Hands-on Laboratory Projects for Non-Science Majors: Learning Principles of Physics in the Context of Everyday Technology

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Abstract

A set of hands-on laboratory projects has been developed for undergraduates who are not majoring in science or engineering. The projects are intended to help explain the principles of physics to non-science majors. The projects explore both the technological and scientific aspects of familiar technological devices, and demonstrate how technology incorporates a scientific understanding of nature. All projects result in tangible evidence of accomplishment such as construction of a simple radio, a loudspeaker, a one-octave electronic keyboard, and a compact disc-to-cassette tape adapter. The projects are made from inexpensive and simple materials so that each student can take home the working device. It was expected that projects which the students take home serve to amplify the impact of the work to include peers and family members. None of the projects require specialized equipment or facilities, and all of the projects can be modified to suit different institutional circumstances. General characteristics of the types of projects that were found to be effective for the target audience of non-science students are also summarized.

I. Introduction

The quality of education in science and technology for all undergraduates is becoming an area of increasing concern[1]. In the United States, the National Science Foundation is requesting that Science, Math, Technology and Engineering (SME&T) programs concentrate more effort on the 80% of college students who are not SME&T majors. This latest initiative comes shortly after the completion of a major effort by the Sloan Foundation to improve the quality of education that undergraduates receive in the areas of technology and quantitative reasoning[2].

In response, science and engineering faculty are developing courses intended to specifically address the needs of the non-SME&T students. A review of some historical background information and relevant new developments has been compiled by Byars[3]. A physics textbook for the general student addressing the basic principles of physics in the context of familiar technological devices has been written by Bloomfield[4]. The unique role that engineers can play in non-science education has been identified by Krupczak[5].

In these initiatives for non-SME&T students, a need exists for laboratory exercises to accompany the lecture component of the course. The work reported here describes a set of laboratory projects developed to accompany a technological literacy course for non-science majors taught at Hope College[6,7].

II. Laboratory Project Objectives.

The laboratory projects were developed with the three objectives. First, generate excitement and interest about the subject matter. Second, enhance student understanding of scientific and technological concepts. Third, empower students from non-science disciplines to attempt to more directly engage hands-on scientific and technological activities beyond those required for the course.

The intent of courses for non-science majors is to foster a positive attitude toward learning about science and technology and generate excitement and interest about subject matter. It is hoped that if a more direct connection is made between science and technology and daily life, more enthusiasm and appreciation for these subjects will develop. It was thought that the act of actually building a working technological device inspires confidence in the individual student's own ability to understand scientific and technological subjects.

It was also expected that laboratory activities will enhance the student's understanding of selected concepts in science and technology. Student interest is piqued by direct contact with familiar technological devices in a supportive, experiential environment. This situation provides a window of opportunity for educators to promote a deeper understanding of the subject.

From these general goals, a set of requirements or characteristics for laboratory projects for non-majors was developed. These project characteristics are summarized in table 1.

Table 1. Desired Characteristics of Laboratory Projects.

Desired Project Characteristics	**Constituency**		
	Student	**Instructor**	**Institution**
Take home finished product	**x**		
Intrinsically rewarding	**x**		
Clear connection to common technological device	**x**	**x**	
Tangible evidence of accomplishment	**x**	**x**	
Inexpensive	**x**		**x**
Easy to construct	**x**	**x**	
Use readily available materials		**x**	**x**
Robust	**x**	**x**	
Explained by a few basic scientific principles	**x**	**x**	
Uses common tools and equipment		**x**	**x**
No specialized expertise needed to teach		**x**	**x**
Simple project setup		**x**	**x**

Several characteristics must be designed into the projects to make them especially suitable for non-science majors. Laboratories which are taken from majors' courses with the mathematics removed are not likely to meet the needs of non-science majors. Projects which the students take home with them must have a low cost per student. All designs must be robust and tolerant of error or misalignment in construction and use. Projects are optimized for non-engineering and non-science students with little prior experience working with tools. While simplicity is important, the technological device should not be so overly simplified as to provide little information about the workings of manufactured versions of the product. For example, it is possible to find highly simplistic designs for electric motors, however students benefit more from building a motor that includes an readily identified field magnet, armature, brushes.

Projects must have a high degree of novelty and intrinsic interest. That is to say, a compelling output should result from a modest input of time and resources. A good example of this the crystal radio. Nearly everyone is fascinated and intrigued how a such a simple combination of a coil and a diode can actually be a functional radio. This intrinsic interest provides an opportunity to acquaint the student with a scientific principle underlying the observed effect. Projects are most readily explained when it is possible to identify one or two primary scientific principles which are sufficient to understand how the device works.

The laboratories should not require any specialized equipment or facilities and be must capable of being modified to suit different institutional circumstances. Since courses for non-science majors may be taught by instructors with a wide range of expertise, the laboratory projects must not require an in-depth familiarity with special field of engineering or physics. The relative importance of the various design characteristics to the different constituencies of students, instructors, and the institution are highlighted in the table.

III Laboratory Projects Developed.

The laboratory projects developed to are summarized in Table 2. Five projects were developed, building a DC motor, constructing a simple radio, building a one-octave musical keyboard, construction of a loudspeaker, and building a CD-to-cassette adapter. Each student builds his or her own device and each student takes the completed project home when finished.

The projects described in Table 2 represent only one type or style of laboratory project that may be included in a course for non-science majors. These projects form a portion of the laboratory work done. The entire laboratory experience should include more traditional inquiry type investigation into scientific principles. To provide non-science students with an appreciation of engineering, design projects could serve as possible laboratory experiences. Further details on the use of design projects in technological literacy courses in described by Byars[3].

Table 2: Projects Developed for Non-Science Majors.

Laboratory Project	**Summary of Activity**	**Physics Principle**	**Technological Issue**
Electric Motor	Build a DC motor	Electromagnetism	Conversion of electrical to mechanical energy
Radio	Build a crystal radio	Radio Waves / Resonance	Telecommunications using AM carrier
One-Octave Keyboard	Etch circuit board, Solder components	Resistance / Capacitance	Integrated circuits and Printed circuit boards
CD-to-Cassette Adapter	Adapt CD output to cassette tape input	Electromagnetic Induction	Digital to analog conversion
Loudspeaker	Build a loudspeaker from simple components	Electromagnetism / Sound	Information conversion electricity into sound

The first project developed is the construction of a simple DC electric motor. A view of a completed motor is shown in Figure 1. although often hidden from view, the electric motor is an extremely common and essential technological device. In this laboratory students build a simple DC electric motor from basic components. The project is adapted from a commercially available kit[8]. Construction requires that students wind the field and armature coils and assemble the component parts. Students keep the completed motors. The project shows an application of electromagnetism in the form of a versatile technological device.

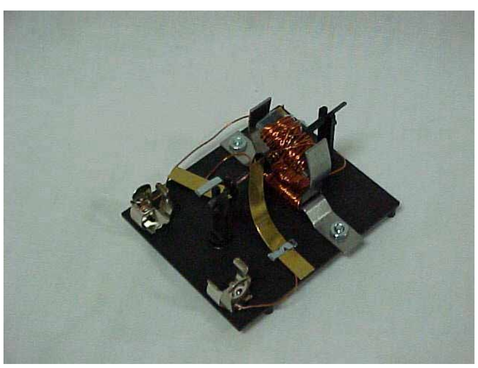

Figure 1: Simple Electric Motor.

In constructing the simple motor, a kit available from Science First Inc.[8] is used as the basis of the project. The kit inexpensive, costing less than 2 dollars per motor when purchased in bulk quantities. The basic is modified in several ways primarily to make it more robust and easier to assemble. The supplied brushes are replaced by brass strips cut from 0.004 inch thick shim stock. These are easier to assemble and require less adjustment. The wiring connections are soldered rather than crimped . The use of soldering irons is possible to accomplish in the college laboratory setting, but could not be assumed by the original manufacturer. The students also receive a small cardboard box in which to store the completed motor. This reduces the damage caused by transportation or rough handling.

In the radio laboratory each student builds a simple AM "crystal" radio. To facilitate the understanding of the basic principles at work, the radio design is extremely simple utilizing only a coil wound around a cardboard tube, a germanium diode, an earphone and an antenna. Figure 2 shows and assembled radio. The radios are kept by the students. The radio facilitates an understanding of electromagnetic waves, resonance, and the important principle of information encoding in the area of telecommunications.

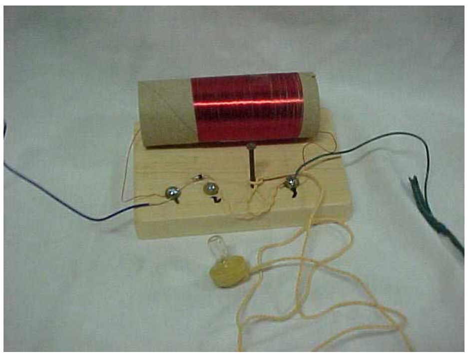

Figure 2: Simple Radio

The radio is constructed on a 5 inch long piece of standard 1 x 4 clear white pine. This material is chosen because it is a soft wood that is easy for the students to work with. The coil is made from 160 turns of 28 gage magnet wire wound around a tube from bathroom tissue. The tube is fixed to the base using push pins. The diode used is a 1N34 germanium diode. A high impedance earphone is used (Mouser Electronics[12] part number 25CR060).

The simple one octave electronic music keyboard is constructed from elementary components and a single integrated circuit. This is shown in Figure 3. Students make a printed circuit board on which the components are soldered. The completed keyboards are kept by the students. This project serves to provide students with a hands-on experience in electronics. Most of the student effort is devoted to constructing the device and getting it to work. The underlying function of electrical resistors and capacitors is addressed, and the concept of sound pitch and frequency is explained.

The basic circuit used for the keyboard is adapted from a square wave generator described by Coughlin and Driscoll[13]. In this case the operational amplifier used is a common LM324, which can be operated from a single 9-Volt battery. The circuit board and other components are assembled by the students on a wooden base. Simple but durable keys are fashioned from brass strips of 0.010 inch thickness. To facilitate tuning of the device, a 10 k ohm trimming potentiometer is included in series with each key. Other non-obvious characteristics are the use of a 100 ohm speaker which is of sufficient impedance to be driven directly from the op amp without the need for an additional components. The keyboard is intended to play the major C scale. When a 0.1 microFarad capacitor is used in the free-running multivibrator circuit, proper tuning is achieved using feedback resistors ranging from 10 k ohm to 25 k ohm.

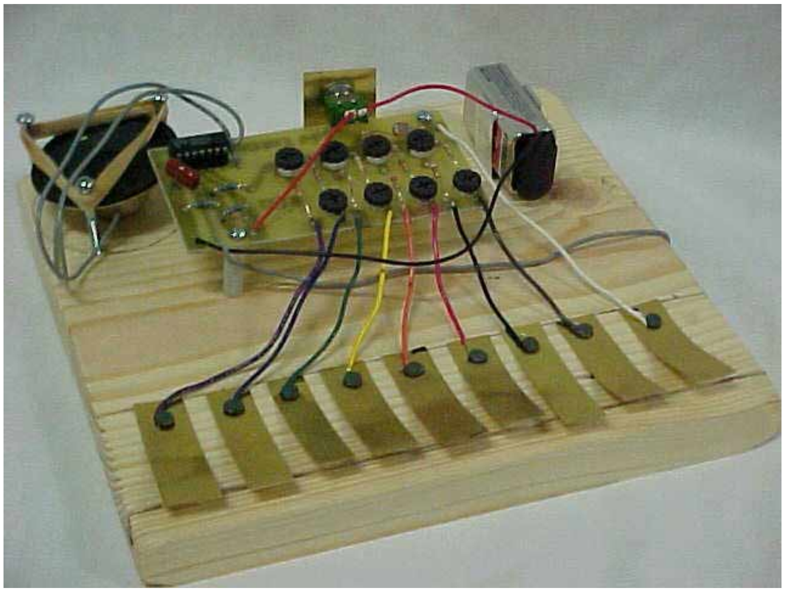

Figure 3: One-Octave Keyboard

The CD-to-cassette adapter project involves making a device to allow a personal "walkman" type CD player to be used in an automobile cassette tape player. Figure 4 shows a completed device. The idea for this project was inspired by the modulated coil demonstration reported by Rathjen[9]. The CD output from each channel is used to drive an electromagnet mounted inside an empty tape cassette. When installed in the tape player, the varying magnetic field from the electromagnet induces a current in the tape heads. This project is a compelling demonstration of electromagnetic induction and affords an opportunity to discuss digital to analog conversion in the CD player.

The electromagnets in the device are created from two "jumbo" paper clips. Each clip is surrounded by 200 turns of 28 gage magnet wire. These electromagnets are then connected to the left and right channels from a standard 3-mm headphone jack. Although the impedance is low, the magnets can be driven from the headphone output of a personal compact disc player.

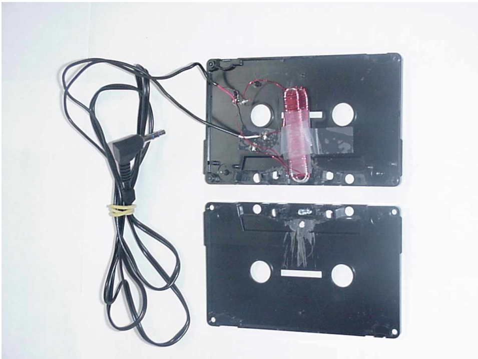

Figure 4: CD-to- Cassette Adapter

The speaker project consists of the construction of an electrodynamic loudspeaker from simple components. This project is adapted from lecture demonstration speakers described by Heller[10] and Keeney, and Hershey[11]. In our project, students wind the voice coil and fabricate a cone from construction paper. A permanent mounting is created. The completed speaker can be connected to a home stereo to produce sound. This project highlights an application of electromagnetism different from that applied in the DC motor. The nature of sound as vibration can be readily observed in the completed device. From a technological viewpoint, the speaker is seen as converting an electrical signal originally obtained from a microphone back into sound.

Figure 5: Simple Electrodynamic Loudspeaker

The major features of the speaker are the coil and the magnet. The coil is wound from 80 turns of 38 gage wire. This is wound around a 0.75 inch diameter cylinder, created from construction paper. The impedance of this arrangement is 8 ohms at 1 kHz. The coil is attached to bottom of the 6 inch diameter cone by using hot glue. When assembled the coil is surround by a ceramic disk magnet fixed inside a portion of a mailing tube. The magnet has a 2.75 inch outer diameter, a 1.00 inch inner diameter, and a thickness of 0.25 inches (Adams Magnetics[14] part number 30A0010). The coil leads are attached to a standard speaker terminal block (Mouser

Electronics[12] part number 15CT200). This type of connector is common in consumer audio systems and facilitates use of the speaker at home.

IV. Results and Conclusions

All of the laboratory projects have been successfully completed by non-science majors. Non-science majors are able to complete and understand the projects. The projects described meet the requirements outline in Table 1. The projects result in tangible evidence of accomplishment and help to generate interest and excitement about scientific and technological topics.

V. Directions for Future Work.

Future work will focus on formal assessment of the effectiveness of the projects and completion of a laboratory manual containing detailed information and assembly instructions. Assessment will focus on determining if the projects increase student enthusiasm for working with technological devices and investigate increases in science content knowledge gained through these projects. Assessment instruments include student surveys, focus groups, and review of test results. Assessment activities are being conducted in collaboration with the Carl Frost Center for Social Science Research at Hope College. A review of results of the assessment activities is expected to be the subject of a future publication.

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