Assessing the Impact of Experiential Learning through Engineers Without Borders on Sustainable Engineering Education

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Introduction

The National Academy of Engineering (NAE) is a prestigious non-profit organization in the USA that provides insight into national needs in the engineering profession. In line with one of the themes of the NAE Grand Challenges for Engineering, sustainability is a topic of greatest interest and priority in several engineering disciplines [1]. Furthermore, the Accreditation Board for Engineering and Technology, or ABET, requires all accredited engineering education programs to include the consideration of environmental factors in engineering design [2].

However, the topics of sustainability and sustainable engineering are not frequently discussed in extensive detail within the required courses of the undergraduate engineering curriculum, which often emphasize the technical viability of a project rather than the application of systems-thinking approaches that consider economic and environmental factors [3]. While problem-based learning (PBL) has gained traction as a method to integrate education for sustainable development (ESD) into the undergraduate curriculum, this method suffers from limited participant-directed learning and limited interdisciplinary knowledge and collaboration [4]. As a result, the responsibility is often placed upon the students to take specialized, elective courses, which may not be available at many institutions [4]. Alternatively, students may engage in experiential learning about sustainability outside of the classroom through engagement in extracurricular student organizations. This paper aims to assess the educational significance of experiential learning on sustainable engineering through a case study inspired by the student chapter Engineers Without Borders (EWB) at the University of Delaware (UD). Groups like these may benefit from an understanding of what teaching methods are most beneficial for students in such experiential learning environments.

Engineers Without Borders USA (EWB-USA) is a nonprofit humanitarian organization in the USA that collaborates with partnering communities around the globe [5]. At EWB-USA, volunteers take the responsibility of working on engineering projects with the purpose of meeting basic human needs in partnered communities. Ethical and sustainable solutions are highly valued by the organization of EWB-USA and its student-run chapters spread across the USA [5]. At UD, participation in the EWB student chapter is a popular way for students to learn about issues facing low-resource environments and gain firsthand experience working on sustainable engineering projects for outside communities. Similar to that of other institutions, UD's EWB student chapter is divided into numerous project teams. Amongst the project teams within the UD student chapter, the Research Team is focused on the development of water filtration systems using low-cost materials, and frequently attracts students interested in sustainable engineering.

This study, completed by EWB-UD's Research Team, aims to understand how different methods of presenting informative material on sustainability influenced undergraduate students' understanding of and engagement with the topic. Each of the teaching methods is hypothesized to be successful in significantly increasing student interest, knowledge, and confidence in sustainable engineering topics in the short term. This study defines self-reported confidence in sustainability as a student's confidence in explaining the topic of sustainability to another student. Additionally, this study sought to determine how prior experiences and involvement with sustainability-oriented organizations or groups, such as an EWB student chapter, influenced the metrics of student engagement with topics in sustainable engineering.

Methods

Data were collected for this study by surveying undergraduate engineering students during a short seminar on sustainability in engineering. Three half-hour sessions of this seminar were conducted to evaluate the effectiveness of three different teaching methods: teaching through literature review, teaching with a tactile aid, and teaching using a hybrid of the two methods. These teaching methods reflect the methods that the Research Team projects' use while onboarding new members in the first few weeks of every semester. During the onboarding process, students learn about the current projects through review of literature that influenced each project and learn basic lab skills through hands-on learning in the Research Team lab space. Each teaching method was employed at a separate seminar session. The seminars followed a set schedule, with parts of the schedule being interchanged depending on the teaching method used in the seminar. The schedule for the seminar is displayed in the following table.

Table 1. Sustainability Seminar Schedule with Sections and Allotted Time.

Seminar Section	Allotted Time
Statement of Project Goals	5 mins
Demographic Survey and Pre-Survey	5 mins
Teaching Activity	10 mins
Guiding Questions and Discussion	5 mins
Post-Survey	5 mins

A Google Slides show following this schedule was used to pace the seminars when they were conducted. The guiding questions for each teaching method (Table 2) were used to encourage students to engage with the presented material and stimulate discussion among participants in the seminar. In addition, the discussion of these guided questions was mediated by the researchers running the sustainability seminar, contextualized by the United Nations

Brundtland Commission's framework of sustainable development [6]. The primary variation between the three seminars was due to the teaching methods used.

Table 2. Guiding Questions used for the Three Teaching Activities in the Sustainability Seminar

Teaching Method		
Literature Review	**Tactile Aid**	**Hybrid Learning**
What is sustainability? How do you think engineers participate in sustainable engineering, and what is its role in today's society?		
How do you think waste is currently being disposed of? What impacts might this have on the environment?	What are some considerations that engineers have when they build sustainable products?	
Based on the article, what is a soil stabilizer, and why do engineers use it? Do these soil stabilizers have any negative effects on the environment?	What do you think when you hear the word "biomaterials"? What are the implications of using biomaterials, like the biochar that you see in front of you?	What do you think when you hear the word "biomaterials"? What are some of the implications of using biomaterials, like biochar and biomedical waste?
In terms of sustainable waste management, what are the implications of using BMW ash?	What are your thoughts on these water filters and the experimental design process? How do you think it compares to filters that aren't as sustainable?	What are your thoughts on these water filters and the experimental design process? How do you think it compares to the process seen in the paper?
What are your thoughts on the influence of BMW ash? What do you think about the process of sustainable engineering and how it occurs?	Is there anything that surprised you about these filters and the design process for sustainable engineering?	Is there anything that surprised you about the design process for sustainable engineering?

When conducting the literature review, students were prompted to take approximately fifteen minutes to read the paper, *Sustainable Engineering: Utilisation of Biomedical Waste Ash for Untapped Potential in Soil Stabilisation* [7]. Afterward, the seminar leaders facilitated a discussion about the paper using the guiding questions in Table 2. To simulate a learning environment using tactile aids, the seminar leaders passed around sustainable, homemade water filters, and students were asked to explore each component. They explained the overall concept

of the water filters, explaining how the filter systems worked and the purpose of each specific element. Afterwards, a discussion was held using a similar set of guiding questions for the literature review, as seen also in Table 2 below. In the hybrid learning session, both methods from the literature review and the tactile aid were combined and abbreviated. First, students were asked to read the abstract, introduction, and results of the same paper used during the literature review session. Then, the same homemade water filters were passed around, and similar descriptions were provided for each component of the filters. Finally, a similar set of guiding questions (Table 2) was asked, and a discussion was held after students had the opportunity to read the paper and personally interact with the tactile aid.

The demographic survey, pre-survey, and post-survey were disseminated to seminar participants using the REDCap web application. The surveys were created using the REDCap online designer tool. The demographic survey asked about students' majors, graduation year, prior research experience, prior experience with sustainability in their education, and status within the university chapter of EWB. This survey used branching logic to gain further insight into the answers to certain questions. The pre-survey prompted students to rate their interest, knowledge, and confidence in sustainability from one to ten. Interest, knowledge, and confidence in sustainability were the metrics used to measure the effectiveness of each teaching method. Each metric was identified by project managers of EWB-UD's Research Team to be a measure of the progress of Research Team members during the onboarding process. The post-survey asked students to rate these same metrics after the seminar, as well as identify which teaching method was used in the seminar that they attended. The surveys were developed so that all three were in the same queue, and one survey needed to be completed to be granted access to the next. The order of access of the surveys was the demographic survey, then the pre-survey, and lastly the post-survey.

The demographic, pre-seminar, and post-seminar survey results were transferred from the REDCap software to Microsoft Excel for analysis. Data was removed if the student had not completed both the pre-survey and post-survey. Demographic data assessed included students' graduation year, major, research experience, and involvement in a registered student organization with a goal of increasing student engagement in global sustainable engineering. All statistical tests were conducted in Excel using the Data Analysis Toolpack or in Python using the *statsmodels* library.

Results

A total of 43 undergraduate students attended the sustainability seminar over the three sessions held. Table 3 shows the representation of engineering majors among the seminar attendees. The majority of the students attending the seminar were chemical engineering majors (25 attendees, 58.14%). There were no more than four attendees from each of the other

engineering majors. Figure 1 shows other demographic details of the seminar attendees. Figure 1 (a) shows the graduation year of undergraduate students attending the sustainability seminar. The majority of attendees were from the graduation class of 2029, i.e., first-year undergraduate students (33 attendees, 76.74%). The sophomore (2028) and junior (2027) classes each had four attendees, while the senior class (2026) had two attendees. Figure 1 (b) shows affiliation with the EWB student organization of the seminar attendees—non-members, general members, and executive board (e-board) members. There was an approximately even split between EWB members and non-member attendees of the seminar. Additionally, the majority of the EWB student chapter members who attended were members of the organization's e-board. Figure 1 (c) displays how many of the students attending the sustainability seminar were involved in undergraduate research. The majority of the students attending the sustainability seminar have not been involved in undergraduate research.

Table 3. Majors of Students Attending the Sustainability Seminar

Major	Number of Attendees
Biomedical Engineering	3
Chemical Engineering	25
Civil Engineering	4
Computer Engineering	1
Computer Science	1
Electrical Engineering	2
Environmental Engineering	2
Materials Science and Engineering	1
Mechanical Engineering	4

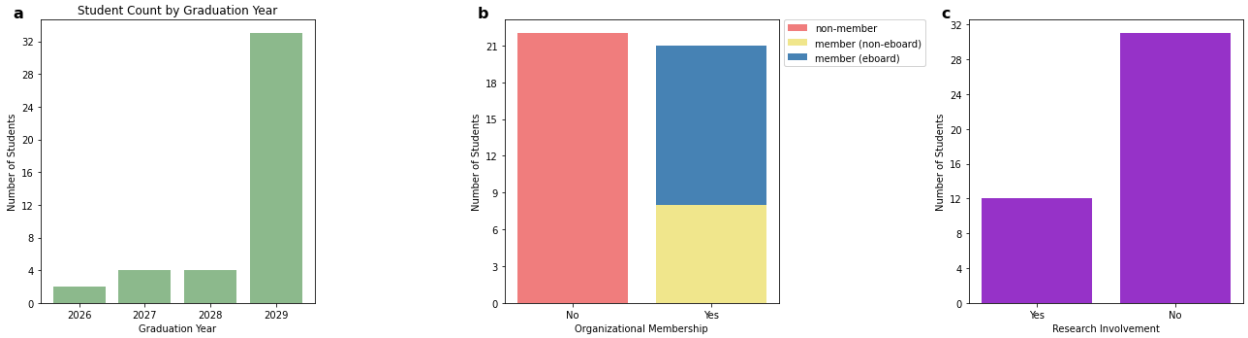

Figure 1. Demographics of Seminar Attendees. 1a) Number of Students From Each Graduation Year Attending the Sustainability Seminar. 1b) Engineers Without Borders Student Chapter Involvement in Attending the Sustainability Seminar. 1c) Independent Research Involvement of Attending the Seminar.

Figure 2 compares the self-reported metrics of interest, knowledge, and confidence of students before completing the seminar activities for members of the EWB student chapter versus those of non-members. The only metric where a significant difference between members and non-members was the self-reported knowledge about sustainability. Across all three seminar teaching methods, there was an increase in students' average self-reported knowledge and confidence in the post-seminar survey, as shown in Figure 3.

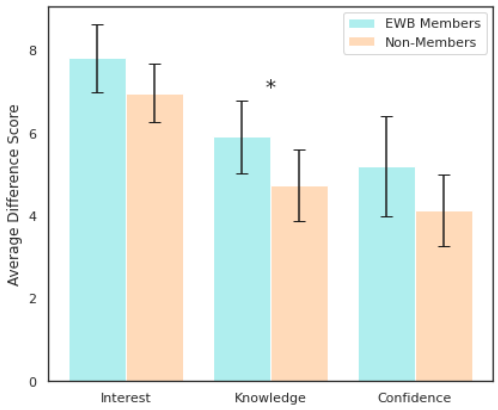

Figure 2. Self-Reported Pre-Seminar Interest, Knowledge, and Confidence (with Error Bars representing the 95% Confidence Interval of the Mean)

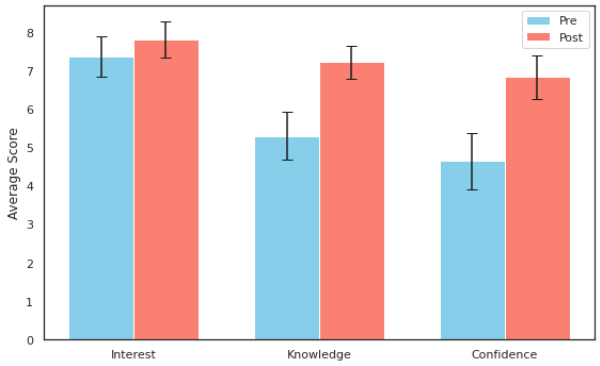

Figure 3. Self-Reported Student Metrics Pre and Post-Seminar Across All Seminar Styles (with Error Bars Representing 95% Confidence Interval of the Mean)

Figure 4 displays the average self-reported student interest, knowledge, and confidence about sustainability topics before (pre) and after (post) the literature review, tactile aid, and hybrid teaching methods before and after the sustainability seminar. The average of each metric for each teaching method before the survey is displayed as a blue bar. The average of each metric for each teaching method after the survey is displayed as a red bar. A statistically significant increase in all metrics from the literature review method and the self-reported knowledge and confidence from the tactile aid hybrid teaching methods was identified.

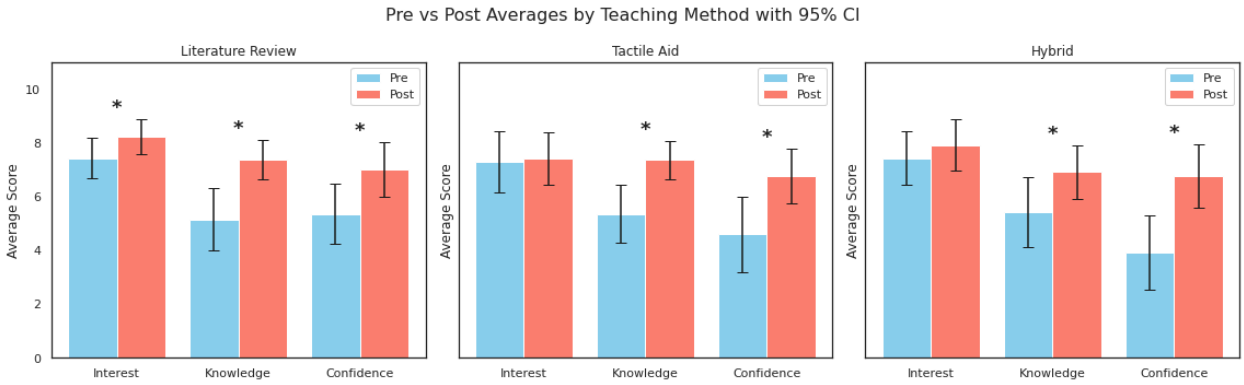

Figure 4. Self-Reported Student Metrics Pre and Post-Seminar For Three Seminar Styles (with Error Bars Representing 95% Confidence Interval of the Mean)

The results of the statistical analyses are shown in Tables 4 and 5. A Shapiro-Wilk test was used to determine if the self-reported scores for each seminar-metric pair were normally or non-normally distributed, informing whether the paired t-test (Table 4) or Wilcoxon test (Table 5) was used to assess the change in score after the seminar. For all seminar formats, students' self-reported knowledge and confidence showed a significant increase after the seminar, while students' self-reported interest only increased after the literature review format seminar.

Table 4. Statistical Significances Using a t-Test for Differences Self-Reported Pre- and Post-Seminar Scores

Seminar	Metric	Shapiro-Wilk Statistic	Shapiro-Wilk p-Score	t-Statistic	p-Value
Literature Review	Knowledge	0.922	0.233	5.6097	0.0000
Literature Review	Confidence	0.946	0.504	3.7349	0.0012
Tactile Aid	Knowledge	0.911	0.104	4.9727	0.0001
Tactile Aid	Confidence	0.897	0.061	4.7767	0.0001
Hybrid	Knowledge	0.876	0.078	4.4497	0.0005

Table 5. Statistical Significances Using a Wilcoxon Test for Differences Self-Reported Pre- and Post-Seminar Scores

Seminar	Metric	Shapiro-Wilk Statistic	Shapiro-Wilk p-Score	Wilcoxon Statistic	p-Value
Literature Review	Interest	0.857	0.028	49.0000	0.0122
Tactile Aid	Interest	0.789	0.001	18.0000	0.2414
Hybrid	Interest	0.796	0.008	28.0000	0.0752
Hybrid	Confidence	0.841	0.029	78.0000	0.0002

Discussion

Following the implementation of three different seminar styles focused on sustainability in engineering, changes in students' interest, knowledge, and confidence related to sustainability in engineering were analyzed. The Engineers Without Borders Chapter, in which this study is affiliated, aims to empower students by teaching them how to promote the chapter and its work. It is believed that the confidence metric, as it is defined in the methods, would be an adequate parameter, along with interest and knowledge, for measuring if students are gaining this

supplemental benefit regarding sustainable engineering topics. Across the board, the results indicate an overall statistically significant increase in knowledge and confidence after participating in the seminar. Thus, the null hypothesis was rejected for the knowledge and confidence metrics for all three teaching methods. Although no major differences were noted in the average self-reported interest, these averages were remarkably high, ranging between 7 and 8 on a 10-point scale (Figure 3). This general assessment is further supported by Tables 4 and 5, demonstrating the difference in self-rated interest, knowledge, and confidence before and after each session.

The paired t-test and Wilcoxon test results in Tables 4 and 5 show that the literature review was the only teaching method able to cause a significant increase in all three self-reported metrics, allowing for rejection of the null hypothesis. Thus, the data from Tables 4 and 5 suggest that the literature review is the most effective teaching method when aiming to increase all three metrics. In addition, since the comparisons using the t-tests and Wilcoxon tests only show a significant increase in interest for the literature review when comparing the pre-survey and post-survey results, it may suggest that the literature review is more proficient in increasing short-term interest in sustainability compared to the other two teaching methods. These results only discuss whether the increase in the self-reported metrics for the teaching methods is significant; the magnitude of the increase in the metrics across teaching methods would compare if one performs better than the other. The ANOVA and Kruskal-Wallis test results show that there is no significant difference when comparing the average increase in self-reported score before and after the seminar for any teaching method for a given metric.

While it was unable to be concluded whether a specific seminar style had a more profound effect on students than another in improving the metrics outlined (Tables 4 and 5), the results still underscore the importance of educating students and the ability for these self-reported scores to be improved, even in the short-term. As indicated by the demographics, most participants were current undergraduate first-year students (Figure 1 (a)). This correlates to the data in Figure 1 (c), which shows that the majority of attendees in the seminar have less technical experience because they are earlier in their collegiate careers. This also suggests that the literature review teaching method may be more effective in increasing all three self-reported metrics for younger students, while the tactile aid and hybrid methods show the same for just the knowledge and confidence metrics.

Due to the lack of equal age diversity of the attendees of the seminar, future research should examine the effects of sustainability curricula across various age groups to understand the relationship between interest, knowledge, and confidence with the timing of their exposure to the subject matter. Moreover, the retention of knowledge should also be measured in future studies to understand the effectiveness of each presentation method over time. Additionally, the data in Figure 1 (b) shows that there is about an even split between members and non-members of the

EWB student chapter. Furthermore, the data from Figure 2 shows that there was a significant difference in knowledge between non-members and members of EWB, suggesting that involvement in extracurricular organizations like EWB may increase students' baseline knowledge about sustainability and sustainable development. However, it was expected that members of the EWB student chapter would have higher interest, knowledge, and confidence than non-members. The lack of a difference between members' and non-members' self-reported interest and confidence may be due to the fact that the majority of attendees in both categories were first-year students, because it may have been too soon for those students to attain the supplementary effects of the EWB student chapter on sustainability education. This suggests that a follow-up study with more longitudinal diversity in students' educational years may provide more concrete results about how extracurricular involvement affects older students' confidence and interest in sustainability. The same need for enhanced diversity in a follow-up study can be seen in Table 3, where 25 of the 43 participants in this study were chemical engineering students. This may bias the results of the survey if the chemical engineering program addressed more or fewer sustainability topics than other programs.

Conclusion

ABET-accredited programs require sustainability topics to be addressed in their curriculum, yet many times it falls upon the initiative of the student to engage in activities or electives that immerse students in sustainable topics. This study set out to determine if the supplemental benefit of an EWB student chapter to sustainability education could be identified in a self-reported score of three metrics. It was determined that there was only a significant increase in the metric of knowledge from non-members to members. The study also used a short seminar on sustainability to determine if literature reviews, teaching with a tactile aid, or a hybrid of the two was the best in increasing self-reported scores of the metrics of interest, knowledge, and confidence in sustainability. It was found that only the literature review was found to have a significant increase in all three metrics, suggesting it may be the best teaching method to achieve increases in the metrics in the short term. By the same tests, the tactile aid and hybrid teaching methods were found only to have significant increases in knowledge and confidence about sustainability. When comparing the data for all three metrics for each teaching method to each other, the increases were not significant. Thus, we cannot definitively conclude whether one teaching method had a greater effect on students' self-reported interest, knowledge, or confidence compared to the others.

In the future, a more diverse and proportional set of subjects at various stages in their education and majors should be evaluated to see the results of a future seminar to better understand the relationship between the three metrics. Though a specific seminar-style teaching method was not identified as being the most effective, these results remain crucially encouraging in that *all* methods were successful in strengthening the average knowledge and confidence of

engineering students. Overall, this study evaluates the best teaching method for ESD in an extracurricular seminar format. Additionally, we demonstrate that participation in extracurricular activities related to sustainability, such as Engineers Without Borders, can improve students' engagement with materials in sustainable engineering. Such activities can supplement PBL in the engineering curriculum to enhance students' experience of ESD in the engineering curriculum taught across universities.

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