both activities included a design component by allowing students to select components from an inventory of parts, and allowing the freedom to choose the mechanical fastening arrangement for the printed circuit board.

After presenting a Quad chart describing the design and receiving peer review feedback (see Appendix for templates of both), each student made any necessary modifications, assembled a Bill Of Materials and submitted it to the instructor for ordering. In addition, all of the printed circuit board designs were submitted to the instructor for panelizing to reduce costs associated with procuring almost 100 unique printed circuit board designs made to professional standards (double sided, plate thru holes, silk screen, solder mask, complex perimeter shapes).

Materials, diced printed circuit boards, and 3D printed parts were delivered to the students by week 11. For the remaining 4 weeks of the semester, students assembled, debugged, modified and tested their prototypes. Each student submitted a data sheet describing the prototype after lamp operation was verified. An optional contest for best aesthetic design (with prizes but no impact on grade) was held at the end of the semester, judged by an independent panel. Approximately 35 designs participated in the contest. Students were allowed to keep their lamps.

Results

It should be noted that other than the first few weeks of the semester, attendance was not taken or required for this course. The class was presented to the students as an opportunity to improve their own skills, and it was up to them to prioritize the demands of this course versus their other
classes. The student response to the course became evident after the first two sessions in the fabrication rooms, around week 7. It was not uncommon to announce that the class had ended 30 or 45 minutes earlier. Students were not graded on their assembled practice printed circuit boards, yet many students approached the instructor to demonstrate their success. Some students actually wore their completed practice assemblies around campus as a fashion accessory. A significant number of the freshmen engineering students were extremely grateful to use a cordless drill and a soldering station for the first time. Faculty, staff, and administrators noted that students spent a significant amount of their free time discussing their lamp designs.

Completion Rate

Out of a total of 103 students, 94 completed a working prototype that met specifications for light output and stability under translation, resulting in a completion rate of 91%. The high completion rate for a design project with hardware deliverable may be due to simplistic requirements. However, this is not consistent with student feedback for the course, or the high quality of many of the completed projects, in some cases on a par with the hardware deliverables created in capstone design classes by senior undergraduate students. The high completion rate is more likely due to the flexible nature of the deliverable. By giving students sufficient creative freedom in their design, they were able to tailor the complexity and sophistication of their prototype to match their individual capabilities. Since the students were also notified at the beginning of the semester that they would be able to keep their lamps, there was a personal motivation to complete a working prototype.

Prototype Quality

The quality of some of the prototypes was exceptional. Several examples are shown in Figures 3-6. Some students spent more than 50 hours assembling and testing their prototypes during the last 5 weeks of the semester. Many students took advantage of resources off campus to complete portions of their designs. This was an extraordinary level of engagement and commitment from freshmen students.
Figure 3- Photos of prototype lamps under construction. On the left, custom 3D printed components, printed circuit board, and wiring of LEDs. On the right, top and bottom views of hexagonal angled LED assembly using custom printed circuit boards soldered together to achieve electrical and mechanical contacts. Design by Mr. Joshua Watkins (left) and Ms. Shelby Sims (right).

Figure 4- Photo of levitating prototype lamp. The student machined the components from aluminum and nylon stock. The wireless power receiver was housed at the base of the levitated structure. The LED mounted at one end of the tilt-adjustable horizontal arm was counterbalanced by a hollow end piece. Design by Mr. Alex Hessler.
Figure 5- Photo of levitating prototype lamp. The custom PCB was machined to fit inside the 3D printed custom shell. A fan cooled the heat sink to which the high power LED was attached. The lamp included a rechargeable battery. Design by Mr. Alberto Pinero.

Figure 6- Photo of levitating prototype lamp. The levitated hollow sphere was 3D printed. Although a green LED was used, the Lux specification was met. A Bluetooth-enabled audio module placed inside the levitated housing provided an audio loop on demand. Design by Mr. J. Collin Hoedtke.
Another indication of prototype quality was by how much the light output exceeded the minimum specification of 250 Lux provided to the students. An informal competition arose as prototypes were assessed for Lux level at the table surface. The measured values from all completed lamps are shown in Figure 7. There were no grades or bonus points associated with achieving the highest values, some of which exceeded the design specification by more than a factor of 100. The competition was driven purely by student pride in their unique designs.

A third measure of the quality of the prototypes designed by the students was a serendipitous fundraising campaign on Kickstarter for a levitated desk lamp named Flyte. The campaign ran for one month from April 21 to May 21, 2015, and raised over $600,000. Some of the designs produced by the freshmen undergraduate students were at least as creative as the Flyte prototype. The fact that the student project had appeal as a consumer product may have contributed to the strong student interest in completing a prototype.

Figure 7- Log graph showing the light output from all lamp prototypes. The vertical axis is logarithmic. The horizontal axis is roughly chronological as students submitted their prototypes for testing. The horizontal dashed line indicates the minimum Lux design specification provided by the instructor.
Course Assessments

Course assessment used publicly available data collected for every course by the Office of Institutional Research and Effectiveness. Anonymous responses were provided by 62% of the enrolled students. Each quantified question could be answered with a score from 1 (lowest) to 5 (highest). The overall evaluation for the course (6 sections) was 4.85. Questions related to the course structure received a score of 4.84, and the instructor received a score of 4.80. All three scores were among the highest of any course offered that semester.

The responses to two of the open-ended questions were evaluated. Responses to the open-ended question “What did you like about the course?” were grouped and summarized below in Table 1, along with the number of students in each grouped response.

<table>
<thead>
<tr>
<th>Response</th>
<th># of responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Able to show creativity.</td>
<td>15</td>
</tr>
<tr>
<td>Hands-on project.</td>
<td>12</td>
</tr>
<tr>
<td>Lots of engineering content.</td>
<td>11</td>
</tr>
<tr>
<td>Use knowledge we gained during the semester.</td>
<td>11</td>
</tr>
<tr>
<td>Able to complete prototype. Not too complicated.</td>
<td>11</td>
</tr>
<tr>
<td>Learned new skills. Encouraged me to expand capabilities.</td>
<td>9</td>
</tr>
<tr>
<td>Keep the final product.</td>
<td>6</td>
</tr>
<tr>
<td>Well funded.</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 1- Grouped responses to “What did you like about the course?”

The top response was having the ability to inject some creative content into the prototype design. Learning new skills, using knowledge gained during the semester and having a hands-on project were all popular positive aspects of the class. Many students commented that the project was within reach of their abilities, and not too complicated. This response supported the contention that the lamp project was flexible enough to be within reach of each student’s knowledge frontier.
Surprisingly, only one student considered significant the fact that the projects were funded, which supports the assumption that most students were comfortable with a $50 - $100 course fee in lieu of a required textbook. In addition, a relatively small number mentioned keeping the final product as an important feature of the course.

To identify weaknesses or shortcomings of the course structure and delivery, the open-ended responses to the question “What would you recommend to improve the course?” were grouped and are listed below in Table 2 along with the number of students mentioning each particular shortcoming.

<table>
<thead>
<tr>
<th>Response</th>
<th># of responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>More credit hours, more time.</td>
<td>29</td>
</tr>
<tr>
<td>Encourage students to ask for help early on.</td>
<td>4</td>
</tr>
<tr>
<td>Add more courses like this.</td>
<td>2</td>
</tr>
<tr>
<td>More access to lab.</td>
<td>1</td>
</tr>
<tr>
<td>Make material more general.</td>
<td>1</td>
</tr>
<tr>
<td>Do not limit to a specific prototype.</td>
<td>1</td>
</tr>
<tr>
<td>More tools in the lab.</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 2- Grouped responses to “What would you recommend to improve the course?”

The overwhelmingly popular suggestion (almost half of the responses) was that the number of credit hours and time for the class should be increased. This is an interesting recommendation given that a large fraction of the student cohort designed and fabricated a prototype that vastly exceeded the requirements for the course, in one or more of complexity, light levels, added features and/or fabrication techniques used.

Discussion- Comparison with MIT Course

Comparisons were tabulated between this course and the Electric Go-Kart project that was implemented in the freshman/sophomore class Introduction to Design and Manufacturing at MIT. Table 3 provides a side-by-side comparison of the two courses, showing the remarkable
similarities even though the current course was developed with no prior knowledge of the MIT course structure. It is gratifying to find that excellent student engagement was achieved for dramatically different projects at two different academic institutions when the course structure was organized in a similar manner.

<table>
<thead>
<tr>
<th><strong>MIT 2.007 Electric Go-Kart</strong></th>
<th><strong>This study- Levitating Desk Lamp</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>2-student team per prototype</td>
<td>1 student/prototype, ad-hoc teamwork</td>
</tr>
<tr>
<td>Hands-on, immediate validation</td>
<td>Hands-on, immediate validation</td>
</tr>
<tr>
<td>Student learns all aspects of the design</td>
<td>Student learns all aspects of the design</td>
</tr>
<tr>
<td>Students source components</td>
<td>Students source components</td>
</tr>
<tr>
<td>Fabrication skills taught in lab</td>
<td>Fabrication skills taught in lab</td>
</tr>
<tr>
<td>Just-in-time lecture material</td>
<td>Just-in-time lecture material</td>
</tr>
<tr>
<td>Weekly milestones</td>
<td>Weekly milestones</td>
</tr>
<tr>
<td>10:1 student/instructor ratio</td>
<td>15:1 student/instructor ratio in lab</td>
</tr>
<tr>
<td>Immerse learning experience</td>
<td>Immerse learning experience</td>
</tr>
<tr>
<td>Contest with completed prototypes</td>
<td>Contest with completed prototypes</td>
</tr>
<tr>
<td>Student BOMs ordered by instructor</td>
<td>Student BOMs ordered by instructor</td>
</tr>
<tr>
<td>Instructor knowledge and participation were pivotal to class success</td>
<td>Instructor knowledge and participation were pivotal to class success</td>
</tr>
<tr>
<td>Instructor received highest ratings</td>
<td>Instructor received highest ratings</td>
</tr>
<tr>
<td>Lab notebook required</td>
<td>Lab notebook required</td>
</tr>
<tr>
<td>Class attendance not mandatory</td>
<td>Class attendance not mandatory</td>
</tr>
<tr>
<td>Students used prototypes afterward</td>
<td>Students used prototypes afterward</td>
</tr>
<tr>
<td>3 hrs lecture and 3 hrs lab per week</td>
<td>1 hr lecture or 2 hrs lab per week</td>
</tr>
</tbody>
</table>

Table 3- Comparing aspects of the current course (levitating lamp project) with the MIT course (Electric Go-Kart project).11
Divergent thinking

One of the most important aspects of an engineering design class is an assessment of how much divergent thinking was involved in the creation of the unique prototypes in the class. One useful tool is a qualitative assessment of the diversity of designs among the final prototypes. Since the instructor encouraged students to seek help from each other when confronted with challenges during the semester, there was initial concern that some uniformity in prototype designs could result. Assessing design diversity was accomplished using the final prototypes and three milestone deliverables: the quad chart presented by each student; the printed circuit board design submitted by each student; and the Bill Of Materials (BOM) submitted by each student. Each of these is discussed below.

First, the quad charts displayed a wide variety of design concepts, some of which were considered by the student cohort to be too ambitious or simply unworkable. The peer review of the quad charts was conducted as a poster session, with students present to discuss their designs. Every student in a particular section was required to fill out a simple assessment sheet for each design (see Appendix for examples of the quad chart and the assessment sheet). These sheets were collated and given to each student to provide documented feedback on their design, in addition to comments made in person during the peer review poster session. Avoidance of presentation style discussions created a more informal environment that was conducive to exchanging both compliments and constructive criticisms. Student designers responded to comments from their peers by making design changes prior to submitting BOM and printed circuit board layouts.

Second, students submitted a wide variety of printed circuit board designs. Recall that one ‘basic skill’ lab involved students selecting components to solder onto a printed circuit board provided by the instructor. The CAD files for this circuit board were provided to the students to use as a guide or template while they designed their own printed circuit boards. Initially, it was assumed that a large fraction of the students would simply re-use the layout with minor customizations such as labels. This concern turned out to be unfounded. Two of the panelized printed circuit
boards are shown in Figure 8. Note that many students took advantage of the opportunity to fabricate either multiple identical boards or several different circuit boards that connected to each other or were mounted at different locations in their prototype.

Third, the variety of BOM content was reflected in not only the types of components students requested from a list of recommended vendors to allow grouping of orders for efficiency (for example, DigiKey offers over 20,000 unique LEDs), but also by the variety of components from other vendors selected by students, including numerous Amazon and Ebay vendors. The BOM also included any 3D printing requests for the on-site printing facility. It was clear based on comments made by the 3D printing facility supervisor that a rich variety of objects were submitted for printing. Some students chose to use 3D printing services from outside, in the few cases where an unusual material, finish or assembly was needed (such as UV sensitive plastic).
Several students chose to avail themselves of CNC machining services at a nearby machine shop, after designing their custom support structure in a CAD program of their choice or by submitting dimensioned hand drawings of the desired parts.

Finally, the wide variety of levitated structures was an unexpected surprise, given the small number of examples provided by the instructor early in the semester, and the limited attention students usually allocated to a one credit hour class. All four of these assessments are strong indicators that students employed divergent thinking processes.

Ancillary learning outcomes

Aside from the student learning outcomes listed on the class syllabus, several undeclared learning outcomes resulted from the course structure and project choice-

1) Acquiring an appreciation for not being too ambitious under a given set of constraints. This life lesson is important for practicing engineers, who inevitably work under time and cost constraints for their entire careers. At least one of an inability to print 3D designs, poor quality of 3D printed components, student-selected components arriving late or out-of-stock, low light output of prototype, failure of supplied components (the failure rate of the levitators was over 20%), LED overheating (one prototype lamp LED fell off when the solder melted due to overcurrent) or extensive redesigns were experienced by many of the students. This was reflected in some of the data sheets prepared by the students, including one student who named his fictitious company ‘I Was Wrong Electronics.’

2) Collaborating with informal groups and minimizing social loafing. Students helped each other within the lab times and outside of class. Often students from different sections would be seen working together on their designs outside of class. Students already familiar with soldering and power tools would often help other students during class, even though it resulted in them staying past the end of class time. There were very few students “staring at the walls” or otherwise distracted in the workshop classrooms.
3) Delivering a functional prototype is vastly different from a term paper, a proposal, a report or assembling a prefabricated kit. Having a blank sheet of paper as a starting point is much different from following a page of assembly instructions. Students experienced some frustration during the process of designing and assembling a unique piece of hardware, but not so much that they lost confidence in their ability to complete the task.

4) Develop confidence in one’s ability to self-teach. Successful engineering careers rely on lifelong learning and the ability to self-teach, including the ability to identify sources of accurate information. The instructor encouraged students to talk with their peers, use online instructional videos and seek others for help as they designed and assembled their prototypes. Emphasizing the acquisition of new skills and de-emphasizing the importance of the final grade helped to create a learning environment where students felt comfortable helping each other.

Student Engagement

Informal discussions with students 9 months after the completion of the class indicated that most of the students were still using their lamps. Several students explored using their lamps as table centerpieces for student club fundraising events. The class and the project, in particular, are regularly reported by students to be among their favorite class and activity at the institution.

The surprising quality and creativity shown in many of the designs, the exceptional student engagement indicated by high class attendance rates (even though optional) and time invested outside of class hours, and the high course assessments, appear to contradict the overwhelming call for increased time and credit hour allocation in future offerings of the class. The obvious conclusion is that the class would be even more enjoyable if students were given more class time. Giving students the credit-hour acknowledgment of the time they invest in a project is fair, but it is not a predictor of student engagement. Engineering programs are littered with courses that foster little student engagement.

An alternative interpretation is that the class was so enjoyable because the lack of class time forced students to create ways of working on their projects outside of class. Providing students
with software tools they could access anywhere alleviated the spatial constraint commonly created by computer labs with unique software tools loaded onto workstations. Once the components were procured, much of the assembly and troubleshooting could be completed without access to specialty test equipment. The small size of the prototype made it portable and easy to carry to and from class.

Both the MIT class and this class had high student engagement. Comparing the class time allocated at MIT (6 hours per week) with this class (1 or 2 hours per week) indicates that class hours are not a predictor of student engagement. Rather, it is more likely that the project expectations need to be tailored to the student’s ability and realistic time commitment. For example, it is not clear if student time spent on the lamp project would change if class time increased to 6 hours per week. Rather, students may simply reduce their out-of-class time commitment to the project and still achieve the same prototype quality.

Conclusions

Project Based Learning was implemented in the cornerstone course Introduction to Engineering Design. Exceptional student engagement, as measured by project completion rate, out-of-class effort and course evaluations, was achieved by tailoring the project to have sufficient flexibility that each successful prototype would have its technical sophistication selected by each student. In effect, the students were entrusted with the personal responsibility of defining how much they wished to expand their knowledge frontier. Although student feedback demanded more class time and credit hours for future offerings, there is some evidence that the limited class time increased student engagement by forcing them to find ways to work on their projects outside of class. This was supported by the use of freely available, shallow-learning-curve software tools and minimal reliance on specialty hardware and equipment. Prototype quality in some cases was comparable to high-quality prototypes created in a capstone (senior) design class. The diversity of design as indicated by several milestones and the final prototype suggests that students engaged in divergent thinking, an important characteristic of engineering design. The class, in hindsight contained many features found in a comparable (and very successful) course offered to
freshmen at MIT, indicating that the course structure may be successfully used with a wide variety of projects and a wide range of credit hours at a variety of teaching institutions.

Acknowledgements

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Appendix
Quad chart template and quad chart assessment form

### Proposer Name

<table>
<thead>
<tr>
<th>Top Left Quadrant:</th>
<th>Top Right Quadrant:</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Your Desk Lamp’s Name (optional)</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Design goals for your desk lamp</strong></td>
<td></td>
</tr>
<tr>
<td>- specification 1 (e.g. 250 lux at desk surface)</td>
<td></td>
</tr>
<tr>
<td>- specification 2</td>
<td></td>
</tr>
<tr>
<td>- etc</td>
<td></td>
</tr>
<tr>
<td>Highlight specifications that are the most important to you. Highlight specifications you will not meet.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Bottom Left Quadrant:</th>
<th>Bottom Right Quadrant:</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Approach (how) in bullet format detailing your design.</strong></td>
<td></td>
</tr>
<tr>
<td>- What is levitated</td>
<td></td>
</tr>
<tr>
<td>- Where are the LED’s, and how many</td>
<td></td>
</tr>
<tr>
<td>- Estimated size of illuminated spot and lamp structure</td>
<td></td>
</tr>
<tr>
<td>- LED colors chosen</td>
<td></td>
</tr>
<tr>
<td>- Location of wireless power link(s)</td>
<td></td>
</tr>
<tr>
<td>- Technique used to turn LED’s ON/OFF</td>
<td></td>
</tr>
<tr>
<td>- Other features unique to your design (original 3D design, re-purposed parts from existing lamp, hand-crafted parts, CNC machining of parts, active electronics to provide additional capabilities, etc.)</td>
<td></td>
</tr>
</tbody>
</table>

| Milestone 1 | Date completed |
| Milestone 2 | Date completed |
| Etc. (should be consistent with course syllabus) |

**NOTE:** All BOM’s, PCB layout files and requests for 3D printing and/or CNC machining must be submitted to the instructor on or before midnight, March 10, 2015.
Design Review

LEVITATED DESK LAMP

Does the design address the following design criteria:

0 = NO   1 = KINDA   2 = YES

The lamp shall provide illumination of the table upon which it is placed using one or more white Light Emitting Diodes (LED).

The lamp shall have the ability to illuminate a standard 7 x 10 inch sheet of paper.

The LEDs shall be powered through a wireless power link comprised of one or more pairs of coils forming an air-core transformer.

The wireless power link shall have the ability to be turned on or off independently of the levitation system.

The lamp shall require no more than one (1) minute to set up.

In the event of a power failure, the lamp shall assume a safe configuration (i.e. not fall over), and not suffer mechanical damage.

TOTAL (maximum 12 points)

What are the best features of this design?

What parts of this design need the most help/are missing?
References


