AC 2011-1197: DEVELOPMENT OF ENGINEERING LABORATORY PROJECTS FOR GENERAL EDUCATION ENGINEERING COURSES

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Development of Engineering Laboratory Projects for General Education Engineering Courses

Abstract

A group of laboratory projects is being developed for use in either general education engineering courses to improve technological literacy or in introduction to engineering courses. The projects each focus on the construction of a working technological device that each student takes home upon completion. Projects include building and testing devices such as an LED light, an electric motor, a working speaker, a simple radio, a transistor amplifier, and a photovoltaic battery charger. The projects were developed specifically for use in the two-year college environment. The projects use basic component parts that are easy to obtain. The target average cost is five to ten dollars each. No special tools are required for construction and the projects can be conducted in virtually any room equipped with tables. The projects are robust and durable and provide an unmistakable indication of proper operation. The projects can be taught by a faculty member from any engineering discipline. All necessary supplies fit in a box which can be readily shipped. This allows colleges to borrow, rent, or lease rather than own the equipment. Laboratory procedures and questions can be modified to better suit the needs of either and introduction to engineering or a technological literacy course for non-engineers. Testing was based on subject matter content tests administered to the students before and after completing the projects. Students completing the projects show statistically significant increases in content knowledge related to the project topics. A method of assessments is also being explored that involves having each student design and construct his or her own simple version of some of the technological devices studied. This work was supported by the National Science Foundation under award: DUE-0633277.

Introduction

Engineering programs are being called upon to help to insure that all undergraduate students develop an understanding of engineering and technology. In a survey conducted by the American Associate of Colleges and Universities, eighty-two percent of employers cited "new developments in science and technology" as an area needing more emphasize in colleges and universities[1]. The National Academy of Engineering (NAE) has also called attention to an inconsistency of modern life. The NAE states "Despite the ubiquity of technology most citizens are not equipped to make well-considered decisions or to think critically about technology[2]." The NAE further points out that "Capable and confident participants in our technologically-dependent society must know something about engineering[3]." All Americans would benefit from a general understanding of the wide range to technologies vital to everyday life. This understanding of technological principles, or technological literacy as it is sometimes called, should encompass more than just an ability to use personal computers and information technologies and include knowledge of a broad range of technological processes and systems.

A difficulty in helping non-engineers to develop an understanding of technology is the limited number of engineering courses that are intended for the general education of non-engineers.

Most engineering courses are intended primarily for students pursuing an engineering major. The large body of perquisite knowledge considered necessary for these engineering courses inhibits participation by non-engineering majors.

In the midst of this situation some positive developments can be found. The National Science board has advocated that engineering departments should offer courses for non-engineers[4]. A number of engineering departments offer service, or general education courses, for non-engineers[5-16]. These technological literacy courses have attracted consistent interest from non-engineering students.

A challenge to extending the number of general education engineering courses available is the limited amount of appropriate material available for faculty attempting to teach these courses. In courses for engineering majors there is a well-developed body of course material available in the form of textbooks, laboratory projects, and assessment materials. A need exists for and appropriate range of course materials for general education engineering courses.

On the issue of technological literacy, the potential role of existing introduction to engineering classes should not be overlooked. Due to their limited prerequisites introduction to engineering courses have the potential to be general education courses open to all students. In addition, these courses have the possibility of exposing engineering students to a broader range of technological devices and issues than they are likely to encounter in advanced course work in a specific engineering discipline. Achievement of either of these goals would require appropriate curriculum materials and learning activities. Some of the curriculum materials used in current existing introduction to engineering courses may require modification to better meet the technological literacy goal of a broad understanding of a wide range of technology.

An additional consideration regarding introduction to engineering courses lies in acknowledging that not all students enrolled in an introduction to engineering course will persist to completion of an engineering major. Setting aside the issue of why these students leave engineering, it is reasonable to suggest that introduction to engineering should provide these students with knowledge relevant to their general education. Some of the material in introduction to engineering courses should prove beneficial even to those students who do not elect to continue in engineering.

Importance of Two-Year Colleges

Consideration of any issue that impacts undergraduate education should not overlook the important role that two-year or community colleges in higher education. Increasingly two year schools represent an affordable higher education option for many students. Efforts to attract students to an engineering career must acknowledge that two-year institutions or community colleges represent the fastest growing segment of higher education[17]. Recent data shows that 40% of individuals earning bachelor or master's engineering degrees started higher education in a community college. The trend is higher in some states such as California for which more than 48% of graduates with science or engineering degrees started at a community college[18].

Conditions in two year colleges present challenges for both students and faculty. Engineering programs in two year colleges are typically small. These programs often have only one or two faculty members who teach courses running the gamut of the engineering curriculum. Faculty teaching loads are high compared to other areas of higher education. Access to facilities such as laboratories is limited and laboratory space is typically shared by multiple departments. Space for storage is severely constrained as are equipment budgets. Support staff for laboratory preparation is frequently non-existent. In these circumstances, faculty at two-year colleges have difficulties carrying out extensive curriculum development work.

Goals of this work

The goal of the work reported here is to develop eight laboratory projects suitable for use in general education engineering or technological literacy courses for non-engineers. The projects should also be appropriate for introduction to engineering courses, however there may be differences in some of the details of how the projects are used with engineers and non-engineers. The projects are intended to be amenable for use in either the community college environment or in four year programs. Initial stages of this work have been reported earlier[19].

Laboratory Development Process

A general theme of establishing a sense of empowerment guides the development of the projects. Learning about engineering and technology should be an empowering process especially for the non-engineering student. One of the reasons that technology and engineering are important to society is because they provide new capabilities not otherwise possible. The same holds true for individuals. Individuals use technology, like the automobile for example, to achieve capabilities that they would not otherwise posses. Projects should therefore emphasize the practical utility or usefulness of technology.

The key general themes or characteristics desired for the projects are listed in Table 1. The projects should focus on technologies that are important to daily life. The term core technologies was adopted to describe technological devices and systems that are common because they are particularly influential in some way. This was seen as important for both the non-engineering students and the engineering students. For the non-engineers it is important to promote an understanding of foundational technologies to establish a knowledge base for life long learning. For students who may be continuing on in engineering, establishing a familiarity with influential technologies helps to establish prior knowledge and a context for more detailed advanced study.

An appropriate level of project sophistication is sought for the projects. The projects should be such that there are one or two most important underlying principles of operation which are highlighted through the project operation. In other words the projects should not be overly complex requiring extensive background knowledge to understand. However given that the target group is undergraduate students, overly simplistic projects should also be avoided.

The projects should focus on building or constructing a working technological device. Each person should be able to make his or her own device and keep it when completed. Alternatively if the student does not want to keep the completed project, it should be possible to recycle the project and reuse most of the materials. The average cost of the projects should be in the range of 5 to 10 dollars each. This would allow the cost of the set of projects to be within the cost of a typical laboratory class fee of 50 to 100 dollars. The projects should use materials and components parts that are relatively easy to obtain from hardware, office supply, or grocery stores or be obtainable from readily located online sources.

The projects should be robust and durable. The construction should not involve delicate adjustments. However construction of the devices should involve an appropriate level of engagement on the part of the students. The devices should not just snap together in a few minutes. It is expected that completing the project should involve concentration and effort but be possible for most students to complete in a one to three hour laboratory period.

When properly completed the projects should produce some clearly recognizable indication that they work. There should be some unmistakable outcome that results from a successful project. Non-functional projects should be amenable to troubleshooting and repair. If a student constructs a device and it does not work, then the design should be such that the student can carry out an analysis to find and correct the problem.

It should be possible to complete the projects using commonly available hand tools. No specialized or expensive equipment should be needed. It should be possible to conduct the laboratories in a wide variety of different types of rooms. The only assumption made regarding space is that some type of flat-surface table space is available on which each student can work.

The projects should involve basic technologies and principles of operation such that any engineering faculty member should be able to carry out the laboratories. Engineering faculty may have to review background material related to the project, but a high level of expertise in the subject should not be necessary to conduct the laboratories.

Little if any storage space should be needed for the laboratory materials. To address the problem of obtaining equipment, it should be possible to fit all the materials needed for a group of approximately 24 students into a box of 20-50 pounds. The material and can be shared between schools or potentially obtained from a commercial supplier. When the laboratory is completed most of the materials leave with the students in the form of the completed projects. Projects that are not taken home are recycled back into basic components that fit inside the original box.

Table 1: Desired Characteristics for Projects.

1	Involve construction of a working technological device.
2	Represent the application of a principle of science.
3	Each person keeps the device or major parts can be recycled and reused.
4	Use common parts that are easy to obtain.
5	Average cost of 5-10 dollars per project.
6	No special tools required.
7	No special type of laboratory space or facilities needed.
8	Robust, durable designs.
9	Clear unmistakable indication of proper operation.
10	Any engineering faculty member can teach.
11	Potential of all materials arriving in a box of 20-50 pounds.
12	Require 1 to 3 hours to complete.

Laboratory Projects under Development

Book light

The basic series electrical circuit is an important concept that should be understood as part of the technological literacy of non-engineers. In addition, it should not be assumed that beginning engineering students fully grasp the idea of a complete circuit or even a conductor for that matter. Some laboratory activity is needed to help to solidify understanding of the series circuit. A common laboratory exercise to address this idea involves lighting a small bulb using a battery and one or more lengths of wire. While the battery and bulb activity conveys the concept, it was desired to have a laboratory project on this topic in which students could become more personally interested. The booklight project was developed to achieve this goal.

The project involves constructing a light that clips on to a book. The booklight is based on an LED and uses a binder clip to attach to the book. Other materials needed to create the basic circuit are a push-button switch, solid wire, two AAA batteries, and a battery holder. A piece of tubing is used as the neck of the booklight. Figure 1 shows the materials needed for the project. A modification of the project uses a plastic “chip clip” in place of the binder clip.

Figure 2 is a circuit diagram for the booklight. The LEDs used are amber or white with a forward voltage of approximately 3 Volts. This makes it possible in most cases to dispense with a series resistor for the LED.

An example of the completed project is also shown in Figure 1. The students are encouraged to decorate or otherwise customize the appearance of the light. Many students embrace this creative aspect of the project.

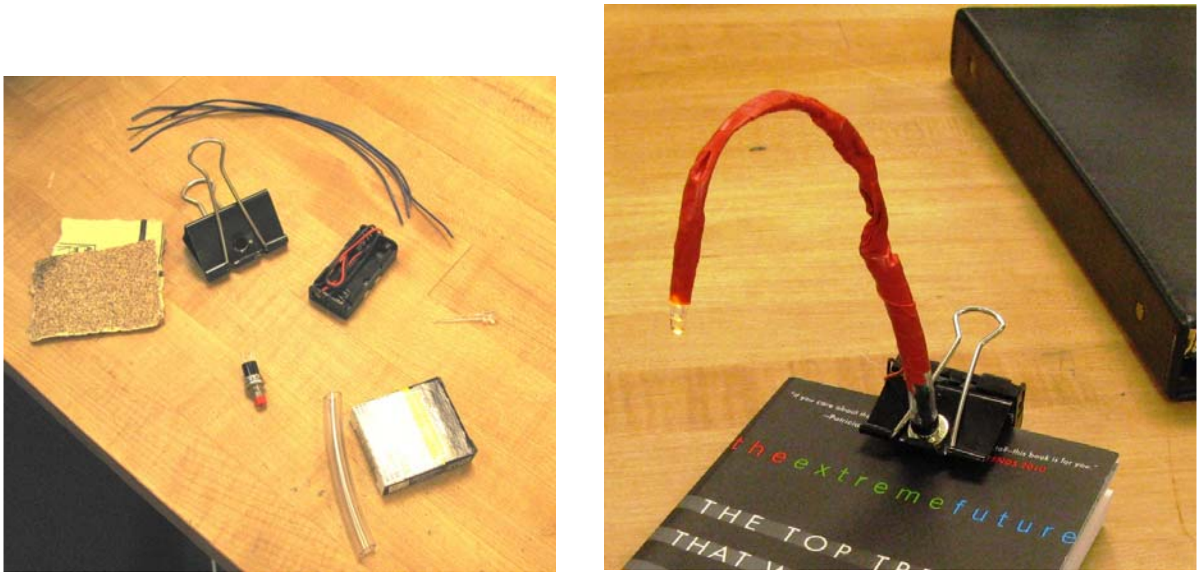

Figure 1: Booklight Components and Example of Completed Device.

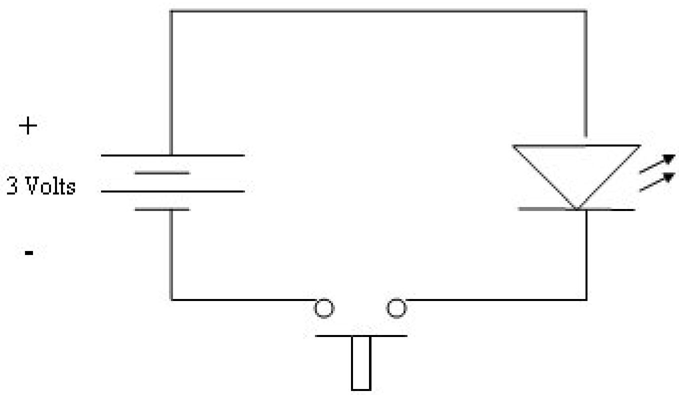

Figure 2: The Booklight Circuit.

Electric Motor

The electric motor is an important component in a wide variety of technological devices. The electric motor is a compelling application of electromagnetism. A key aspect of the classic DC electric motor is the reversal of the direction of current through the rotating armature each half rotation. It is difficult for students to absorb the importance of this design feature, and the means through which it is accomplished from diagrams or written descriptions of electric motors. However it is relatively easy to construct a functional DC motor.

A number of electric motor kits are available commercially. Also a wide range of simplified do-it-yourself motor designs exist. It was decided to develop an electric motor design for this project made from simple commonly available parts to help students to focus on the function of that particular motor component. By using familiar objects outside of their familiar use, attention is drawn to the function that component. This facilitates discussion of how the particular attributes of that object help to fulfill a specific function in the motor. It was felt that using a motor constructed from specifically manufactured parts would encourage the tendency to see that special attributes somehow embedded in those parts allow the motor to function. Therefore the project avoids any prefabricated parts and uses only general purpose materials and common hardware.

An example of the electric motor is shown in Figure 3. Components include: wire, cork, bamboo skewer, brass strips, bolts, and a plastic tray. Construction requires that students wind the field and armature coils and assemble the component parts. Students keep the completed motors. A gearbox is constructed and used to measure output power and torque. The gearbox is part of the laboratory equipment and is not taken home. The motor works well using either ceramic or neodymium magnets for the stator magnet.

The design of the motor was also intended to not be overly simple. It was specifically determined that the design should include an armature, commutator, brushes, and stator that correspond to the same components in a typical DC electric motor.

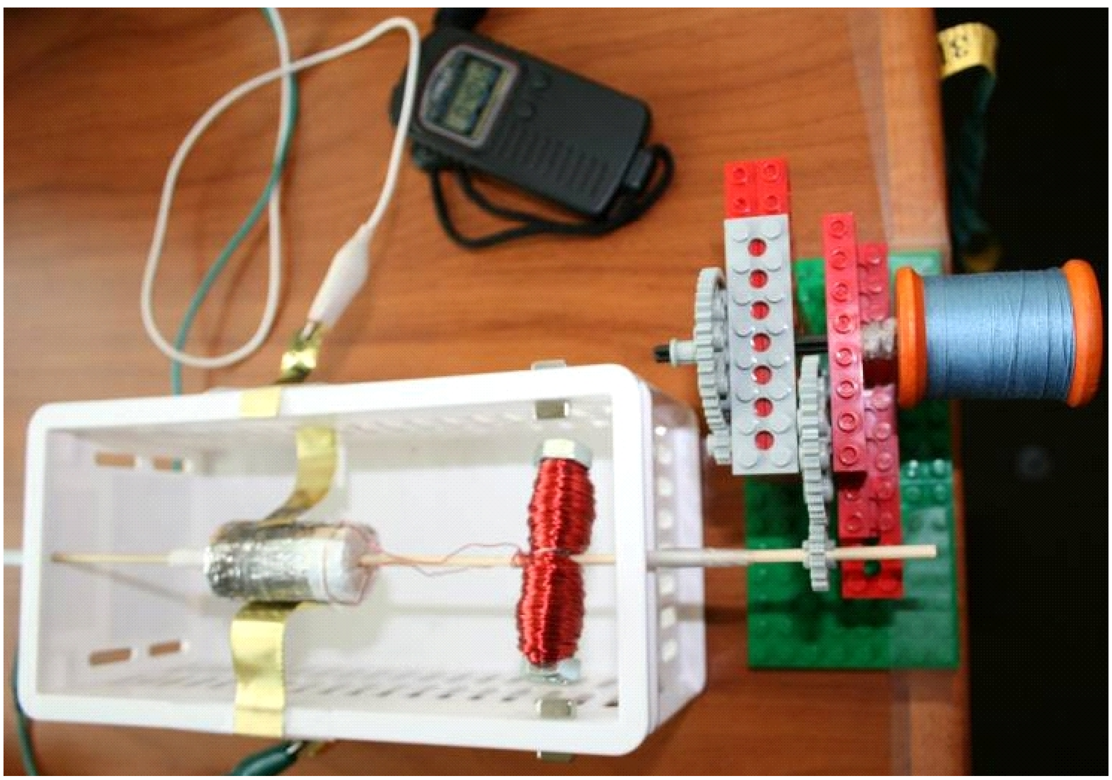

Figure 3: Electric Motor and Gearbox Used for Torque and Power Measurements.

A basic measurement of electric motor performance can be accomplished by measuring the time required to raise a known weight through a specific distance. A basic gearbox is used to connect the electric motor to a spool as shown in Figure 3. No corrections were made for the friction introduced by the gears.

Typical results are shown in Figures 4 and 5. Figure 4 shows the data for motor torque as a function of rotational speed. Figure 5 is motor power as a function of speed. Due to the crude nature of both the motor and the measurement methods there is significant scatter in the data. However, both the torque and power curves have the appropriate behavior for a DC permanent magnet electric motor.

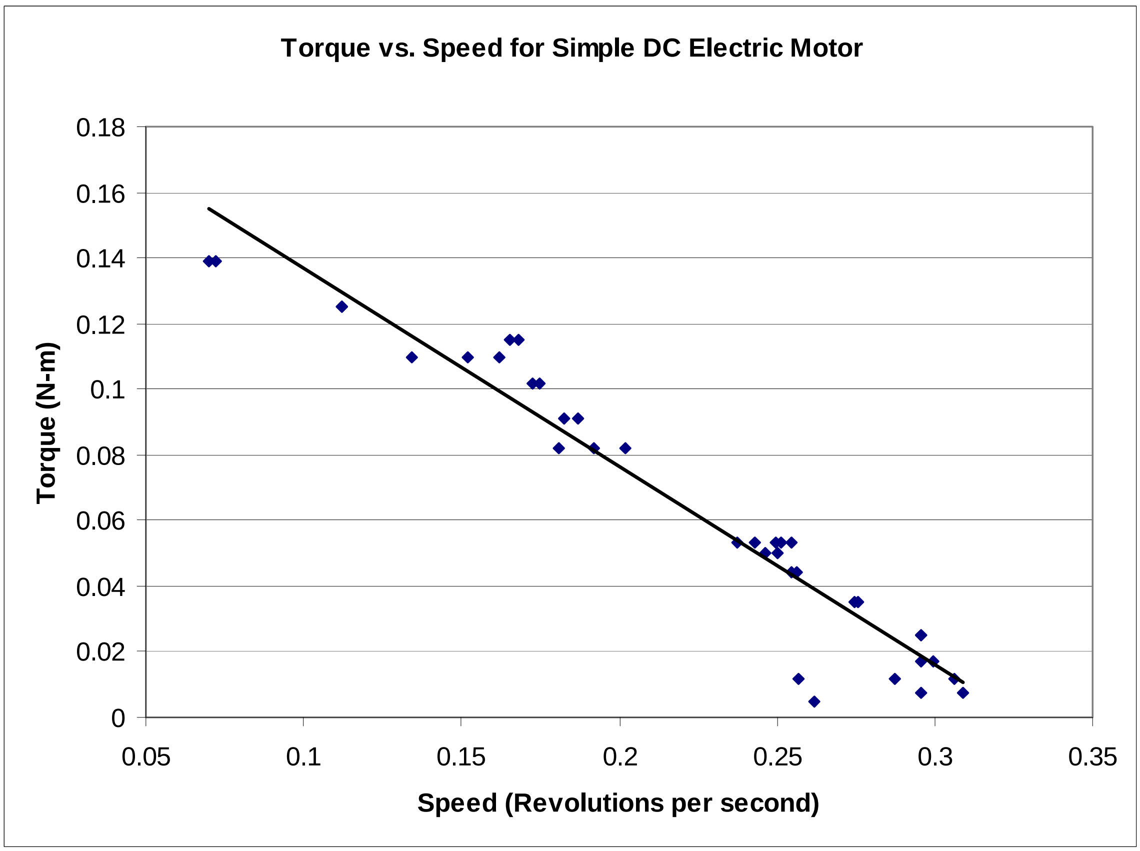

Figure 4: Representative Results for Torque vs. Speed Behavior of the Simple Motor.

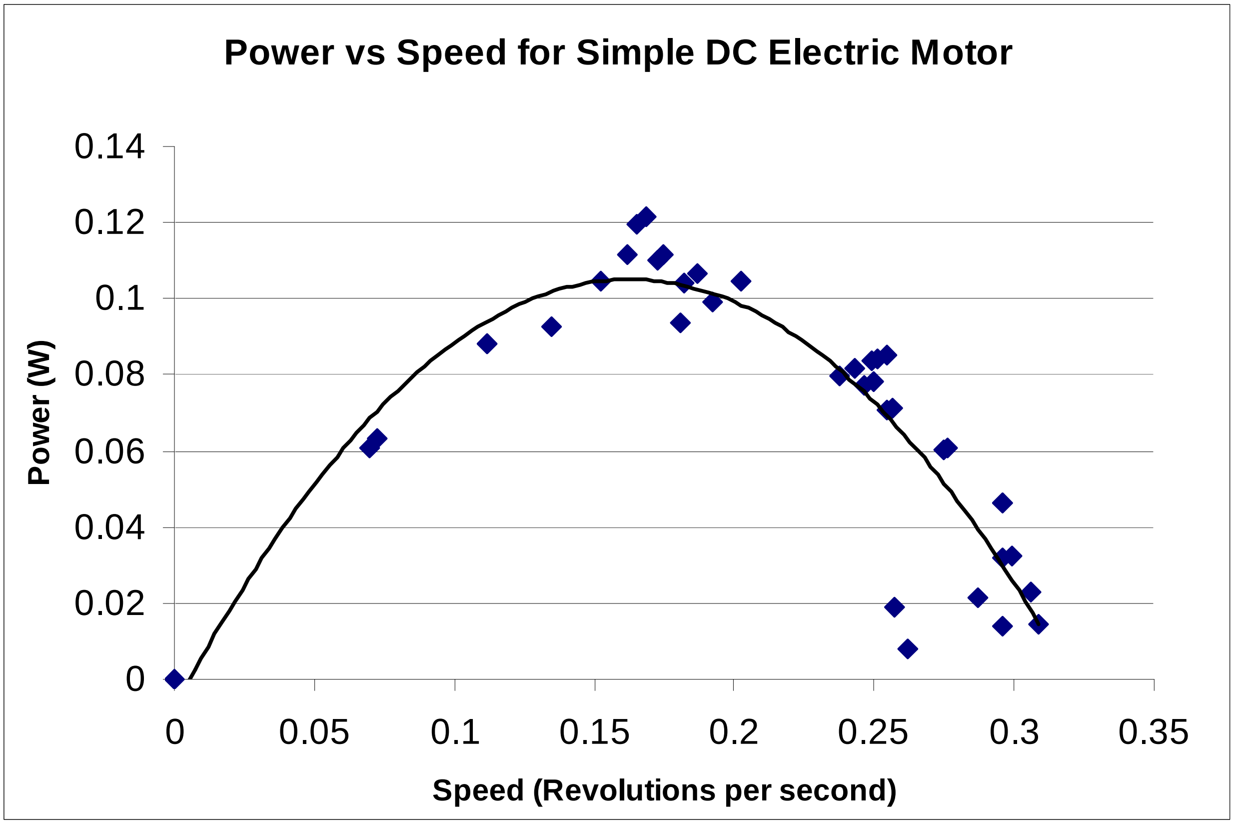

Figure 5: Representative Results for Power vs. Speed Behavior of the Simple Motor.

Electrodynamic Speaker

Some type of audio output is an important aspect of a wide range of consumer electronic devices and telecommunications equipment. The expectation of most non-engineering students is that a speaker which converts an electrical signal into audible sound must be an incredibly complex and intricate device. This project seeks to illustrate how an electrodynamic speaker works through the construction of a simple yet surprisingly effective speaker made from simple components.

The simple loudspeaker has been developed is shown in Figure 6. The speaker is made from a plastic drinking cup with a tight-fitting lid and a straw. The speaker coil is wound around the end of a straw. A ceramic disk permanent magnet is placed in the bottom of the cup. The straw extends through the lid of the cup as is normally done when the cup is used for drinking liquids. The coil wires extend through a hole cut in the cup, and then connect to a standard audio compression terminal. The cup and the terminal are mounted on a foamcore base. Steel washers are used on the disk magnet to direct the magnetic field to a concentrated central region where the coil is placed.

The most important detail of the simple speaker design is the coil. The coil is made from 5.5 meters, (18 feet) of 36 gage magnet wire. This results in 8 ohms impedance so that the speaker is compatible with consumer audio equipment. It is important that the coil have low mass so fine gage wire is used. The specific type of permanent magnet used is less critical so long as the field strength is relatively strong. Ceramic disk magnets and cylindrical neodymium magnets have been found to be suitable.

The design is deliberately simple. The intent is to draw attention to the major functional components of the speaker. The only specialized component used is a standard audio speaker compression terminal to facilitate interconnection with consumer audio devices. With this simple design the speaker can be easily constructed in one hour or less. The only tools required are sandpaper and pair of scissors. However a glue gun is a helpful option.

The cup speaker works similarly to any other electrodynamic speaker. This type of speaker works through the interaction of two magnets. In the basic design one magnet is a permanent magnet and the other is an electromagnet. An analog electrical signal is sent to the electromagnet coil. The analog electrical signal voltage varies in direct proportion to the amplitude of the original sound wave which is to be reproduced. An electric current in a conductor produces a magnetic field. In this case because the signal is not constant but time varying the magnetic field in the coil is not constant but varies in time with the time varying signal. Because the coil is therefore, a magnet of varying strength, the force exerted on the coil by the other permanent magnet is not constant but changes in direct proportion to the sound signal. The coil is consequently pushed or pulled back and forth by the permanent magnet to varying degree in direct proportion to the sound signal. The pushing and pulling of the coil is transferred via the straw to the lid which moves up and down, or in other words vibrates, reproducing the original sound. Despite the simplicity, the speaker produces a loud, clear sound and is capable of reaching 90 dB.

The speaker allows for a range of simple investigations that help to explain how the speaker works. For example if the straw is pulled up away from the permanent magnet the sound stops because the coil is outside the strong region of the permanent magnetic field. In operation the lid vibrates noticeably and these vibrations can be felt by touching the lid. If the lid is removed the sound produced decreases. The straw also vibrates itself and this produces some sound independently of the connection to the cup lid.

Simple Radio

The transmission of information via radio signals is a central aspect of a wide range of modern telecommunications technologies ranging from satellite communications to mobile phones. The process of extracting a signal from the air and reproducing audible sound might be viewed as an incomprehensibly intricate process by non-engineers. Beginning engineering students may also have difficulties grasping the key principles of telecommunications from a baffling array of seemingly different devices and applications. This project intends to develop an understanding of an important property of electromagnetic waves along with the fundamental process of encoding and decoding of information central to all methods of telecommunication.

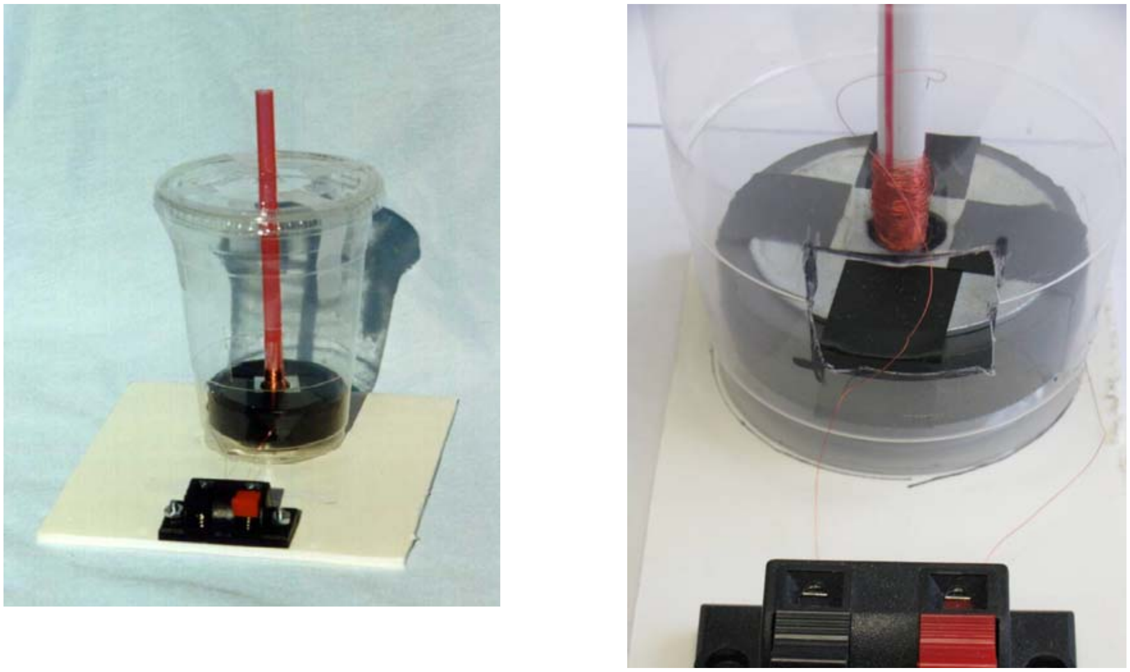

Figure 6: Electrodynamic Loudspeaker Constructed from a Plastic Cup.

Figure 7 shows a view of the radio receiver that was developed. The design is a modification of the classic AM crystal radio. The design is substantially simplified by not including a tuning mechanism. The design is easy to construct, very rugged, and receives commercial AM broadcasts well.

The simple radio design requires only five major components. These components are an antenna, germanium diode, wire coil, earphone, and a ground wire. The antenna wire and ground wires are 2 meter and 1 meter lengths respectively of 22 gage solid wire. The coil is wound around a common cardboard tube. A 1N34 or 1N84 germanium diode is used. The coil is 160 turns of 26 gage solid magnet wire. This results in a coil length of 67 millimeters (2.625 inches) along the tube. This was found to have the proper resonance characteristics through inductance and self-capacitance so no separate capacitor is needed. Foamcore is used as a base, and common paper binding brads are used to connect the components together. The design dispensed with tuning for the sake of simplicity. This design is able to receive stations across the commercial AM band and typically whatever is the strongest signal is what is heard.

A key principle conveyed is an understanding that electromagnetic waves carry energy. The radio produces audible sound without the aid of a battery or amplifier. In the absence of a battery or external power source, it is relatively easy for students to conclude that the energy represented by the faint but audible sound must come from the electromagnetic waves incident on the antenna.

Figure 7: Photograph of the Simple Radio.

Transistor Amplifier

The transistor and the integrated circuit are routinely cited as among the most important inventions of the twentieth century yet even the word transistor is barely recognized outside of engineering. An important aspect of telecommunications is amplification of signals of various types. This project considers the transistor in the context of its use as an amplifier. An integrated circuit is also used as a means of including this important technology that was derived from the single transistor.

In this project students construct an amplifier that uses a single transistor as a preamplifier and an integrated circuit power amplifier. With this device students are able to amplify the output of the crystal radio sufficiently to drive the homemade speaker. Using the amplifier it is also possible to listen to a personal MP3 player using the simple loudspeaker.

The circuit is shown in Figure 8. The transistor would seem unnecessary with use of an integrated circuit audio amplifier such as the LM386. This was a deliberate decision in designing the circuit to make use of a single transistor amplifier. This was done to both draw attention to the transistor as an amplifier and so that it would be possible to measure or observe the gain of the amplifier with just a single transistor. The integrated circuit provides additional gain to allow increased volume of the output sound.

Two versions of this project have been developed. One uses a printed circuit board. The other version uses a solderless breadboard as seen in Figure 9. In either case students do all of the assembly and keep the completed device. In the solderless breadboard version, no custom-designed parts are needed.

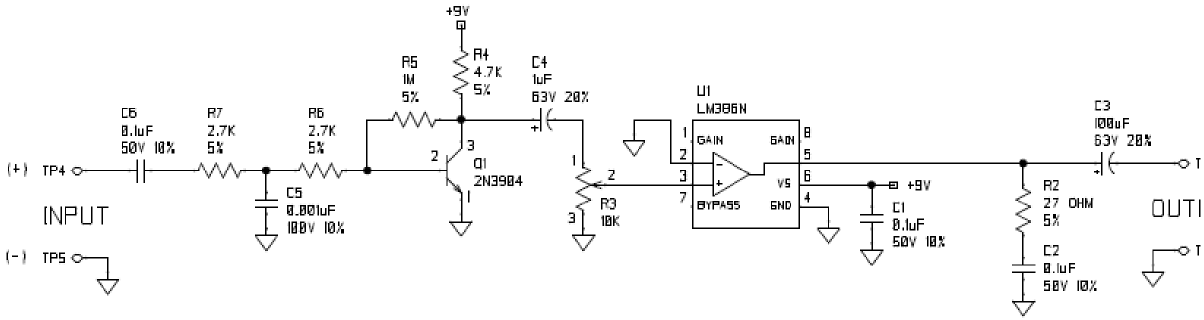

Figure 8: Amplifier Project Schematic Diagram.

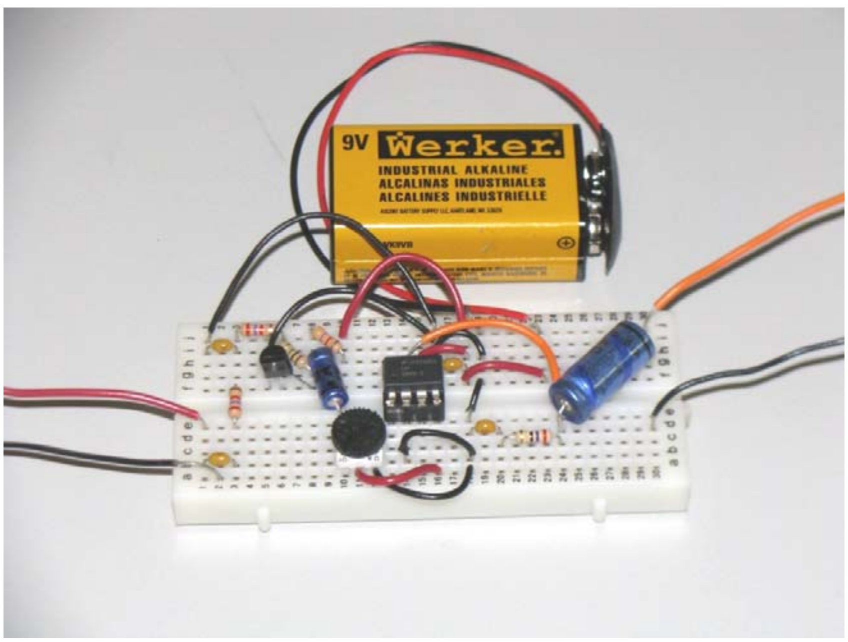

Figure 9: Photograph of Amplifier Project Constructed on Solderless Breadboard.

Photovoltaic Battery Charger

There is a high degree of interest in sustainable energy sources among both engineering and non-engineering students. To support this interest, a project using photovoltaics was developed. Thin-film photovoltaic cells are used to recharge two AA NiMH batteries. The project helps to illustrate the capabilities and the limitations of photovoltaics.

The project is shown in Figure 10. Two thin film photovoltaic cells are used[20]. These have a nominal rating of 3 V and 50 mA (Powerfilm MP3-37). The device is intended to be used outdoors but will operate acceptably well using a 200 W (equivalent) compact fluorescent light. Foamcore is used as the base upon which the components are mounted. The reverse side contains two AA NiMH rechargeable batteries and battery holders. A 1N5817 diode is used in series with the photovoltaics to prevent the batteries from discharging backwards through the photovoltaics in low light conditions. The photovoltaics are connected in parallel while the batteries and diode are connected in series. Figure 11 is a simple diagram of the wiring for this device.

The project is amenable to carrying out a variety of measurements of current and voltage. Output power can be determined for different conditions of lighting, incidence angle, and load resistance. Representative student data is given in Figure 12. The design makes it possible to measure the current supplied while charging. From this, students calculate the time needed to recharge the two AA batteries under the operating conditions.

The thinfilm photovoltaic used in this project is not as readily available as the components in the other projects. However it can be obtained from the manufacturer when purchased in quantities of 100 or more[20]. The thin film photovoltaic is well-suited to this application. While not the most efficient photovoltaic, the thin film is very durable and does not require any additional packaging or coating to protect the device from being damaged.

An important student learning outcome of the project is the development of a realistic understanding of the capabilities of current photovoltaic technology. A typical student-constructed device is able to supply about 75 mA of recharging current to the AA batteries in sunny conditions. Two fully discharged batteries can be recharged to a usable degree in a few hours of direct sun. However, students calculate that a complete recharge a 2000 mAh batteriy requires on the order of 40 hours of full sunlight conditions with this device. This leads to an important grounding in reality concerning the actual capabilities of photovoltaics in relation to power demands of modern society.

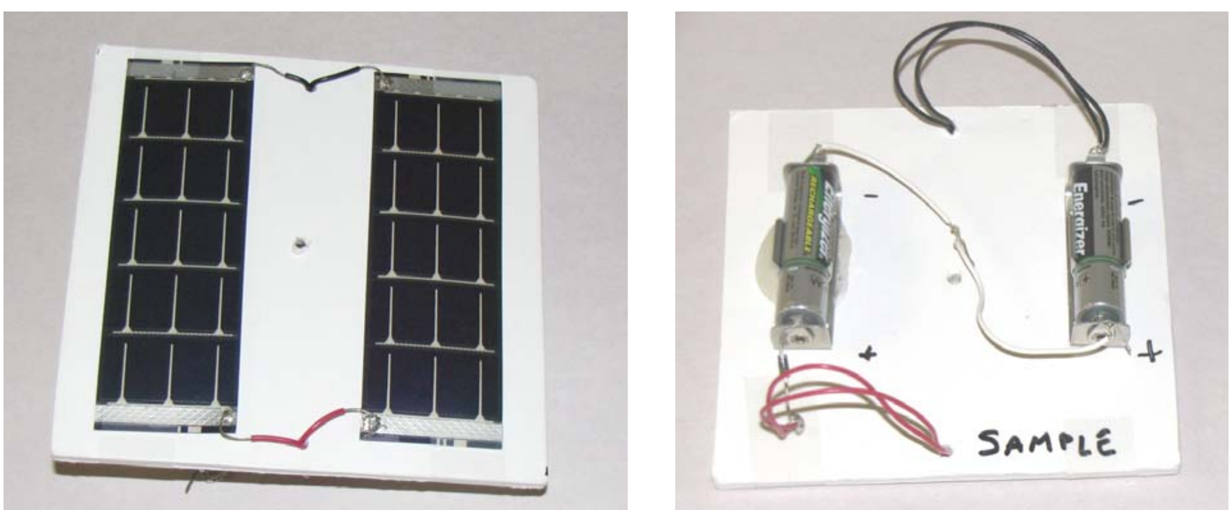

Figure 10: Photograph of the Front and Reverse Sides of the Photovoltaic Charger.

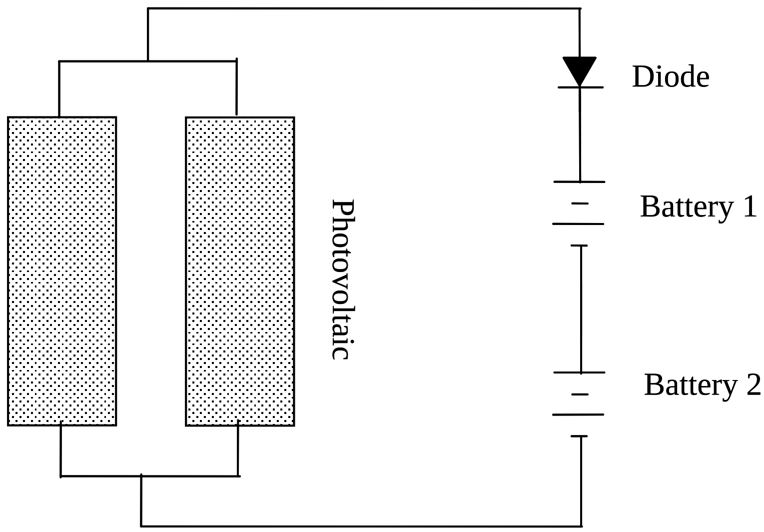

Figure 11: Diagram of Wiring of the Photovoltaic Battery Recharger.

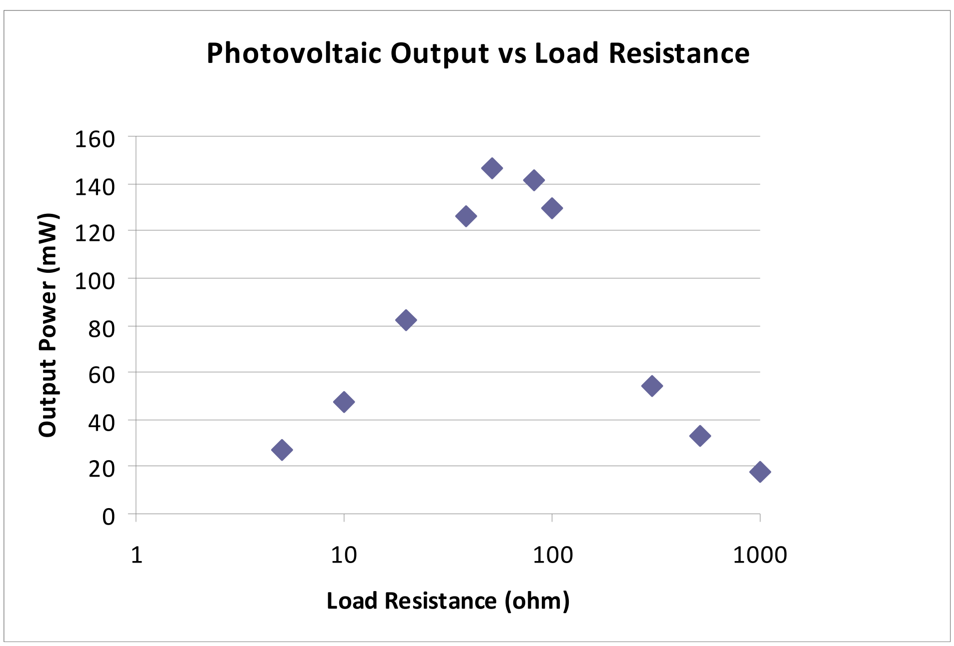

Figure 12: Representative Student Data on Photovoltaic Output Power.

Evaluation Methods

Evaluation is based on tests of student content knowledge before and after the laboratory. Student surveys about various aspects of the laboratory are also part of the evaluation process. Preliminary student data is currently available.

Content tests were based on the underlying principles involved as well as how the device works. The “how it works” questions addressed specific components in the device and the purpose or function of those components in the device operation.

Available content test results are summarized in Table 2. The content tests are based on a scale of 0 – 100 points, with 100 points being a perfect score. The result reported in the pre and post test for each laboratory is the average score of the students tested. All post-tests show statistically significant improvements over the pre-test scores ($p < 0.05$). For most of the laboratory projects, the average for the post-test is close to double the pre-test average.

Table 2: Subject Matter Content Test Pre and Post Laboratory Results.

Subject Content Tests	PreTest (max = 100)	Post - Test (max = 100)	Percent Change
LED Booklight	36	66	83%
Electric Motor	44	71	61%
Speaker	27	80	196%
Radio	62	84	35%
Transistor	13	91	600%
Photovoltaic	53	86	62%
Average	**39**	**80**	**103%**

Also reported is an overall average for the entire set of laboratory projects. This gives an approximate estimate of the effectiveness of the laboratory projects as a group. The pre-test average is 39 out of 100. This might be interpreted as a poor understanding of technology (technologically illiterate). The post-test overall average is 80 out of 100. This is a substantial improvement in content knowledge across these areas. As a group the students could be considered to have improved from “failing” to understand technology to a “fair” degree of understanding.

Students were also surveyed about their opinion of the laboratory projects. The available results for six laboratories are summarized in Table 3. The questions were based on a 0 to 5 point scale with 1 being “strongly disagree” and 5 being “strongly agree.” The students were asked to rate the laboratory as interesting, educationally useful, and whether or not they feel more competent about the course material as a result of the particular laboratory project.

The students found all of the projects interesting. Results ranged from 4.3 to 4.9 on a 5.0 scale. The students also gave the projects high ratings in terms of being educationally useful. The four projects had an average rating of 4.5 on the 5.0 scale. The student rating was slightly lower for the question that asked students if they felt more competent about the course material after having completed the lab. It may be that students are more confident in assessing what interests them compared to estimating their degree of mastery of the course materials. Overall the laboratory projects were well-received by the students.

Table 3: Result of Student Evaluations of Laboratory Projects (1 – 5 point scale).

Average Student Rating (1-5 scale)	Interesting	Educationally Useful	Improved My Competence in Course Material
LED Booklight	4.9	4.5	3.9
DC Motor	4.6	4.6	4.2
Speaker	4.6	4.4	4.0
Radio	4.7	4.6	4.0
Amplifier	4.3	4.5	3.9
Photovoltaic Charger	4.6	4.6	4.0
Overall Average	**4.6 / 5.0**	**4.5 / 5.0**	**4.0 / 5.0**

Evaluation Based on the Design Process

An approach to evaluation based on the application of the design process is underdevelopment for use in this project. The approach is based on the view of technical systems as being composed of components which carryout subfunctions in support of the overall functioning of the system[21-24]. Students are asked to design and construct their own version of the technological device. Design process evaluation using the electrodynamic speaker has been developed thus far.

To support students in this process, an explanation is given of how the speaker works in terms of the functions that must be accomplished. This functional analysis or functional decomposition is drawn from techniques used in engineering product development [21-24]. A functional analysis diagram of an electrodynamic speaker is shown in Figure 13. This type of analysis emphasizes the transformations or flows of material, energy, and information that occur in the system.

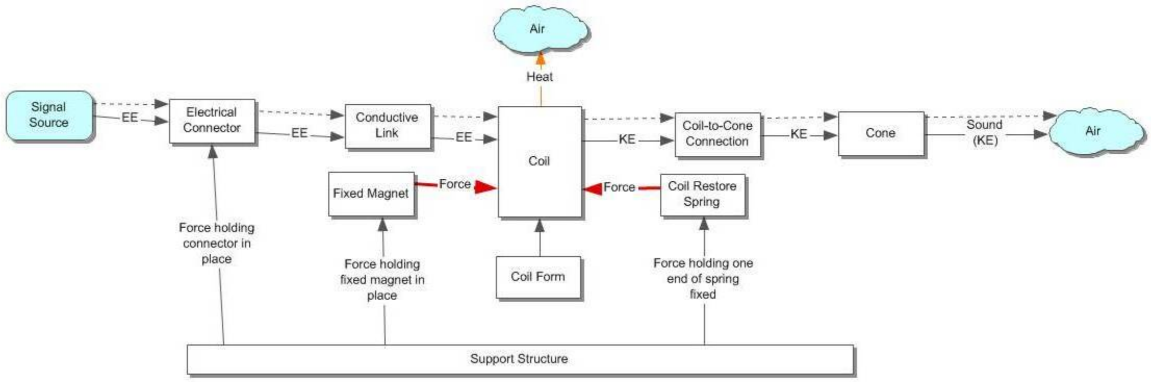

Figure 13: Functional Description of How a Speaker Works.

The operation of the speaker was explained in terms of nine key components responsible for transforming the input electrical signal into the sound vibrations output. The function of the component is described and the important design requirements or characteristics of that component are reviewed. This information is summarized in Table 4.

Table 4: Key Component Sub-Functions of an Electrodynamic Speaker.

	Component	Function	Characteristics
1	Fixed Magnet	Push/pull on coil	Very strong magnetic field
2	Coil	Create varying magnet field	Light weight, 8 ohms resistance
3	Coil form	Hold coil wire in place	Light weight , hold coil wire in place
4	Conductive link	Transfer current to coil	Transfer current without hindering coil motion
5	Support structure	Hold components	Sturdy, easy to construct
6	Cone-coil-link	Transfer KE from coil to cone	Light weight, transmit axial force without bending
7	Cone	Transfer KE into Sound energy	Relatively light, able to flex but somewhat stiff
8	Restoring spring	Push/pull on coil opposite fixed magnet	Appropriate stiffness not too stiff but able to exert sufficient force to keep coil in place with respect to the fixed magnet
9	Electrical Connector	Connect to signal source	Secure to prevent accidental pulling or tugging on the coil

The students are then given access to a wide variety of basic materials which can serve as component parts for an electrodynamic speaker. This includes items such as paper plates, cups, cardboard, plastic sheeting, cloth, and construction paper. Each individual student completes his or her own design. Students create designs for each component using basic materials. Some materials are specified. In this first effort, the gage and length of wire to be used in the coil was specified. Also the electrical connector was provided. The supply of basic materials also included a variety of different types of magnets which could be selected by the student to provide a permanent magnetic field.

In completing this process, students were not told about the assignment ahead of time. Also they were restricted to the laboratory without access to the internet. These restrictions were used to prevent students from looking online for the design of a speaker using basic components and then replicating that design. The intent was to require students to think through the design process and to use the idea of “form follows function” to develop a unique design.

Some examples of completed speakers designed and built by students are shown in Figure 14. In the group of 42 students tested all were able to design and build their own speaker. Each speaker was required to produce audible sound when connected to the same amplifier used with the cup speaker described above. The project could be completed in three hours by most students. While all of the students were successful, some required considerably more coaching or guidance than others. Students were allowed to keep the working speakers and take them home. The total cost of the materials in each student-designed speaker including the connector, wire, and magnet was approximately five dollars.

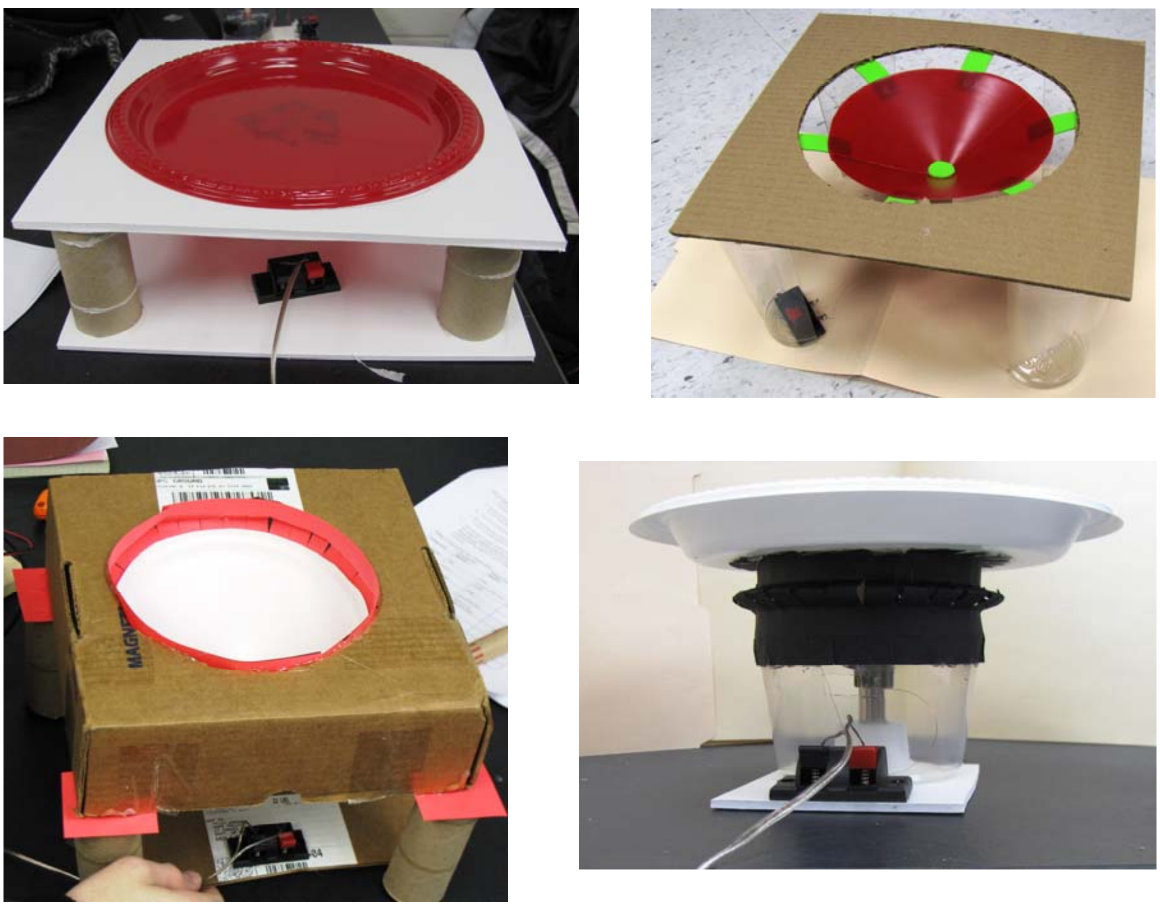

Figure 3: Examples of Working Simple Speakers Designed and Built by Students.

The evaluation based on the design process shows promise as a means of assessment of student learning. While the designs have the same basic function structure of any electrodynmaic speakers, getting the device to work requires a level of understanding of the principles involved in this device. The students themselves have a feeling of accomplishment when they are able to create a functioning device of their own design.

Discussion

The students completing the projects demonstrate increases in content knowledge related to the project areas. The content knowledge increases are statistically significant. Students were able to progress from a poor to a fair level of technological literacy. These results are encouraging indicators that it is possible to establish a functional level of understanding of technology among all undergraduate students. The students see the projects as educationally useful and interesting. Some success was found in having students develop their own designs for simple technological devices based on knowledge acquired by completion of these projects.

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