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Examples of Free Choice Open-Ended Design Projects in a First-Year Engineering Course

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Abstract - **This complete evidence-based practice paper investigates the implementation of a pilot section with free-choice in selecting an open-ended design project for the NYU Tandon School of Engineering first-year Introduction to Engineering and Design course. This pilot section has been offered for both Fall 2016 and Spring 2017 semesters. The faculty for this 3 credit hour first-year course are developing an advanced project for students who want a challenge beyond the current options. There are three different project choices that focus on either Lego Mindstorms, LabVIEW, or AutoCAD for all course sections. The same topics are addressed in each project: programming fundamentals, technical drawings, the engineering design process, teamwork, and project management. This new project focuses on the same learning objectives, but it also allows students to take ownership of their design project by generating their own idea.**

The project combines entrepreneurial thinking and maker technology to allow students to address large-scale multidisciplinary engineering problems. In addition to the introduction to engineering course, a 1 credit hour first-year course, called the Innovation and Technology Forum, that focuses on the Lean Launchpad methodology and design thinking is a co-requisite for students in the pilot section. The same group of at most 15 students were enrolled in the same sections for both the 3 credit and 1 credit hour course. For this pilot section, the project requirements are a combination of the two courses. The 1 credit hour course focuses on ideation for the project while the three credit hour introduction to engineering course provides the support and resources for creating physical, technological prototypes. Care must be taken to provide the necessary additional support and resources for these prototypes with clear expectations of grades and deliverables. With that support, interested students can succeed in integrating a free-choice aspect to their first-year design project.

Index Terms – Invention, Innovation, and Entrepreneurship; Prototyping; Makerspace; Multidisciplinary; Free-Choice; Open-Ended Design Project

INTRODUCTION

The introduction of inexpensive, hobbyist electronics on the market has provided new opportunities for engineering education. Many engineering students seek out courses they can take that give them hands-on experience. The Maker Movement has helped to establish a community of Science, Technology, Engineering, Arts, and Math (STEAM) oriented creators. Makers who participate in these projects learn from the creativity and technical skills required to turn their ideas into reality. As hobbyists, these makers are afforded the ability to work on any project that interests them. However, even with cheaper electronics and prototyping tools many people still do not have access to or seek out the resources necessary for this type of experiential learning. So, why not bring Making to the classroom?

At the NYU Tandon School of Engineering a pilot section of the first-year engineering courses was created to bring making into the classroom. Students in this section were required to identify a problem that they wanted to solve using technology. This project was an alternative to pre-defined projects in Lego robotics, computer-aided design (CAD) of a building, and a LabVIEW digital logic problem. The first weeks of the pilot section were devoted to students identifying a problem, then they spent the rest of the semester designing and building their solution. Teams were instructed on design thinking and consumer-oriented design. Students also learned how to program microcontrollers and model 3D objects in CAD through laboratory exercises. Mentorship from faculty and teaching assistants was available throughout the project as they ran into problems with their prototypes. The project culminated in a product pitch presentation and competition.

This paper documents examples of the projects students chose in the first-year of testing the pilot section. It will also include a discussion on lessons learned for operating and developing such a course. Analysis of this pilot section includes results from class surveys. The survey included questions about the project, the resources available to students, improvements for the future, and how the course changed their view of studying engineering.

LITERATURE REVIEW

There is some consensus amongst first-year programs that there are a number of essential curriculum topics. Figure 1 is a word map of some of the most common concepts and skills addressed in first-year course related to research on open-ended design projects. The goal of NYU's new first-year engineering project was to maintain the same critical curriculum, but provide a more challenging and rewarding experience to advanced students. Some of these advanced students have used Lego Mindstorms since middle school.

FIGURE 1
WORDMAP OF THE COMMON FIRST-YEAR TOPICS COVERED IN ENGINEERING [1,2,3,4,5,6,7]

The open-ended free-choice projects can provide a creative outlet for these students to apply the engineering skills already acquired. This pilot section of the course has been named the Invention, Innovation, and Entrepreneurship (i^2e) section to support the mission of the NYU Tandon School of Engineering. Innovation and entrepreneurship are being adapted by several first-year engineering programs across the country [1].

The success of the i^2e section is dependent on providing foundational instruction on the engineering design process [2]. Students also often need help with computer-aided design, programming, and project management. This core instruction often influences the rubrics used to grade open-ended projects. Common attributes for assessing an open-ended project include: a prototype, documentation of testing, commented code, engineering drawings, 3D printing, team evaluations [3,4,5,8]. 3D printing has become more common due to the availability and affordability of printers; it also appears that 3D printing effectively teaches 3D modeling to both men and women as well as honors and non-honors students [9]. Documenting grades using a rubric and providing the project rubric to students are important for the clarity of project expectations [10].

Free-choice open-ended projects can vary widely, but many first-year courses provide an orientation to popular and important engineering topics. Some define the design projects as service, research, or entrepreneurship focused [1,2]. Others provide multidisciplinary areas of engineering like energy, systems, humanitarian, arts, and environmental [11]. There has been a large number of first-year programs focusing the cornerstone design project around the National Academy of Engineers Grand Challenges for Engineering [7]. However, these are commonly limited to the Grand Challenges accessible to first-year students such as: Provide Access to Clean Water, Enhance Virtual Reality, Restore and Improve Urban Infrastructure, Reverse Engineer the Brain, Advance Health Informatics, and Make Solar Energy Economical. Some courses that provide this survey of engineering topics have pre-defined projects, but others allow students to select, combine, and manipulate these topics.

Some examples of the pre-defined projects focus on implementing inexpensive hobbyist electronics. Northeastern University has developed projects around robotics, energy transfer, games and virtual reality, sustainability, security [5]. A first-year computer engineering course focusing on microcontrollers developed projects on automated pill delivery, automatic turning off of appliances, an in house asynchronous audio communication console, and an automated cat food dispenser [6]. A K-12 summer STEM program in engineering offered a completely free-choice project in realm of the Internet of Things (IoT) [13]. Although, the project was free-choice a list of potential project ideas was provided to students related to apps, wearable technology, home automation, and biomedical. Some of these projects included shoes that generate electricity, a wearable that detects anxiety attacks, exoskeleton for a hand, an amphibious drone, air quality tester and app, shoes with swappable soles, and an armband that wakes up transit users at their stop. Free-choice projects inevitably will lead to a wide variety of topics chosen by students.

Previous implementations of free-choice or open-ended have provided a few guiding principles. Only a small fraction of students (5-15%) wish to participate in a free-choice option over a predefined project [14]. The greatest barriers for choosing a project come from anxiety around regret, opportunity cost, expectation, and self-blame [15]. Despite this Harvey Mudd's innovative curriculum has found poorly structured open-ended design project throughout the four years of undergraduate engineering to be an essential learning process for training engineers [16].

One of the greatest difficulties with open-ended engineering design is providing a fair assessment of the final project. One model is 25% for a functional prototype, 25% for individual performance, 25% for project documentation, and 25% for peer assessment [15]. Another model focuses more on process and less on product, this is based on the Vertically Integrated Project program. This grading schemes is 33% engineering notebook documentation, 33% individual performance, and 33% peer assessment [17].

The survey used for this study is derived from a selection of surveys on design thinking and open-ended design in engineering education [18,19].

METHODS

The i^{2}e pilot section with a free-choice project for the first-year engineering courses at NYU operated in Fall 2016 and Spring 2017. Only one section of a maximum of 15 students ran each semester. In the fall and spring semester, 14 and 12 students enrolled, respectively. The first-year engineering faculty worked with first-year advisors to recruit students for these sections. A call for application was sent out to the top 100 admitted students based on their application criteria for Fall 2016. 26 of the 100 applied to be in the course. 15 students were initially selected, three of which dropped the course and two alternates replaced them. The spring semester was more difficult, since the pool of students was limited to those who had not taken either course in the fall semester. Of the 110 students who still needed to take both courses, only 7 applied. The first-year advisor identified five other students who would be willing to try the course.

The course project requirements were administered in the second week of class. Students were introduced to the Maker Movement, the Internet of Things, the NYU Tandon School of Engineering research focuses (biomedical engineering, information technology, and urban systems), and the National Academy of Engineering Grand Challenges for Engineering. The goal was to introduce students to topics at the forefront of engineering and technology. Then, they were given the next week or two to brainstorm any problem they wanted to solve with technology. In the fifth week, their first milestone, students proposed the problem and the technology they wanted to develop to solve it. At this point, they were expected to have some proof of concept. Throughout the semester there are 2 more milestones where the students must present pivots from their initial idea, consumer interviews, technical specifications, and their next steps. At the end of the semester they are expected to have a functional prototype and pitch their idea in a final presentation to judges.

A kit was provided to each team consisting of rapid prototyping boards and sensors. Figure 2 is a representative picture of the custom kit made for this course.

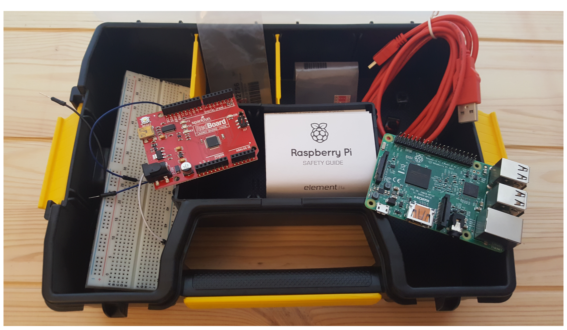

FIGURE 2
SPARKFUN REDBOARD (ARDUINO) AND RASPBERRY PI BASED PROTOTYPING KIT

All of the materials provided in the kit are listed in Table 1. The items in the kit consist mostly of microcontrollers (Arduino), single-board computers (Raspberry Pi), and sensors.

TABLE I
PROTOTYPING MATERIALS IN CUSTOM STUDENT KIT

Part	Description
Arduino	Programmable microcontroller with I/O pins
Raspberry Pi 3	Single board computer with Wi-Fi and Bluetooth
Breadboard	Prototyping board for connecting electronics
Photocell	Light sensitive resistor
Transistors	Electronically controlled switches
Accelerometer	Triple axis (x, y, z) motion detector
GPS breakout board	GPS chipset and antenna
Flex sensor	Bending sensitive resistor
Temperature sensor	Outputs voltage proportional to $^{\circ}$C temperature
IR sensor	Outputs voltage proportional to IR light
Pushbutton	Momentary mechanical switch
LCD screen	Full 16-bit color display
Accessories	USB cable, jumper wires, resistors, micro SD card, kit box

Students are also given the opportunity to purchase an additional $50 in materials if they can justify the need in their design and budget. Some of the equipment that students have purchased and other recommendations provided to students are included in Table 2.

TABLE II
ADDITIONAL MATERIALS AVAILABLE BASED ON NEED

Part	Description
RPi camera	HD video and picture camera
RFID controller	Radio frequency identification
Accessories	DC power supply, DC level shifter, batteries
Gas sensors	Methane, liquefied petroleum, hydrogen, carbon monoxide, alcohol
Air quality sensors	Particulate matter 2.5, volatile organic compounds
Weather sensors	Humidity, barometric pressure, soil moisture, altitude, UV light
Biometric sensors	Fingerprint scanner, pulse
Actuators	DC motor, stepper motor, pump, solenoid, relay
Imaging and sound	Touch screen, speaker, buzzer
Power generation	Solar panel, inductive charging, piezoelectric

The university opened a makerspace in Fall 2016 just before the first semester of this pilot section. This makerspace is equipped with 3D printers, laser cutters, and CNC machines. The makerspace also has electrical benches with multimeters, DC power supplies, oscilloscopes, and function generators. These materials and resources provided the fundamental support for the teams to complete their projects. The project requirements encouraged the use of and provided training for the advanced equipment in the makerspace. Each team was paired with a mentor teaching assistant with experience and interest in the area of their chosen project.

A survey was conducted at the end of each semester asking students their opinion of the project. The full survey is in the Appendix. Qualitative results from these surveys including student comments on different aspects of the project will be discussed. An overview of the projects that were complete will also be presented. The paper will then summarize with recommendations for those who are trying to start a similar type of project.

ANALYSIS

Over the two semesters nine projects were completed. The sections were divided up into teams of two or three. In Fall 2016, a first and second place team were chosen from the five competing teams. In Spring 2017, only one winning team was chosen. In the fall and spring semesters only five and four students, respectively, completed the survey. These lower response rates provide more power as qualitative results.

I. Fall 2016 Projects

The winning project from Fall 2016 was an educational tool with multiple sensors that can connect to a smart phone. Their inspiration was the Star Trek tricorder, and they turned their idea into an inexpensive device that could be used in high school science labs. They incorporated over 20 sensing capabilities and connected it to a mobile app that walks students through the scientific method. Their products can be seen in Figure 3. This team went on to win second place in an innovation, invention, and entrepreneurship competition at the university. This award won them $15,000 to continue working on their product.

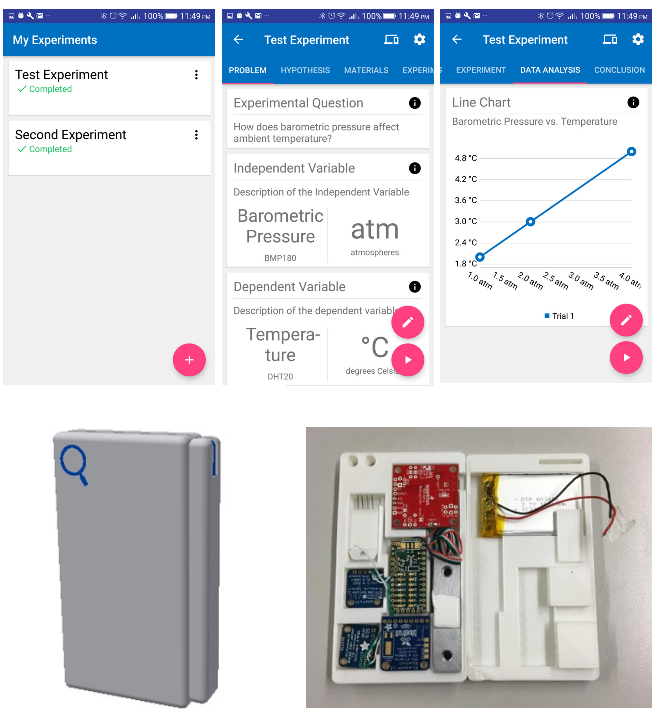

FIGURE 3
MOBILE APP, CAD DRAWING, AND ELECTRONICS OF FALL WINNING TEAM

Another project was a device that could automatically notify users when a 3D print was completed. They were inspired by working in the MakerSpace on the project and created a design that could be used by the 3D printers they used to make their product. This product is in Figure 4.

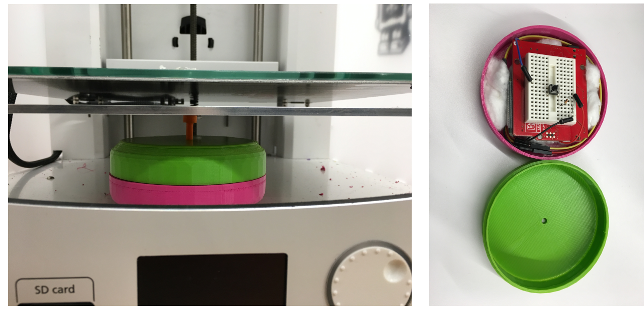

FIGURE 4
SENSOR DESIGN FOR 3D PRINTER NOTIFICATION DEVICE

The second place team project from the first semester was a RFID tracking technology for tools in a workspace. Another project was an emergency kit with solar panels and GPS for recharging a phone and sending out a notification on the user's location. The final project was a digital weight lifting trainer that used the Xbox Kinect sensors to track the user's movements. The device would then provide suggestions for improving the user's form.

II. Spring 2017 Projects

In the spring semester, another team worked on a RFID project. This time the RFID sensor was used as an organizer for books that a student needs based on the day of the week and their class schedule. Another teamed developed a wearable device that allowed them to submit a notification to a friendship mobile app. The user inputs what activities they want to do, and if there is another user nearby on campus the app matches them and provides information on how to connect to one another.

Another team wanted to create a robot that could travel through air ducts for cleaning, monitoring, and maintenance. They used a Raspberry Pi camera that they set up to connect remotely to a computer and view the inside of a duct. They also 3D printed omniwheels that were used by the robot to grip the sides of a duct and propel itself through. These designs can be seen in Figure 5.

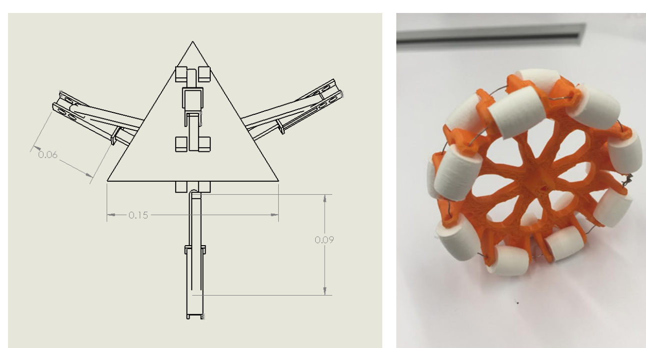

FIGURE 5
CAD DRAWINGS AND OMNIWHELL FOR ROBOT THAT CAN CRAWL THROUGH DUCTS

The winning team for the spring semester created an instructional typing game for young kids. Their product was a standalone keyboard with a screen that would display letters and words for the user to type. The device would provide feedback on the accuracy of the typist and move to more advanced levels after mastering a skill. The product can be seen in Figure 6.

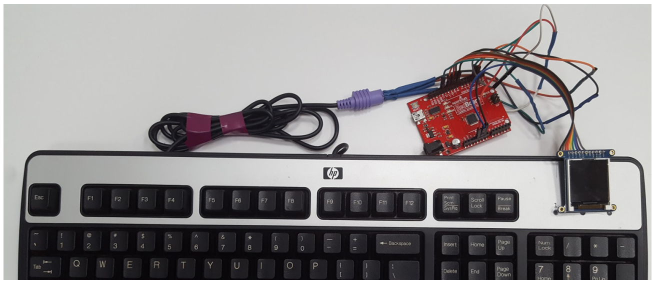

FIGURE 6
SETUP FOR TYPING LEARNING GAME

III. Survey Results

The survey was made up of questions related to the project, the engineering design process, and design thinking. The full survey can be seen in the Appendix and was based on previous research on these topics [18,19]. In response to the question, "which part of the project took the most time and effort?" most students replied programming and prototyping. The students felt that the technical design and construction was the largest part of the project. The next most common response was CAD and 3D printing. Table 3 indicates what students thought when asked what the most important design activities were for the project. Prototyping was found to be both the most effort and the most important.

TABLE III
MOST COMMON SELECTION OF IMPORTANT DESIGN ACTIVITIES

Most Important Design Activities	Number of Responses
Prototyping	8
Iterating	6
Communicating	5
Planning	4
Brainstorming	4

When responding to the free-response questions students provided valuable insight into how to improve the course in the future. Table 4 lists the most important responses.

TABLE IV
SELECT STUDENT FREE RESPONSES TO SURVEY QUESTIONS

What did you struggle with the most during this course?

1. The **open mindedness of the project definitely scared me at first** because I am usually more of a structured person but once the project was decided upon it was a lot better.
2. Coming up with a **feasible timeline to create a prototype** within the semester
3. Definitely trying to **design the prototype as well as debug the code**

What did you enjoy most during this course (what shouldn't change)?

1. I enjoyed being able to **work on a project I cared about**
2. Having the **freedom to choose my own idea** without any restrictions
3. Additionally, my favorite part was probably the fact that we could really do anything. Yes, **it did scare me at first** because there are so many options but it was really cool to **just take a break from structured leaning and kind of go off and do our own thing** with the project.
4. It was fun to be able to attempt to **design something almost fully independently with the safety net of a mentor** behind you.
5. Being able to **build a prototype was very satisfying**
6. Being **totally free in the design choices** we made.

What tools and resources would you have wanted for your project?

1. For other resources, throughout the semester, I wish I can have more support on CAD drawings and 3D modeling in general in class. I like the 1003 labs with **Arduinos and 3D drawing** at the beginning of semester. It would be great if we could have more labs like these
2. I definitely think that a TA to help specific sections would be amazing. Not necessarily one per team, but perhaps 2 or 3 TAs total. **1 to help with programming, one with 3d printing, and one with concepts**.
3. What we had was fine. The **maker space basically provides you with everything you need**

Do you have any other recommendations for this course?

1. I really liked this course, and was surprised to see **how much we can actually achieved in one semester in freshman year**
2. I loved the course and would recommend it to everyone. However, I think it is still **very important for there to be an application process because this class is not for everyone**. Also, I think it was very important that everyone in this class genuinely wanted to be in the class, so having it open to everyone may not be best for this class.
3. MAKE SURE IT SAYS THAT THIS IS AN **ADVANCED/TECHNICAL SECTION ON OUR TRANSCRIPT** PLEASE.

The takeaway from their responses was that the open-ended project and lack of structure can be scary for first-year students. Also, it can be intimidating to go from idea to prototype in such a short time with so little experience. However, students enjoy working on the projects that they chose and are important to them. Students, once they completed the project found creating the final prototype was thrilling and fulfilling. To support students, it is important to provide instruction on programming, prototyping, CAD modeling, and 3D printing. It is really important for students to have a dedicated space to work and mentors who they can go to when they run into obstacles. Students also reinforced that the course is not for everyone and that there should be an application process.

CONCLUSIONS AND RECOMMENDATIONS

Creating a new free-choice open-ended project for first-year engineering students is a challenging and rewarding process. Student projects will benefit from instruction on engineering topics and suggestions for types of project they can choose. Orienting students to engineering and real world problems gives them a better perspective of the relevant problems that can be solved with technology.

This initial pilot section confirms previous research that suggests a small fraction, 5-15%, of students are capable and interested in a free-choice open-ended project. This pilot section started with 5% of the student population. This fraction is a good starting point to work out issues with a new project like this. The pilot section at NYU will continue with at least one section in the fall and spring, and the potential to increase to 10%, or 2 sections in the fall and spring. Also, it highly recommended that students should be in the top half of their class with previous experience in team projects, programming, making, or 3D modeling.

Initially, there were no restrictions placed on the projects other than they must be multidisciplinary team projects. Types of projects suggested to students included: mobile applications, smart devices, sensors, robotic parts, lab equipment, or measurement tools. After two semesters, the faculty for this project chose to no longer accept mobile apps, websites, or software. Mobile apps, websites, and software only projects make it easier to fake progress and prevent students from learning some of the desired course outcomes. The course project requirements have changed slightly and now include: a functional prototype, documentation of design and testing, commented algorithm and code, engineering drawings, 3D printing, and teamwork agreements. Table 5 is a subjective ranking of the different project topics by their successful completion of the project requirements.

TABLE V
PROJECTS RANKED BY FACULTY BASED ON SUCCESSFULLY COMPLETING THE COURSE LEARNING OBJECTIVES

Project Topic	Learning Objectives Rank
Multiple sensor physics lab	1
RFID tool tracker	2
Xbox Kinect workout trainer	3
Typing instruction game	4
3D printer finished notification	5
GPS emergency box	6
RFID book organizer	7
Robot for air duct inspection	8
Friendship app and wearable	9

Some other recommendations from the experience of the first two semesters of operating this pilot section relate to personal interaction and logistics for assessing the project.

This type of project requires much more interpersonal interaction than a typical first-year engineering course project. A pilot section with a free-choice open-ended design project requires an involved and dedicated professor. The professor will be required to make judgments about the proposal, project progress, and team decisions. These projects also require extra time and money. Time is required for teaching assistants to help students with 3D modeling, 3D printing, circuit wiring, coding, and prototyping. The course should also provide additional technical instruction and labs for new topics, which requires time and effort to plan. Extra money is needed for the kits and additional materials that students purchase.

Finally, some logistical considerations for assessing the project include student and team selection. Students should be selected based on their motivation and experience. Teams should be preselected to reduce the number of choices students need to make related to their project. When students first propose a topic they should propose multiple options. This way if one idea is infeasible, then less time is wasted trying to come up with another idea. Deadlines, as in milestones with clear guidance, should be set early in the semester and held to a strict schedule. Assessment should focus primarily on project documentation, individual performance, and peer evaluation.

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APPENDIX

Likert-Scale Questions

(Strongly Disagree/Disagree/Neutral/Agree/Strongly Agree)

ABET Related Questions

1. In this course we gain an understanding of the design process.
2. In the course project we gained an understanding of contemporary engineering practice.
3. I have enhanced my ability to design a system, component, or process to meet desired needs.
4. I intend to practice, conduct research in, or teach engineering for at least 3 years after graduation.

Motivation and Interest

5. Overall, this class has increased my interest in engineering or computer science.
6. The hands-on experience in this class has improved my confidence in my ability to succeed in engineering or computer science.
7. The manufacturing and fabrication experience in this class has increased my motivation for school work.
8. The in-class exercises, such as programming, working with breadboard circuits, fabrication has increased my motivation to study math, physics and chemistry.

Satisfaction with the Project

9. I am happy with my team this semester.
10. I am happy with my project selection this semester.
11. I plan to continue working on the product developed in class.
12. I am proud of the product I created in class.
13. I am interested in creating another product in the future.
14. I am interested in working on a team to change an existing product.
15. I feel more equipped to solve problems when I'm stuck.

Special Questions

16. Which part of the project took the most time and effort?
    a. Brainstorming
    b. Algorithm
    c. Prototyping
    d. Programming
    e. CAD and 3D Printing
    f. Measurement and testing
17. Of the twenty-three design activities below, please put a check mark next to the SIX MOST IMPORTANT.
    a. Abstracting
    b. Brainstorming
    c. Building
    d. Communicating
    e. Decomposing
    f. Evaluating
    g. Generating alternatives
    h. Goal setting
    i. Identifying constraints
    j. Imagining
    k. Iterating
    l. Making decisions
    m. Making trade-offs
    n. Modeling
    o. Planning
    p. Prototyping
    q. Seeking information
    r. Sketching Synthesizing
    s. Testing
    t. Understanding the problem
    u. Using creativity
    v. Visualizing
    w. I prefer not to answer

Open-ended Questions

18. What did you struggle with the most during this course?
19. What did you enjoy most during this course (what shouldn't change)?
20. What tools and resources would you have wanted for your project?
21. What additional instruction would be helpful for the design project?
22. Do you have any other recommendations for this course?