MAKER: Simple Motor for a Freshman Class

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Make It: Simple Motor for a Freshman Class

ABSTRACT

This will be a demonstration of a simple motor that can be designed and manufactured by freshmen in an introductory hands-on class. The class introduces the students to the Making community at the Massachusetts Institute of Technology and also gives them basic skills in CAD, manufacturing, and electronics.

INTRODUCTION

Introductory freshman classes are a great way to engage freshmen in engineering and get them excited about their future major. Previous studies have found that a hands-on or project freshman experience can have major impacts on student persistence in engineering. This paper describes a simple project that can be accomplished by university freshmen with only general backgrounds in physics. Through the semester, the students are introduced to CAD (Computer-Aided Design), basic circuits, magnets, electromagnets, and Raspberry Pi microcontrollers, as well as the manufacturing processes of laser cutting and 3D printing. The students created working motors in a variety of self-designed configurations in six weeks using off-the shelf components and their own rotor designs which they manufactured with the laser cutter. In a class of 36 students, all were successful in achieving a running motor at the end of the activity.

BACKGROUND

Introductory freshman classes are a great way to engage freshmen in engineering and get them excited about their future major. Experiential education, such as utilizing hands-on projects, is widely acknowledged as an effective way to learn. [1] Students are given opportunities to direct their own learning, focusing on a fun and exciting outcome that is beyond simply the knowledge required. [2, 3] Previous studies have found that a hands-on or project freshman experience can have impacts on student attitudes and persistence in engineering. [4-7]

A critique of the MIT curriculum is that the core classes in the freshmen year are all science and humanities classes, however the majority of the students complete a degree in engineering. To better connect freshman core science classes to engineering concepts, a class was developed that focused on hands-on projects in the freshman year. This seminar, called Mens Et Manus (Mind and Hand), included a 6-session project on electric motors. The students were introduced to motors and how they work and then were led through a series of lectures and activities to design and build their own motor. The seminar met once a week for two hours and outside of class there were approximately four hours of work per week. The class was led by two instructors, two teaching assistants, three undergraduate assistants, and also utilized the help of various shop instructors across campus.

MOTOR PROJECT

Students see electric motors every day, but many students do not know how motors work. In this freshman seminar, six sessions were devoted to understanding electric motors by designing and building small desktop motors. The six sessions of the motor project were (1) electricity and current, (2) magnets and electromagnets, (3) Raspberry Pi microcontrollers, and CAD, (4) lasercutting, (5) assembly of motors, (6) debugging and running and racing the motors. The topics will be discussed in this paper in terms of background theory of motors via physics concepts (sessions 1 & 2), manufacturing techniques for fabrication of motors (3 & 4), microcontrollers to control electromagnets (3 & 5), and then final thoughts and observations (focused on the outcomes of the completed motors in session 6).

Background Theory

The first-year students at MIT have all had introductory physics at the high-school level, but approximately half of the students are enrolled in a Physics Mechanics class and half are enrolled in the subsequent class, Physics: Electricity and Magnetism during the semester of the seminar. All students are enrolled in a Calculus or subsequent class. Therefore, the introductory material has to introduce concepts with only general physics background but can involve some mathematical depth.

The concepts that were chosen for class time were specifically focused on the knowledge needed to complete the motor design and fabrication. The first lecture introduced students to the concepts of electricity, current, resistance, and impedance. These concepts were then extended in the second lecture into an understanding of electromagnets. Students made their own electromagnets as part of the class, winding magnet wire onto clear sewing bobbins and powering them from a power supply. The students then used their hand-made electromagnets to discover various properties about electromagnets, such as the effect of number of windings, or the diameter of the magnet wire, on the strength of the electromagnet. The strength of the magnet wire was measured by the height from which the electromagnet could pick up a permanent magnet vertically off the workbench. From these two lectures on introductory electricity and magnetism, the students understood how to create an electromagnet and the properties of electromagnets based on the interactions with permanent magnets.

Controlling

In order to allow the students to control their electromagnets, the class introduced Raspberry Pi microcontrollers as a control system. From pre-class survey data, 78% of the students had some experience with microcontrollers and 48% had previous experience with Raspberry Pi. (The most common microcontroller experience was Arduino, with 70% of students reporting previous experience with the Arduino platform. Students could select more than one response for this survey question, so some overlap was also observed with students having experience with multiple different microcontrollers.) The author notes that this was an unexpected observation and the selection of Raspberry Pi occurred before surveying the students. In the future, it might be possible to introduce a new and lesser-known microcontroller to allow more of the students to be exposed to a different technology, or instead choose to focus on Arduino since the students have the most familiarity with it.

The activities with the microcontroller focused on controlling the electromagnets: turning the electromagnets on and off and switching their polarity. Additionally, the students used a Hall Effect sensor and the Raspberry Pi to sense the change in magnetic field as the electromagnets were turned on and off.

Design & Manufacturing

After the students understood the basic electricity and magnetism concepts, they needed to learn how to fabricate materials that could be used to create a motor. Two following lectures were focused on CAD (Computer Aided Design/Drafting) and lasercutting. The students were given access to machine shops on campus that trained the students in basic shop safety. In class, the students learned about lasercutting from a theoretical standpoint and also saw examples of other lasercut parts not related to motors. The CAD lecture then extended the ideas of lasercutting flat materials and helped the students visualize how to create geometries that would be appropriately constrained and functional to be able to create motors. The students were completely free to design their own motors. Their materials limitations were one 12”x12” piece of ¼” thick acrylic, a reasonable number of #10-32 nuts, bolts, and washers, up to 10 sewing bobbins and associated magnet wire, and one raspberry pi microcontroller. They were also given up to 8 angle brackets to allow them to mount the electromagnets some distance off the baseplate of their motors. Initially the idea was for the students to design and 3D print these angle components, but due to constraints on 3D printing time, it was decided to purchase these standard plastic angle brackets, McMaster-Carr part number 13135A61. The students designed their motors on paper first, then used Solidworks to create a CAD drawing for the lasercutter, and then they went to the campus machine shops during open hours to cut their designs.

Final Motor Assembly & Observations

During the final lecture of the Motor Building sessions, the students brought in all their materials, wound their electromagnets, and assembled their motors. The students wired the electromagnets and connected the electromagnets to their Raspberry Pi and using some example code that read in a Hall Effect sensor and switched the electromagnet polarity, the students got their motors running. The majority of work in this final session was debugging. Some examples of the variety of motors that the students designed and created can be seen in Figure 1. The course staff (two instructors, two Teaching Assistants, and three Undergraduate Assistants for the 36 students) rotated between students to assist with assembly, wiring, and programming. Some backup materials of lasercut parts were available in case any of the student designs were not functional, but these backup parts were not needed. Most students had already begun to assemble their parts on their own time before class and therefore had been able to correct any issues with sizing or form factor before arriving to the class session. The largest number of issues were with wiring. The students may have not been as careful as necessary when winding their electromagnet coils, so some of the coils had kinks that led to shorting or open circuits. Other students confused the polarity of their electromagnets and had to be reminded how to test using permanent magnets. Overall, the debugging process was an unexpected but excellent outcome. Many engineers note that designs often do not function perfectly on the first try, so giving the students experience with debugging and how to isolate issues in a large system was a great benefit.

Of the 36 students who attempted to build motors, by the end of class, approximately 30 students had functional (spinning) motors. The rest attended open lab hours with the Teaching Assistants to finish debugging their designs. In the end, all motors were functional. In a debriefing session with the course staff, the staff was surprised by the variety of student designs and also by the fact that all of the students were successful in creating a motor. Several staff observed excitement from the students regarding this project and the students felt that this was an interesting and authentic experience. They were proud to show their designs to their friends and family members, often taking videos with their phones during the assembly and debugging process to share with others. The use of acrylic was especially good for this project because it added a high-tech look to the motors and the variety of colors allowed the students to express their creativity through their designs.

CONCLUSIONS

Designing and fabricating a simple electric motor is a fun and satisfying project for students to complete in an introductory class. In this case, freshmen were able to apply concepts from their introductory science core classes into a more engineering-style project. However, a similar project with associated introductory material could even be used for younger students, such as those in high school. The cost of this project was relatively low and utilized fabrication facilities already in place around the university. However, the success of the project was supported by the high faculty-to-student ratio in this seminar. A variety of personnel were available to help the students in class, and also during office hours and in the machine shops across campus. Without these people, the students would have been much less likely to succeed in their first attempt to create a motor. Having many people available for help throughout the process assured that the final products were successful and increased the students' confidence with their design and manufacturing abilities. Additionally, the focus of the project was quite narrow (build an electric motor from a constrained set of parts), but the design freedoms allowed to the students led to an increased sense of pride and satisfaction in their final designs.

The author hopes that this style of motor design project will be adopted by other classes and programs to give students an introduction to design and manufacturing while connecting the fabrication techniques to core science concepts. Please come see some examples of these motors during the Make It poster session!

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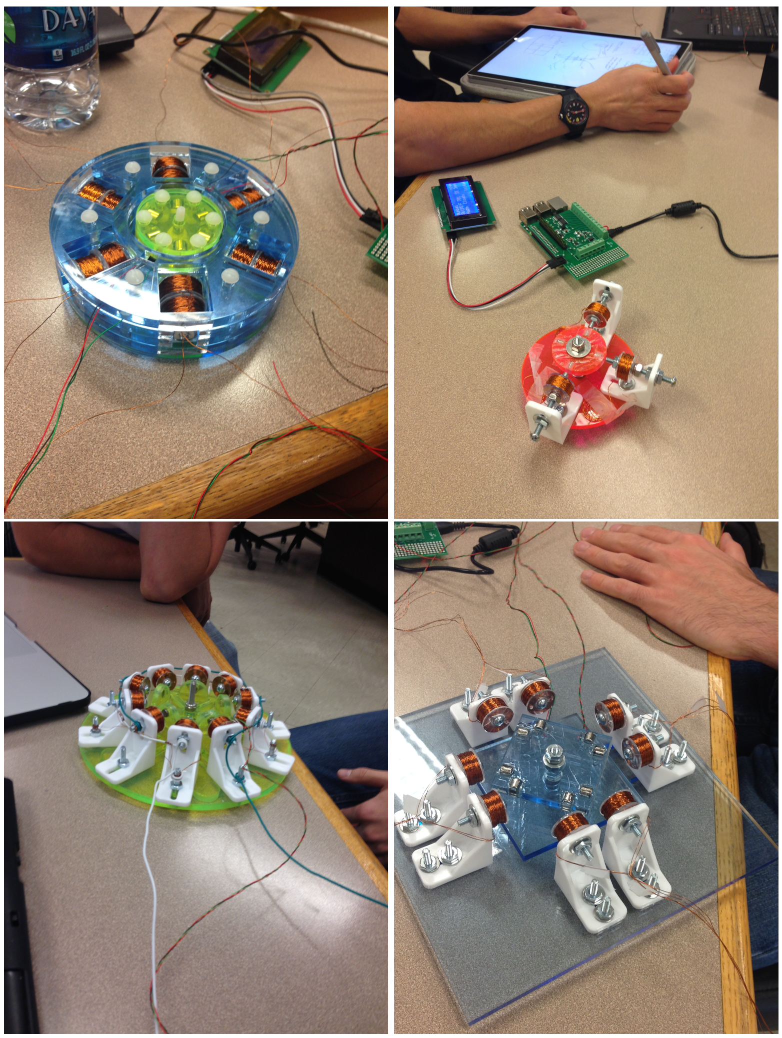

Figure 1: Variety of Student-designed and manufactured motors. Each of these motors was successful in spinning using the control of a Raspberry Pi microcontroller.