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Freshman Engineering Project on Energy Scavenging*

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This paper describes the design, development and implementation of an energy scavenging project for an introduction to engineering course. The overall objective of the project is to provide students with a hands-on experience on all the components of a renewable energy system. After completing this project students should be able to understand the basic engineering concepts as well as the principles of the design process. Energy scavenging is a form of renewable energy technology at micro or nano scale level. In this project students design and build a small vibrating system that takes the place of the energy source. A piezoelectric material is used to collect the energy produced by the vibrating system. The output of the piezoelectric material is fed to a rectifier circuit whose output charges a battery. Over two hundred freshman engineering students from four different disciplines: civil, computer, electrical, and mechanical have completed this project. Students' reports, reflection papers, and the results from surveys clearly show that, in addition to be a very appealing project, its objectives are achieved.

Keywords: freshman engineering; energy scavenging; concept learning; piezoelectric material

1. Introduction

Engineers play a major role in the area of renewable energy. The well being of future societies will depend on how well we generate, distribute and manage the energy needed to have every person lead a comfortable life. A crucial component of this process is to increase the use of renewable energy sources (e.g. wind, water, solar). These sources produce almost no waste to be disposed of and therefore their negative impact on the environment is very small. It is therefore desirable to have engineering students exposed to this important topic as early as possible in their studies.

It is also important to expose incoming engineering students to basic engineering concepts, such as gear ratio, spectrum, diodes, and transducers. Understanding these concepts will help students appreciate better the content of fundamental courses in their specific field, such as circuits, statics, and dynamics. To introduce these concepts to freshman students is challenging. Many of these students feel that these concepts are too abstract. Hands-on activities have several advantages over traditional methods when explaining a variety of principles and concepts [1]. Hands-on activities also have a great effect in stimulating students' interest in engineering and therefore they have become a necessary component in any freshman engineering curriculum to ensure and increase retention [2]. To increase the effectiveness of hands-on projects they should also address contemporary issues.

Harvesting renewable energy, at a very small scale, is usually called energy scavenging. Energy scavenging is suitable for applications where the power requirements are small (less than 100 mW). Examples of these applications are wireless sensor networks used in the medical care field [3, 4] and embedded systems used to monitor the structural health of buildings, bridges, airplanes, etc. [5, 6].

Piezoelectric materials are good candidates to harvest vibration energy for wireless and self-powered microsystems [7]. Piezoelectric materials become electrically polarized when subjected to mechanical strain and the degree of polarization is proportional to the applied strain. A hands-on energy scavenging project that uses a piezoelectric material was therefore chosen for our freshman engineering course, ENGR/ETCS 101, which students take during their first year after being admitted into the university.

ENGR/ETCS 101—Introduction to Engineering, Technology, and Computer Science, is a one hour per week course specifically designed for first year engineering and engineering technology students [8]. The overall purpose of this course is to prepare students for a successful academic performance, to introduce the engineering field, and to make students aware of the engineering problem solving strategy. The current course outcomes are:

1. Understand and apply the concepts of professional and ethical responsibility
2. Communicate effectively through essays and reports
3. Understand the engineering profession and appreciate the contributions of engineers and engineering to today's society.

In order to achieve these outcomes, the students are asked throughout the semester to read material in

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their textbook [9] and news articles and to write memos and essays. They are also given a series of lectures about particular engineering and technology fields of study. These fields include civil, computer, electrical, and mechanical engineering, which are the four majors in our department. To gain an understanding of professional ethics, they are also asked to use the engineering code of ethics and apply it to a real case. For the past several semesters the case was the I-35W bridge collapse in Minnesota that took place in 2007 [10].

ENGR/ETCS 101 also requires students to conduct a group project to give them experience in engineering problem solving strategies. When ETCS/ENGR 101 was first launched (in 1999) students were asked to design, build, and test an autonomous robot using the Lego Challenger set (similar to the Lego Mindstorms set) that had recently become available. This project proved to be very successful and played an important role in improving the retention of engineering and technology students [11]. The project was discontinued in 2003 because the faculty members involved with the course moved into different academic roles. A reverse engineering project was then implemented to take the place of the robot project. The reverse engineering project requires students, working in groups, to find and research a specific device, disassemble it, and understand how the device works. Students are also asked to conduct quantitative measurements related to the device. The reverse engineering project always had the challenge for students to find a device with the right level of complexity. Also students often had difficulties conducting enough quantitative experiments to gain experience in engineering problem solving strategies. The reverse engineering project also lacks enough hands-on and design component to attract students' interests.

After one of the author started teaching this course in the fall of 2008, a new hands-on group project was deemed to be necessary. The decision on the project topic was made based on several factors. The topic of scavenging energy from the environment is an area that we have been exploring for our own research interests. Therefore having a project in this area not only fell within our academic interests but it also has a great deal of societal impact. Furthermore, this type of project also fits very well the requirements of the IEEE Real-World Engineering Projects (RWEP) program that funds high-quality, tested, hands-on team-based society-focused projects for first-year students [12]. These projects are designed to increase the recruitment, persistence to degree, and for satisfaction of all students, and particularly women, in baccalaureate EE, CE, CS, BE and EET degree programs. We then decided in April 2009 to introduce a freshman level design project in energy scavenging from vibrations using a piezoelectric material. At the same time this project was proposed to the IEEE RWEP program. The project was developed during the summer of 2009 and implemented in the fall of 2009 and spring of 2010 with over two hundred students in nine sections of ENGR/ETCS 101. After three review cycles, this project has been accepted by the IEEE RWEP program, and it is currently published in its online library [13]. The project materials in the library include: the detailed project description for students and faculty who plan to adopt this project; background and review lectures; instructions for the experimental measurement and battery charging; and a sample students' report.

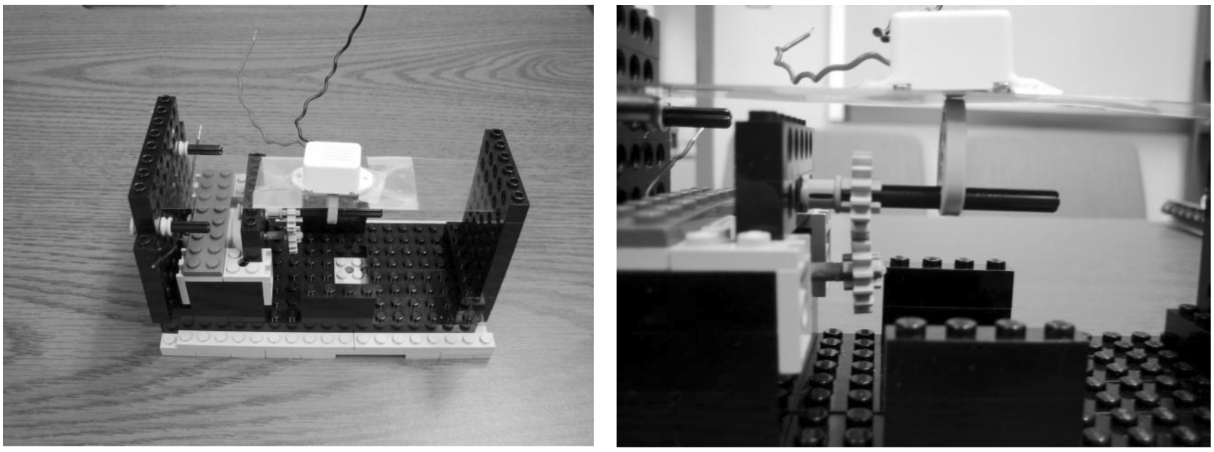
Results from pre- and post-surveys and students' comments in their reflection papers show that this project is a very enjoyable learning experience. More importantly, the project helped students learn several basic engineering concepts as well as principles of the engineering design process.

The remainder of this paper is organized as follows. In Section 2, we introduce the development, components and unique features of this hands-on project. In Section 3, we present students' activities and samples of their work. Challenges and changes made during the implementation are presented in Section 4. In Section 5, survey results are presented to show the effectiveness of this project. Finally, we conclude the paper in Section 6.

2. Description of this project

2.1 Project development

We started the development of the project in the summer of 2009 by first selecting the DC motor, the piezoelectric device and the components used to generate vibrations. The detailed description of the materials and equipment needed in this project can be found in [13]. The Lego Challenger sets that were used in the earlier freshman engineering robotics hands-on project had been left in the storage room for quite a few years. Lego pieces, including bricks, beams, axles, gears, offer great flexibility and yet enough complexity for students to design and build a large variety of systems. Because Lego pieces can be readily obtained the project can be easily adopted by any other school worldwide. Thus it was decided Lego pieces were to be the main components for the vibrating system to minimize the implementation costs. A simple vibrating station composed of Lego pieces and a DC motor was first built as a prototype to test the performance of three different piezo buzzers bought from RadioShack. Once a workable prototype was built and tested there was a good level of confidence that students



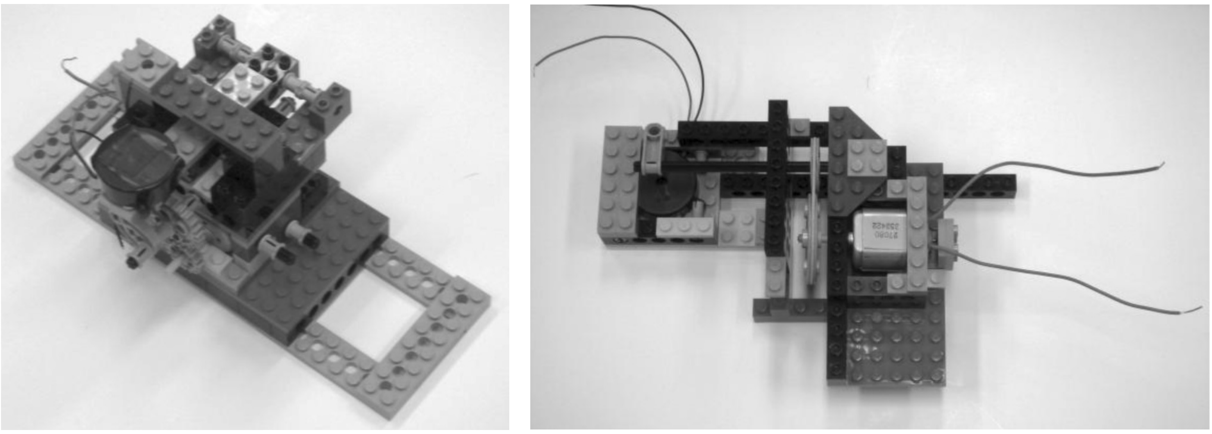
(a) The prototype station (b) The asymmetric cam location

Fig. 1. An example of a vibrating station using a cam built by the course instructors.

would be able to design and build their own units with the components available to them. Figure 1 shows the prototype. During the implementation of this project, not surprisingly, many of the prototypes built by the students had superior features to those built by the instructors. This project provide an opportunity for the students to experience the most important aspect of what is to be an engineer, that is, *to be able to design, build, and test something, and in doing so to be as creative as possible.* Figure 2 shows two vibrating systems built by the students in the introduction to engineering course where this project was implemented.

To harvest the energy produced by the piezo buzzer, a circuit that includes a rectifier and an energy-storage subsystem is needed. The system adopted for this project is a circuit that is slightly modified from the one used in [14]. Figure 3 shows the circuitry. Two NiMH rechargeable batteries (button cells) rated at 40 mAh and 80 mAh were tested using this circuit and the vibrating system shown in Fig. 1 with three different piezo buzzers. The testing results showed that the combination of the piezo buzzer with the highest power rating and the battery with the lower rating gave the most effective results. Thus the piezo buzzer and the battery were determined.

Once the components of the project were determined, measurement tools had to be selected for the testing and evaluation of the effectiveness of the vibrating system. To test and evaluate the effectiveness of their design, students need to measure and observe the electrical signals generated by the piezo buzzer due to the vibrations. In order to minimize the cost of the project, it is important to be able to do this task without the use of a physical oscilloscope. The price of a software oscilloscope is usually low (less than $30 per copy). Several software oscilloscopes that are available from several suppliers, such as Winscope, Zelscope, and Virtins Multi-Instrument, were then examined and compared. It was concluded that the Virtins Multi Instrument



(a) Vibrations created by a level attached to the motor (b) Loose fixture of the motor to generate vibrations

Fig. 2. Two testing stations built by students in ENGR/ETCS 101.

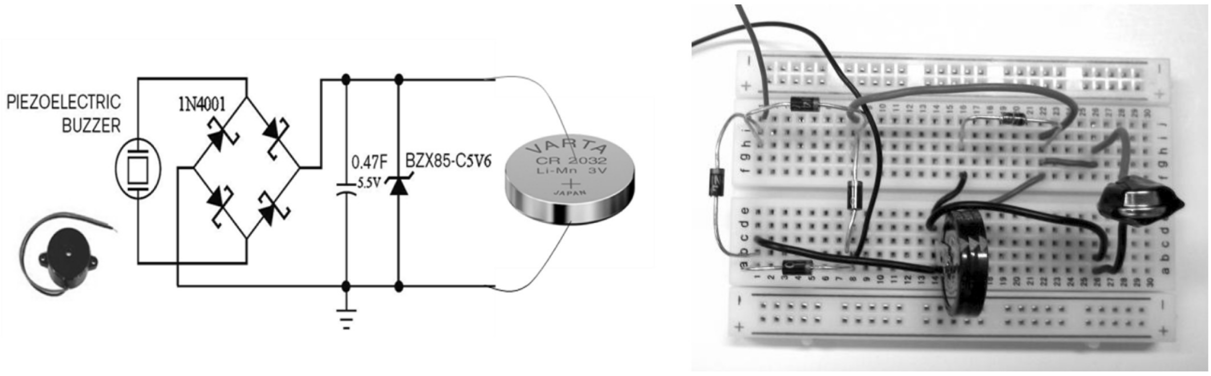


Fig. 3. Energy scavenging circuitry.

Pro 3.1 had enough complexity to measure the magnitude and spectrum of the electrical signals, and thus it was chosen as the software scope.

Since the software scopes use the computer's audio card (the microphone input) a special cable is needed, which can be bought (around $30 per cable) or built at a much lower cost. We decided to use the latter option, which has as drawback the labor time dedicated to making the cables and the need to use a voltage divider to have it work properly. For our project we used a decade resistor box to implement a voltage divider. The detailed instructions on how the cable is built and how the voltage divider is constructed can be found in [13].

2.2 Project description

The design, experimental testing and implementation steps of this project are:

1. The design and construction of a vibrating system
2. Experimental measurements, data acquisition, and analysis
3. The use of an energy harvesting circuitry to charge a battery.

The design component of this project is the construction of a vibrating system. The vibrating system is driven by a DC motor with different discrete values of input voltage. Each team is asked to design two test stations that generate vibrations of different amplitudes and frequencies. One of the test stations must include a gear train in the vibrating system in order to match as closely as possible the resonant frequency of a piezo buzzer. Figure 4 shows a sample of the components provided to the students. When constructing the two test stations, students have access to more Lego pieces than the ones shown in Fig. 4.

Students are then required to conduct experimental measurements of the magnitude and spectrum of the electrical signals generated by the piezo buzzer when it is vibrating. Students can modify and improve their design as they see fit, based on the measurements. After several iterations of experimental testing and redesign, the two final best de-

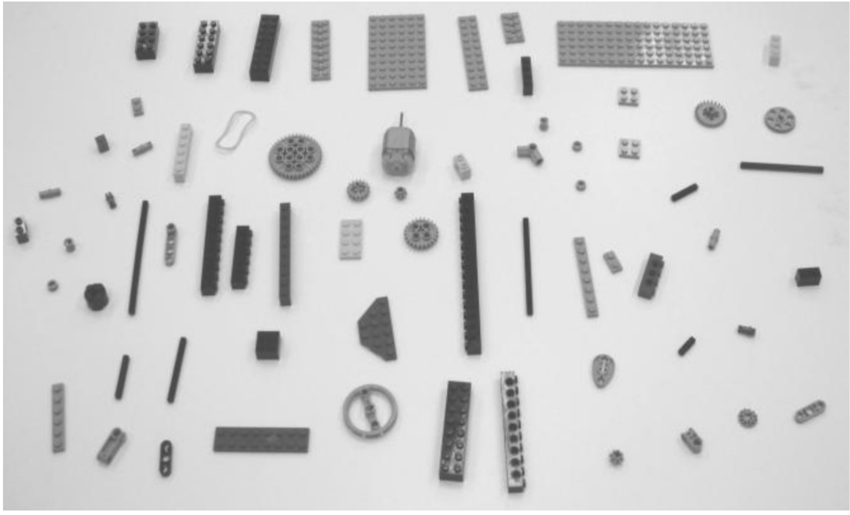


Fig. 4. A sample of components provided to students.

signs are used for the battery charging experiments. Students connect the piezo buzzer from each of their vibrating systems to an energy harvesting circuit built on a breadboard (Fig. 3) to charge a 40 mA cell button battery for half an hour. The voltage across the battery is measured every five minutes to observe how effective the charging process is.

2.3 Design trade-offs and constraints

In industry, engineers must take into account several constraints when designing a specific system, and should know how to weigh the pros and cons when making decisions. It is then important to expose engineering students to design trade-offs and constraints as early as possible in their education. In this project, each team is asked to design two types of testing stations that generate vibrations for the piezo buzzer. One of the designs does not gear down or gear up the motor. The other design should include a gearbox with different gear ratios so that it decreases or increases the speed provided by the motor in order to match the resonant frequency of the piezo buzzer. The gearbox must be designed based on the ratios between the quantized values of the speed of the motor and the resonant frequencies of the piezo buzzers. The gearbox is to be constructed using Lego gears. Adding a gearbox provides a better chance for the piezo buzzer to generate the largest response. The comparison of the output voltage of the piezo buzzer, using the two different testing stations, can illustrate the trade-off between design complexity and the energy generated. The more complex the design is, the longer the time and higher the costs needed to implement it, but the more energy it should generate. The designed system has to meet the following constraints:

- Vibration frequency as close as possible to the resonant frequency of the piezo buzzer
- Size limited to $12' \times 8'' \times 6''$ $(L \times H \times W)$
- The vibrating system should be able to work continuously for at least half an hour
- A minimum of 2 volts peak to peak output signal to be obtained from the piezo-buzzer
- The use of glue, tape, or any bonding substance that permanently connects the Lego pieces are not allowed (the same rule applies to the piezo-buzzer).

2.4 Differences of this project when compared with other freshman engineering projects

There are several features that make this project unique when compared with other freshman engineering design projects. To the best of our knowledge, this project is the first design project in energy scavenging that includes a vibrating system and piezoelectric materials at a freshman level, or even at an undergraduate level. The efficient design of energy scavenging systems using piezoelectric materials are topics for Masters' theses [15] or even Ph.D. dissertations [16, 17]. We are very aware that the complexity of projects/research at undergraduate, masters, and Ph.D. levels are not of the same magnitude and complexity. However, the idea of introducing freshman engineering students to a cutting-edge topic through a doable hands-on project is of great significance. Unlike most conventional freshmen engineering design projects, that target a particular engineering field, this project combines elements from electrical engineering (energy harvesting circuitry), computer engineering (data acquisition), mechanical engineering and civil engineering (vibrations). These four majors are the four largest engineering majors in most universities. Thus, this project has the potential of being disseminated to a large population of engineering students. This project also helps students in the following ways. For students who haven't decided on a specific engineering field, the project gives them a good exposure of different engineering fields via hands-on activities. It helps all students gain multidisciplinary skills during their freshman year. Finally, it is a low cost project and therefore it can be easily adopted by many schools.

3. Students' activities and work

3.1 Students' activities

This project is a group project. In the fall of 2009, the whole class was divided into groups of 3 or 4 students. Figure 5 shows students working on the project. We learned from that semester that 4 students are too many in one single group, so in the spring of 2010 we divided the class into groups of 2 or 3 students. The comparison between the projects' performance corresponding to each semester did show that students were overall more satisfied in spring 2010 than fall 2009. More details are given in Section 5.

The project takes fifteen hours to accomplish. The timeline for students' activities, expressed in hours, is shown in Table 1. Two and a half hours are dedicated to the lectures that provide the necessary background information, instructions on experimental measurements, and a summary. In our school, six weeks were allocated to the project, where in each week there is 50 minutes of class time dedicated to the project. This amount of time is not enough to complete the project. Students then need to find time outside the class to build their design and conduct experimental tests. After the first lecture, students are asked to brainstorm and write initial design proposals prior to the next lecture. To help them with this process several

Fig. 5. Students working on the project.

Table 1. Timeline of students' activities

Students' activities	**Timeline**
Initial vibrating system design	2.5 hours
Construction, experimental measurements, tests, and evaluation	8 hours
Report writing	2 hours

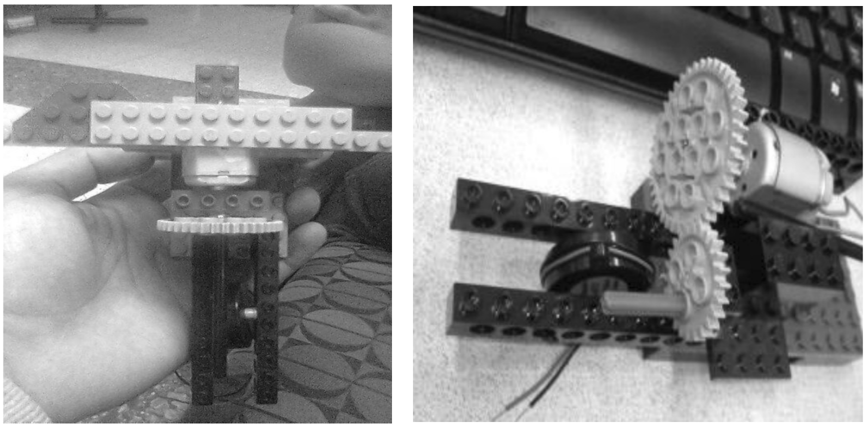
small plastic boxes each with a sample of the Lego pieces as well as the motor and the piezo buzzer are made available to them on a check-out basis. Starting from the second lecture, students build the vibrating systems, conduct experimental measurements. They go through these two steps for several iterations to obtain the best design to charge the battery. After the project is finished, each group must write a technical report that includes a description of their designs, the experimental results, and what they learned from this project.

3.2 Students' work

Figure 6 shows two vibrating systems designed and built by one of the teams that took ENGR/ETCS 101 in the fall of 2009. Figure 7 shows the results when charging the battery for 30 minutes using both designs. The voltage across the battery was measured every 5 minutes. These measurements show that the design with gear trains (design 2) has a better charging performance. More examples of students' activities and work were presented at [18], a mini-workshop organized by IEEE RWEP program.

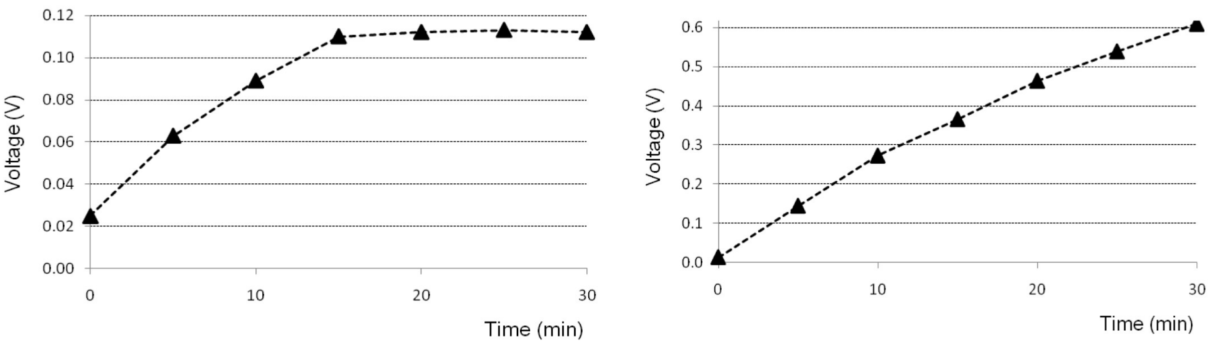
4. Challenges and changes made during the project implementation

One of the IEEE RWEP program's main requirements for the project was that the overall cost be kept to a minimum. The intention is that successful projects should be able to be implemented even in regions in the world where laboratory resources are scarce or too expensive for the host institution. Therefore readily available hardware and software components were chosen such as a PC based oscilloscope instead of a regular physical oscilloscope. Other components chosen are a simple small DC



(a) Design 1: without a gear train (b) Design 2: with a gear train

Fig. 6. Two vibrating systems built by students.



(a) For design 1

(b) For design 2

Fig. 7. Battery charging results (*Voltage* vs. *Time*).

motor, Lego pieces, a resistor based voltage divider to match the output of the piezo-buzzer to the input of the PC's audio card, and a small breadboard used to construct the rectifying circuit.

It was found necessary to monitor the work of the students continuously as they progress in their project, since minor complications took place on a regular basis. For example the button shaped cell battery comes without leads. To make connections in the breadboard, two wires need to be soldered to the battery ends. This soldering can come lose with time and thus it is suggested that it be executed in the best possible way and then to use a small strip of tape wrapped around the battery ends to reinforce the connection.

This project was first implemented in the fall of 2009. Students' survey results are presented in [19, 20]. In [19] a simple description of this project was presented along with the survey results from the fall of 2009. In [20] the design process and implementation of this project was discussed. Based on students' feedback and reflection papers, we made the following changes in the spring of 2010. Section 5 shows a comparison of the project effectiveness between the two semesters.

- The class was divided into groups of 2 or 3 students instead of 4.
- Soldering on a button cell battery can be dangerous. Therefore in the spring of 2010 we switched to using small plastic clothes clips to keep the wire leads tightly attached to the battery ends.
- A small sized plastic box to store the breadboard circuit was used to protect the circuit when stored with the Lego components in the larger storage container.
- A common comment found in the students' reflection paper was that the time spent on the project was too much for a one-credit hour course. 'One thing that I would recommend to improve the execution of this project would be to give more time to be able to do it. With more time, I think that the results of the projects would be more accurate since we would be able to run more and more tests.' Therefore, in spring 2010 students were only required to construct one design and conduct experimental measurement and battery charging using the best design from the two designs generated.
- In the fall of 2009 we allowed students to use a tape to fix the piezo buzzer to the vibrating system. However, we found that many teams were able to produce a design without using any tape at all, which is also a good feature to keep the piezo buzzer loose. Hence in the spring of 2010 no tape was allowed.

5. Measurement of effectiveness of the project

The purpose of this project is twofold: first, to teach students several fundamental engineering concepts and second, to stimulate their interest in engineering and help with retention. Survey results and students' reflection papers are used to measure the effectiveness of this project in achieving these two goals.

In both semesters, a survey was given to students before they started the project to assess their understanding of the following concepts: diode, AC vs. DC, gear ratio, simple gear train, compound gear train, frequency, spectrum, asymmetric cam, signal rectifying, and harmonic vibration. Students were asked to rate their understanding over these concepts using a range of 1–5. After the project was finished, a post-survey on the same concepts was conducted for comparison. In fall 2009, 113 students took the pre-survey, and 117 students took the post-survey. In spring 2010, 81 students took the pre-survey, and 73 students took the post-survey. The survey was given to students during the class time for a better return. Because not every student attended those two classes when the survey was given, the total numbers of students who took the pre- and post-survey are slightly different. The students were from the following majors, Electrical Engineering (EE), Computer Engineering (CmpE), Mechanical Engineering (ME), Civil Engineering (CE), Mechanical Engineering Technology (MET), and Industrial Engineering Technology (IET), as well as a few students from other majors. For each semester the ratings from students in all of the sections were analyzed together by taking averages for students in the same major. Table 2 shows the pre- and post-survey results for different majors in both semesters. In such an early stage in their studies, there are no significant differences of students from different majors. The results are also presented graphically in Figures 8 and 9. Figure 8 shows two charts to compare the pre- and post-survey results for fall 2009 and spring 2010. These results show a significant improvement in the understanding of these concepts for both semesters. Figure 9 shows the difference between the pre- and post- survey results for both semesters. It is observed in Fig. 9 that there is a relatively large improvement in the learning of the 'signal rectifying' concept. We believe that this result is due to the decreased length of time spent building just one test station, in the spring of 2010. These time savings provided more opportunities for students to measure and understand better the output from the signal rectifying circuit.

At the end of the project, each student wrote a reflection paper about their experiences in the project. These are some comments from the students. 'Personally this project definitely helped me learn a little bit more of just what an engineer does every day. It helped me to see that it involves lots of time, perseverance, and ingenuity to attain a specific goal, but once you reach the said goal, it can be a very beneficial thing to you and those around you.' 'The benefits that I received were in knowledge. I learned a lot about electronics that I never knew before and about how to run and execute test on electronics. I also learned what a piezo buzzer is and learned about the piezoelectric effect. There was a lot of knowledge in this. I also learned about what kind of work I have to put in for college.' 'I really enjoyed this project. It really expanded my knowledge of the electrical and mechanical aspects of engineering.'

Enhancing the hands-on team activities of our engineering students during their first year was one of the motivations for the development of this project. ET 311, the classroom used for this course was specially designed by a faculty member from our department to enhance students' engagement. Detailed background information about the room design, the assessment methodology and results can be found in [21]. The assessment of effectiveness of the room use was conducted for four semesters,

Table 2. Pre- and post-survey results by majors

	Civil ENGR				**Computer ENGR**				**Electrical ENGR**				**Mechanical ENGR**				**MET**				**IET**				**Others**			
	Fall 09		**Spring 10**		**Fall 09**		**Spring 10**		**Fall 09**		**Spring 10**		**Fall 09**		**Spring 10**		**Fall 09**		**Spring 10**		**Fall 09**		**Spring 10**		**Fall 09**		**Spring 10**	
	Pre	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**
Number of students	**18**	**16**	**15**	**13**	**7**	**9**	**4**	**6**	**17**	**14**	**18**	**15**	**41**	**41**	**25**	**17**	**14**	**20**	**8**	**6**	**1**	**1**	**3**	**3**	**15**	**16**	**8**	**13**
Diode	1.9	3.3	2.1	3.4	3.0	3.6	2.3	3.3	2.1	3.5	2.3	3.2	2.0	3.3	1.9	2.9	1.5	3.4	1.8	3.3	3.0	4.0	1.7	2.7	1.3	3.4	1.5	3.2
AV vs. DC	2.7	3.9	2.4	3.8	3.6	4.2	2.5	4.0	3.2	4.3	3.1	4.0	3.0	3.9	2.4	3.8	2.9	3.8	2.0	3.7	3.0	4.0	3.3	3.3	2.1	3.8	2.3	3.8
Gear ratio	2.8	4.1	2.2	3.6	2.4	4.1	2.3	4.0	2.7	4.0	2.6	3.2	2.9	4.1	2.6	3.8	2.5	4.2	2.4	3.8	3.0	5.0	3.0	4.3	2.2	3.8	1.9	3.7
Simple gear train	2.4	4.2	2.1	3.7	2.0	4.0	1.3	3.8	2.4	3.7	2.1	3.4	2.7	4.1	2.3	3.9	2.4	4.0	2.4	3.8	1.0	5.0	2.3	3.7	1.9	3.9	1.8	3.8
Compound gear train	2.1	4.1	1.7	3.0	1.6	3.7	1.3	3.5	1.6	3.4	1.5	3.1	2.2	3.9	2.0	3.5	2.1	3.7	1.8	4.0	1.0	5.0	1.7	3.0	1.5	3.9	1.4	3.6
Frequency	3.6	4.2	3.0	3.9	3.7	4.2	3.0	3.8	3.2	4.2	2.7	3.9	3.2	4.0	2.5	3.8	2.8	3.8	3.3	4.3	3.0	5.0	2.3	2.7	2.6	4.3	2.8	4.0
Spectrum	2.9	3.1	2.4	3.2	2.9	3.3	2.3	3.0	2.5	3.5	2.4	3.3	2.6	3.0	2.0	2.8	1.8	3.2	1.9	3.5	3.0	4.0	2.0	2.3	2.2	3.5	2.5	3.4
Asymmetric cam	1.6	2.5	1.5	2.5	1.1	2.9	1.3	2.3	1.4	3.2	1.7	3.1	1.7	3.2	2.0	3.2	1.7	3.1	1.3	2.3	1.0	4.0	1.7	2.3	1.4	3.1	1.4	3.4
Signal rectifying	1.5	2.8	1.3	2.5	1.7	3.1	2.0	3.8	1.6	3.2	1.6	3.3	1.7	3.2	1.5	2.9	1.4	3.2	1.1	3.3	1.0	4.0	1.0	2.0	1.2	3.3	1.3	3.0
Harmonic vibration	2.4	4.1	1.9	3.7	1.9	3.7	2.3	3.5	2.6	4.1	2.1	3.8	2.4	4.0	1.8	3.3	1.6	3.9	1.5	4.2	3.0	5.0	2.0	3.3	1.7	4.0	2.1	3.8

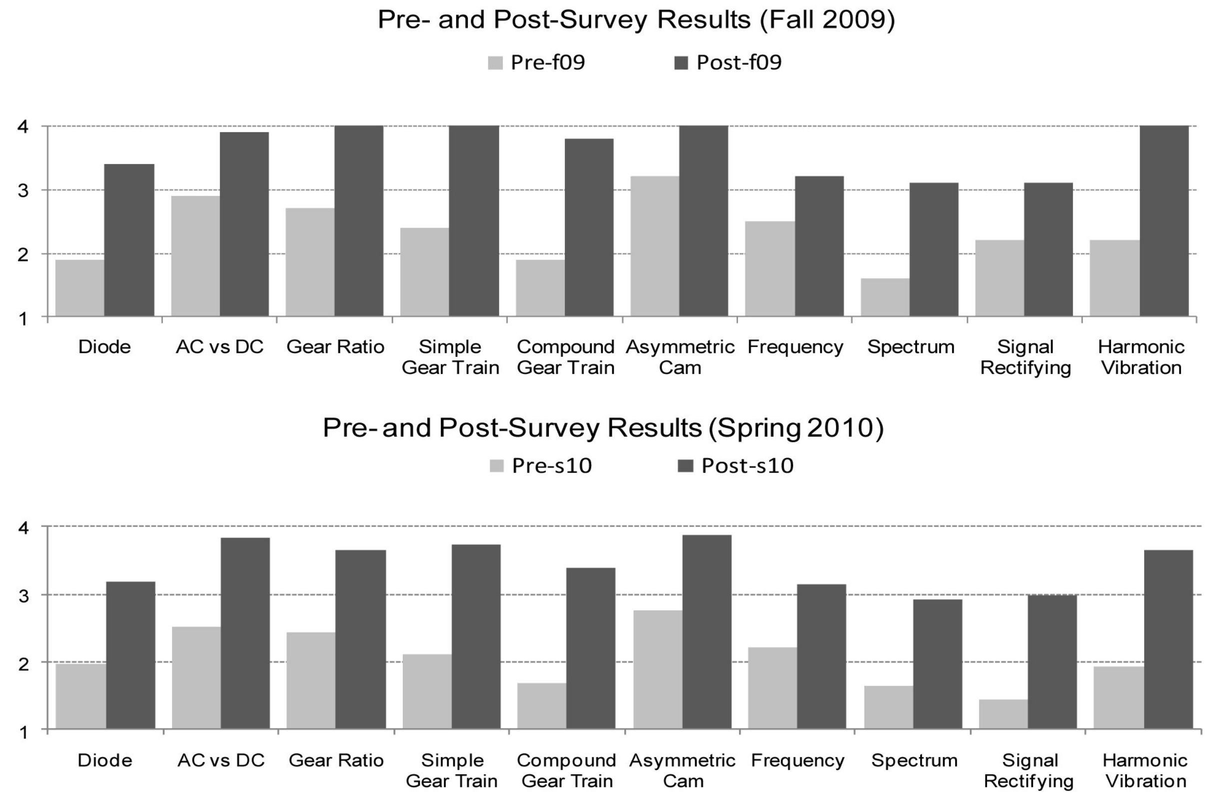


Fig. 8. Pre- and post-survey results.

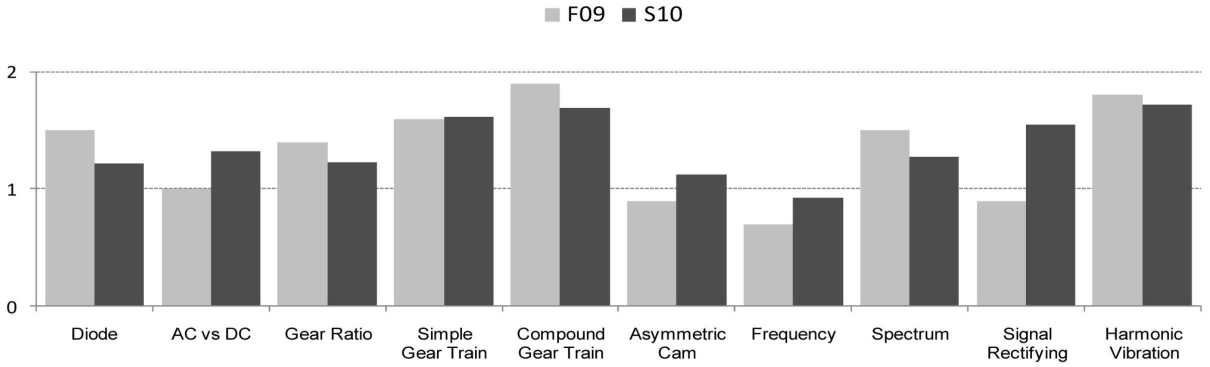


Fig. 9. Difference between pre- and post-survey results.

fall 2008, spring 2009, fall 2009, and spring 2010. Prior to fall 2009, the reverse engineering project was the group project used in this introduction to engineering course. A portion of the survey includes questions asking students to compare their experiences directly in ET 311 with other classrooms. These questions ask directly about interactions with other students and the instructor, time spent on group activities and time focused on a classroom task or problem. These questions directly reflect four of the Chickering and Gamson's *Seven Principles for Good Practice in Undergraduate Education*. Here we want to show the comparison of students' responses to the two different projects, with the instructor being the same. The results show an increase in the students' engagement when performing the energy scavenging project. The survey includes four Likert-scaled items asking students to directly compare their experiences in the classroom of interest with other classrooms. These questions ask directly about interactions with other students and the instructor, time spent on group activities and time focused on a classroom task or problem. Students rate each questions with 1 = much less than other classrooms, 2 = less than other classrooms, 3 = same as other classrooms, 4 = more than other classrooms, and 5 = much more than other classrooms. Figure 10 shows the percentage of students who

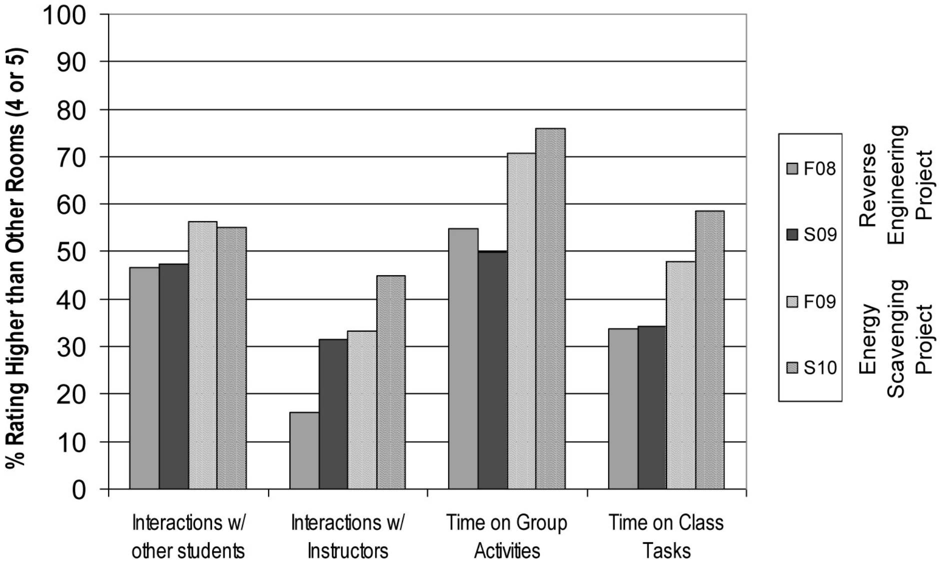


Fig. 10. Comparison of classroom use for two different projects.

rated this room higher than other rooms, i.e. 4 or 5. It is evident that students who did the energy scavenging project interacted more with the instructor and other classmates, and spent more time on group activities compared with the reverse engineering project. This means that the new project achieved the goal of enhancing the hands-on team activities to stimulate students' interests in engineering.

6. Conclusions

This paper describes the development and implementation of a freshman engineering hands-on project in energy scavenging or harvesting renewable energy at a very small scale. This project does not require students to have knowledge of calculus, thus it can be implemented even during the first semester in any engineering curriculum. In our school, this project was implemented in the fall of 2009 and in the spring of 2010 semesters with over two hundred students from four different engineering disciplines: Civil, Computer, Electrical, and Mechanical Engineering. The results from the pre- and post-surveys and students' comments in their reflection paper show that this project is a very enjoyable learning experience. Moreover, this project helped students learn several basic engineering concepts as well as principles of the engineering design process.

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