Entrepreneurial Minded Sustainability through Industrial Engagement

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Abstract

Sustainability and its applications in engineering are now finding its way into the engineering curriculum. It is essential that the next generation of engineers is trained in sustainability principles, enabling them to design products that account for environmental impact, life cycle assessment, and environmentally responsible material selection from the earliest stages of design. Experiential learning practices such as industrial visits and interaction with experts can positively impact students' entrepreneurial mindset (EM) and cognitive levels, leading to a deeper understanding of course content. At Western New England University an elective course titled 'Sustainable Manufacturing' was developed with industrial visits to local medical device manufacturing companies for real-world experience and making students curious about sustainability. Engineering for one Planet (EOP) framework's nine focused areas were used to develop classroom topics, discussion activities and group presentations. It was hypothesized that after taking this course, students will demonstrate high cognitive skills related to Bloom's taxonomy and gain knowledge and skills about topics such as Life cycle assessment and costing, Lean manufacturing, Environmental impact, Industrial standards, Packaging and Green supply chain. The impact of this work was assessed using summative assessments such as graded presentations, quizzes and reflections. EOP and EM student learning outcomes were assessed using an Institutional Review Board (IRB) approved survey consisting of 5-choice Likert-scale (0-4) questions related to nine sustainability topic areas aligned with Bloom's taxonomy and KEEN framework. Results demonstrated high level of students' perception of gain in their skills related to EOP and EM skills covered during the course. Students showed a statistically significant improvement in their knowledge about sustainability related topics covered as lectures, discussions and industrial visits. The inclusion of industrial visits presented an opportunity for the students to make meaningful connections between the course content and real-world applications that led to improvement in their cognitive and EM skills. Hence, the experiential learning elevated student learning and engagement as well as helped them to be better engineers while developing a sustainable outlook.

1. Introduction

Sustainability in engineering education is essential in preparing future engineers to address societal and environmental challenges [1]. It is essential for students to develop systems thinking that goes beyond the interest of one stakeholder or just a good design. In addition to developing new and innovative products, engineering students must develop a mindset to be aware of the societal and environmental impact of their designs [2, 3]. They must be able to account for all the stakeholders associated with the manufacturing, product users and end-of-life disposal of the product. This mindset is possible when students are motivated to develop an entrepreneurial mindset and taught topics such as design for environmental impact, life cycle assessment pre and post product development, circular economy, and environmentally responsible material selection. The impact of sustainability education in engineering classrooms can be enhanced by incorporating experiential learning strategies that help students in identifying the value of their education in the real world [4]. Often, topics related to sustainability can be viewed as superficial and students are not able to see the value of sustainability in engineering. Experiential learning strategies include hand-on activities, immersive experiences and industrial engagement in classrooms that can help bridge the gap between classroom and the real world [5,6]. Among these strategies, industrial engagement and interaction with experts can augment student learning as well as help them make connections between the course content and industrial applications of the work [7]. Site visits are a great example of industrial engagement in engineering education. These educational experiences provide cognitive and problem-based learning opportunity, gives students an insight into the surroundings that they will work in after graduation, develop professional communication skills through interaction with engineering experts in the field and develop a mindset of identifying engineering stakeholders [8, 9]. Well-structured pedagogical strategies such as SEAR (Summarize, Elaborate, Apply and Reflect) have been developed to quantify the impact of industrial visits on engineering education [10]. These strategies have helped industrial visits to be more meaningful rather than being a fun outdoor activity.

In this work, a new course was developed on 'Sustainable Manufacturing' as an effort to include sustainability in the biomedical engineering curriculum. The course was designed to teach sustainability assisted with industrial visits that focused on student learning, application of sustainability principles in a manufacturing process, change in mindset to incorporate sustainability and learning through industrial application and reflection in a classroom. Engineering-for-One Planet framework (EOP) as well as KEEN framework (Habits of Entrepreneurial Mindset) was used as a model to design classroom topics and activities [11, 12, 13, 14]. Figure 1 shows the EOP framework and the major elements of the KEEN framework that were implemented in this course. The overall goal of the course was to successfully inculcate sustainability in one engineering discipline at Western New England University and assess the impact of this work to progressively launch a series of such courses for all the engineering disciplines. This work focused on three aims: (1) develop a course that significantly impacts students' knowledge and mindset about sustainability in engineering, (2) assess cognitive learning through reflection and connecting observations during industrial visits to classroom content and (3) cultivate entrepreneurial minded learning in sustainable manufacturing.

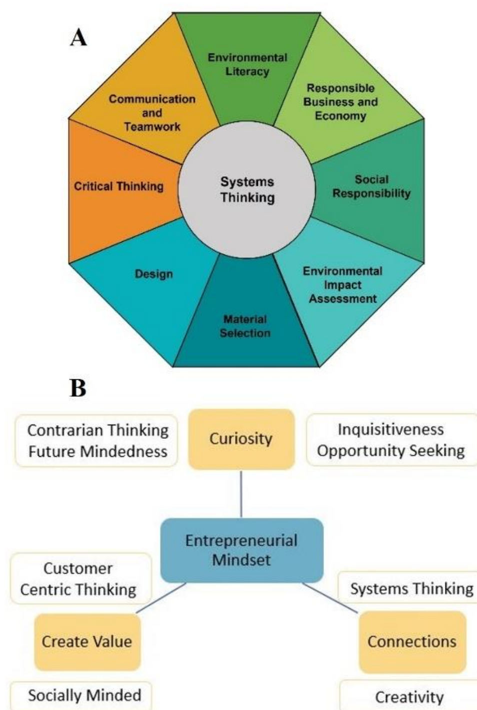

Figure 1: (A) Engineering-for-One-Planet framework showing 9 topic areas related to sustainability and (B) KEEN Framework with entrepreneurial minded learning at its center surrounded by 3Cs and Habits of EM [12].

2. Method:

At Western New England University (WNE), there is no formal course in engineering that targets sustainability. Previous efforts include incorporation of sustainability themed micro-insertions throughout the 4-year engineering curriculum, one module per grade from first-year to senior year [15]. A new elective course was introduced in Biomedical Engineering focused on Sustainable Manufacturing (n=15 students). The course was divided into two distinct features (1) classroom lectures and discussions and (2) industrial visits. Classroom topics were based on EOP framework learning objectives and sustainable manufacturing curriculum from the U.S. Environmental Protection Agency (EPA) website [16, 17]. As there is no formal textbook that covers all the topics related to sustainability, course material was developed from textbooks covering sustainability topics such as material selection, waste management, carbon footprint, design for sustainability, value stream mapping, energy efficiency, lean manufacturing strategies and sustainable manufacturing topics such as Environmentally Conscious Quality Function Deployment (ECQFD) analysis, life cycle costing and life cycle analysis [18, 19, 20]. The course was mapped on 9 EOP topic areas: Systems thinking, Environmental literacy, Responsible business and economy, Social responsibility, Environmental impact assessment, Material selection, Design, Critical thinking, Communication and Teamwork. During classroom sessions, students were given background information about the topic supported by case studies and class discussions helped in development of systems and critical thinking skills.

Three industrial visits (Cardinal Health, Eppendorf, UFP Technologies), one guest lecture with a Sustainability consultant and a field trip to the local botanical garden (Botanical Garden of Smith College) were added to the course in place of mid-term and final exams. This was done to focus on student-centric learning and motivate students to develop a mindset for sustainability. Highly weighted exams can sometimes demotivate students and prevent students from exploring the course topics which hinders deep learning and understanding [21, 22]. As this was the first offering of its kind, the objective of the course was to change the mindset of students who felt that sustainability is only a word. Three industrial visits were scheduled with the help of WNE alumni network. The course was scheduled once a week for 3hrs. All three industries and the botanical garden were within 20-30mins drive from the university, which made it possible for students to drive to the location and return back to the campus within the class hours. The industrial visits included a short lecture from the team at each company covering topics such as manufacturing lines and sustainable practices at the plant, guided tours of the manufacturing unit, and question and answer sessions with the students. The botanical garden visit was focused on biomaterials. Students focused on learning from nature and identified untapped opportunities from plant-based materials for medical devices. Every visit was preceded with an in-class discussion session where students researched the company's products and prepared questions for the on-site team. After each site visit including the botanical garden, students were given 15 days and a detailed prompt for a team presentation. The prompt included a reflection of what students observed during the visit, sustainability practices and standards, and product design change to improve sustainability or sustainable practice recommendation for the team to help the manufacturing unit become more sustainable. For example, students were asked to redesign compression sleeve manufactured by

Cardinal Health to make it more sustainable, apply ECQFD analysis to all the designs, and choose the most sustainable design as per the ECQFD analysis.

The course also adopted de-grading as a strategy to keep the students engaged in the classroom. Each student was given 100% for class participation (80% of the final grade) at the beginning of the semester. Students were expected to actively engage in class discussions, activities, industrial visits, and presentations. Throughout the semester, students took it upon themselves to maintain their 100% grade. This transferred the onus of getting a target grade on students and helped them to take accountability of their actions.

The impact of this work was assessed using summative technical assessments such as graded presentations and reflections and formative assessments such as quizzes. EOP and EM student learning outcomes were assessed using an Institutional Review Board (IRB) approved survey consisting of 5-choice Likert-scale (0-4) questions related to nine sustainability topic areas aligned with Bloom's taxonomy. Cronbach's test was conducted to assess the internal consistencies across the sustainability topics and Bloom's taxonomy. Non-parametric Friedman test was conducted on post course survey Likert style questions. For this test, each EOP sustainability topic and Bloom's taxonomy category was considered as a repeated measure within the same student and statistical significance across the categories were compared. Students also scored their knowledge about major sustainability topics covered in the course on a 6-choice Likert-scale (0-5). Paired t-test was conducted to assess gain in knowledge related to sustainability topics before and after the course. Correlation between the subjective and objective sustainability knowledge gain was assessed through linear regression.

3. Results:

EOP learning objectives:
The IRB approved survey covered questions throughout the 9 EOP main topics related to the course content (Figure 2). The survey data (n=15) was analyzed to check for internal consistency of the responses. Cronbach's alpha of 0.74 suggested that students responded similarly throughout all the questions. Student's perception of gain in knowledge and understanding was similarly impacted in all the topics covered in the course such as Life Cycle analysis and costing, circular economy, design for sustainability and application of these concepts through industrial visits. Students showed a high level of competency in life cycle assessment, material selection for durability and biodegradation, design for disassembly and

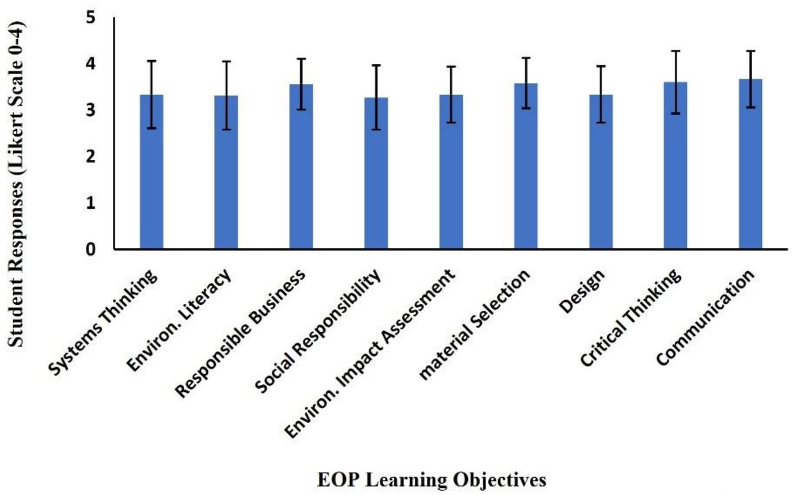

Figure 2: Students' perception of their skills related to nine EOP learning objectives. Students rated all the topic areas between 3 and 4 showing the impact of the course on their knowledge and technical skills. Friedman test showed no significant difference between the nine topic areas (p-level >0.05)

recycling, reprocessing medical devices, environmental costing and decision-making, and lean manufacturing. Friedman test comparing the nine groups showed no significant difference between the categories (p-value> 0.05). The average score for all the categories was above 3.2 on the Likert scale across all the EOP topic areas demonstrating a high level of student's perception of skill development related to sustainability (Figure 1). In addition, students' technical knowledge and grasp on the subject matter were assessed through five quizzes where students scored an average of 87±8% grade (n=15). The objective assessment through the quizzes covered topic areas listed

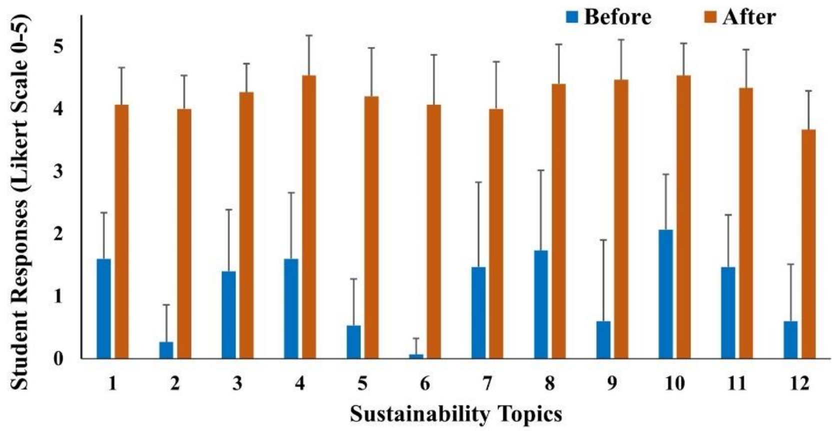

Figure 3: Sustainability topics knowledge evaluation before and after the course. Students perception of improvement of their knowledge about all the topics covered during the course was significantly different than their knowledge before the course (p-value< 0.001). All the topic areas were evaluated similarly showing the high impact of the course on student knowledge.

Sustainability Topics Covered in the Course
Environmental Justice and Socially responsible decision making (1)
3-Pillar Model and nested model of sustainability (2)
Greening the supply chain and environmental cost (3)
Transport Packaging (4)
Life cycle assessment, analysis, and costing (5)
ECQFD analysis (6)
All the policies and acts for environment and environmental waste (7)
Lean Principles (8)
Takt Time and cycle time analysis (9)
Material Selection and recycling of paper, metal, glass, and plastic (10)
Design for sustainability, disassembly, and recycling (11)
Sustainability Standards (12)

in Figure 3. The average score for quiz 1 through 5 was 80±26%, 90±8%, 92±7%, 83±12%, and 95±7%, respectively. The quiz score reflects improvement in student technical knowledge regarding sustainability topic areas. Quiz 4 was based on ECQFD analysis of a single use medical device and sustainable design ideas. A decrease in score was observed for quiz 4, but it can be attributed to the complexity of the topics for upper-level undergraduate students. Students' perceptions of their knowledge about sustainability topics covered in the course showed significant improvement after completing the course compared to their perceived knowledge prior to enrollment (figure 3, p-value< 0.001). Linear correlation between the objective quiz assessment and subjective student survey assessment demonstrated that perceived knowledge gain reported by the students significantly predicted quiz scores (β=27.07). This confirmed that high self-reported learning was supported by high technical skills and sustainability knowledge gained by students in this course.

Bloom's taxonomy:

EOP framework is mapped onto Bloom's taxonomy and the survey data was analyzed to assess the impact of the course on students' cognitive levels (Figure 4). The average response was highest for 'Create and Evaluate' demonstrating students' confidence in their ability to evaluate existing medical products and come up with creative ideas for improvement. Friedman test showed no significant difference between categories of Bloom's levels (p-value>0.05). This showed that all the cognitive levels of students related to sustainability were similarly impacted by this course. In addition, students were curious about the manufacturing paradigm shift related to sustainable practices and worked on creating value for stakeholders such as medical device companies and the customer. These results can be attributed to the experiential learning methodology of this course. A combination of lectures, discussions, and four informative site visits enabled students to deepen their understanding and apply their knowledge to real-world contexts. Students mentioned that they became more curious and critical about corporate sustainability practices after this course.

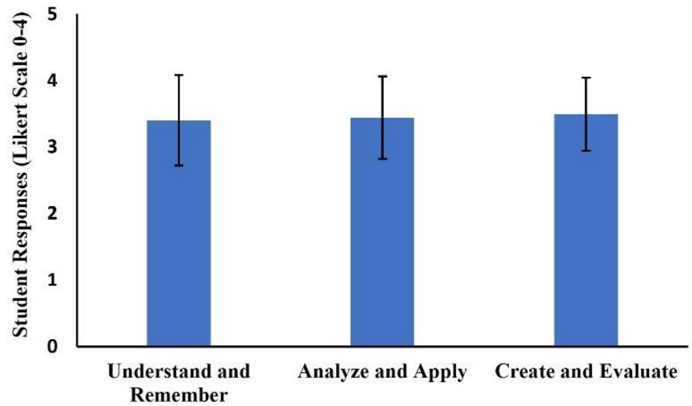

Figure 4: Bloom's cognitive levels impacted by experiential learning practices in class exhibiting high levels of creativity, analysis and application skills. Post-hoc pairwise Wilcoxon test showed no significant difference (p-value > 0.05) in between the three cognitive levels.

EM Learning Objectives

The EM learning objectives were based on KEEN framework of development of entrepreneurial mindset (3Cs) among undergraduate engineering students. The impact of the course on instilling curiosity through development of contrarian thinking and future mindedness by fostering a shift in students' mindsets toward sustainability, finding alternate solutions and identifying unmet sustainability needs in manufacturing units were assessed. Students' ability to make connections was measured by asking questions about their ability to integrate information from various resources and development of systems thinking where students recognized the interdependencies of factors that impact the environment. The survey also asked questions about students' ability to identify various stakeholders and create extraordinary value for them with positive social impact. Action orientation and agency were measured by asking students about their ability to be resourceful when finding novel solutions. In all the categories, students rated themselves more than 3.3 on the Likert scale between 0-4 (Figure 5A). Students' ability to make connections between real-world industrial visits, knowledge gained, and course content was assessed using

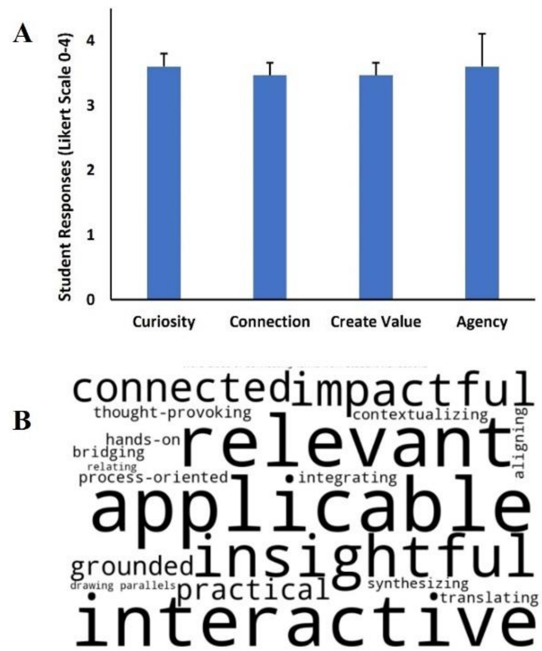

Figure 5: (A) Entrepreneurial minded learning objectives showing high levels of 3C's and student's ability to solve problems using the available resources. (B) Word cloud created from student reflection showing students found the industrial visits relevant, insightful and thought-provoking.

student reflection. Connective words were provided to the students that were highlighted in the reflection, and their frequency of usage was quantified and depicted in a word cloud (Figure 5B). Words such as connecting, eye-opening, relevant, insightful, applicable were used in high frequency by more than 50% of students. Students used the terms hands-on, process-oriented and thought-provoking to describe the industrial visits and how it connected with their classroom teaching. Students described the industrial visits as *"The company partnerships and industrial visits during the course were incredibly insightful and significantly reinforced my understanding of sustainable practices in real-world manufacturing environments"*.

4. Discussion

Sustainability education in engineering is an important step towards cultivating future engineers with a sustainable mindset. This educational practice will ensure future engineering decisions such as design, material choice and product development to be guided by the principles of life cycle assessment, carbon footprint, end-of-life disposal, design for disassembly and energy efficiency for a better and greener planet [23]. However, sometimes students see this course as a tedious theoretical course that is just a filler course with no significant impact. This work aimed at designing a course embedded with experiential learning to augment student learning, help students make connections, and understanding the importance of sustainability in the real world with the help of industrial visits. Industrial visits have been used in higher education as a method to bridge the gap between classrooms and real-world experiences [24]. Through these visits, students immersed in practices such as process planning through Lean manufacturing and Kaizen techniques to make the process energy efficient and reduce waste, reprocessing medical devices through cleaning processes to extend the life of single use medical devices, recycling single use plastic packaging containers and reusing them as recycled packaging material, business models to promote procurement of single use devices from the customer for reprocessing, balancing company's economics, FDA regulations and sustainable practices and innovation focused on new products that are easy to reprocess and reuse. Figure 2 shows that students' perception of gain in knowledge related to 9 EOP topic areas was high and students also perceived to gain knowledge of individual topics pre and post the course (Figure 3). Student comment corroborates the results "*I went from knowing very little to a strong knowledge of sustainability practices in the medical field*".

Bloom's taxonomy maps cognitive skills on a hierarchical triangle with 'understanding and remembering' at the lowest level, 'analyze and apply' at the medium level and 'create and evaluate' at the highest level of cognitive skills [25]. The Sustainable Manufacturing course's EOP learning objectives covered all three areas of Bloom's cognitive skills. Students' level of 'understanding and remembering' the content was assessed during quizzes and lecture discussions. Classroom knowledge combined with experiential learning during industrial visits helped students develop a higher level of cognitive skills as seen in Figure 4. Students effectively interacted with their environment, made connections with the real-life experience and situations to create dynamic knowledge which can change with their environment [26]. Through reflective presentations based on industrial visits, students showcased their ability to apply the knowledge and create innovative sustainable solutions for the stakeholders by balancing economics and business with sustainability. Students demonstrated a balance of gain in knowledge about important sustainability topic areas and creative application of the knowledge to offer sustainable solutions. Based on the open response given in the survey, all the students mentioned industrial visits as the most interesting section of the course as it helped them to see the real-world process and learn from it as mentioned in the comment "*I liked the site visits as they allowed us to see how companies were implementing sustainability in their locations*". The course also helped students in developing an entrepreneurial mindset which promoted their ability to create value for a broad range of stakeholders during presentations. During the presentations, students presented novel sustainable ideas, business models, and environmental analysis for industrial partners. Students reflected on their experience during the industrial visit and made valuable connections between skill development and knowledge gained in the classroom and during industrial visits [27]. Figure 5 shows students highly rated their curiosity level for changing the world and finding alternate solutions to problems related to sustainability. The course aided in student ability to make connections, create value, and be resourceful in gathering information from various sources including the classroom, interaction with experts in the field and industrial visits to foster ideas for their stakeholders. Their ability to make positive connections can be seen through the word cloud generated from student reflection (Figure 5B). In addition, students also reflected accountability through the ungrading policy of this course. By placing the responsibility of the grade in this course on the student, it helped students feel responsible for their actions and fully immersed in the experience offered in this course. Ungrading in a course has shown positive results with students feeling motivated to learn and develop accountability and self-assessment skills [28].

5. Conclusion

In conclusion, the course incorporated with experiential learning through industrial visits was successful in developing systems thinking in students towards sustainable practices in the medical industry. Students connected course material with industrial practices and developed curiosity for sustainability in engineering with an economic and social impact. Courses focused on sustainability that help students recognize the value of this topic can serve as a steppingstone toward developing products that are sustainable from their inception. It is important for future engineers to design products with a sustainability perspective, thereby reducing waste and carbon footprints.

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