Exploring the use of Photovoice with Entrepreneurial Design Projects as a High Impact Practice in Engineering Technology Education

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In the recent years, interdisciplinary research has become a necessary tool for successfully finding solutions to real-world problems. Yet, in the undergraduate engineering technology curriculum interdisciplinary projects is extremely limited (if used at all), particularly in non-capstone project courses. In this study we present findings and lessons learned from an interdisciplinary research project that integrates entrepreneurial mindset, bio-inspired design, and art into in an engineering technology classroom in the sophomore-year of the post-secondary engineering technology education. Engineering technology students enrolled in the Principles of Mechanical Systems course participated in this study, and were tasked with the design of a vehicle that would solve overcrowdedness in urban areas in the next century. Focus of the research was on innovative bio-inspired design that is backed by scientific evidence and the use of arts to convey the design. The students then expressed their opinions on their design project using a photovoice reflection of their learning. Student responses to the photovoice reflection prompts related to the design were qualitatively categorized under three themes: 1) demonstrating the importance of entrepreneurial thinking from the end user's perspective 2) stressing the importance of teamwork and communication and 3) using art as a communication tool.

1. Introduction

1.1 Problem Identification

Almost all scientists that left a big impact on human civilization such as Isaac Newton, Descartes, and Michael Faraday were interdisciplinary researchers. The famous mathematician and astronomer La Place says "to discover is to bring together two ideas that were previously unlinked" [1]. In the recent years, interdisciplinary research has become a necessary educational tool for successfully finding solutions to real-world problems. It increases the experience-based learning, assists students in exploring unknown fields and discover new ideas and motivates them to complete their degrees. However, interdisciplinary collaboration can mostly be seen in the postgraduate degree levels, while it remains poorly implemented in undergraduate education [2].

In engineering technology, as in many engineering programs as well, students can cruise through all required and elective courses in the curriculum without having to work in a team with students from other educational programs [3]. Furthermore, very little evidence exists on interdisciplinary and transdisciplinary [4] education that targets junior-tertiary students of engineering technology such as in community and technical colleges, and for the first two years of four-year educational institutions (Freshman and sophomore years).

High Impact Practices (HIPs) were first introduced in 2007 by the American Association of Colleges and Universities (AAC&U), and included ten educational practices that feature active learning components of a modern educational system. The ten HIPs include: 1) First-year seminars and experiences, 2) Common intellectual experiences, 3) Learning communities, 4) Writing-intensive courses, 5) Collaborative assignments and projects, 6) Undergraduate research, 7) Diversity/global learning, 8) Service and community-based learning, 9) Internships, and 10) Senior capstone courses and projects [5] [6].

Excluding senior capstone courses, using a High Impact Practice that is interdisciplinary and that enhances entrepreneurial creativity remains poorly addressed in the Engineering Technology field, particularly at the junior-tertiary level.

1.2 Current Approaches to the Problem and Gaps

In response to the aforementioned problem, many efforts are underway at the higher education level. Yet, gaps remain.

A very commonly used approach for interdisciplinary education is the STEAM (Science, Technology, Engineering, Arts, and Math) approach. However, the STEAM approach is primarily applied in preliminary and secondary education [7] [8], and has scarcely been documented in tertiary education.

Some practices that are interdisciplinary or even more transdisciplinary in nature, and follow the STEAM approach are referred to as Innovation-thinking frameworks [9]. However, the use of these frameworks in engineering technology programs is not well-documented in literature. In addition to that, engineering technology is not given a distinct identity but rather it is absorbed in engineering education.

1.3 Study Overview

In this work, we present an approach that is used to overcome the lack of inter- and multi-disciplinary learning in engineering technology education at the junior-tertiary level by the use of a High Impact Practice (HIP) in a course that is traditionally content-heavy.

In this approach, the interdisciplinary entrepreneurial-minded learning framework [10] was used to enhance the educational experience for mechatronics engineering technology students in a sophomore-year course, in which students followed the scientific method to conduct an innovative research that can benefit society.

In this learning framework, students used the "Entrepreneurial Mindset" avenue coupled with bio-inspired design and arts for problem solving and expression of ideas.

2. Literature Review

2.1 The Lack of Interdisciplinary Education in Engineering Technology

Interdisciplinary Engineering Education (IEE) has been extensively studied in literature [11] [12] as a tool to produce engineers that are socially-connected and have the ability to work outside the boundaries of their disciplines [13]. In the work of Asgill [14], it was shown that interdisciplinary education was used as a tool to improve enrollment in engineering technology programs.

In a 2018 study lead by Dalhousie University, it was found that while 89% of scientific research in academic institutions was interdisciplinary, only 28% of the undergraduate research was interdisciplinary [2] [15]. That rate likely drops significantly for junior-tertiary education as no documented evidence was found in literature that quantifies the percentage of interdisciplinary research in that educational level.

Most of the U.S. population is inexperienced in interdisciplinary research. It is estimated that approximately 50% of adults in the United States aged 25-32 have attained at least a 2-year degree, thus, at least half of the U.S. adult population went through two years of education, but the rate drops considerably to about 40% for adults that attained at least a bachelor's degree [16]. Thence, the majority of the adult population in the U.S. has likely never engaged in an interdisciplinary research that implements the evidence-based scientific method. Which further highlights the need for interdisciplinary learning at the junior-tertiary education level.

One recent example that highlights the need for interdisciplinary knowledge can be found in the aftermath of the Corona Virus (CoVid-19) pandemic. The need for a scientific system that decreases "scientific isolationism" as well as the need to champion evidence-based scientific method in public decisions and societies even increased [17] were evident in the "hydroxychloroquine roller coaster" of 2020 [18] [19] [15], in which scientists found themselves unheard among the crowds, and the malaria medication was used for treatment of Covid-19 in most countries in the world without a scientific-based evidence [20].

Although some post-secondary institutions offer collaborative interdisciplinary capstone projects, this collaborative nature is in the culminating experience courses which are usually offered as end-of-study projects. In addition to that, these types of projects are very limited, and only a small number of institutions implement them. The most recently updated ABET student outcomes, do not require functioning in multidisciplinary teams [21].

Moreover, for engineering technology, the isolated form of coursework may be more prominent than in engineering programs due to the fact that all engineering programs share calculus-heavy backgrounds, and mixing curricular requirements among closely related disciplines such as industrial and mechanical engineering or electrical and computer engineering is a common practice. Therefore, providing interdisciplinary education and interaction opportunities for engineering technology students remains a challenge. Traditionally, the integrating experience capstone project has been used as a tool that bridges the gap in the communication and non-technical skills as required by the Accreditation Board for Engineering and Technology (ABET) [22] for ABET-accredited programs.

2.2 Current Approaches:

The STEAM educational approach was first proposed by Sanders [23] who referred to it as "Integrative STEM" to highlight the strong impact of integrating arts into the STEM educational approach. It was then refined by several authors into its final "STEAM" acronym [24] [25] [26] to underscore the significance of integrating arts into STEM. However, the STEAM approach, as pointed earlier, is primarily applied in preliminary and secondary education [7] [8].

Innovation-thinking frameworks [9] that follow the STEAM approach include a wide array of methodologies such as entrepreneurial-minded learning [10], Systems Thinking [27] and value proposition canvas [28] However, the use of innovation-thinking frameworks in engineering technology programs has been poorly documented in literature, and often engineering technology is not given a distinct identity but rather absorbed in engineering education.

Furthermore, transdisciplinary or even interdisciplinary research is scarcely documented in literature for engineering technology programs other than in end-of-study projects. Scientists define Transdisciplinary research to be the highest form of integration of disciplines followed by Interdisciplinary, and then by Multi-dsciplinary research [29] [30].

2.3 Contribution to Literature

In this work, we present an implementation of the sixth high-impact practice (undergraduate research) in which a transdisciplinary entrepreneurial design project with photovoice reflections is used to enhance the educational experience of students in the junior-tertiary level of engineering technology education. In the Photovoice methodology, students use narratives and photographic techniques to describe their ideas [31] [32].

In their work, Bosman and Shirey outline a transdisciplinary approach in which three components: STEAM, Bio-inspired Design, and Entrepreneurial Mindset are coupled together to expand engineering participation and transdisciplinary problem-solving [33].

Here we use Bosman and Shirey's approach with four distinct features and defining characteristics: 1) the intervention prompts a transdisciplinary innovation-driven solution of a projected future problem 2) the educational discipline in this work is the Mechatronics Engineering Technology field 3) the design project used for this study is offered at a required course in a junior -tertiary level, and finally 4) The two components: STEAM with emphasis on the use of Arts in design and creativity with a bio-inspired design are used as tools in the project to sharpen the entrepreneurial mindset in the Mechatronics Engineering Technology students.

3. Methods

3.1 Study Design

A conceptual design project was given to students at the sophomore-year course titled: Principles of Mechanical Systems, with the course number ETME 2130. The project duration was four weeks, and the project topic was to conceptually design a vehicle that will be able to solve the overcrowdedness of the streets of the super cities of the year 2100. This research was designated as exempt by the Institutional Review Board (IRB) of the University of Tennessee at

Chattanooga with the IRB approval number 22-135. Problem statement and requirements of the project are shown in insert 1 below.

Problem Statement:
Scientists estimate that the earth population will reach 11.2 Billion by the year 2100 [40], and some of the super large cities will have populations of as many as 90 million inhabitants. In the U.S, over 30 million inhabitants will live in New York City by the year 2100 [41]. Furthermore, the median life expectancy in the United States is expected to reach 100 years or more at that time [42]. Therefore, overcrowdedness, traffic jams, and air quality will be primary concerns at that time.

The project requirements and deliverables:

- To research and explore mechanical technologies that have a potential to be used in the vehicles of the next century to solve the problem of overcrowdedness in the large city road networks. The technical constraints included the requirement of having mechanical systems in the design.
- To use one mechanical system that has the potential to reduce the problems of overcrowded traffic and air quality in a design of the vehicle of the next century.
- The conceptual design has to take into account the environmental constraints as well, and be tied to bio-inspired features.
- To express the design using an artistic drawing and/or animations or other means to convey the idea to others.
- Finally, the students were required to present the conceptual design to the class.

Insert 1. Problem statement, requirements, and deliverables of the class project.

The graded project had a 10% share of the final grade in the course. Students were given four weeks to complete the project. About 30 minutes were allocated for project discussions every week. In addition to that, the instructor provided seven weekly office hours. The learning outcomes sought from the project included the following:

1. To describe the trends in technology for improving human lives based on scientific data available, and entrepreneurial mindset.
2. To apply knowledge in classical mechanics and body motion, and CAD drawing in engineering design such as using Newton's laws of motion and the laws of thermodynamics and using proper CAD software to describe the design if possible.
3. To dentify the environmental and other constraints as well as biological systems that may be mimicked in the design
4. To describe the system using mechanical components and drives.

Student works:
During the last week of the project, each student group presented its design to the class. Overall, the student groups came with very creative ideas that were based on scientific evidence from patents and published scientific research. Some of the student designs and main features of each design were as follows:

Team 1- Mecanum wheels: The first team presented the idea of having mecanum wheels on future vehicles. Current research suggests that the current power trains composed of combustion engines with transmission systems will be obsolete in the 22nd century, and will be replaced by electric vehicles that use decoupled motorized wheels, giving way to the utilization of mecanum wheels. The wheels will allow vehicles to make turns at a very limited space, giving them a lot more flexibility in mobility, this is similar to the high level of flexibility in human beings that allows us to make 360^{o} turns while standing in the same spot. Current challenges for using mecanum wheels include the high cost and low life span, but improvements in materials will allow the wheels to last longer and at a lower cost, thus making them a strong feature of next-century electric vehicles.

Team 2- High-efficiency combustion engines: the team argues that combustion engines will continue to dominate the roads. Current technologies have engines with efficiencies only in the range of 30-40%, therefore, there is much room for improvement. With improvements in cylinder and piston materials, engine components can be made from non-metallic composite materials, which have significantly lower thermal conductivity, and consequently significant improvements in efficiency are sought that electric batteries may not be able to compete with. The significant improvement in efficiency in the non-metallic combustion engines that results, means that the engines will be smaller in size, much lower in weight, and can even use a wide range of low-cost fuels such as oils, and therefore much smaller engine compartments and much cheaper fuel. In addition to that, the combustion engine is a bio-inspired machine, similar to living things that consume fuels such as carbohydrates and breathe oxygen for metabolism.

Team 3- Modular and Morph-Changing Vehicles: Many organisms can change their shapes or physical build up to adopt to environmental constrains, such as amoeba that changes its shape for movement, and rodents that squeeze themselves through holes with much smaller widths than their normal sizes. In the same way, the student team presents the idea of modularity and morph-changing in vehicles, in which a vehicle will be able to change its shape such as reducing its width and increasing vertical length, or temporarily splitting into independent parts to be better fit with traffic jams. Current technologies in electric vehicles allowed them to avoid many mechanical components that lack flexibility such as transmission systems and drive shafts. Therefore, flexibility in design can be significantly improved and modularity in vehicles will be achievable. In addition to modularity, improvements in materials, may allow the vehicle structure to be elastic enough for a controlled change in the vehicle shape or structure. A sample artistic description is shown in Figure 1.

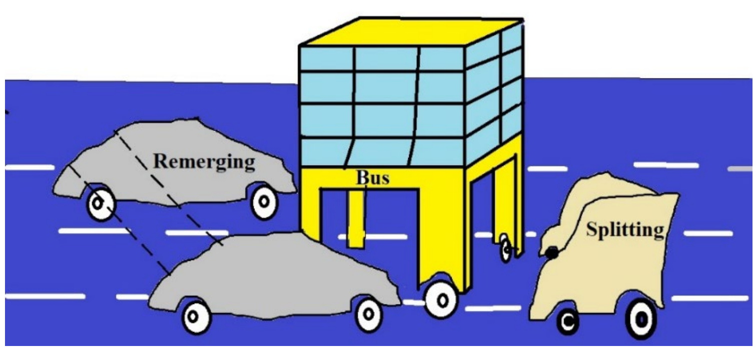

Figure 1. Vehicle modularity as a solution to over-crowdedness in the cities of the 22nd century. The absence of unflexible parts like transmission systems in electric vehicles, allows for modularity in them such as changing height, width or even splitting into smaller subvehicles.

3.2 Participants

The graded class project included 13 students (12 male and 1 female) in total, and was given in the course ETME 2130 Principles of Mechanical Systems as pointed earlier. The course is a required course for the Mechatronics Technology program. The course learning outcomes were as follows:

1. Analyze fundamental classical mechanical principles and body motion, such as force, torque, speed, power, energy..etc.
2. Identify basic mechanical components and drives such as clutches, gears, brakes, belt and chain drives …etc, and explain their role in a mechatronic system.
3. Apply principles of mechanical systems to find mechanical advantage of pulley systems
4. Calculate the output torque, speed, and power of mechanical power transmission systems such as gear drives, belt drives, and chain drives
5. Identify and properly select lubrication systems and lubricants in a mechatronic system.
6. Identify types of gears, couplings, belts, and chains, and other components.
7. Perform work in accordance with safety rules and procedures.

3.3 Data Collection Instrument(s)

Data collection instruments are detailed by Bosman and Shirey [33]. Upon completion of the module, students submitted photovoice metacognitive reflection. Prompts are provided in insert 2:

Photovoice Reflection Prompt A (**Entrepreneurial Mindset**): The entrepreneurial mindset is defined as "the inclination to discover, evaluate, and exploit opportunities." Explain how participating in the newly developed curriculum incorporated the entrepreneurial mindset, and lessons learned relevant to the entrepreneurial mindset.

Photovoice Reflection Prompt B (**STEAM**): STEAM (science, technology, engineering, arts, math) goes one step beyond the well-known STEM to acknowledge the importance of integrating the arts and humanities into more analytical coursework such as that found within engineering. Art can be incorporated through pieces, process, and movements. Explain how participating in the newly developed curriculum incorporated STEAM (specifically, the arts), and lessons learned relevant to STEAM (specifically, the arts).

Open-Ended Reflection Question C (**Connect to Real World**): What skills did you learn? Please consider both professional skills (e.g., communication, collaboration, etc…) and context specific skills (e.g., topic area). Why are these skills important for engineers in the real world?

Insert 2. Reflection Prompts used for the study.

3.4 Data Analysis Procedure(s)

Several methods can be used to assess the effectiveness of the project that range from complex quantitative analysis methods such as that conducted in references [34] [35] to qualitative analysis methods that are used for preliminary assessments, or a mix of both quantitative and qualitative [36]. In this work, student responses are analyzed by Deductive Thematic Analysis [37] [38]. In this top-down approach of preliminary analysis, researchers look for patterns in the student responses and identify themes. In this work we follow this analysis, and support our findings with quotes drawn from the data in order to give the reader the ability to make his/her own judgments on accuracy, fairness, and credibility of the data analysis conducted [39]."

4. Results

To assess the effectiveness of the approach presented here, Deductive Thematic Analysis, is applied and the following three themes could be identified from the photovoice reflections:

4.1 Considering the Lens of the Customer and the Customer Needs:

For this result, the Photovoice Reflection Prompt A (**Entrepreneurial Mindset**) shown in insert 2 was used. In general, students demonstrated the importance of entrepreneurial thinking from the end user's perspective:

- It was interesting to have to navigate through the pros and cons of these wheels. It helped us to **understand how to think in terms of what people want and what is important to the cons**umer.

- When this project was assigned, we first had to brainstorm ideas on what kind of car **would solve the problems we will face in the future. Such as fuel shortage and limited space in our economy**. We came up with several ideas that would possibly work to solve these problems in the future.
- The entrepreneurial mindset begins with **finding out what problems face society**. What can be improved upon? What is working? Figure out the root cause of these problems facing the world.
- Another part of the entrepreneurial mindset is being able to sell your product. The **product must be enticing to its customers**. If the product is boring and has no creativity, you will be unable to sell it. We really focused on the benefits of Mecanum wheels to help make our product appealing for sale.

4.2 Stressing Importance of Teamwork and Communication

For this theme, the Debrief prompt was used. In general, students commented on how the group functioned and communicated. In some cases, it didn't go so well; in other cases, intention was used to ensure it went well. The main takeaway is that students commented on these professional skills which implies they recognize the important of these skills.

- I think that the project went fairly well. We were able to get with each other fairly often to go over what we had done so far. We also **created a checklist so that we knew what each group member was going to do**.
- Our **group was very disorganized**. I would like to have seen more inter-cooperation, but **scheduling issues** were a constant threat. The skill and interest levels between members were quite noticeable, and I ended up having to take on the bulk of the research.
- Our group worked well as a team and **decided together how to move forward** and complete the project in a timely matter. **Together we split the project into sections** so that we could each focus on a topic. This way each of us could become masters of each individual topic and be able to present each of our topics.
- We **wasted a lot of time** bouncing ideas around. It can be **difficult to come up with original ideas** or ideas that actually make sense to make into reality. In the future I would probably try to have each person in the team find three to four different ideas that they liked and **then come together and choose one of those as a team**.

4.3 Art as a Communication Tool:

Using the STEAM photovoice prompt, this theme is deducted. Art has many different benefits including introspection and contemplation to consider different perspectives and ideas. In this study, many students expressed the main benefit of art as a tool to enhance communication; in other words, art was used to better explain the product features and design.

- I think **virtual models are a very good way to explain an idea** to an audience that may not know much about the topic or product. In the classroom setting I am personally primarily a kinesthetic learner but I also appreciate when there are **visuals to help engage** me. Anytime slides can have videos explaining real world examples or explanations of how something **works I find myself far more interested** than if there was just a word description.

- There's a reason the old adage is "**a picture is worth a thousand words**." When conveying messages clearly, sometimes it's **difficult to find just the right words** that really hit your intent home. Language barriers are a major hurdle we face as the world grows smaller. Some cultures have multiple words that can be used to describe a tree, but there's no doubt a picture of a tree is a tree.
- STEAM can be thought of as a more **visually representative** form of STEM. When talking about complex or specific subject matter, it can be very **beneficial to include visual aids**. This is especially helpful when considering some people in your audience may be less knowledgeable than you.

5. Discussion

5.1 Theoretical Interpretation

The project that was provided to the students in the Principles of Mechanical Systems course gave students the opportunity to explore recent advances in research in multiple disciplines such as power systems, artificial intelligence, energy storage systems, and material science to solve potential problems that societies may face in the future in a complex mechanical system (the automobile).

The transdisciplinary research project used Bosman and Shirey's approach outlined in reference [33] in which three key elements were integrated: Entreprenuerial Mindset, STEAM, and Bioinspired Design.

Entrepreneurial creativity can be observed in the student final works in which they ivestigated recent advances in science to solve potential problems that would arise in the future, as evidenced in the designs that the students developed to solve the projected overcrowdedness of the cities of the 22^{nd} century. It was also evident in the first theme that was identified in the student photovoice reflections: "Considering the Lens of the Customer (and Customer Needs)".

Bioinspired design is observed in the designs to solve the future problems with maximum efficiency. For example, the argument that combustion engines can still be the future of vehicles with current advances in engine efficiency, and that it resembles living organisms in that most efficient forms of energy is through the consumption of fuel to produce energy and byproducts such as carbon dioxide.

Art was used as a means to explain the designs. The effectiveness of the integration of Arts in engineering technology is evident in the theme that was deducted from the student responses to the photovoice reflection "Arts as a Communication Tool".

Therefore all three elements of Bosman and Shirey's approach were used.

5.2 Implications for Practitioners

One of the major challenges faced during the project, was allocating time for the project in a content-heavy course. This difficuly was overcome by having small time slots for project discussion at the end of class sessions, and by linking assignments and class lessons to the project. Another challenge was that students had little knowledge in using scientific databases for scientific articles and patnets such as the Google Scholar and Google Patent databases. This was overcome by giving studets examples on using these databases for scientific research.

6. Conclusion

Undergraduate research is considered an effective high impact practice (HIP) in education. When this practice is inter- or transdisciplinary in nature, it becomes a strong tool for successfully finding solutions to real-world problems. However, interdisciplinary research remains poorly documented in the undergraduate level other than End-of-Study capstone projects. The use of this HIP tool is particularly scarce in the field of engineering technology, and more particularly in the junior post-secondary education (first two years of college).

In this work we present the use of this high-impact practice in a transdisciplinary research project that couples three elements: Entrepreneurial creativity, Bio-inspired design, and STEAM, for a sophomore-year course in Mechatronics engineering technology, which can be applied at any junior-tertiary level (first two years of college).

To assess the effectiveness of the project, Deductive Thematic Analysis on Photovoice reflections was conducted. Three themes were identified from the patterns in the student responses. The themes show that students stressed the importance of team work to solve problems, the use of Arts to express ideas, and the need to consider the lens of the customer in engineering design.

The analysis along with the delivered project presentations and artistic explanations indicate that project met the objectives of providing an interdisciplinary high impact practice in a junior-tertiary education class in engineering technology in which three elements are incorporated (Entrepreneurial Mindset, Bio-inspired Design, and Art in STEM).

The primary limitations in this work are that only qualitative analysis was conducted, and the approach was implemented only once in one course. Future perspectives include integrating it in other courses, and in other institutions, particularly, community colleges or other two-year institutions, or again in the same course to get more data for analysis and the use of quantitative research for more accurate analysis.

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