2026 ASEE ANNUAL CONFERENCE June 21–24, 2026 | Charlotte Convention Center, NC
Host Sponsor UNC Charlotte
ASEE AMERICAN SOCIETY FOR ENGINEERING EDUCATION
Paper ID #50365

NSF-Lemelson Initiative (NLI) Project: Applying Engineering for One Planet Framework to Teach Industrial and Systems Engineering Courses

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Abstract

Integrating social and environmental sustainability into engineering education is critical for preparing students to address complex global challenges. This project studies how to embed these principles into Industrial and Systems Engineering (ISE) curricula using the Engineering for One Planet (EOP) framework. In selected ISE courses, instructors developed specialized modules focused on sustainability in manufacturing and service systems. Assessment data were collected from the courses, including pre-and post-tests, log files, formative and summative assessments, and self-reports using questionnaires. By analyzing assessment data from these courses, we are demonstrating how to effectively prepare students to become sustainability-literate professionals. The findings demonstrate a path for effectively equipping future engineers and provide a scalable model for other engineering disciplines to adopt the EOP framework.

Introduction

The United Nations has identified poverty eradication as a fundamental prerequisite for sustainable development, as outlined in its 2030 Agenda. This agenda establishes 17 Sustainable Development Goals (SDGs), with SDG 12—"Ensure sustainable consumption and production patterns"—holding direct relevance for engineering [1]. This focus on sustainability is echoed by leading engineering institutions. The National Academy of Engineering (NAE) lists sustainability as one of four overarching themes among its fourteen Grand Challenges, noting that such challenges are fundamental to securing the future itself [2, 3]. Similarly, the National Academies of Sciences (NAS) advocates for advancing sustainability education.

Moreover, sustainability is a focal point of student outcome 4 established by the Accreditation Board for Engineering Technology (ABET) [4]. This outcome mandates that engineering students possess the ability to recognize ethical and professional responsibilities in engineering contexts, making informed judgments that consider the broad impact of engineering solutions within global, economic, environmental, and societal frameworks.

In this NSF Lemelson Initiative (NLI) project, we seek to meet this need by developing a sustainability integrated curriculum at North Carolina A&T State University (NCA&T), addressing not only the current industry demands but also preparing for future transitions and challenges. Integrating the concept of sustainability into the curriculum is essential for developing an environmental and social sustainability-focused workforce that is not only equipped with the holistic skill sets for addressing traditional engineering problems related to productivity, efficiency, and quality but also leads in the transition toward sustainable practices.

Traditionally, sustainability is introduced as a separate topic outside the technical training an engineering student will receive at a university. This practice often results in engineering students considering sustainability in their design as an afterthought. That approach no longer works given the environmental and social crises we are facing today. Engineering education can no longer treat sustainability as an optional topic. There is a strong need for a pedagogical shift to prepare engineers to understand social and environmental impacts and constraints and are equipped with knowledge and green skills and tools that allow them to design and make products and solutions for a sustainable future.

This research adopts the Engineering for One Planet (EOP) framework as the foundation for integrating sustainability into our curriculum. The center piece of the EOP is "Systems thinking" which is interconnected with all other student learning outcomes [5]. We believe Industrial and Systems Engineering (ISE) is uniquely positioned to systematically integrating sustainability into its curriculum since systems thinking is an essential part of the training an ISE student receives and therefore, they are more likely to understand and willingly to adopt the proposed approach.

The overall goal of this project is to investigate how integrating sustainability, particularly environmental and social aspects, will enhance student learning and prepare them to become professional engineers that are ready to address sustainability in complex systems. Specific objectives are to: (i) integrate sustainability into various ISE Courses using the EOP framework, (ii) prepare course materials for sustainability following the design based engineering learning model (DBEL) [6], (iii) conduct research on student learning using data collected from the courses, including pre- and post-tests, log files, formative and summative assessments, and self-reports obtained through questionnaires, and (iv) develop and implement a course material transferability plan to broaden the breadth of the impact of this project beyond NCA&T.

Course selection

We have carefully selected 10 courses (1 freshman, 2 sophomore, 3 junior and 4 senior courses) that would be directly impacted by this project. Table 1 provides details of these courses.

Table 1: Selected Courses

Course ID	Course Name	Course level
GEEN 100	Engineering Design and Ethics	Freshman
ISEN 246	Industrial Production Processes	Sophomore
ISEN 286	Engineering Teams and Leadership	Sophomore
ISEN 361	Engineering Economy and Cost Analysis	Junior
ISEN 386	Systems Approach to ISE	Junior
ISEN 465	Facility Design	Junior
ISEN 475	Design of Experiments	Senior
ISEN 400	Problem Solving in ISE	Senior
ISEN 480	Systems Engineering	Senior
ISEN 453	Engineering Entrepreneurship	Senior

These courses are strategically chosen to allow for the horizontal and vertical integration of sustainability into the ISE curriculum. We begin with the freshman course *GEEN 100: Engineering Design and Ethics*, and end with the senior-level courses—*Design of Experiments, Problem Solving in ISE, Systems Engineering, and Engineering Entrepreneurship*, allowing students to leverage their sustainability expertise acquired throughout their academic journey.

EOP course integration plan

We aim to integrate sustainability into the ISE curriculum through a systems approach, preparing the next generation of engineers with the knowledge, tools, and ethical responsibility needed to address complex socio-environmental challenges. To achieve this, the project employs whole systems mapping—a methodology that aligns the department's strategic vision with social and environmental sustainability goals to drive innovative course design.

The ISE department at NC A&T is strategically committed to developing students as Leaders, Integrators, and Transformers (LIT). This process will be mapped across the curriculum, from enrollment to graduation, with sustainability as a unifying theme. Course development is guided by the Design-Based Engineering Learning (DBEL) framework to create materials that effectively incorporate sustainability principles. Each course emphasizes one or more of the three EOP learning outcome categories: systems thinking, knowledge and understanding, and skills, experiences, and behaviors.

Progress and results

To establish a common foundation for integrating sustainability across the curriculum, faculty participated in a series of weekly meetings during the initial months of the project. This training ensured a consistent approach and established quality control measures.

The project focuses on two application areas, manufacturing and service, which are incorporated into the course content. Accordingly, we developed two distinct assessment instruments to measure student sustainability knowledge in these domains. Both instruments evaluate the following constructs: resource management, minimizing pollution, ecological balance, circular economy, social equity, health and wellbeing, and resilience.

In Fall 2025, sustainability was integrated into five courses: *GEEN 100, ISEN 246, ISEN 361, ISEN 400, and ISEN 453*. Instructors aligned EOP learning objectives with ABET student outcomes using a design-based engineering learning approach. The first two courses (GEEN 100 and ISEN 246) emphasized manufacturing applications, while the final three (ISEN 361, ISEN 400, and ISEN 453) focused on service applications.

A sustainability knowledge assessment was administered at the beginning and end of the semester. Tables 2 and 3 present the basic statistics for the pre- and post-assessments, along with t-test results for each construct. Table 3 details the results from the service survey, and Table 4 details findings from the manufacturing survey, for which only three constructs were assessed based on the course curriculum.

Table 2 Service survey results

	Pre			Post			T test	
Construct	**N**	**Mean**	**Standard deviation**	**N**	**Mean**	**Standard deviation**	**t**	**p**
Resource Management	35	4.0857	0.4924	50	4.275	0.7147	$t_{82.989}$=1.45	0.1520
Minimizing pollution in service	35	4.2381	0.6292	50	4.1933	0.8936	$t_{82.992}$=-0.27	0.7871
Ecological Balance.	35	4.1570	0.5913	48	4.2604	0.6684	t_{81}=0.73	0.4679
Circular Economy	35	4.0000	0.5423	47	4.1702	0.6937	t_{80}=-1.20	0.2326
Social Equity	35	4.3333	0.5483	46	4.4130	0.6174	t_{79}=-0.60	0.1996
Health and Well-being	35	2.5333	0.5897	46	2.7029	0.5805	t_{79}=-1.29	0.5478
Resilience	34	2.0735	0.6757	46	2.0435	0.7946	t_{78}=-0.18	0.8558

Table 3: Manufacturing survey results

	Pre			Post			T test	
Construct	**N**	**Mean**	**Standard deviation**	**N**	**Mean**	**Standard deviation**	**t**	**p**
Resource Management	21	1.7937	0.4531	10	1.9667	0.4568	t_{29}=0.99	0.3297
Minimizing pollution in manufacturing	21	2.0238	0.5804	9	1.7778	0.5652	t_{28}=--1.07	0.2929
Circular Economy	21	2.7143	1.14641	9	2.7778	0.9718	t_{28}=0.14	0.8858

As shown in the tables, no statistically significant difference was found between the pre- and post-assessment scores for any construct. This is an interesting finding, suggesting that students entered the course with a strong baseline knowledge of sustainability and that the instructional modules did not significantly alter their self-assessed understanding. While this may reflect a greater generational awareness of sustainability among engineering students, it highlights a need for future assessment. Specifically, subsequent surveys should evaluate students' familiarity and comfort with sustainability design tools and their experience applying them, as well as their knowledge of frameworks like EOP.

Future work

Over the coming year, we will expand sustainability integration to the remaining five ISE courses. We will also revise our survey instruments to include questions on sustainability design tools and

EOP-specific topics. To ensure the effectiveness of these efforts, we will conduct focus groups with instructors and students and use their feedback for continuous refinement.

Acknowledgements

This material is based upon work supported by the National Science under Grant No. 2430739. Any opinions, findings, conclusions, or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

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