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Incorporating Projects into a Theory-Based Electromagnetic Fields Course

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Abstract: Electromagnetic Fields at York College of Pennsylvania was designed to provide students with theoretical backgrounds on Maxwell's equations and their applications to engineering problems. Topics include electrostatics, magnetostatics, magnetic fields and matter, induction, and electromagnetics waves. Students' feedback from the initial offereings of this course indicated that students would like to have hands-on activities to apply the theories they were learning in the class. Students also pointed out that this course looked like another Mathematics course without any hands-on activities. To facilitate hands-on experiences in the course, the instructor added two small-scale team projects: one on electrostatics and another on magnetostatics. This paper discusses the method of incorporating projects into a theory-based electromagnatic fields course as well as students' feedback regarding project expereicnes and the overall course. This paper also includes brief descriptions of student projects along with testing and fabrication results.

Keywords: Electromagnetic Fields, Project Based Learning, Hands-on Experience

Introduction: Fundamental concepts of Electromagnetic Fields is the building block for many engineering designs and applications such as wireless communications, radar systems, transportations, RFID systems, medical imaging systems, and bio-electromagnetics. Fundamentals of Electromagnetic Fields includes abstract Physics and Mathematics. Students have difficulties to make a connection between Electromagnetic Fields (EMF) and engineering applications due to the abstract nature of the subject matters. Some institutions reported that students' interest in EMF was waning due to the lack of hands-on activities [1]. One of the reasons behind this waning of interest is the missing connection between theory and applications. Without establishing this link, EMF courses fail to attract and engage engineering students.

Teaching EMF requires special care and attention from the instructor. Traditional EMF class tends to concentrate on abstract theory and numerical analysis. A lecture based engineering course focusing on legacy materials is not an effective style of learning since engineering students are adopted to hands-on activities and learn better from course related activities and sensory information [2] [3]. Various active learning techniques including problem solving in class, peer discussions, clicker responses, virtual laboratory experiments, and videos were used to teach electromagnetic theories [4]. Some instructors use visualization tools such as MATLAB to improve students' learning in class and assigns software-based projects to enrich the interpretation of fundamentals of electromagnetics [5]. While simulations are helpful to explain theories, studies showed that students who can create and analyze simulations, already have a good understanding of the theory [6]. Thus, computer simulations do not help all students in core EMF courses to develop a deeper interpretation of abstract theories. According to Dale [7], people learn and retain 20% of what they hear, 30% of what they see, 50% of what they hear and see, 70% of what they say, and 90% of what they directly experience or practice doing. Active learning techniques improve the students' learning but certainly cannot replace the hands-on activities. This paper describes a way to incorporate hands-on projects into a theory-based electromagnetic fields and waves course to enhance active learning.

Projects Management: Instructor provides project outlines in the beginning of the semester and asks students to form a team of 2-3 students and think about possible project ideas. Each project has five weeks to finish. Project outlines indicate the following requirements:

- Brief description of the proposed sensor/device and its applications
- Relation to Electromagnetic Fields
- Mathematical analysis and/or simulation to proof the concept
- Hardware implementation and testing
- Calibration chart
- Comparison between theoretical analysis and test results
- In class demonstration and presentation

Course syllabus provides a timeline for project proposal, class demonstration, and presentation. Students submit first project proposal on electrostatics during the third week of the semester. By this time, students have enough background on electrostatics to propose a project. The proposal must include a timeline to finish the project in five weeks as well as a parts list. Instructor reviews all project proposal and suggests changes if necessary. After finalizing all proposals, the instructor orders parts for each project. This process takes one week altogether. While the instructor is working on ordering parts, students are busy with mathematical analysis and/or simulation to proof the concept. Magnetostatics and magnetic fields projects follow the same procedure with appropriate timeline. The following sections briefly describes one electrostatics project and one magnetostatics project.

Electrostatics Project: *Capacitive Weight Sensor*

This team designed a capacitive sensor to measure mass. The basic circuit diagram and laboratory setup is shown in figure 1. The relationship between output voltage and mass is established using a simple voltage divider technique and can be expressed as:

$$m = \frac{kDC_1(V_{in} - V_{out}) - \varepsilon A V_{out} g}{gC_1(V_{in} - V_{out})} \tag{1}$$

where, k is the spring constant of the foam (dielectric material), D is the distance between plates, g is the gravitational constant, m is the mass of the object, and ε is the permittivity of the dielectric material. Figure 2 shows the calibration plot based on laboratory testing results. The range for this sensor is 0.0 kilogram to 9.0 kilograms. This team simplified the relationship between a mass (m) and an output voltage (V_{out}) using the curve fitting method. The simplified relationship is:

$$m = 9.6221V_{out}^2 - 4.0348V_{out} + 42.549 \tag{2}$$

The Team conducted several tests to find the accuracy of the device and the sensor output was within ± 5% accuracy.

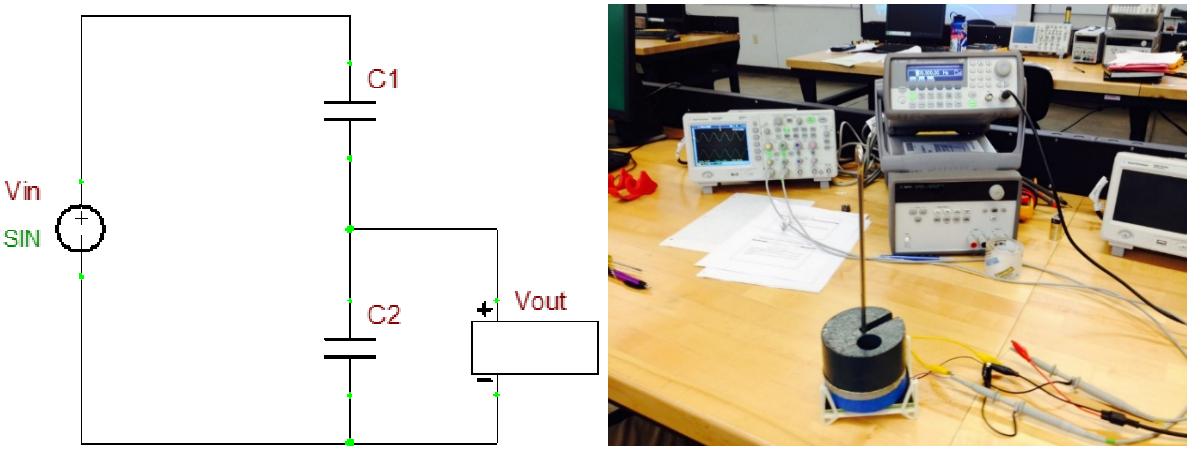

Figure 1: Capacitive sensor circuit diagram and laboratory setup

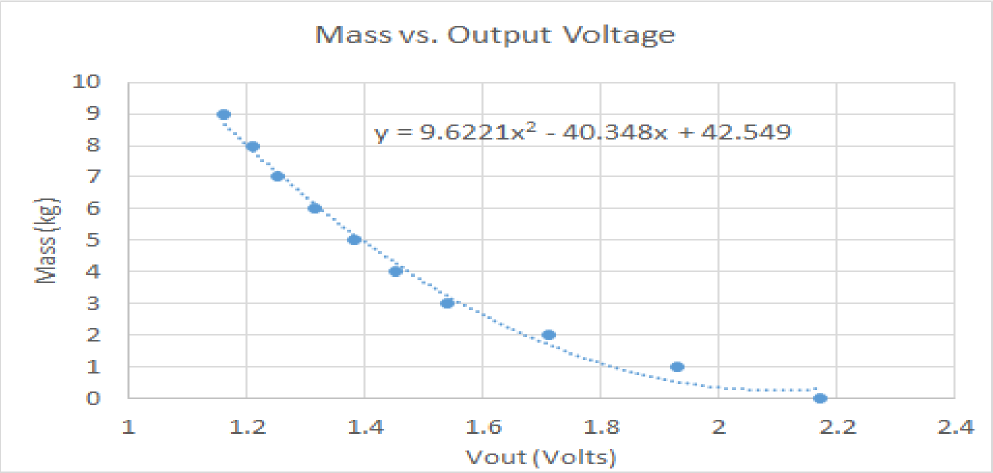

Figure 2: Calibration plot for capacitive weight sensor

Magnetostatics and Magnetic Fields Project: *Inductive Proximity Sensor*

Inductive proximity sensor senses metallic objects by changing the impedance of the coil. Impedance change happens due to the change in flux linkage. Inductance of the sensor can be calculated using resonant frequency of the RLC circuit if necessary. Figure 3 shows the CAD model of the device and laboratory setup. The team used an iron shell for outer cylinder to have better magnetic field direction. The laboratory setup uses an interface electronic to collect sensor data. This interface includes an RLC circuit, amplifier, and rectifier.

To gather data, the sensor was placed at a reference position and the output voltage was recorded. A large square of steel was then moved back in at a 1.0 mm increment until there was no longer a visible change in the output voltage. Figure 4 shows the calibration plot. This sensor successfully demonstrated the fundamental concepts of magnetostatics and magnetic fields. The team summarized the following observations:

- Output voltage changes due to a change in inductance.
- The change in inductance is a result of a metallic object being placed in front of the sensor, and interfering with the magnetic field to change the impedance of the coil.
- The winding of wire around a ferromagnetic core generates a magnetic field when an AC signal is applied.
- The sensor is to be used in small proximity applications (within 0 - 15mm).
- The amplified output voltage allows for recordable voltage values due to small proximity changes during testing.

Figure 3: CAD of model of the inductive proximity sensor and the laboratory setup

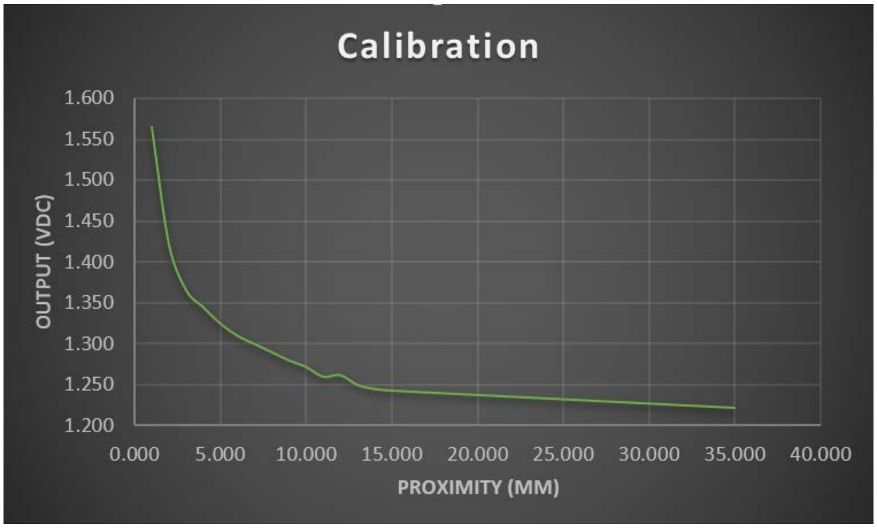

Figure 4: Calibration plot for inductive proximity sensor

Student Feedback: At the end of the semester, the instructor asked students to participate in an anonymous survey regarding their experiences on projects and the overall course. Survey also asked students to list three things they liked about the course and three things they did not like about the course. Ten out of eleven students liked having projects in the course. They stated that project experience enriched their understanding of fundamental concepts of electromagnetics. Only one student said that project was an added work for the course. Most students complained about abstract mathematics used in the book. Students preferred more frequent shorter exams than having only two big exams. Figure 5 shows that 82% of students learned a lot from the projects. 100% students agreed that doing these projects helped them better understand practical uses of electromagnetic fields. Most importantly, 55% students found the project was enjoyable and fun. This is very significant achievement for a theoretical math-based electromagnetics course. Only one student disagree somewhat with the projects.

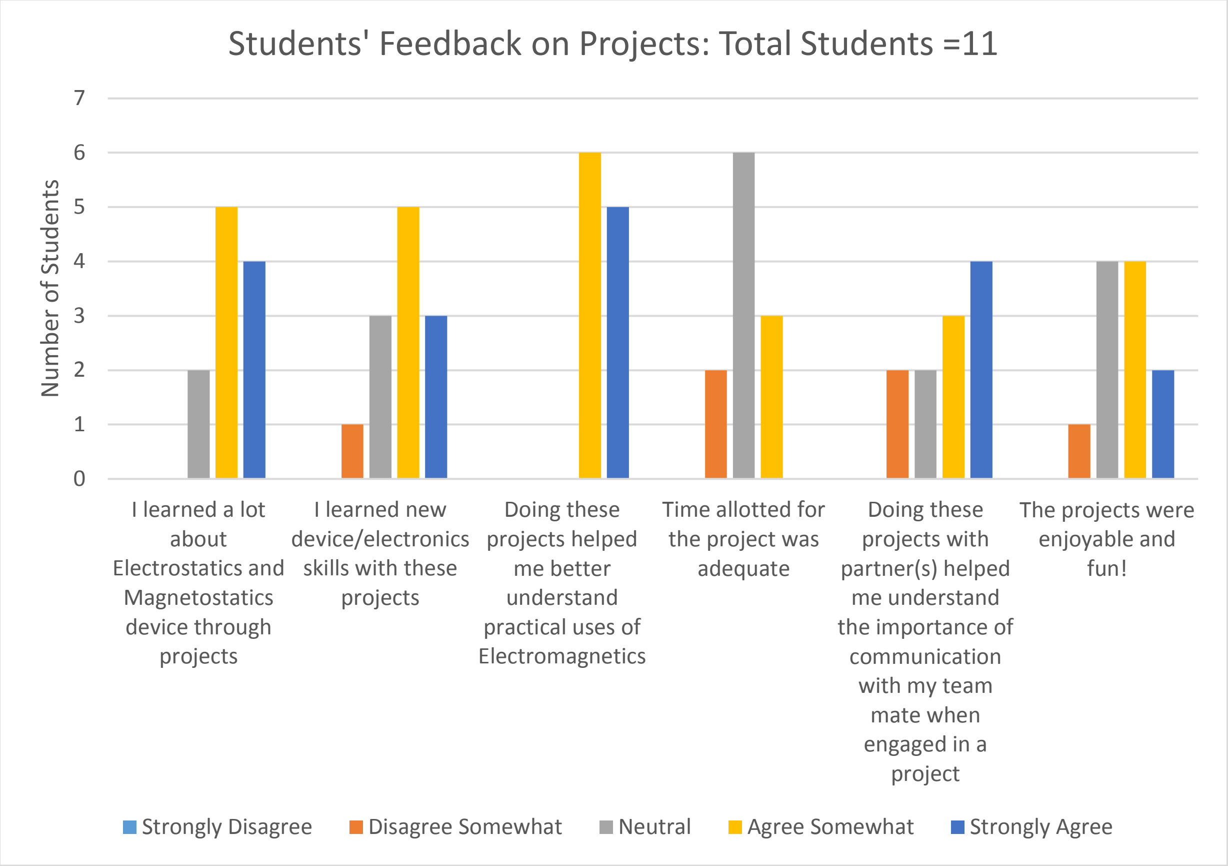

Figure 5: Students' feedback on projects

The institution also collects anonymous students' feedback on courses and compares each instructor to his/her peers in the department and to the overall campus. Instructors can see responses after the grade submission is completed. The scale is 0.0 to 5.0, where 0.0 is the lowest rating and 5.0 is the highest rating. Two particular questions correlate student's interest and their learning in the course. These questions are *Q2) I learned a great deal in this course, Q3) I had a strong desire to take this course.* Figure 6 shows that even though, students' desire to take the course was the lowest compare to the departmental and campus peers, the students' learning was the highest. It is clear from the survey that incorporation of projects made positive impacts on the students' learning.

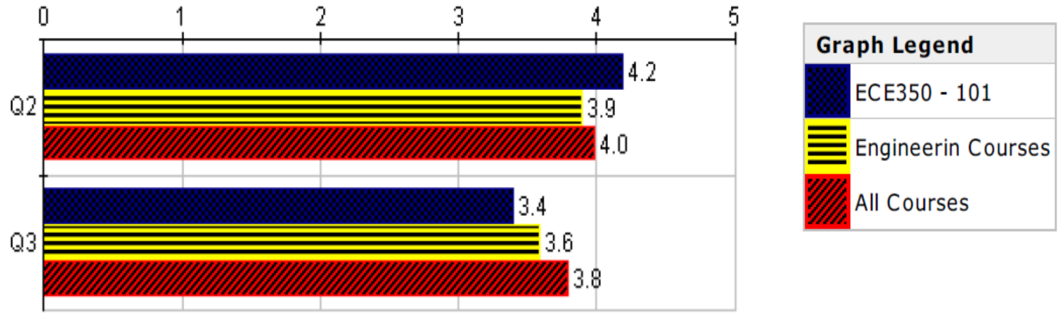

Figure 6: Course evaluation report

Conclusions: This paper demonstrated a successful incorporation of projects into a theory-based Electromagnetic Fields (EMF) course. Projects provided an opportunity for the students to evaluate EMF theories with hands-on experiments. Students' feedback showed that more than 80% of students had positive learning experiences with projects. Overall, students enjoyed the course structure that adopted active learning techniques with projects. From the instructor point of view, managing projects in a theory-based course require early planning and continuous communication with students.

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