AMERICAN SOCIETY FOR ENGINEERING EDUCATION

Paper ID #35057

Experiential Learning through Undergraduate Research on a Roadway Energy Harvesting Design (WIP) ASEE NCS

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Dr. Tony Kerzmann's higher education background began with a Bachelor of Arts in Physics from Duquesne University, as well as a Bachelor's, Master's, and PhD in Mechanical Engineering from the University of Pittsburgh. After graduation, Dr. Kerzmann began his career as an assistant professor of Mechanical Engineering at Robert Morris University which afforded him the opportunity to research, teach, and advise in numerous engineering roles. He served as the mechanical coordinator for the RMU Engineering Department for six years, and was the Director of Outreach for the Research and Outreach Center in the School of Engineering, Mathematics and Science. In 2019, Dr. Kerzmann joined the Mechanical Engineering and Material Science (MEMS) department at the University of Pittsburgh. He is the advising coordinator and associate professor in the MEMS department, where he positively engages with numerous mechanical engineering advisees, teaches courses in mechanical engineering and sustainability, and conducts research in energy systems.

Throughout his career, Dr. Kerzmann has advised over eighty student projects, some of which have won regional and international awards. A recent project team won the Utility of Tomorrow competition, outperforming fifty-five international teams to bring home one of only five prizes. Additionally, he has developed and taught fourteen different courses, many of which were in the areas of energy, sustainability, thermodynamics, dynamics and heat transfer. He has always made an effort to incorporate experiential learning into the classroom through the use of demonstrations, guest speakers, student projects and site visits. Dr. Kerzmann is a firm believer that all students learn in their own unique way. In an effort to reach all students, he has consistently deployed a host of teaching strategies into his classes, including videos, example problems, quizzes, hands-on laboratories, demonstrations, and group work. Dr. Kerzmann is enthusiastic in the continued pursuit of his educational goals, research endeavors, and engagement of mechanical engineering students.

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Abstract
Experiential learning is a fundamental building block for improved concept retention and increases student engagement. Through the application of knowledge to subjects that students find interesting; a personal connection is formed with the concepts and the project itself. The emersion into the academic and hands-on aspects of engineering concepts lead to increased interest in lifelong learning and more permanent cognitive memory formation. Experiential, hands-on research projects that involve design and critical thinking apply all six levels of Bloom's Taxonomy of Learning. This paper presents an undergraduate research project which focuses on a kinetic energy harvesting device designed for roadways. The project requires a literature search, multiple design iterations, interaction with potential device users, and critical thinking about multiple design aspects. As this is a work in progress, future consideration will include CAD drawing, prototyping, and testing. The authors will discuss how the research project focused on each component of experiential learning: 1) experiencing, 2) reflection and 3) application. This work will also discuss the preliminary findings of a questionnaire used to guide the student's direction during the initial portion of the application phase.

Introduction

Innovating new energy harvesting techniques that do not rely on fossil fuels is a critical step towards expanding sustainable infrastructure and fighting the effects of climate change. The Yale Program for Climate Change Communication (YPCCC) conducted a survey with Climate Nexus and the George Mason University Center for Climate Change Communication that found 78% of voters support upgrading the electrical grid and expanding renewable energy sources using federal funds [1]. One possibility to consider when integrating renewable energy into our existing infrastructure is through harnessing the enormous amount of vehicular kinetic energy that is available on our roadways.

As of 2017 the Federal Highway Administration reports that there are 4,184,471 miles of public road in the United States alone [2]. These roadways provide a diverse environment for energy harvesting within the vast amount of infrastructure that already exists. The near constant exposure to solar radiation, wind, run-off from precipitation, and repetitive mechanical loading creates an opportunity to implement a system that takes advantage of one or more of these resources. Two separate comprehensive reviews of roadway-based energy have concluded that there is a wide-open space for further research of in-roadway energy harvesting devices [3,4].

This research focuses on the feasibility of implementing a roadway-based energy harvesting device. The project also considers the possible long-term impact of the device on the environment while keeping in mind its effects on the surrounding roadway. There is an emphasis on the enthusiasm and support of this concept from the public. In an effort to design a device that would be able to garner public support as well as improve the outlook of the climate crisis, multiple questionnaires were used to gather opinions to help shape the design of the energy harvesting device. Outcome 2 of ABET Criterion 3 states that students should be able "to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors" [5]. The use of outside opinions to narrow and revise the initial designs allowed the student to take specific concerns into consideration. Many of the opinions focused on a concern for public safety, economic factors, and environmental factors.

Experiential, hands-on research opportunities relate important concepts which are delivered in the classroom to real-world applications. While the classroom setting is effective at introducing basic engineering concepts, Student engagement is typically limited to the first three levels of Bloom's Taxonomy: 1) Knowledge, 2) Comprehension and 3) Application. Many students have an increased understanding and appreciation for engineering concepts when they are actively engaged in a project or problem outside of the lecture hall. A project, such as undergraduate research engages students on all six levels of Bloom's Taxonomy. Many courses lack hands-on components that facilitate making important connections between course material and the real-life concept application. The ability to connect concepts with applications is one of the true signals that a student's understanding is complete, along with gaining the ability to recall the information taught to them and recognize where outside of the classroom the material may be useful [6]. When a student fails to do these things, it is because they cannot recognize the relevance of the information they are taught and therefore cannot recall what they have learned when the student is given an opportunity to transfer their knowledge to a real-world situation [7]. A research project is an impactful option for undergraduate students to attain real-world hands-on experience, while also receiving an introduction to research methods. Undergraduate research is also a valuable way for students who are interested in graduate school and want to get a flavor for research while also jumpstarting their graduate careers. The benefits to undergraduate research also include a clearer understanding of how the scientific literature process works, valuable technical reading experience, and the potential to uncover their passion for research [8].

Experiential Learning

According to the University of California Science, Technology and Environmental Literacy (STEL) workgroup, experiential learning can be split into phases. The first phase is based on an observation and exploration of the topic being discussed. This part of the experiential learning process must include an engaging experience, such as research, as learning will not be as effective unless there is a deeper understanding of the concepts at play and the student is able to draw conclusions that can be properly applied to other situations. Secondly, the target learner must reflect and form theories as to what happened and why it happened in the first experiential learning phase. Lastly, the theories that the learner develops in the reflection portion of experiential learning are put to the test and applied. The goal of this application is to gather evidence to either support or disprove the tested theories and hypotheses [9,10].

Daniel Kahneman reports in his essay, *Attention and Effort* that a subject who is mentally engaged in an activity or experience can expend little effort but be able to demonstrate increased amounts of memory recall [11]. Since many educators consider an experience to be an essential step in a student's ability to truly learn and retain knowledge, it is imperative that the experience physically involves the student and piques their interest in the subject matter [9]. Experiential learning incorporates this core part of education as the first step and furthers the student's understanding of the presented concepts with the additional phases of reflection and application.

The project integrated the three phases of experiential learning, plus the unwritten fourth step of the iteration of the entire cycle. Figure 1 shows the breakdown of each phase.

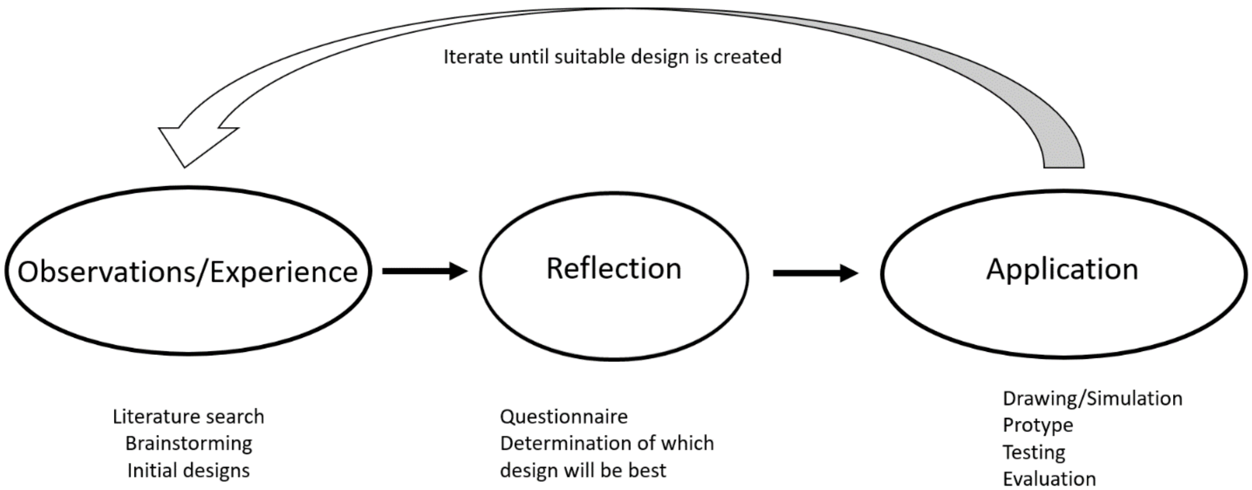

Figure 1: Diagram of experiential learning phases

The first phase of observation includes a literature search, brainstorming, and the initial design of 3 potential forms for the device to take. The student will use the opinions from the questionnaire to help determine which of the three initial designs could best solve the problem statement. After the reflection stage the student will then move to the application phase in which they will use CAD to create a model of the design which will open the path towards a prototype. The eventual prototype can then be tested and evaluated. At this point, the student may need to iterate through the entire process.

Experience

With a goal of increasing hands-on experiences, the undergraduate student sought out experiential learning in the form of a research project. The intended goal was to gain valuable experience in the research process, as well as supplement the engineering coursework with a long-term project that would help the student to connect the concepts learned in lectures to a real-life experience.

To begin the process, the authors identified the problem of the acceleration of climate change due to the continued dependence on nonrenewable energy sources. The student and educator worked together to narrow the scope of the project to roadway energy. We examined the possibility of utilizing roadways to minimize the impact society has on the global environment and increasing the use of renewable technologies. An integral part of this research experience was the background literature search that the student conducted.

Phase 1: Observation & Exploration Phase

I. Literature Search

During the literature search portion of the experience, the student explored several potential solutions that fit the project criteria. This exploratory phase of the project introduced the student to technologies that they had previously been unaware off, such as piezoelectric devices. Several models of piezoelectric devices were shown to have similar lifespan compared to paved road surfaces [3]. This similarity in lifespan is important to consider when designing a system that would need to be embedded within the roadway. Another technology introduced to the student through the literature search was pyroelectric materials, which generate electricity by utilizing temperature changes in the local environment. While only a few pyroelectric materials would be suitable for use along roadways, and therefore not ideal for the current project the student gained in-depth knowledge on a topic of interest. Additionally, devices that were integrated within speed bumps were reviewed in several comprehensive reviews of roadway-based energy harvesting technologies [3,4]. The individual mechanisms varied from pneumatic or hydraulic to electromechanical [3]. The student found great interest in these types of devices and began to further research the design and testing methods used in their creation. One specific example of this technology is the Waynergy Vehicles system, which was developed and tested in Portugal [12].

The comprehensive reviews were valuable resources because they highlighted the efficiency of existing technologies and exposed the student to concepts and designs that they would not otherwise come across in the traditional curriculum. The technologies discussed in the papers peaked student's interest and provided ongoing motivation throughout the experience phase. It was also through these reviews that the student was able to affirm that there is space for research in multiple aspects of roadway-based energy harvesting. Some of the most available spaces for research include technical feasibility, environmental impact after implementation, and the life-cycle costs of such devices [3,4].

II. Brainstorming

During the early application phase, the student created an informal questionnaire with the intention of gathering anonymous opinions on the idea of roadway-based energy harvesting from those who would be likely to encounter such a device. The primary results of the questionnaire revealed a wide-spread support of the implementation of this type of technology across respondents, as well as concerns that the student had not taken into consideration previously. A total of 38 anonymous responses were recorded. Respondents were asked if they would support the implementation of a technology that would allow roadways to generate electricity, 55.3% responded yes and 44.7% responded that they would like more information before deciding, as shown in Figure 2. Additionally, 76.3% of the respondents reported that they would be more likely to drive on a road with more noise if they were aware that it was a source of clean energy, as shown in Figure 3. For this question, respondents were allowed to write in a response if those listed did not exactly align with their thoughts.

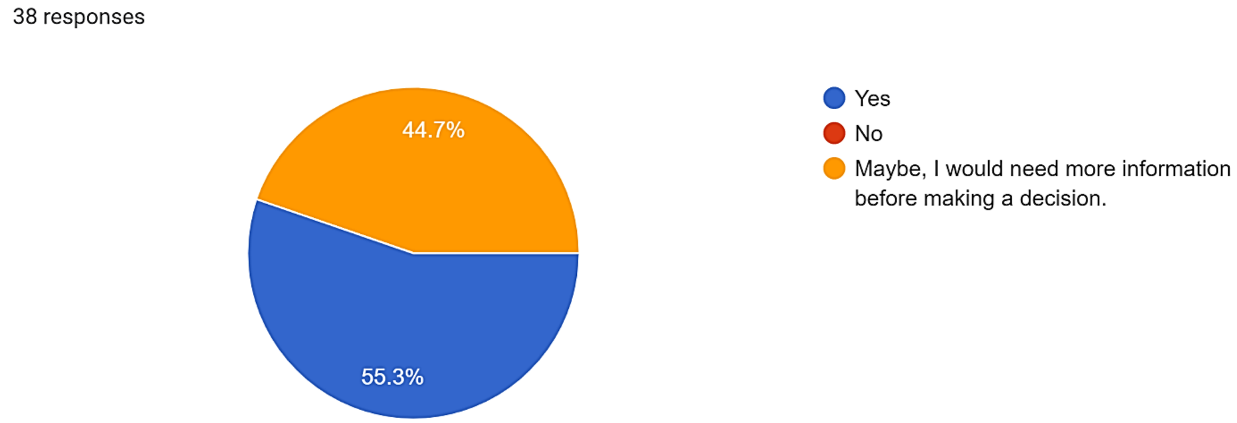

Figure 2: Survey Results when Respondent was asked, “Would you support the implementation of a technology that would allow roadways to generate electricity?”

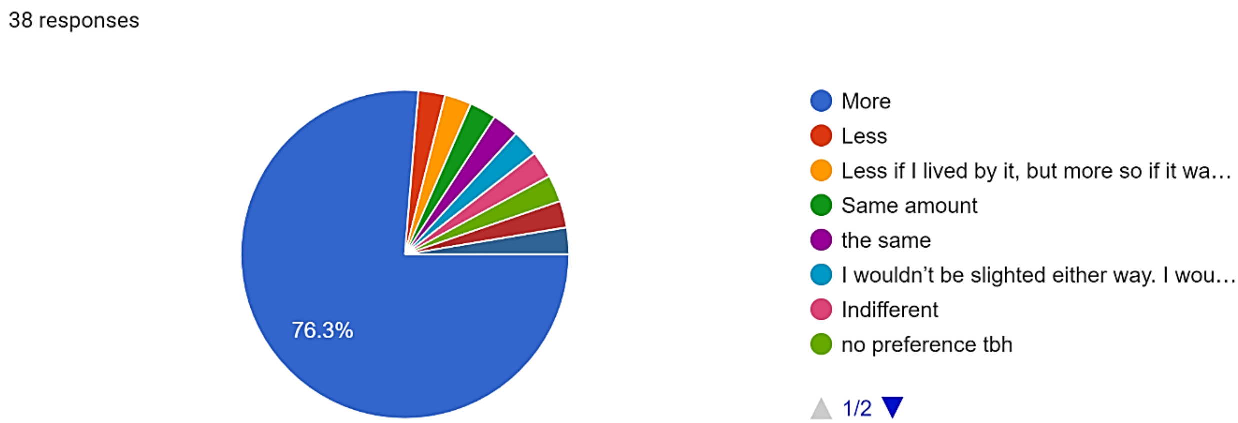

Figure 3: Survey Results when Respondent was asked, “Would you be more likely to drive on a road with more noise if you were aware that it was a source of clean energy?”

An additional portion of literature review was conducted during the application phase in order to answer questions as they arose during the early stages of the design process. The design process started with a single brainstorming session. Utilizing a brainstorming method used in a previous class, the student split the overarching idea into categories which included: type (or physical form), mode of energy harvesting (mechanical, hydraulic, etc.…), and energy source (solar radiation, geothermal, etc.…). After the categories were defined, each column was filled with numerous ideas, as shown in Table 1.

Type	**Mode**	**Source**
Speed bump	Mechanical	Kinetic Energy
Trailing system	Electrical	water
Plate	Electromechanical	Wind
Barrier	Pneumatic	Solar
	Hydraulics	Geothermal

Table 1: Categorical Brainstorming Table

The third step to the brainstorming process was to pick one item from each category and form at least ten options, even if some combinations did not seem feasible. This application of a brainstorming method was beneficial for the project because it allowed the student to incorporate aspects of previously discussed device ideas while creating space for new combinations of characteristics.

III. Initial Designs

Once the student completed the brainstorming stage, the next step was to hand sketch three of the most appealing combinations. The three sketched out ideas included two mechanical systems and one that focused on incorporating photovoltaic cells into the barriers commonly found on stretches of roadway. The two mechanical systems were similar except for how they would be implemented. Design 1 was designed to be in the form of a speed bump that could be placed above the pavement, as shown in Figure 4. This design would provide ease of installation and could be easily removed, but it would have a higher hinderance to vehicular traffic and would have a limited number of potential installation locations. Design 2 was designed to be installed as an integrated system in the roadway itself, as shown in Figure 5. Both of these differ from the existing designs found in the literature. This design would be permanent, and the installation would be more extensive, but the design would allow for integration into most existing roadways and could provide a much broader deployment.

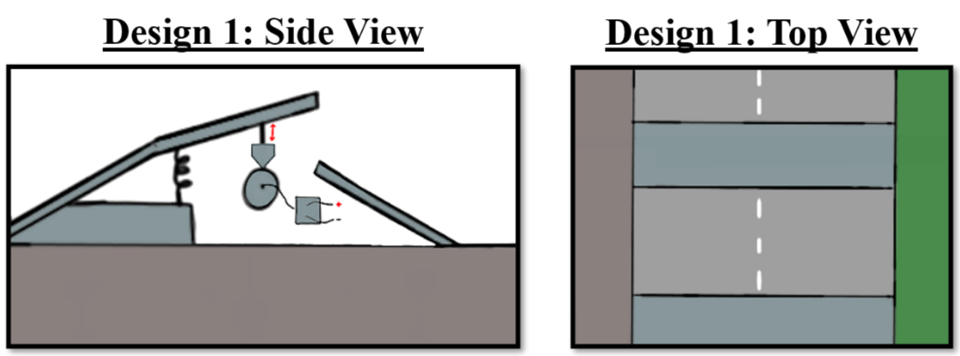

Figure 4: Speed Bump Kinetic Energy Harvesting Device Design

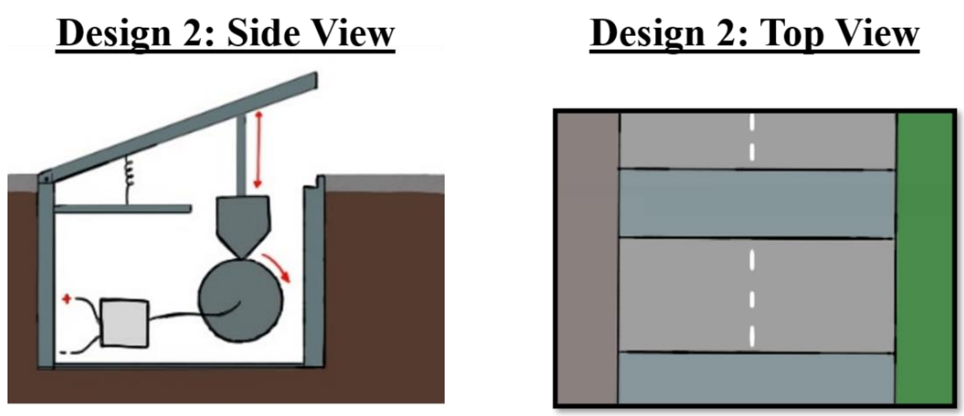

Figure 5: Roadway Integrated Kinetic Energy Harvesting Device Design

Phase 2: Reflection

After the observation and exploration phase was complete, the next step in the cycle was reflection. The student and advisor met regularly throughout the project to provide an opportunity to discuss questions, ponder design issues and better direct both the literature search and initial design phase. After reviewing the information accumulated through the early stages of the research process and combining them with the concepts learned through traditional coursework, the student was able to form the plan for the application phase.

Phase 3: Application – Next Steps in the Project Evolution

As this project is a work in progress, the undergraduate research project is not complete. Utilizing the information from the questionnaire and the information gathered in the Reflection phase, the researchers will narrow down the brainstorm ideas to the most suitable options. Next, work on the initial prototype design will begin. The research will continue on to CAD drawing, software simulation, and prototyping as well as important analyses of the chosen device design.

Conclusion

The student found the research project to be advantageous, especially during a semester of mostly online courses. The project created a connection between lectures and a direct interest, which helped the student to maintain motivation for coursework throughout an atypical semester. After participating in a project that used the experiential learning model, the student recognized how important an active component is for the retention of information. Additionally, the use of a primary questionnaire brought potential problems with a design to the student's attention before the project was well underway. For example, the potential for extra wear on a car's suspension system may deter drivers from traveling on a road with this type of technology integrated into it.

As the student progresses through their major, they will continue to apply important concepts learned in the classroom to the project. The hands-on research project has been a valuable experience throughout the semester because the student was able to use it to connect the lecture content to a real-life, hands-on project. Although the project was not at a stage where failure theories, or the use of specific equations was appropriate, the student was able to learn about these concepts in a traditional educational setting and begin to plan out the remainder of the application phase to incorporate these lessons. The use of the experiential learning model created an environment that allowed the student to further their understanding of engineering concepts introduced during a formal classroom setting.

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