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Integrating Sustainability into Materials Courses through the Engineering for One Planet Framework

Dr. Pranshoo Solanki P.E., Illinois State University

Dr. Pranshoo Solanki is an Assistant Professor at Illinois State University with over 10 years of academic and professional experience in the field of construction materials and geotechnical/pavement engineering. He received his doctorate in civil enginee

Prof. Ali Barenji, Illinois State University

Dr. Barenji's research is mainly focused on Smart Manufacturing, and Emerging Technologies to improve training and testing process. He has taught both undergraduate and graduate-level courses and supervised five bachelors, three masters, and a Ph.D. student. He has published more than 35 articles in international journals and International Conference Proceedings Series.

Dr. Matthew Aldeman, Illinois State University

Matthew Aldeman is the Founding Associate Dean of the Illinois State University College of Engineering. Prior to joining the College of Engineering, Aldeman served as an Associate Professor in the Department of Technology, where he taught in the Engineering Technology and Sustainable and Renewable Energy undergraduate programs.

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Abstract

In the context of the growing demand for sustainability-oriented education, this paper presents a case study on integrating sustainability principles into two similar Materials courses taken by students from two different undergraduate majors at a mid-size public Midwestern university. The two materials courses, namely, Mechanical Properties of Materials and Construction Materials Technology, are taken by students in the Engineering Technology and Construction Management programs, respectively. The courses allow students to gain knowledge about the behavior of different materials, strength of materials, and standardized testing procedures. There was little to no emphasis on sustainable materials in either course. However, the course instructors believe that students in both courses will benefit from revised courses that put greater emphasis on sustainable materials. Therefore, this on-going study utilized the Engineering for One Planet (EOP) framework, a model that emphasizes living within Earth's limits while balancing environmental, social, and economic needs, for implementing sustainability concepts in both courses.

The integration process followed a systematic approach, involving the alignment of course objectives with key sustainability principles, followed by the incorporation of hands-on activities designed to apply these principles in a practical context. The modified curriculum was structured around six sustainability aspects: general understanding of sustainability, environmental sustainability, social and economic sustainability, sustainable technologies and innovations, personal perspectives and actions, and assessing knowledge and attitudes. By embedding these aspects into the existing course structure, the redesigned curriculum aimed to deepen students' understanding of how their future professional work could contribute to global sustainability challenges. To assess the effectiveness of this integration, pre- and post-course surveys were administered to gauge students' knowledge and attitudes towards sustainability. These surveys included a total of 16 questions covering six categories, consistent with the EOP Framework, to measure changes in students' general understanding of sustainability, environmental and socio-economic impacts, awareness of sustainable technologies, personal perspectives, and commitment to sustainable practices. The preliminary results indicate that curriculum changes focused on sustainability not only enhance student learning but also foster a more profound commitment to sustainable engineering and construction practices.

Introduction

Sustainability represents a balance that accommodates current human needs without diminishing the health and productivity of natural systems, and without diminishing the ability of future generations to accommodate their own needs. From a civil engineering and construction perspective, sustainability relates to systems that prevent environmental degradation and utilize resources efficiently so that the environmental, economic, and social benefits minimize the environmental degradation created through the life cycle of the built environment [1]. From a mechanical engineering and renewable energy perspective, sustainable energy means using energy resources wisely and efficiently to meet the energy needs of the present without compromising the ability of future generations to meet their own energy needs. Sustainability is a professional and ethical imperative [2]. It is unethical for a group of people from the current generation to ignore or diminish the abilities of future generations to provide for themselves. Sustainability issues should take on an increased presence in university classrooms. The purpose of the Engineering for One Planet (EOP) Framework is to provide engineers with the necessary skills and knowledge to safeguard the planet and its ecosystems, ensuring their sustainability for the benefit of all living beings [3]. This study aims to address this need by applying the EOP framework to integrate sustainability knowledge into two key materials-focused courses: *Mechanical Properties of Materials* and *Construction Materials Technology*. These courses, offered within the Engineering Technology and Construction Management programs at Illinois State University, serve as an ideal platform to embed sustainability principles, equipping students with the knowledge and skills necessary to address global challenges. These courses are currently taught with a primary focus on Mechanics of Materials topics, with minimal emphasis on sustainability. To address this gap, the courses were redesigned following the EOP framework. The redesign introduced new units on sustainable material alternatives, group projects, and student design challenges, emphasizing sustainability as a core component. This approach aims to foster a deeper understanding of sustainable practices and encourage students to apply these principles in their future professional endeavors.

The integration process was methodically planned to align course objectives with key sustainability principles. This involved incorporating hands-on activities that allowed students to apply these principles in practical scenarios. The redesigned curriculum emphasized six core sustainability aspects: general understanding of sustainability, environmental sustainability, social and economic sustainability, sustainable technologies and innovations, personal perspectives and actions, and assessing knowledge and attitudes. By embedding these components into the existing course framework, the redesign sought to equip students with a comprehensive understanding of how their future professional roles could address global sustainability challenges.

To evaluate the effectiveness of this integration, pre and post surveys were conducted to assess changes in students' knowledge and attitudes toward sustainability [4]. The surveys were structured around the six categories of the EOP Framework, measuring gains in areas such as general sustainability understanding, awareness of environmental and socio-economic impacts, knowledge of sustainable technologies, and personal commitment to sustainable practices. Preliminary findings suggest that these curriculum changes not only enhance students' understanding of sustainability but also inspire a stronger commitment to adopting sustainable engineering and construction practices in their future careers.

In this paper the structure of each course will be described, followed by a discussion of how sustainability principles were inserted into the courses in accordance with EOP principles. Finally, results of the anonymous student surveys will be provided and discussed.

Course Structure

In this study, the focus on sustainability was increased in two similar Materials courses namely, TEC 292: Construction Materials Technology and TEC 293: Mechanical Properties of Materials. The two courses are very similar, but they are taken by students from two different undergraduate majors at Illinois State University. Students in the Construction Management undergraduate program take Construction Materials Technology, while students in the Engineering Technology program take Mechanical Properties of Materials. Both courses are required core courses for students in these respective majors, and the courses are typically taken by students in the third year of their programs. Each course has a maximum enrollment of 24 students and meets twice per week for 110 minutes over a 15-week semester.

Construction Materials Technology (TEC 292)

This course is offered every fall and spring semester. It is a combined lecture and laboratory-based course in which three-quarters of the semester consisted of five lab activities, during which students learn about sample preparation and testing in compression, tension, flexure and shear modes. The class was divided into four groups consisting of five to six students. Specifically, topics covered in this course were material testing introduction, masonry, Portland cement concrete, asphalt materials, alternative concretes, steel and wood. The following is a listing of lab activities: density, compression testing of concrete and wood, flexure testing of wood and concrete, and tensile testing of metals, wood and concrete. The laboratory experiences are designed to be completed within the allotted time in the class hours.

The required tasks in this course are quizzes, laboratory reports and a final presentation. Quizzes were given frequently in this class in order to help measure comprehension of the lecture and reading material. Most of the quizzes required reading material or watching posted audiovisual materials and completing comprehension questions. Quizzes were taken online through the Canvas learning management system. Laboratory activities were assessed through reports related to laboratory activities. Additionally, out-of-lab activities were provided occasionally. The purpose of out-of-lab activities was to utilize time when students are not working in the lab and provide students with background information related to laboratory report questions. At the end of each lab activity, students prepared and submitted a laboratory report. Each individual student was required to submit his/her own report via Canvas by the due date.

Mechanical Properties of Materials (TEC 293)

This course is also offered every fall and spring semester. This is a combined lecture and laboratory course: eight lab activities and reading materials with lecture notes provide knowledge about 1) how the properties of metals, ceramics, and polymers relate to the atomic and intermolecular bonding present in these materials, 2) terminology associated with strength of materials and materials technology, 3) how to read, interpret, and apply accepted industry-wide standards for the testing of materials, 4) methods to perform destructive and non-destructive tests according to ASTM standards to analyze and evaluate properties of engineering materials, and 5) procedures to collect, calculate, interpret, and communicate technical laboratory test data.

The lecture portion provides an overview of materials, focusing on how atomic and molecular structures influence material properties. It then transitions to more detailed discussions on ferrous and non-ferrous metals, including existing techniques for their extraction and production. The required tasks in this course are 3 exams, multiple quizzes, and technical laboratory reports. Quizzes were given frequently in this class in order to help measure comprehension of the lecture and reading material. Most of the quizzes required reading material or watching posted audiovisual materials to complete questions. Quizzes were taken online through the Canvas learning management system. Like the Construction Materials course, laboratory activities were assessed through reports related to laboratory activities, with out-of-lab activities provided occasionally. Similarly, at the end of each lab activity, students prepared and submitted a laboratory report, with each individual student required to submit his/her own report via Canvas by the due date.

Integration of sustainability

To integrate sustainability concepts into these existing courses, the EOP framework was adopted, with a focus on three key aspects: sustainable material alternatives, life cycle analysis, and systems thinking. This approach helps students develop a deeper understanding of the environmental, social, and economic impacts of material selection and usage. Specifically, both courses utilize existing datasets and documents provided by VentureWell [5], available as open-access resources, to support the life cycle analysis section of the curriculum. This enables students to apply sustainability principles using real-world data and tools.

Sustainability in *Construction Materials Technology*

For integrating sustainability concepts in this course, new reading and presentation materials around sustainability were created and labs were revised by incorporating testing of sustainable materials alongside traditional materials. Specifically, a Sustainable Concrete term project was developed relating to the creative use of recycled materials in concrete. This project began after mid-semester with extensive literature review for students to come up with the most interesting and novel idea. Then, students were engaged in research to design their Sustainable Concrete using recycled materials, industrial wastes, and by-products. Students worked together in groups (a total of four groups with six students in each group) to perform all the steps of the project from design to manufacturing and testing. Each group was also required to build laboratory scale samples, conduct compressive testing, determine cost, and propose a real-world application for their Sustainable Concrete, based on the experiments. Additionally, in the last class student groups made project presentations. Overall, during the Sustainable Concrete project students learned how construction materials can be made more environmentally friendly and economical.

Sustainability in *Mechanical Properties of Materials*

To integrate sustainability concepts into Mechanical Properties of Materials, new reading and presentation materials focused on sustainability were developed, and the lab activities were revised to include testing of sustainable materials alongside traditional ones. Figure 1 provides a fishbone diagram that visualizes this integration. The green color bar and its transparency shows that by moving towards the end of semester the integration of sustainability aspect increased. The lower section of the diagram highlights the resources incorporated into the lectures, such as PowerPoint slides, videos, reading assignments, and hands-on activities, all designed to introduce sustainability concepts and explain life cycle analysis (LCA). The upper section, marked with a green line, illustrates the progressive integration of sustainability topics throughout the course, starting with foundational concepts and building toward more advanced discussions and applications.

The integration begins in Week 1 with a basic definition of sustainability and continues in Week 2 with an introduction to sustainable metals, aligned with the fundamentals of engineering materials. A video regarding aluminum extraction and its impact on the environment was provided to students in this week as well as an activity to select optimal sustainable material was performed in the class by considering recycled aluminum as a possible solution. This focus expands until Week 5, where system thinking methodology is introduced during the lectures on ferrous and non-ferrous metals. More specifically, it starts by introducing renewable energy resources, recycling, and going green. Subsequently, critical thinking is fostered through hands-on examples such as reducing plastic waste by promoting reusable containers. The course includes a detailed explanation of life cycle analysis, and students engage in a class activity during the first LCA lesson to select sustainable materials for a case study [6].

The course concludes with a hands-on project centered on beam design and testing, emphasizing the selection of sustainable materials. This structured approach ensures that students gain practical knowledge and critical thinking skills for applying sustainability concepts in engineering contexts.

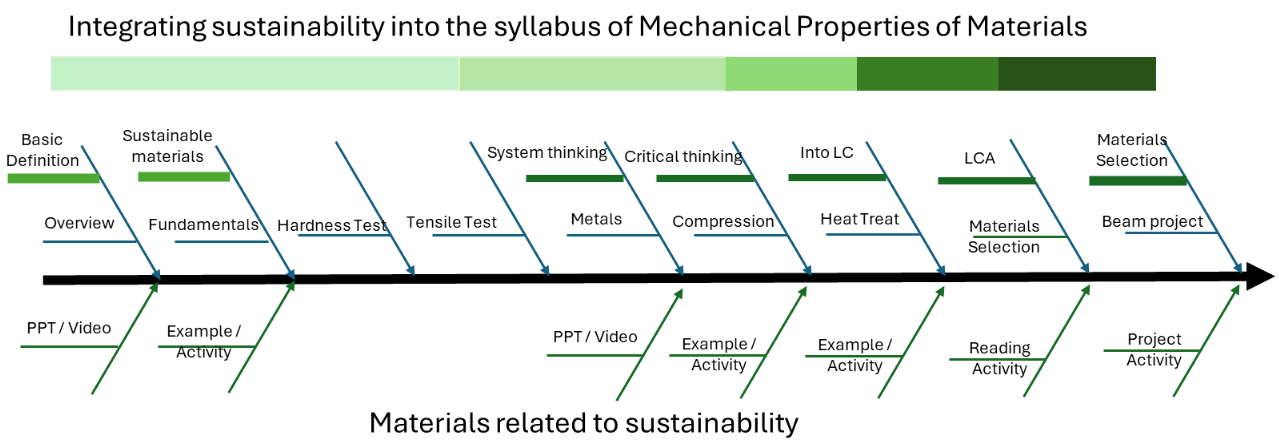

Figure 1. Fish bone diagram for integrating sustainability into Mechanical properties of materials.

As illustrated in Figure 1, the integration of sustainability, represented by the green color, progresses steadily from the first week to the last week. This gradual enhancement reflects the increasing emphasis on sustainability aspects in both the classroom and laboratory activities. The progression demonstrates how sustainability concepts are reinforced and expanded upon throughout the course, ensuring students gain a deeper understanding and practical application of these principles over time.

Student Assessment Data Collection

To evaluate the effectiveness of this integration, pre- and post-course surveys [7] were conducted to measure changes in students' knowledge, attitudes, and understanding of sustainability concepts. These surveys aimed to assess how well the redesigned curriculum met its objectives of integrating sustainability principles into both theoretical and practical components of the course. The survey questions were carefully structured to capture students' baseline knowledge at the start of the semester and to identify any improvements in their understanding by the end. The survey questions were classified into six main categories, as shown in Figure 2, which also indicates the number of questions allocated to each category. These categories include General Understanding of Sustainability (2 questions), Environmental Sustainability (4 questions), Social and Economic Sustainability (3 questions), Sustainable Technologies and Innovations (2 questions), Personal Perspective and Actions (3 questions), and Assessing Knowledge and Attitudes (2 questions). This categorization allowed for a structured evaluation of various aspects of sustainability knowledge and attitudes, ensuring comprehensive coverage of key areas. The detailed questions used in this survey (provided below), offered a complete overview of how each category was addressed and contributes to the robustness of the evaluation process. This systematic approach ensured that the survey captured a holistic picture of students' growth in sustainability knowledge and perspectives throughout the course.

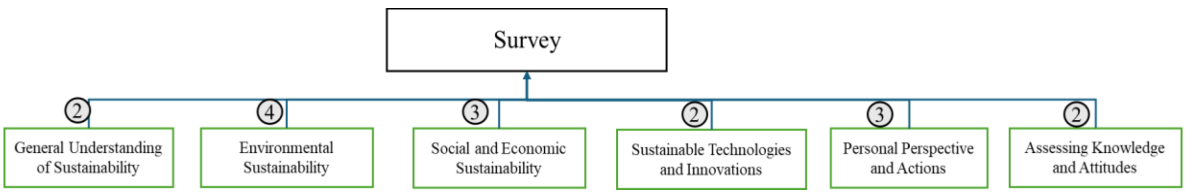

Figure 2. Structure of survey questions.

Each question was rated on a Likert scale of 1 to 5, 1 representing strong disagreement, 3 representing the neutral or not sure response and 5 representing strong agreement. The pre-survey was administered on the first day of class to establish a baseline understanding of students' knowledge, attitudes, and perspectives on sustainability. In contrast, the post-survey was conducted at the end of the semester to measure changes and improvements in these areas after the completion of the redesigned curriculum. This before-and-after approach allowed for a direct comparison of students' progress, providing insights into the effectiveness of integrating sustainability concepts into the course [[8].

The specific survey questions are as follows:

1. General Understanding of Sustainability

Q-1 I understand the concept of sustainability in my field of study (engineering technology and/or construction management).

Q-2 To what extent do you agree that sustainability should be one of the core focuses on your field of study?

2. Environmental Sustainability

Q-3 I understand the concept of life cycle assessment (LCA) in evaluating the sustainability of products.

Q-4 To what extent do you agree that engineering technology and/or construction management should consider the environmental impact of designs?

Q-5 How strongly do you agree with the statement: "Renewable energy sources and recycled materials are effective in reducing environmental impact"?

Q-6 To what extent do you agree the life cycle of materials and products is important in sustainability?

3. Social and Economic Sustainability

Q-7 To what extent do you agree that introducing sustainable practices in engineering technology or construction management improves social equity and community benefits?
Q-8 How strongly do you agree with the statement: "I understand the economic benefits of sustainable practices"?
Q-9 To what extent do you agree that ethical decision-making is important in achieving sustainability in your field?

4. Sustainable Technologies and Innovations

Q-10 How strongly do you agree with the statement: "I am knowledgeable about sustainable technologies in my field of study"?
Q-11 To what extent do you agree that incorporating sustainable design principles can lead to more innovative products?

5. Personal Perspective and Actions

Q-12 How strongly do you agree with the statement: "I regularly engage in activities or projects that promote sustainability"?
Q-13 To what extent do you agree that you are motivated to pursue a career that focuses on sustainability?
Q-14 How strongly do you agree with the statement: "I am confident in my ability to contribute to sustainable practices in my future career"?

6. Assessing Knowledge and Attitudes

Q-15 To what extent do you agree that implementing sustainable practices in engineering technology and/or construction management projects is challenging?
Q-16 How strongly do you agree with the statement: "It is important to stay informed about sustainability trends and developments in my field"?

Findings and Discussion

In this paper, we analyze the survey results for each course individually, providing a better understanding of course improvements in each setting.

Construction Materials Technology results

As discussed earlier, in the first and last week of semester students were given pre-course and post-course survey questionnaires, respectively. The pre-course and post-course survey responses of 24 subjects in the questionnaire are presented graphically in Figures 3 (a) and (b), respectively. Based on pre-course and post-course results, responses to Q-1 through Q-4, Q-6 through Q-12, Q-14, and Q-15 show positive improvement in response of 4 or 5 (moderately or strongly agree) which indicates that revised course material helped students in their understanding of sustainability concepts. Specifically, Q-8 (*How strongly do you agree with the statement: "I understand the economic benefits of sustainable practices"?*) and Q-10 (How strongly do you agree with the statement: "I am knowledgeable about sustainable technologies in my field of study"?) showed an improvement by 45.1% (from 45.8% in pre-course to 90.9% in post-course survey) and 52.3% (from 25.0% in pre-course to 77.3% in post-course survey) in agree responses. The improvement in Q-8 responses could be attributed to cost analysis study conducted by students during the Sustainable Concrete project.

However, a decline was noticed in responses to Q-5 and Q-13. The decline of 4.9% (from 95.8% in pre-course to 90.9% in post-course survey) in Q-5 (*How strongly do you agree with the statement: "Renewable energy sources and recycled materials are effective in reducing environmental impact"?*) could be attributed to reduced strength of concrete specimens prepared and tested during Sustainable Concrete project. It should be noted that out of four groups, only one group was able to prepare Sustainable Concrete which had strength higher than control concrete; the remaining three groups' Sustainable Concrete was cost-effective but showed strength lower or similar to the control concrete. Due to limited time, students were not able to prepare and test additional concrete specimens. Some students might have thought that recycled materials are not effective in making Sustainable Concrete because they reduced concrete strength. The responses to Q-13 (*To what extent do you agree that you are motivated to pursue a career that focuses on sustainability?*) showed decline of 20.5% (from 25.0% in pre-course to 4.5% in post-course survey). It is possible that Construction Management students are not aware of any jobs and career specifically in the sustainability area. It should be noted that these are preliminary results based on only 24 subjects, and additional data (48 subjects enrolled in two sections) will be collected in the spring 2025 semester as well.

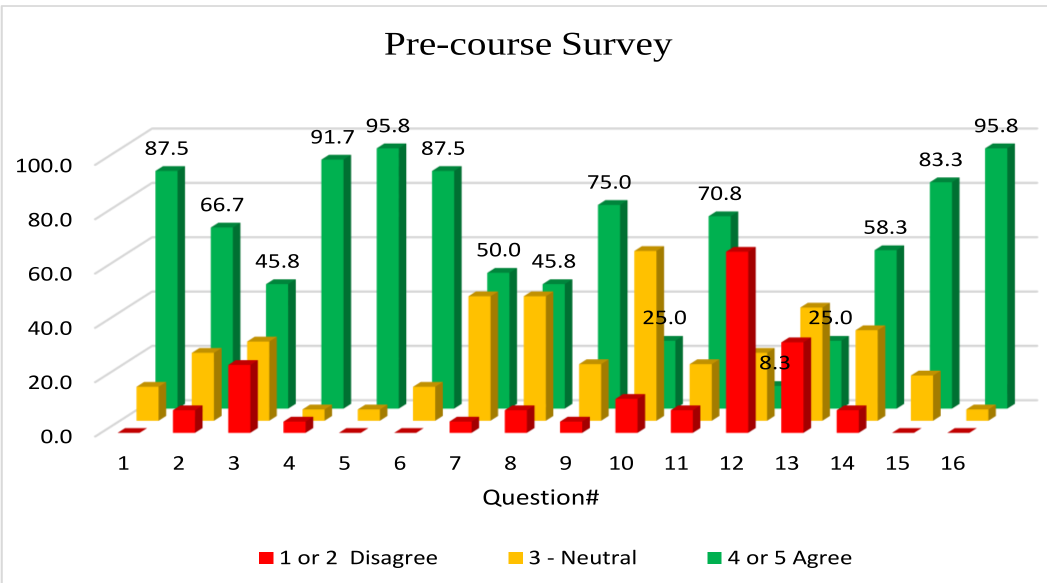

Figure 3 (a) Construction Materials Technology: Pre-course survey results (green bar values shown in the figure).

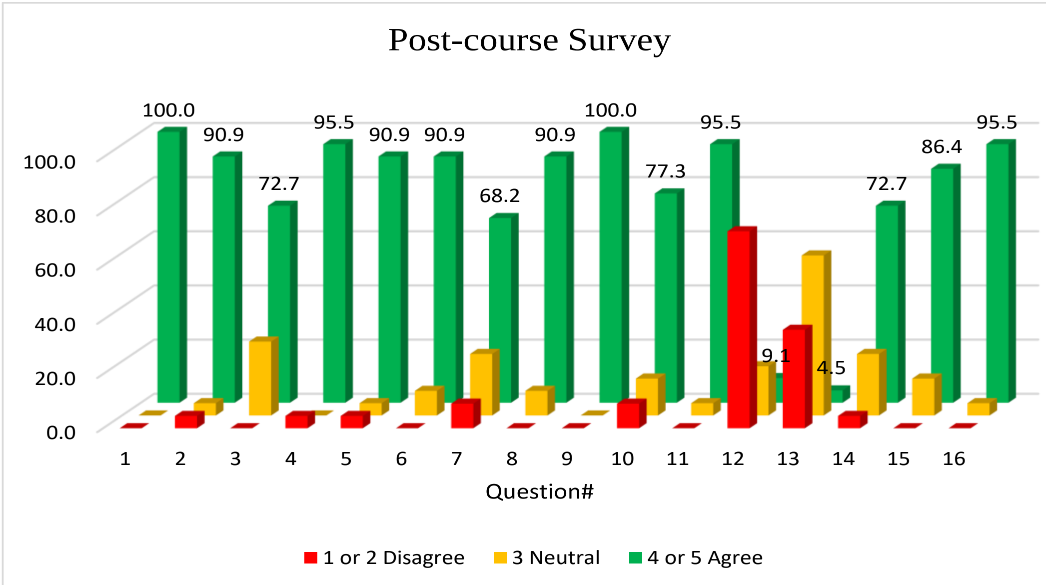

Figure 3. (b) Construction Materials Technology: Post-course survey results (green bar values shown in the figure).

In the grade distribution 10% was assigned to Sustainable Concrete project activity and remaining 90% was assigned to other learning activities such as quizzes, class exercises, exams and four lab reports. Out of 10%, 5% was assigned to Sustainable Concrete project report and 5% was assigned to oral presentation. All groups showed satisfactory performance in both reports and presentations. Also, based on his teaching experience, instructor found that students were more engaged and enthusiastic during Sustainable Concrete project. Course evaluation and feedback was also positive and some of the challenges pointed out by students was limited time, choosing the right type and amount of recycled material for replacement. The instructor believes they will be able to overcome these limitations in the following semester in which additional data will be collected.

Mechanical Properties of Materials

The same pre- and post-survey was administered to students enrolled in the Mechanical Properties of Materials course, with 16 students responding. Figure 4(a) and Figure 4(b) illustrate the pre-survey and post-survey results, respectively. Based on the pre-course and post-course responses to Q1 through Q11, there was a noticeable improvement, indicating that the revised course materials effectively enhanced students' understanding of sustainability concepts.

In particular, Q3 ("I understand the concept of life cycle assessment (LCA) in evaluating the sustainability of products.") demonstrated significant improvement. This suggests that the hands-on project introduced in Week 10 of the course, in which students utilized recent data to evaluate the LCA of different products, was highly effective. Additionally, Q7 ("To what extent do you agree that introducing sustainable practices in engineering technology or construction management improves social equity and community benefits?") showed substantial progress. In the pre-course survey, 68.75% of students selected "agree" or "strongly agree," whereas in the post-course survey, this percentage increased to 100%, reflecting a positive shift in students' perspectives.

Similarly, Q8 ("How strongly do you agree with the statement: 'I understand the economic benefits of sustainable practices'?") showed an improvement of more than 20% from the pre-course to the post-course survey. This finding highlights the direct relationship between the course content and students' understanding of social and economic sustainability. Furthermore, Q10 ("How strongly do you agree with the statement: 'I am knowledgeable about sustainable technologies in my field of study'?") demonstrated a significant increase, further emphasizing the effectiveness of the curriculum revisions.

However, there remains room for improvement in Q12 and Q13, likely due to the nature of the questions. Nonetheless, Q15 and Q16, which assess students' knowledge and attitudes, showed considerable progress. These results suggest that while the revised curriculum effectively strengthened students' grasp of sustainability concepts, additional refinements could further enhance learning outcomes in specific areas.

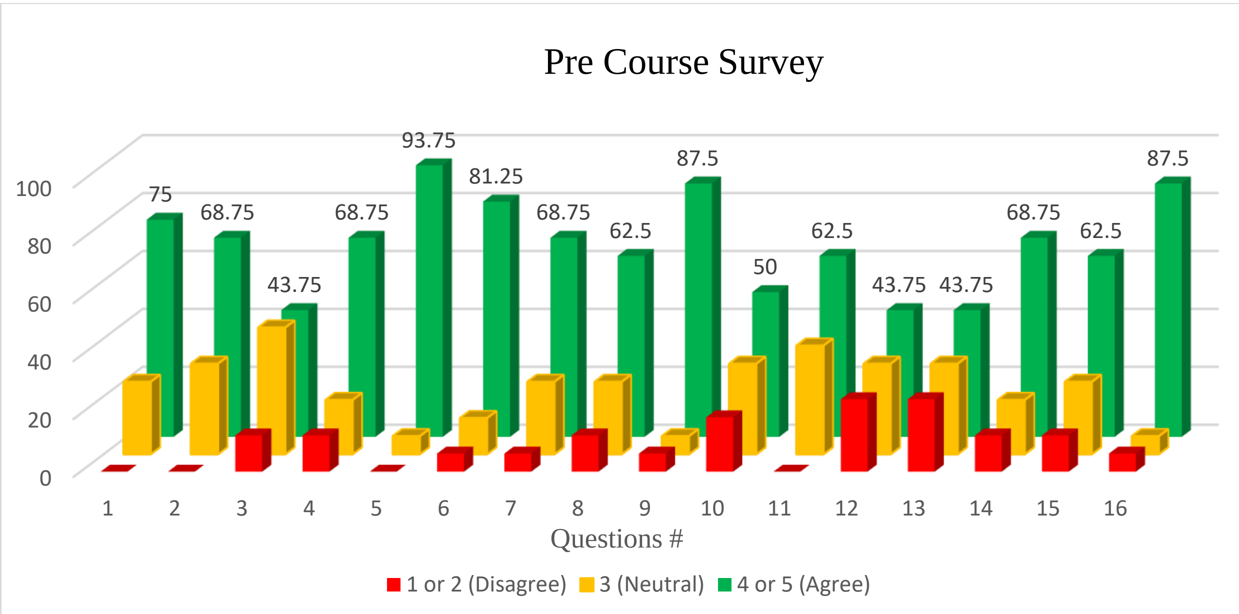

Figure 4. (a) Mechanical properties of materials: Pre-course survey results (green bar values shown in the figure).

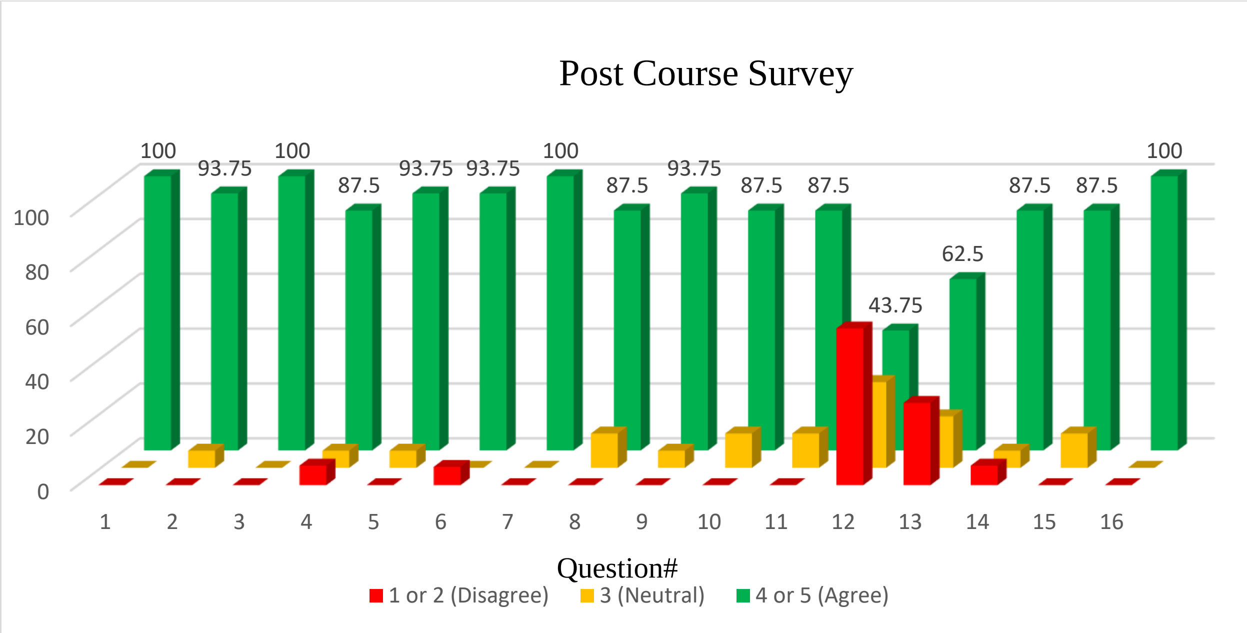

Figure 4. (b) Mechanical properties of materials: Post-course survey results (green bar values shown in the figure).

Comparison of Both Courses

For comparison of pre- and post-course surveys of both courses, an improvement of greater than 20% in "agree" responses between pre- and post-survey was considered significant improvement. It was found that Q2 (sustainability should be core focuses), Q3 (understand the concept of life cycle assessment), Q8 (understand the economic benefits of sustainable practices), Q10 (knowledgeable about sustainable technologies), and Q11 (incorporating sustainable design can lead to more innovative products) responses showed significant improvement in both Construction Materials Technology and Mechanical Properties of Materials courses. Further, significant improvement was noticed in Q9 (ethical decision-making is important in achieving sustainability) only in Construction Materials Technology course. Additionally, significant improvement was noticed in Q1 (understand concept of sustainability), Q7 (sustainable practices in engineering technology or construction management improves social equity and community benefits), and Q15 (implement sustainable practices in construction management or engineering technology is challenging) only in Mechanical Properties of Materials course.

Furthermore, for comparison of pre- and post-course surveys of both courses, an improvement of less than 1% in "agree" responses between pre- and post-survey was considered negligible improvement. It was found that Q5 (renewable energy sources and recycled materials are effective) and Q12 (regularly engage in projects that promote sustainability) responses showed negligible improvement in both Construction Materials Technology and Mechanical Properties of Materials courses. No significant improvement was noticed in Q13 (you are motivated to pursue a career in sustainability) and Q16 (it is important to stay informed about sustainability trends and developments) only in Construction Materials Technology course. As discussed earlier, both courses were taught by different instructors and are in different programs. It is possible that Construction Management students are not aware of sustainability careers and dynamic changes in sustainability trends. This topic (sustainability trends and development) was not discussed by the instructor in the Construction Materials Technology course.

Concluding Remarks

This study explored the integration of sustainability principles into two undergraduate materials-focused courses—*Mechanical Properties of Materials* and *Construction Materials Technology*—at Illinois State University. Utilizing the Engineering for One Planet (EOP) Framework, sustainability concepts were systematically embedded into the curriculum, incorporating hands-on projects, life cycle assessment (LCA) activities, and systems thinking approaches.

The analysis of pre- and post-course surveys demonstrated a positive impact on students' understanding and attitudes toward sustainability. Significant improvements were observed across multiple survey questions, particularly in students' comprehension of life cycle assessment, importance of sustainability as a core focus, economic benefits of sustainability, sustainable technologies, and incorporation of sustainable design for more innovative products. The results suggest that hands-on, project-based learning approaches significantly enhance students' ability to grasp sustainability concepts and apply them in practical engineering and construction contexts.

Despite these positive findings, certain areas—such as renewable energy sources and recycled materials effectiveness and engagement in sustainability-related projects —showed no significant improvement. These results highlight the need for further refinement of course activities, potentially incorporating more sustainability career-oriented discussions, real-world industry applications, and interdisciplinary collaborations to strengthen student engagement in sustainability-driven professional paths.

Overall, this study underscores the importance of integrating sustainability into engineering and construction curricula and demonstrates that curriculum modifications based on the EOP framework can enhance students' learning and commitment to sustainable practices. Future work will expand this research by incorporating additional student cohorts, refining instructional methods, and exploring long-term impacts on students' professional decision-making in sustainability-driven fields.

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