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A New Hands-On Laboratory Approach for Teaching Electromagnetic Concepts to Engineering and Engineering Technology Students

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Abstract

Several years ago, the College of Engineering at Texas A&M University moved from a model of admitting all freshmen directly into their first-choice engineering program to a common first-year model. Students now take a common set of mathematics, science and engineering courses in their freshman year before transitioning to a specific engineering major. This change has helped with providing a consistent experience across all engineering majors, enabled the college to support individual student needs to help with their retention, and given freshmen students an opportunity to explore all engineering majors in order to help them make an informed choice. Very soon after this change, the College identified two curricular changes that would help improve the quality of education and student retention. First, a more rigorous process was put in place to ensure that students were placed into the most appropriate first course in mathematics. Second, changes were made to the lecture/laboratory content of the first two theoretical engineering physics courses in order to make the concepts more "real." Specifically, the labs were changed from one hour to two hours with the second hour devoted to an interactive lecture that ties theoretical physics concepts to real-world engineering applications. The actual laboratory portion of the course was also modified to take advantage of a new state-of-the-art, hands-on test and measurement learning system developed by faculty in the Department of Physics. This paper focuses on the redevelopment of the second engineering physics course on electricity and magnetism and describes the new laboratories and lectures in detail. While this effort is an ongoing work in progress, preliminary lessons-learned and future work are discussed.

Introduction and Background

The link between engineering student retention and their math/science preparation has long been recognized. It has been shown that students who perform poorly in their first advanced math or engineering science course are more likely to struggle or even not complete their intended engineering degree. For example, a study done by Laugerman et al at Iowa State University showed a strong correlation between performance in the first engineering calculus and physics course and engineering graduation rate.[1] As second study done by Bischof at the Joanneum University of Applied Sciences in Graz, Austria demonstrated a strong link between poor performance on mathematics exams and the ability to succeed on first engineering mechanics course exams.[2] For these reasons, many universities have recognized the need to focus on methodologies for improving mathematics and physics success rates as well as many other practices with the goal of impacting retention and graduation rates. A literature review of the many different improvement methodologies tried by universities was done by Desai and Stefanek at Purdue University Northwest and demonstrates the success possible using approaches such as changes in freshmen engineering courses, enhanced mathematics and science preparation, community building, mentorship and supplemental instruction.[3]

For these reasons, the College of Engineering at Texas A&M University created a new First Year Engineering program in 2013 and began admitting all engineering freshmen into this program rather that directly into a major. The rationale was to create a common experience for all freshmen with more centralized control of curriculum and advising so that student performance and course quality could be monitored for continuous improvement. As part of this move, two curricular changes were quickly identified and implemented to support student success and retention. First, the math placement process for new engineering students was modified. A new onsite testing process was put in place for determining math proficiency and ensuring that each student was placed in the most appropriate first course in mathematics. It should be noted that immediately after this change, a measurable improvement in the first engineering calculus course success rate was noted. Second, the freshman engineering courses were restructured to integrate with the first-year science curriculum. Originally structured as two 2-hour courses that focused on engineering design and Matlab, the freshmen engineering course sequence was changed to three 2-hour courses that now align with the first engineering calculus course and the two engineering physics courses, mechanics and electromagnetics. To move these courses from a four-hour to a six-hour sequence, the laboratory hours from the physics courses were integrated into the sequence. Today, the first engineering course focuses on programming in Python and applies concepts such as differentiation (slope) and integration (area under the curve) in both the lecture and programming assignments. The second two courses are co-requisites with the two engineering physics courses and demonstrate how theories learned in those classes are applied in engineering applications. This new sequence was implemented starting in the Fall of 2018, and by the end of Spring 2020, there will be sufficient data to access the impact on student performance in math and science.

This paper focuses on the implementation of the third course in this new sequence: ENGR 217 - Experimental Physics and Engineering Lab III. This course is a one lecture hour, three lab hour class and was taught for the first time during the Fall 2019 semester. The lecture contains topics designed to complement the second engineering physics course on electromagnetics such as electric fields, magnetic fields, and electric DC and AC circuits as well as the application of these concepts to real-world engineering problems. In addition, a number of other topics are addressed including data acquisition, microcontrollers, project management, engineering ethics and art in engineering. The laboratory component is conceptually innovative and uses a newly developed three-axis positioning and data acquisition system that allows students to automate the sensing and data analysis of electric and magnetic fields through the use of Python scripts. This paper will discuss the initial offering of the course, its learning objectives and the curriculum. In addition, the laboratory component will be discussed in detail including the actual experiments and the newly designed test and measurement system used by the students. Finally, lessons learned and future work will be presented.

General Engineering and Common First Year

General Engineering and Entry-to-Major

Approximately six years ago, Texas A&M's College of Engineering moved from a model of accepting students directly into an engineering major to a model where all freshmen begin as general engineering students. During their first year, general engineering students take a common first-year curriculum that includes math, science, and engineering as well as other university core curriculum courses. Once the students satisfy a set of requirements that includes completing a mandatory minimum number of math, science and engineering courses as well as maintaining good academic standing, they can apply to engineering majors through the Entry-to-Major (ETAM) process. In the ETAM process, they are reviewed by their selected majors and placed into one of over twenty engineering programs.

First Year Experience

During their first year, all general engineering students receive a common experience and are advised through College-level staff members. One significant advantage of this methodology is that it ensure all students receive similar education and advisement. It also allows the College to better support retention through direct and individualized student contact and quality control of introductory engineering courses. The first-year experience can be broken down into two components, curricular and extra-curricular experiences.

From a curricular perspective, all students take similar math, physics, chemistry and science courses. For example, because mathematics is a critical skill that is a predictor of success in engineering courses, a math placement exam is administered to all incoming freshmen so that they can be placed into an appropriate level math course to maximize their success. The students are also required to take two engineering physics courses, mechanics and electromagnetics, and at least one engineering chemistry course. Finally, all freshman take three two-hour engineering courses that are designed to prepare students with a diverse set of skills as well as to ensure that they can make the best possible decision when choosing engineering majors.

From an extra-curricular standpoint, the students are given multiple opportunities to learn about the different engineering disciplines and how they relate to different industry sectors. In fact, many students fall into the trap of directly relating their desire for a specific engineering major to the industry sector that is really driving their interest. For example, a student may have an interest in a career with NASA so they immediately gravitate to aerospace engineering. The extra-curricular activities are designed to show students how their industry sector interests are typically supported by several engineering majors. In other words, there is more than one path that can get them to their career goal. For example, NASA hires a diversity of engineering disciplines to support space missions. These extra-curricular activities include industry guest nights, weekend events that expose students to all majors, online modules that allow students to take an in-depth look at each major, and events coordinated through the career center including one-day visits to a broad set of companies.

Engineering Courses

The three 2-hour engineering courses are designed to be taken sequentially and include:

- **Engineering Lab I: Computation –** This first course introduces students to the design and development of computer applications for engineers using the Python programming language. As a secondary goal, the course introduces students to the different engineering disciplines, engineering design, and pathways to success in engineering.
- **Experimental Physics and Engineering Lab II : Mechanics -** The second engineering course is designed to complement the first lecture-only physics course and includes laboratory assignments as well as the description and application of laws of physical motion to the solution of science and engineering problems. The course also includes non-technical topics such as ethics and art-in-engineering.
- **Experimental Physics and Engineering Lab III : Electricity and Magnetism** - The final course is designed to complement a lecture-only physics course on electromagnetism and electromechanical systems and includes laboratory assignments that uses sensing, control and actuation to demonstrate electromagnetic concepts as well

as an introduction to microcontrollers. Also included is a continuation of non-technical topics such as ethics and art-in-engineering.

These three courses were purposefully designed with several goals in mind including teaching students critical think skills through the use of programming, supporting students as they learn highly theoretical concepts in their physics courses, introducing students to those skills that produce a well-rounded engineer, inculcating good engineering habits such as self-motivation and the ability to do independent research, and exposing the students to the different engineering disciplines so they can better choose an engineering major. Both the second and third engineering courses are supported by a highly innovate experimentation system initially developed by Texas A&M University faculty that allows for the demonstration of more advanced physics concepts than could be achieved by the previous, more traditional, physics laboratories. This paper focuses on the third course in this sequence and its goals, topics and implementation.

Figure 1 - The Visual Cortex learning systems and laboratory layout. Each system has an air table, 3D positioning system capability and includes a camera mounted to the positioning system frame that supports dynamic imaging processing (not seen in image).

Visual Cortex System

Overview

The Visual Cortex system [4] serves as the foundational learning platform for the two experimental physics and engineering laboratory courses. The platform was initially developed by faculty in the Department of Physics and supports highly innovative teaching methods that integrate physics and engineering concepts. Each platform, as seen in Figure 1, is used by a team of four students and is made up of three integrated components. First, is the control and embedded intelligence component which runs a compact Linux-based system and allows for the control and automation of experiments. A video processing unit allows for dynamic imaging, tracking, and graphic overlays during experiments. For example, during a magnetic field mapping experiment the video processing capability allows the overlay of a magnetic field vector map over an image of the physical experiment. The platform is programmed through Python and interfaces to an eight-channel, 12-bit data acquisition system, a 3D positioning system, and to external test and measurement equipment through USB. Students connect to the system through a physical ethernet port and terminal software allowing them to run code and download data files. The second component is an air table that is used to support the first engineering physics lab by creating a low-friction surface for supporting velocity, acceleration and momentum experiments. The final component is a 3D positioning system that allows automated scanning of sensors across the experimental field as well as automation of tasks that require dynamic positioning of experimental elements.

Support for Experiments in Electromagnetism

To support the experiments that are part of the ENGR217 – Experimental Physics and Engineering Lab III, the unit comes with several accessories. These include a conductive platform with metal shapes for creating various potential/electric field configurations, a set of permanent magnets and multi-turn wire loop for creating various magnetic fields, an integrated permanent magnet/load cell unit for measuring Lorentz force, resistive and RLC boards for DC and AC circuit experiments, and external test equipment including a power supply and an integrated oscilloscope/function generator with associated cabling. Finally, the system also has electric potential and magnetic field sensors (as seen in Figure 2) that can be attached to the positioning system for mapping electric and magnetic fields.

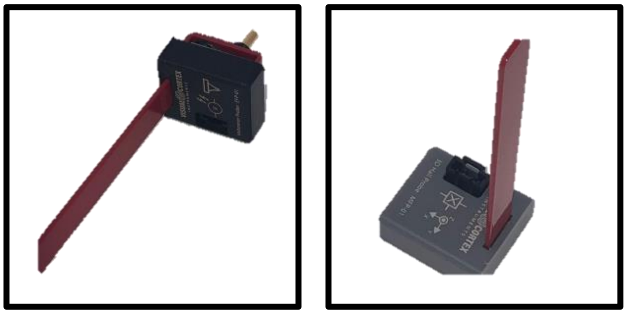
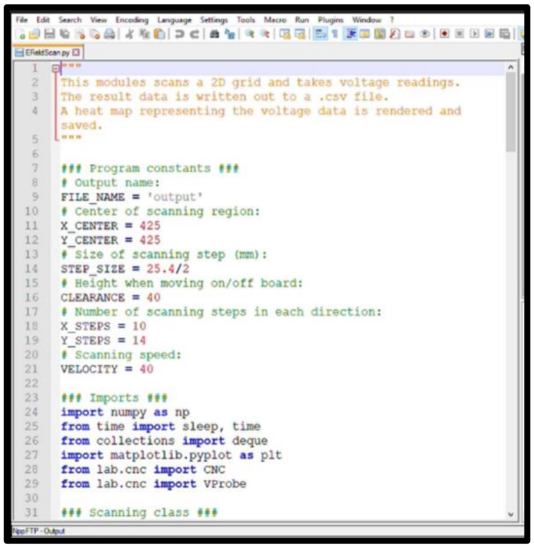


Figure 2 -Visual Cortex Laboratory accessories include a sensor for mapping electric potential (left), and sensor for mapping magnetic field (right).

Support for Python Programming

As indicated above, the primary control unit in the Visual Cortex system is Linux-based and supports Python programming (Figure 3). The base system comes with Python scripts that support data acquisition, video processing and 3D system positioning. Also included are example programs that support each of the seven physics experiments as well as code for creating vector field maps. Students can copy and customize any of the programs to support their own data acquisition needs.

With all students having previously completed a Python programming course, the goal is to give them opportunities to use previous knowledge and increase there competency with programming. For example, in the second lab students must reformat their collected data in order to convert it into an electric field map. While they are not required to use Python for this task, most teams will.



```
"""
This modules scans a 2D grid and takes voltage readings.
The result data is written out to a .csv file.
A heat map representing the voltage data is rendered and saved.
"""

### Program constants ###
# Output name:
FILE_NAME = 'output'
# Center of scanning region:
X_CENTER = 425
Y_CENTER = 425
# Size of scanning step (mm):
STEP_SIZE = 25.4/2
# Height when moving on/off board:
CLEARANCE = 40
# Number of scanning steps in each direction:
X_STEPS = 10
Y_STEPS = 14
# Scanning speed:
VELOCITY = 40

### Imports ###
import numpy as np
from time import sleep, time
from collections import deque
import matplotlib.pyplot as plt
from lab.cnc import CNC
from lab.cnc import VProbe

### Scanning class ###
```

Figure 3 - Example of Python code that runs on the Visual Cortex system and used for automating data acquisition during experiments.

New Course - Experimental Physics and Engineering Lab III

Overview

Starting in the Fall of 2019, the new ENGR 217 - Experimental Physics and Engineering Lab III course was phased in and taught for the first time. The primary rationale for the course was to make the concepts of electromagnetism more “real” for engineering students and to support success in their second engineering physics course. The goals of the course included:

- Introducing real-world applications of electricity and magnetism: Design to complement the second engineering physics lecture-only course, this new class was intended to support student learning through both hands-on laboratory experiments as well as lectures that tied the physics concepts to actual engineering applications of science.
- Reinforcing computer programming skills: As mentioned previously, the focus of the first freshmen engineering course was computer programming, specifically in Python. To reinforce these skills, this new course was designed to require intermediate-level Python programming as part of the laboratory experiments. By requiring students to use Python to run the experiments, collect data, and post-process data, newly acquired programming skills can be reinforced.
- Fostering a deeper understanding of project management, engineering ethics and "Art in Engineering": The final goal was to support the development of a well-rounded engineer. Students were exposed in the lecture component to project management skills, engineering ethics and the relationships between art and engineering. The introduction of engineering ethics also served to support the individual departments' ABET outcome requirements.

Teaching Format

ENGR 217 is taught as a one-hour lecture, three-hour lab course co-listed between engineering and the physics department and is designed to be taken in either the first or second semester of the sophomore year. The course is a co-requisite to the second engineering physics course on electromagnetics and supplies the laboratory component to the three-hour lecture-only theory course. It should be noted that this course was design by and in conjunction with faculty in the physics department to ensure that the schedule of lecture and laboratory topics integrates seamlessly with the second engineering physics course. The one-hour lecture portion of this class meets for fifty minutes, once per week and is used to reinforce theoretical physics concepts by introducing the application of physics to real-world engineering problems. Bi-weekly homework sets as well as a group presentation on engineering ethics are required. The course culminates in a single final course exam that covers both lecture and laboratory technical and non-technical concepts.

The laboratory also meets once per week but for three hours. The students work in teams of four to perform experiments that reinforce the theories learned in their physics courses. Through the use of the Visual Cortex laboratory system discussed previously, students perform modern, interactive experiments that leverage their programming skills and allow for the introduction of concepts related to automation and real-time data acquisition. Unlike many lab procedures that are "canned", the laboratory experiments are designed to be somewhat open-ended, giving the students teams the opportunity to exercise their creativity in solving problems. Also, due to the automated data acquisition, teams can collect large sample sets and use statistics to report average measurements as well as error. Many of the experiments, especially those that require more complex thinking and data analysis, are designed to be two week experiments giving the students the opportunity analyze their initial data and then optionally return to the lab during the second week to refine their experiments and collect new data as needed.

Lectures

Table 1 summarizes the topics and concepts taught during the lecture component of the course. Once can see that in addition to tying the theory learned in the second engineering physics course to engineering applications, the lecture is also leveraged to expose students to other important concepts early in their academic career. First, there is a lecture and homework assignment designed to introduce basic project management skills. The goal is to plant these seeds early so that students can leverage these skills in their junior and senior years where course projects become increasingly complex and require time/resource management. Second is the introduction to engineering ethics over the course of three weeks. This is not only beneficial for the students but also supports departments in meeting their ABET student outcomes. As part of this lesson, students form groups, develop an engineering design, and then address the ethical concerns associated not only with the actual design but its impact on the world. Finally, the students are exposed to the links between art in engineering. The goal of this unit is to help students see how university core curriculum courses can enhance their engineering perspectives and how multidisciplinary teams that transcend engineering can enhance an engineering design.

Experiments

Overall, there are nine experiments, some requiring one week and some requiring two weeks to complete. Most of the experiments are directly related to the physics concepts from the second engineering physics course with one notable exception. Two weeks during the semester are devoted to introducing the students to microcontrollers and embedded programming using the Arduino platform. While the initial reaction might be to question the broad applicability of these concepts to all engineering majors, it should be noted that modern engineering solutions leverage these concepts across most industry sectors and engineering disciplines. Below is a summary of each lab experiment and the associated learning objectives.

Lab 1 – Measuring Voltage with a DAQ

- Summary – In this lab experiment, the students are introduced to the data acquisition system built into the Visual Cortex laboratory system. Coupled with two lectures on data acquisition, they are required to use the data acquisition channels and Python scripting to acquire single as well as multiple samples of voltages created using a simple resistor circuit. Figure 4 shows the eight separate data acquisition channels built into the systems.

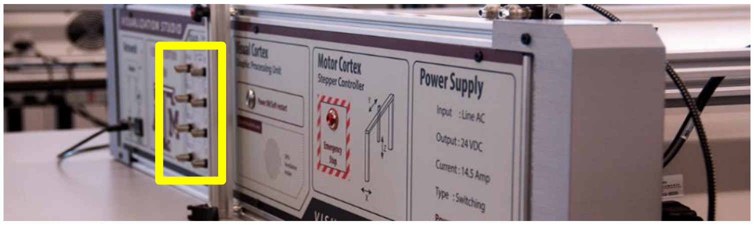


Figure 4 - Front of the Visual Cortex laboratory system. BNC connectors (highlighted in yellow) allow for the connection and acquisition of voltage signals from sensors.

Table 1 – List of weekly lectures including topics and descriptions of concepts covered

#	Topic	Description
1	Data Acquisition	Voltage, current, resistance, data acquisition systems, analog to digital conversions, sampling rate, resolution, input range
2	Analog-to-Digital Conversion, Random Noise	Analog-to-digital converters, flash and successive approximation topologies, random noise, Johnson-Nyquist and shot noise calculations
3	Resistance and Resistivity	Real vs ideal resistors, series/parallel resistors, resistivity, resistance calculations for wires, resistivity's dependence on temperature
4	Project Management	Basic project management principles including work breakdown structures, Gantt charts, critical path and slack
5	Ampere's Law, Faraday's Law, Motors	Introduction to Ampere's and Faraday's law through the use of motors as an example
6	Microcontrollers	Introduction to microcontrollers, microcontroller development boards, and integrated development environments using the Arduino as an example
7	Lorentz Force, Hall Effect Sensors	Lorentz force law, Hall effect sensors, principles behind Hall effect sensors, example applications of Hall effect sensors
8	Electrical Measurements and Microcontroller I/O	In-depth discuss of types of electrical measurements and instruments used in electrical measurements, microcontroller hardware and types of hardware inputs/output (analog, digital, …)
9	Batteries, Capacitors, Induced EMF	Discussion of batteries, battery technologies, capacitors/super-capacitors, introduction to induced voltage in inductive circuits
10	AC Circuits, RLC Elements, Resonance	Introduction to AC circuits, inductors, and capacitors; series resonance; similarities between mechanical and electrical circuits
11-13	ABET and Engineering Ethics	Three-week lesson on engineering ethics with relationship to accreditation, discussion of ethics in engineering design, group presentations on ethical considerations in design
14	Art in Engineering	Discussion of the relationship between art and engineering, review of relevant case studies, essay on personal opinion of how art and engineering intersect

All channels are 12-bits with the first four channels having a input range of +/- 10V and the second four channels having an input range of 0 to 10mV. In the case of multiple samples, students use averaging and standard deviations to characterize errors in their measurements. They also investigate the effects of averaging multiple samples to reduce random noise and associated measurement error.

- Learning Objectives
  1. Become familiar with the equipment used for electrical measurements (power supply, multimeter, DAQ, etc.)
  2. Understand the importance of inherent measurement error in the lab setting. Be able to articulate the difference between relative error and absolute error
  3. Develop and implement an experimental plan to find a mathematical expression for the relationship between voltage and current in a simple resistor circuit

Lab 2 – Electric Potential and Electric Fields

- Summary – In this lab, the students use a conductive board, the 3D positioning system controlling an electric potential sensor, and the data acquisition system to measure electric potential created by various conductor configurations (see Figure 5). From the potential map, they are then asked to calculate and plot a vector map of the electric field. The calculation requires them to take a numerical derivative of the potential map in the X and Y directions. Most students accomplish this using either Excel or Python code. Some of the conductor configurations that they are asked to explore include a dipole, a parallel plate capacitor and a sharp edge (as seen in Figure 5).
- Learning Objectives
  1. Observe the difference in electric potential for different configurations of charges and charged surfaces
  2. Calculate and map electric fields for different configurations of charges and charged surfaces
  3. Understand the relationship between scalar electric potential and the vector electric field

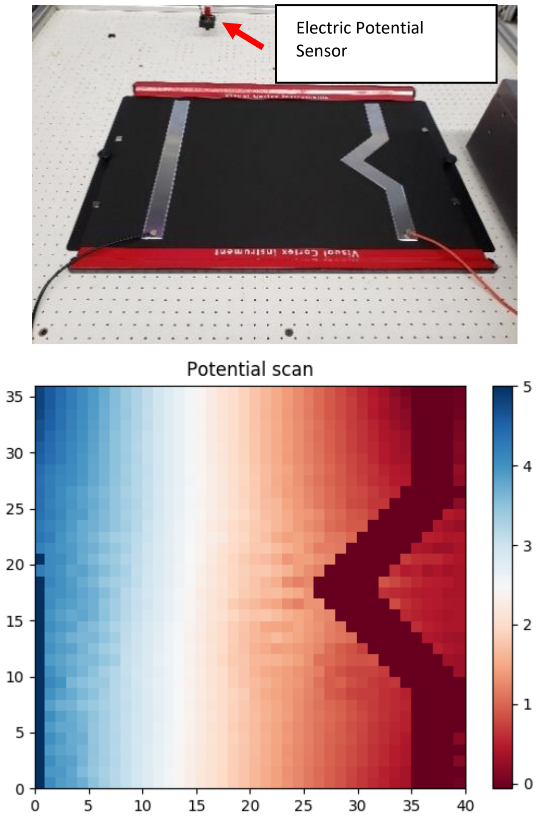


Figure 5 - Example of an electric potential mapping experiment. By scanning the electric potential sensor over a conductive plane with charged metal surfaces (upper), the potential can be mapped and displayed (lower).

Lab 3 – Resistance and Resistors

- Summary – Lab 3 introduces the concept of resistance, resistivity and series/parallel resistor circuits. As seen in Figure 6, students use sections of nichrome wire, a DC power supply, and the data acquisition system to investigate voltage versus current relationships for single and multiple resistor circuits. The experiments also allow them to verify Kirchoff's voltage and current laws. Finally, the students back-calculate resistivity based on resistance and wire geometry measurements. From this calculation, they are asked to find the material used in the wire resistors under test.
- Learning Objectives
  1. Learn how the resistance of an object is dependent upon the length of that material
  2. Observe and describe the behavior of resistors in series and parallel
  3. Measure the resistivity of materials based on resistance and geometry measurements

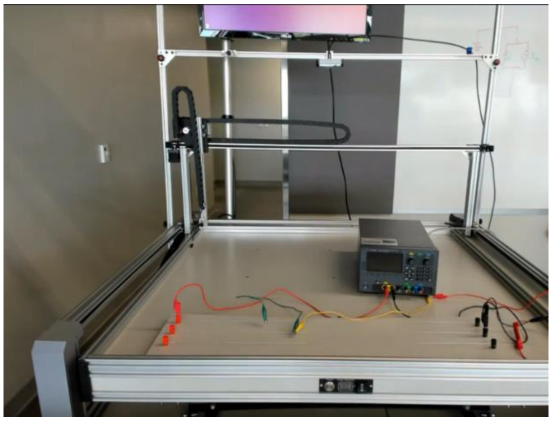


Figure 6 - Example of the resistor experiment. The resistance of sections of nichrome wire can be measured using the power supply and built-in data acquisition system.

Lab 4 – Magnetic Fields

- Summary – In this lab, static magnetic fields produced by individual and combinations of permanent magnets are investigated. Measurements are made by sweeping a Hall effect sensor connected to the data acquistion system over an appropriate region above the system of magnets (as in Figure 7). The data is then used to produce vector magnetic field mappings. Students also invesigate the impact of passive materials with different permeabilitys near the system of magnets.
- Learning Objectives
  1. Observe the impact of the Earth's magnetic field on magnetic field measurements
  2. Observe magnetic fields from different configurations of magnetic field sources (permanent magnets)

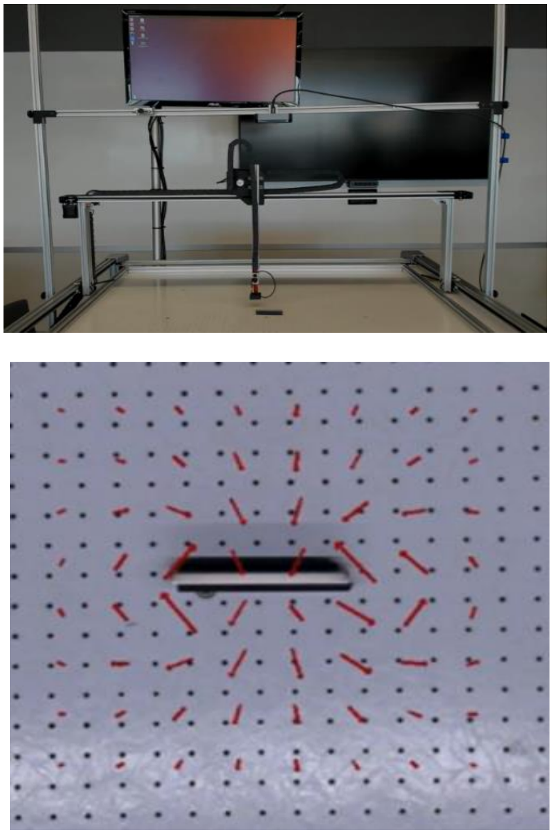


Figure 7 - Example of mapping the magnetic field of a permanent magnet. The system uses the 3D positioning system to sweep a sensor and create a map of the field.

3. Identify the poles and label the poles of a magnet from a measurement of its magnetic field
4. Observe how different metals influence a magnetic field and be able to relate observations to the concept of magnetic permeability
5. Understand the idea of superposition in terms of the magnetic fields from multiple sources

Lab 5 – Arduino I

- Summary – Lab 5 introduces students to the basics of microcontrollers, microcontroller development boards and associated software integrated development environments. For this lab, the Arduino Uno development board is used (see Figure 8). Students learn the difference between microcontrollers and microprocessors and the concept of embedded systems is introduced. Examples of how microcontrollers are applied in the different engineering disciplines are discussed. Finally, students experiment with simple code that blinks an LED.

```
  This example code is in the public domain.

  http://www.arduino.cc/en/Tutorial/Blink
*/

// the setup function runs once when you press reset or power the board
void setup() {
  // initialize digital pin LED_BUILTIN as an output.
  pinMode(LED_BUILTIN, OUTPUT);
}

// the loop function runs over and over again forever
void loop() {$
  digitalWrite(LED_BUILTIN, HIGH);   // turn the LED on (HIGH is the voltage level)
  delay(1000);                       // wait for a second
  digitalWrite(LED_BUILTIN, LOW);    // turn the LED off by making the voltage LOW
  delay(1000);                       // wait for a second
}
```

Figure 8 - The Arduino development board and integrated development environment

- Learning Objectives
  1. Become familiar with microcontrollers and microcontroller development boards
  2. Learn how to use simple microcontroller integrated development environments (IDE)
  3. Use the Arduino development board and IDE to create simple microcontroller applications

Lab 6 – Lorentz Force

- Summary – In this experiment, students investigate the interactions between currents and surrounding magnetic fields. To do this, an energized solenoid is used to produce a known current. This current is then immersed in a magnetic field created by two permanent magnetics attached to a fixture that is instrumented with load cells as in Figure 9. The students use data collected from the load cells to quantify the Lorentz force produced and determine the relationship between this force and the magnitude of the current.

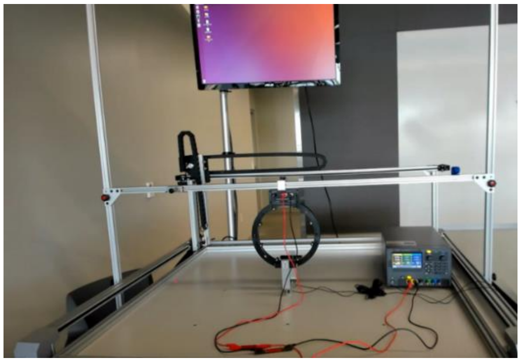


Figure 9 - Example of measuring the Lorentz force. The metal unit below the coil has permanent magnets and load cells mounted to it. The force created is in the downward direction and is measured by the load cells.

- Learning Objectives
  1. Observe the relationship between force and current for a current carrying wire in a magnetic field
  2. Become familiar with creating and applying calibration curves to a given measurement
  3. Learn when and how to apply approximations without sacrificing significant accuracy to facilitate data analysis

4. Observe the impact that the current's direction has on the direction of the applied force

Lab 7 – Arduino II

- Summary – In this second lab using the Arduino, the students go into more depth on the concept of interfacing microcontrollers to the outside world through various input/output (I/O) interfaces. Both analog and digital I/O are introduced. The students experiment with simple code to produce digital inputs, outputs and a serial data stream that drives a LCD user interface.
- Learning Objectives
  1. Enhance knowledge of the Arduino development board and IDE
  2. Learn concepts of hardware input and output signals in a microcontroller environment
  3. Apply previously learned microcontroller programming skills to develop microcontroller software of intermediate-level complexity

Lab 8 – Faraday's Law of Induction

- Summary – Lab 8 allows student to visualize the concept of induced voltages. By using the positioning system to move a permanent magnet across the face of a loop of wire, the students are able to digitize the voltage produced in the loop (see Figure 10). Distance of the permanent magnet from the loop as well as the speed of travel of the permanent magnet relative to the loop (dB/dt) are changed to see the impact of these parameters on the induced voltage.
- Learning Objectives
  1. Observe induced currents in circuit elements by a time varying magnetic flux
  2. Experimentally verify Faraday's Law of Electromagnetic Induction
  3. Determine the relationship between induced current and the position/speed of a nearby magnet

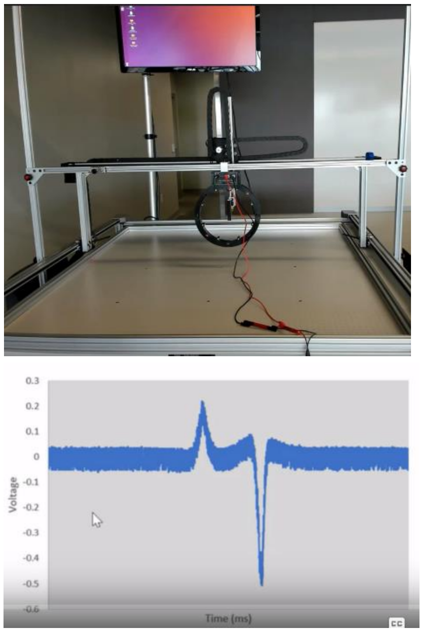


Figure 10 - Example of measuring induced voltage. A permanent magnet is swept across a conducting loop using the positioning system (upper) and the data acquisition system samples the induced voltage (lower).

Lab 9 – AC Driven Circuits

- Summary – In this last lab of the semester, students investigate AC circuits and, in particular, series resonant RLC circuits. An integrated waveform generator/oscilloscope is USB-controlled by the Virtual Cortex laboratory system and the frequency of the generated signal is swept between a minimum and maximum value. The oscilloscope is used to capture and find the magnitude of the resistance's voltage. Peak voltage versus frequency is plotted and then the effect of changing the value of the inductor and capacitor values is investigated.

- Learning Objectives
  1. Learn how to use electronics test equipment including function generators and oscilloscopes
  2. Build and test simple AC electrical circuits
  3. Visualize the concept of electrical resonance
  4. Understand the impact of electrical component values on series resonant circuits

Lessons Learned

For the Spring of 2020, ENGR 217 – Experimental Physics and Engineering Lab III is being offered for the second time. With the first offering now complete, there are a several lessons learned:

- Freshmen and sophomore success with open-ended laboratory assignments – As indicated previously, this experiments in this course were designed to be open-ended. While the final expectations are made clear, the students are expected to work as a team to develop their own experimental methods to achieve the expected outcomes. This is in contrast to most traditional academic lab assignments where students are given a set of instructions to follow. Because the students have already had this experience in the proceeding course, they adapted well to this methodology. However, it was determined early in the first semester that a brainstorming session with the lab instructor accelerated a student team's ability to develop working solutions. To this end, the lab instructors have developed a set of "leading" questions that can be used at the beginning of each lab to assist students in avoiding dead-end solutions for each lab.
- Course grading and attendance - Currently the grading structure heavily emphasizes the laboratory component of the course (54% of grade). Thus, it was found very quickly that a small percentage of the students did not sufficiently value attending the lectures. For this second offering, attendance measures such as in-class quizzes have been put in place. While this is helping, it is anticipated that the grading structure will need to be revisited in the near future.
- Single exam format - The course currently culminates in a single final exam that tests students on all of the concepts learned during the semester in both lecture and lab. Even with the course being a single hour lecture and once-per-week lab, this is a large amount of information. As with the previous item, the grading structure of the course needs to be revisited in the near future.
- Lab Organization – Currently the lab systems and workbenches are shared between two courses. Each course requires different and a substantial number of accessories that are necessary each week to complete a specific lab. On the University's main campus, laboratory technicians are used to ensure that each station is equipped with the appropriate supplies for a given lab, meaning that between sections the technician may have to swap out supplies depending on the class being taught. For this semester, the use of laboratory kits is being trialed on one of the remote campuses. Teams check out the kit they need to complete their lab. This does require a level of responsibility on the part of student teams as they must ensure that the lab kit is complete before turning it in for use by the next team.

Conclusions and Future Work

The ENGR 217 – Experimental Physics and Engineering Lab III course is currently being offered for the second time. The course is designed to complement the second engineering physics course on electricity and magnetism. Through the combination of a one-hour lecture and three-hour lab each week, theoretical concepts in physics are tested and connections between theory and engineering application are made. From anecdotal evidence, it is observed that the students enjoy the laboratory experiments and are able to apply appropriate theory and equations to the required assignments.

After this semester, a few thousand students will have completed both the physics course and this new engineering course. With that sample set, statistics will be run to determine the effect of this course on student success in the physics course including pass rate and average grade. Also, a more formal survey will be administered to students and faculty to determine the satisfaction level with the new course and areas for improvement. A subsequent paper will be submitted to a future conference to discuss these results as they are generated.

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