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# Embedding the Engineering for One Planet (EOP) Framework through Sustainability-Fo Activities in Mechanical and Aerospace Engineering Courses

**Dr. Gurudutt Chandrashekar, Trine University**

Dr. Gurudutt Chandrashekar is an Associate Professor in the Department of Mechanical and Aerospace Engineering at Trine University. His teaching and research interests include composite materials, machine design, computer-aided design, and the integration of sustainability concepts into engineering education.

**Dr. Rizacan Sarikaya, Trine University**

Dr. Rizacan Sarikaya is an Associate Professor of Mechanical Engineering at Trine University. He completed his Ph.D. in Mechanical Engineering at the University of Kansas. He also holds an M.S. in Mechanical Engineering from the University of Kansas and a B.S. in Mechanical Engineering from Istanbul Technical University. His research interests include engineering education, finite element analysis, material modeling, biomaterials, and experimental characterization.

**Dr. Max M Gong, Trine University**

Dr. Max Gong is an Associate Professor in the Department of Biomedical Engineering at Trine University. His teaching interests include engineering design, manufacturing, BME research techniques, and BioMEMS. He also mentors and trains students in undergraduate research in the area of space health.

# Embedding the Engineering for One Planet (EOP) Framework through Sustainability-Focused Activities in Mechanical and Aerospace Engineering Courses

**Abstract:**
Supported by the ASEE Engineering for One Planet (EOP) Mini Grant Program (MGP), sustainability focused activities were implemented in multiple mechanical and aerospace engineering courses in the 2025-26 academic year at Trine University. The activities were aligned with selected learning outcomes from topic areas of the EOP framework; rather than implementing entire EOP learning outcomes, this study targeted specific concept areas derived from selected learning outcomes that could be integrated into existing technical assignments. New activities were created in courses– (1) Machine Component Design, (2) Aerospace Composites, (3) Engineering Materials, (4) Computer Aided Machine Design and (5) Introduction to Engineering. These activities focused on achieving sustainability through EOP topic areas - (I) Design, (II) Environmental Impact Assessment, and (III) Materials Selection. From the selected learning outcomes within these topic areas, the activities focused on specific concept areas including (A) lightweighting, (B) design for repairability and durability, (C) design for disassembly, (D) evaluation of material impacts across the supply chain, (E) lower impact material selection, and (F) basic life-cycle and carbon-footprint analysis. During the 2025 fall semester, the activities were introduced as formal assignments. What set the sustainability activities apart was their guided, self-learning format, which encouraged students to explore concepts independently while reducing the instructor's teaching workload. At the end of each assignment, students were required to write an essay about how the activity supports sustainability. A retrospective pre-post survey at the end of 2025 fall semester assessed the perceived enhancement in students' ability to (1) apply sustainability principles to mechanical design, (2) make informed decisions to improve sustainability, (3) balance technical performance and environmental impact and (4) evaluate environmental trade-offs when selecting materials and designing components. In conclusion, this paper will demonstrate how sustainability practices can be taught at the undergraduate level by incorporating minimal changes to existing mechanical and aerospace engineering curriculum.

## 1. Background and Motivation

Sustainability is becoming an important expectation in engineering practice and aligns with ABET Criterion 3, which requires consideration of environmental and societal factors in design [1]. The Engineering for One Planet (EOP) Framework provides structured topic areas and learning outcomes to guide sustainability integration in engineering education [2]. Prior ASEE studies report positive outcomes when elements of the framework are incorporated into coursework [3–5]. Building on this work, sustainability-focused, guided activities were embedded within selected mechanical and aerospace engineering courses during Fall 2025 at Trine University.

The purpose of this study is to evaluate whether embedding these EOP-aligned concept areas is associated with changes in students' self-reported ability to apply sustainability principles in engineering design. Assessment was conducted using a retrospective pre–post survey and open-ended reflections. The study evaluates perceived learning gains and does not establish causal relationships.

**2. Course Implementation and Alignment with EOP Framework**

Sustainability-focused activities were embedded within five mechanical and aerospace engineering courses during Fall 2025: Machine Component Design, Aerospace Composites, Engineering Materials, Computer Aided Machine Design, and Introduction to Engineering. The activities were aligned with selected EOP learning outcomes (LOs) within three topic areas: Design (D), Environmental Impact Assessment (EIA), and Materials Selection (MS). Rather than implementing entire LOs from these topic areas, this study targeted specific concept areas derived from selected LOs that could be integrated into existing technical assignments. The activities were incorporated within existing coursework with minimal structural modification. To improve clarity and consistency, abbreviated concept area labels were developed and are used throughout this paper.

**Concept area labels used in this study:**

- **D1** – Lightweighting
- **D2** – Design for repairability and durability
- **D3** – Design for disassembly
- **MS1** – Material impact evaluation
- **MS2** – Lower-impact or natural material selection
- **EIA1** – Carbon footprint estimation
- **EIA2** – Basic life-cycle assessment

Table 1 summarizes how each course activity aligns with the EOP framework by identifying the associated topic area, the related LOs, and the specific concept areas implemented. The topic areas indicate the broader framework categories, while the final column clarifies the targeted concept areas integrated into each assignment rather than full LO implementation.

Table 1. Course Activities and Alignment with Selected EOP-Derived Concept Areas

| Course | Assignment / Activity | EOP Topic Area | Related EOP LO | Targeted Concept Area(s) |
|---|---|---|---|---|
| **Machine Component Design** | Material Selection Through Failure Analysis | D | D LO 2 | D1 |
| | Environmentally Conscious Shaft Design | MS; EIA | MS LO 1; EIA LO 3 | MS1, EIA1 |
| | Shaft Design for Fatigue | D; MS; EIA | D LO 2; MS LO 1; EIA LO 3 | MS1, EIA1, D2 |
| | Sustainable Spring Design | D; EIA | D LO 2; EIA LO 3 | EIA1, D2 |
| | Gear Tooth Fatigue for Sustainable Design | D | D LO 2 | D1, D2 |
| | Sustainable Gearbox Design Project | D; MS | D LO 2; MS LO 1 | D1, D2, D3, MS1 |
| **Aerospace Composites** | Composite Plate Design and Sustainability Analysis | MS; EIA | MS LO 5; EIA LO 3 | MS2, EIA1 |

| | | | | |
|---|---|---|---|---|
| | Lamina Material Selection Using Maximum Stress Theory | MS; EIA | MS LO 1; MS LO 5; EIA LO 3 | MS1, MS2, EIA1 |
| | Sustainability-Driven Composite Material Selection | MS | MS LO 1; MS LO 5 | MS1, MS2 |
| **Engineering Materials** | Sustainable Lightweight Structural Rod Design | MS; EIA | MS LO 1; EIA LO 1 | MS1, EIA2 |
| | Sustainability & Safety in Aerospace | MS; EIA | MS LO 1; EIA LO 1 | MS1, EIA2 |
| | Sustainable Manufacturing (Cold Work & Energy Efficiency) | MS; EIA | MS LO 1; EIA LO 1 | MS1, EIA2 |
| **Computer Aided Machine Design** | Material Selection for a Prosthetic Arm | MS | MS LO 1 | MS1 |
| | CAMD Final Project | MS; D | MS LO 1; D LO 2 | MS1, D2 |
| **Introduction to Engineering** | Sustainable Footbridge Design | D; MS; EIA | D LO 2; MS LO 5; EIA LO 1 | D1, MS2, EIA2 |
| | Sustainable Pasta Bridge Challenge | D | D LO 2 | D1 |
| | Sustainable Mousetrap Boat Challenge | D | D LO 2 | D3 |

**3. Implementation of Sustainability-Focused Activities**

The sustainability-focused activities described in Section 2 were introduced as additional structured assignments during Fall 2025. To manage instructional demands and reduce the student workload, the activities were designed in a guided, self-learning format with clearly defined problem statements and analytical steps.

A representative activity, Material Selection Through Failure Analysis in the course Machine Component Design, addressed D LO 2 and targeted the concept area D1 (lightweighting). Students analyzed a solid shaft under combined bending and torsion using von Mises failure theory and a required safety factor. They then redesigned the shaft to reduce material usage—by reducing diameter or introducing a hollow geometry—while maintaining structural integrity. Students compared the material volume of the original and redesigned configurations and justified which design was more sustainable. The full assignment prompt, problem definition, and grading structure are provided in the Appendix to clarify the technical expectations and sustainability components of the activity. The grading scale reflects levels of analytical completeness and justification rather than a simple right-or-wrong evaluation. Yield strength values are provided as representative ranges drawn from standard references; exact values may vary depending on specific heat treatment and processing conditions, which were beyond the scope of this assignment.

Similar structured activities were implemented across other courses, with introductory courses emphasizing exposure to sustainability concepts and upper-level courses requiring quantitative integration of sustainability metrics aligned with the targeted concept areas summarized in

Table 1. After each assignment, students were asked to submit a brief reflective essay describing how the activity supported sustainability; these reflections were not formally assessed.

**4. Assessment Methodology**

Student perceptions were assessed using a retrospective pre–post survey administered at the end of Fall 2025. The study protocol was reviewed and approved by the Institutional Review Board (IRB) at Trine University.

The survey was administered to 213 students across five required mechanical and aerospace engineering courses. A total of 192 students completed the survey, corresponding to a response rate of approximately 90%.

The assessment instrument consisted of eight survey statements aligned with the sustainability-related concept areas introduced during the semester (Table 2). These statements addressed students' perceived ability to apply sustainability principles in engineering design contexts as well as their beliefs and motivation related to sustainable engineering practice. Students rated their level of agreement using a five-point Likert scale, with responses scored from 1 (strongly disagree) to 5 (strongly agree). For each statement, students reported both their perceived level prior to the course and their level after completing the course.

The retrospective pre–post format was selected to reduce response-shift bias by allowing students to reflect on their perceived growth after exposure to the sustainability-focused activities.

To quantify changes in perceived learning, the Normalized Average Gain Percentage (NAG%) was calculated using:

$$NAG\% = \frac{Average(Score_{after} - Score_{before})}{4} \times 100$$

where 4 represents the maximum possible gain (5-1) on the five-point Likert scale. NAG values are reported as percentages, with 100% indicating the maximum possible gain and 0% indicating no change.

In addition to the Likert-scale items, students completed open-ended reflection prompts (Table 3) addressing sustainability trade-offs, revised design decisions, lessons learned, and challenges encountered. These responses were reviewed to provide qualitative insight into how students interpreted and applied sustainability concepts within their coursework.

Table 2. Retrospective Pre–Post Survey Statements (Five-Point Likert Scale)

| **Question ID** | **Survey Statement** |
|---|---|
| Q1 | I understand how sustainability principles—such as carbon emissions, energy use, and recycling—apply to mechanical design decisions. |
| Q2 | I can assess environmental trade-offs when selecting materials or designing mechanical components. |
| Q3 | I can quantify the environmental impact of materials and processes using data such as embodied energy and carbon footprint. |
| Q4 | I understand how to integrate sustainability metrics into the engineering design process. |
| Q5 | I am able to balance technical performance with environmental impact when making design decisions. |
| Q6 | I believe engineers have a responsibility to minimize environmental impact through their design choices. |

| | |
|---|---|
| Q7 | I believe sustainability can be incorporated into technical design without compromising performance. |
| Q8 | I am motivated to continue learning about sustainable engineering design practices beyond this course. |

Table 3. Open-Ended Reflection Prompts

| Section | Prompt |
|---|---|
| Design and Decisions | 1. Sustainability trade-offs faced in your most recent design task. |
| | 2. Design decisions revised to improve sustainability. |
| Reflection | 1. Most valuable lesson or insight gained from this sustainability-focused activity. |
| | 2. Describe a challenge you faced in balancing mechanical design requirements with sustainability goals. |
| | 3. One improvement to future sustainability-related tasks in this course. |

**5. Results and Discussion**

Table 4 presents the Normalized Average Gain (NAG %) for survey items Q1–Q8 across the five courses. Figure 1 shows the average NAG % for each survey item across courses, with standard deviation bars indicating variation among courses.

Table 4. Normalized Average Gain Percentage (NAG%) for each survey question

| | Introduction to Engineering | Engineering Materials | Machine Component Design | Computer Aided Machine Design | Aerospace Composites |
|---|---|---|---|---|---|
| Q1 | 32.7 | 44.3 | 50.6 | 46.9 | 50 |
| Q2 | 36 | 63.6 | 52.2 | 46.9 | 51.9 |
| Q3 | 37.7 | 85.2 | 64.4 | 50 | 72.1 |
| Q4 | 39 | 64.8 | 55.6 | 52.1 | 51 |
| Q5 | 32 | 62.5 | 51.1 | 41.7 | 54.8 |
| Q6 | 20.9 | 25 | 24.4 | 17.7 | 29.8 |
| Q7 | 21.6 | 20.2 | 28.9 | 24 | 36.5 |
| Q8 | 19 | 27.4 | 30 | 41.7 | 36.5 |

From Fig. 1, across courses, higher NAG percentages were generally observed for the technically focused items (Q1–Q5) than for the attitudinal and motivational items (Q6–Q8). Survey questions Q1–Q5 correspond to applying sustainability principles to mechanical design, evaluating environmental trade-offs, quantifying environmental impacts, integrating sustainability metrics into design, and balancing technical performance with environmental considerations. These results align with course activities that required quantitative analysis of material properties, embodied energy, and sustainability-related trade-offs. In contrast, Q6–Q8 exhibited lower average NAG % values across courses. These items address beliefs about professional responsibility and motivation to continue learning about sustainable engineering practices. The comparatively smaller gains on these items suggest that perceived growth in technical application may occur more readily within a single semester than changes in professional orientation or long-term motivation.

Course-level results in Table 4 indicate variation among courses. Engineering Materials demonstrated comparatively higher NAG % values on several technically focused items, including Q3. Upper-level courses such as Aerospace Composites and Machine Component

Design also showed moderate to high gains on items related to environmental quantification and design trade-offs. Introduction to Engineering exhibited comparatively lower gains overall, consistent with its introductory level and students' initial exposure to sustainability concepts. However, because the courses serve students at different academic levels and build upon prior coursework, these differences should not be interpreted as evidence of course-specific effectiveness.

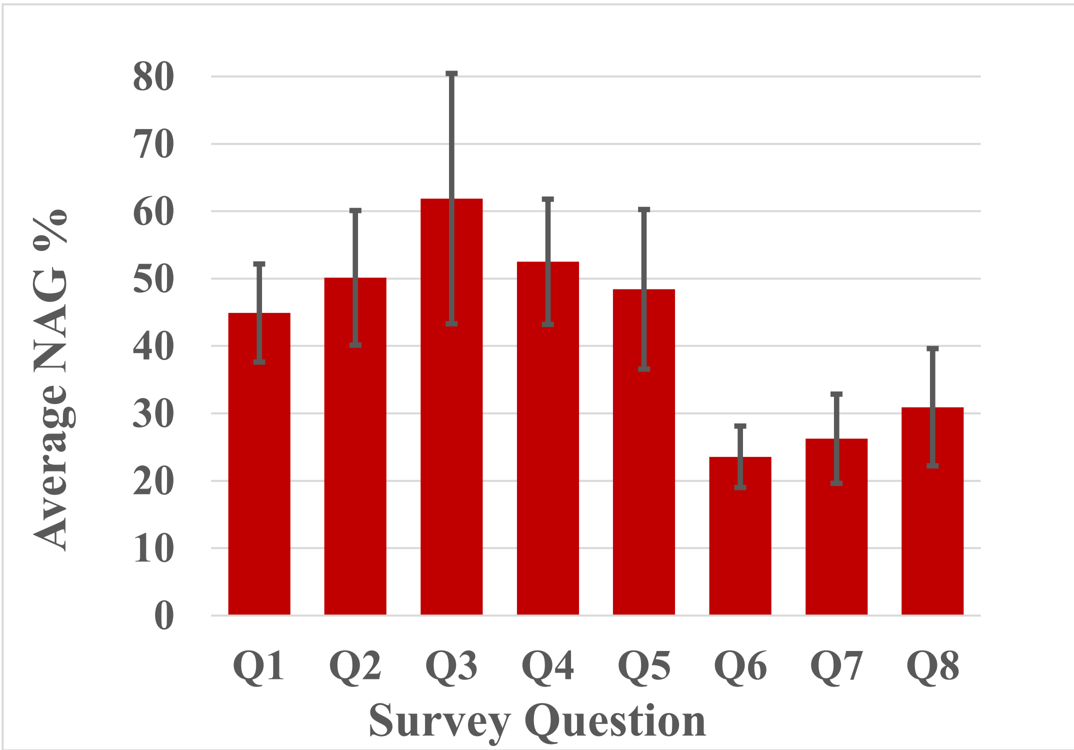


Fig. 1. Average NAG% for each survey question

Open-ended responses, though not presented here, were reviewed to provide contextual insight into how students engaged with sustainability concepts. In Machine Component Design, students described reducing material usage while maintaining safety requirements and exploring alternative geometries to improve material efficiency. In Aerospace Composites, students noted trade-offs between durability and end-of-life disposal considerations. In Introduction to Engineering, several students emphasized the importance of contextualizing environmental metrics and understanding the broader societal impact of engineering decisions. Across courses, commonly referenced ideas included material reduction, environmental quantification, and performance–environment trade-offs. These examples are provided for illustrative purposes and do not represent a formal qualitative analysis.

Since the results presented in this section are derived from retrospective self-reported perceptions, they should be interpreted as descriptive rather than evidence of causal impact.

**6. Conclusion**

The findings of this study suggest that sustainability-focused activities derived from the Engineering for One Planet (EOP) framework can be integrated into existing mechanical and

aerospace engineering courses in a practical and manageable way. Rather than requiring major curriculum redesign, guided activities can be incorporated into existing coursework to support students' ability to apply sustainability principles within technical design contexts.
Variation across courses reflects differences in student level and prior preparation, highlighting the importance of aligning sustainability content with course objectives and student background. While changes in attitudes and long-term professional orientation may require continued exposure across multiple semesters, the results indicate that structured integration within core courses is a feasible first step.
This study is based on self-reported data collected during a single semester and does not isolate the effects of individual activities. As such, the findings reflect perceived learning rather than causal impact. Future work will incorporate direct assessment measures and longitudinal evaluation to better understand how sustained integration of EOP-aligned activities influences technical competency and professional development over time.

**7. Acknowledgements**
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**<u>Appendix</u>**

**<u>Course</u>: <u>Machine Component Design</u>**

**<u>Activity</u>: Sustainability Activity - Material Selection Through Failure Analysis Using Von Mises Theory**

**<u>Problem Definition</u>:**

Apply **von Mises** failure theory to evaluate the safety of mechanical components under **combined loading** and explore **sustainable design improvements** by **reducing material usage** without compromising **strength**.

A solid circular shaft is subjected to bending and torsional loads. The goal is to:
1. Analyze the shaft using von Mises theory.
2. Determine if it is safe for a given material. **Required minimum safety factor** of **2**.
3. Redesign the shaft (e.g., reduce diameter, hollow geometry) while maintaining structural integrity.
4. Justify the new design as a more **sustainable** choice due to **reduced material usage**.

**Given:**

- Shaft diameter = 40 mm (initial design)
- Length = 800 mm
- Bending moment M = 500 Nm
- Torque T = 300 Nm
- Material: AISI 1045 steel (Yield Strength, $\sigma_y$ = 530 MPa)

**<u>Points</u>:**
Excellent: 1
Good: 0.9
Satisfactory: 0.8
Unsatisfactory: 0.5

**Steps:**

1. Calculate the bending, torsional and the resulting von Mises ($\sigma_{vm}$) stresses.
2. Determine whether the shaft is safe $\frac{S_y}{\sigma_{vm}} \geqslant 2$.
3. If the shaft is safe, propose a redesign to **reduce material waste**. Iterate until a minimum SF = 2 is achieved. Options are below:
   Option 1: Reduce shaft diameter
   Option 2: Use a hollow shaft with same outer diameter
4. If the shaft is unsafe, use one of the following materials with the given yield strength: AISI 4340 (745–1080 MPa), 17-4 PH stainless steel (1000–1170 MPa), maraging steels (~1400–1900 MPa), Ti-6Al-4V titanium alloy (830–880 MPa), and AISI D2 tool steel (735–820 MPa).
5. If the new shaft is safe, propose a redesign to reduce material wastage (check step 3)
6. Compare the volume of material used between original and redesigned shafts.
7. Justify which design is more sustainable and why.
8. Discuss how **stress analysis** supports **sustainable mechanical design**. (maximum: 200 words).

**<u>Engineering for One Planet (EOP) Framework</u>**

**https://engineeringforoneplanet.org/wp-content/uploads/2025/04/EOP_Framework.pdf**

**Definition of Sustainability in the EOP Framework:** Designs, practices, innovations, technologies, methodologies, etc., that mitigate negative impacts and/or enable increased positive and regenerative impacts on environmental and social systems.

**<u>Topic Areas:</u>**

1. Systems Thinking
2. Environmental Literacy
3. Responsible Business and Economy
4. Social Responsibility
5. Environmental Impact Assessment
6. Materials Selection
7. **Design**
8. Critical Thinking
9. Communication and Teamwork



**<u>Lightweighting for sustainability</u>**

*Light-weighting reduces material use by optimizing geometry—such as using thinner walls, hollow sections, or ribbed structures—without compromising strength or functionality.*