RFE-NLI: Shifting Perspectives: Measuring Short-Term Sentiment Change in Engineering Students Through Structured Debate on Plastic Waste from 3D Printing

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1. Introduction

The growing use of 3D printing in engineering education has expanded opportunities for hands-on design while introducing sustainability challenges related to plastic waste and life cycle impacts [1]. Engineering curricula often prioritize technical performance over systems-level environmental, social, and ethical trade-offs, limiting opportunities for students to critically examine broader consequences of emerging technologies.

Instructional strategies that foreground civil discourse and structured argumentation offer one pathway for addressing this gap. Prior research in Science, Technology, Engineering, and Mathematics (STEM) education has shown that argumentation-based learning can support deeper reasoning, engagement with evidence, and conceptual understanding, particularly when students are required to articulate and defend claims in response to competing perspectives [2]. This study examines how structured classroom debate influences engineering students' short-term sentiment and systems-level understanding of sustainability issues related to plastic waste from 3D printing. This study examines: (1) how structured debate influences short-term student sentiment toward sustainability, and (2) how it shapes systems-level sustainability reasoning related to 3D printing waste.

2. Background and Literature Review

Integrating sustainability into engineering education remains challenging, particularly in technically focused courses where performance and efficiency are emphasized over systems-level trade-offs [3]. Prior work highlights systems thinking, life cycle awareness, and ethical responsibility as foundational competencies for sustainability education [4]. Active, constructivist approaches—such as case-based learning and structured argumentation—have been shown to deepen engagement and reasoning by requiring students to articulate claims, evaluate evidence, and respond to competing perspectives [2, 5]. The Claim-Evidence-Reasoning (CER) framework supports this process by scaffolding evidence-based argument construction aligned with engineering practice [6].

Affective dimensions such as sentiment and attitude also influence learning, particularly in value-laden domains like sustainability. Short-term sentiment shifts can signal engagement and openness to reflection, even when positions remain stable [7, 8]. The Engineering for One Planet (EOP) framework provides sustainability competencies emphasizing systems thinking and ethical responsibility [9]. Recent studies demonstrate its adaptability across institutional and disciplinary contexts, including environmental risk and climate justice instruction [10, 11]. Aligning structured debate with EOP offers a scalable pathway for embedding sustainability within existing engineering courses.

3. Methods

3.1 Research Design

This study employed a mixed-methods design to examine how structured classroom debate influenced engineering student's sentiment and sustainability-related reasoning about plastic waste in 3D printing. Qualitative analysis was used to explore patterns in student discourse, argument positioning, and integration of sustainability concepts, while quantitative summaries were used to descriptively represent sentiment trends within discussion posts. This combination allowed for a richer examination of both affective and cognitive dimensions of student engagement during a short-term instructional intervention.

3.2 Course Context and Participants

The study was conducted in a Mechanical Engineering Technology course at a single institution during one academic semester. The course incorporated 3D printing as part of its instructional activities, making plastic waste a relevant and authentic sustainability issue for students. Fifteen undergraduate students enrolled in the course participated in the discussion-based activity analyzed in this study. Students represented a range of academic standing within the program, but all were majoring in Mechanical Engineering Technology.

3.3 Instructional Intervention: Structured Debate

Students participated in a structured online discussion centered on the sustainability implications of plastic waste generated through 3D printing. As part of the activity, students were asked to take and defend a position on whether plastic waste from 3D printing represents a significant sustainability concern. To support structured reasoning, students were guided to construct their arguments using the Claim-Evidence-Reasoning framework [6]. Each student submitted an initial discussion post articulating their position, followed by replies to peers that required engagement with alternative viewpoints. The discussion was designed to promote civil discourse, encourage consideration of systems-level impacts, and surface tradeoffs related to materials use, waste, and innovation in engineering practice.

3.4 Data Sources

Data for this study consisted of students' initial discussion posts and their replies to classmates. Following completion of the discussion, all posts and responses were compiled into a single document. To protect student anonymity, all names were replaced with randomized numerical identifiers prior to analysis. Multiple copies of the anonymized document were used for different analytic tasks to avoid overlap or contamination across analyses.

3.5 Data Analysis

Data analysis consisted of four complementary approaches: exploratory lexical analysis, sentiment analysis, argument position tracking, and qualitative interpretation of sustainability related reasoning.

3.5.1 Exploratory Lexical Analysis (Word Cloud)

An exploratory lexical analysis was conducted using NVivo to identify frequently occurring terms across all discussion posts and replies. Common stop words (e.g., "and," "but," "I," "you") were removed to ensure that the resulting world cloud reflected substantively meaningful language. The word cloud was used as an initial descriptive tool to highlight dominant themes and terminology present in the student discourse.

3.5.2 Sentiment Analysis

Sentiment analysis was conducted using NVivo's automated coding functionality to identify positive and negative sentiment expressed at the sentence level within the discussion posts. Sentiment coding was limited to complete sentences to preserve contextual meaning. Following automated coding, irrelevant content (e.g., dates or course identifiers) was manually removed. Sentiment results were used descriptively to examine overall affective trends related to sustainability and environmental concerns associated with 3D printing.

3.5.3 Tracking Argument Positions

To examine stability and shifts in student perspectives, argument positions were manually coded using a separate anonymized document. Each initial discussion post and reply was categorized as expressing one of two positions: "3D printing is a significant sustainability issue" or "3D printing is not a significant sustainability issue." Coding captured whether students maintained or shifted their position across initial posts and peer responses. This analysis enabled examination of how engagement with peers influenced students' expressed stances.

3.5.4 Sustainability Reasoning and Systems Thinking

Student's sustainability reasoning and systems-level thinking were analyzed using a rubric designed to evaluate the quality of CER arguments within both initial discussion posts and peer responses. The rubric assessed four dimensions of student engagement: argument quality, use of evidence, reasoning and analysis, and engagement in replies. Each dimension was scored on a four-level scale ranging from *Needs Improvement* to *Excellent.* Table 1 presents the rubric used for analysis. While originally developed to support instructional feedback, the rubric was applied in this study as an analytic framework to characterize patterns in students' sustainability framing and reasoning rather than to generate summative grades. Rubric scores were used descriptively to identify trends in the depth and sophistication of sustainability reasoning across the discussion.

Table 1. Rubric Used to Analyze Sustainability Reasoning in Discussion Posts

Criteria	**Excellent (5 pts)**	**Good (4 pts)**	**Fair (3 pts)**	**Needs Improvement (1–2 pts)**
Initial Post: Argument Quality	Three strong CER arguments presented clearly and thoroughly.	Two or more CER points presented; some gaps in clarity.	Arguments lack structure or clarity; only one CER point is well developed.	Minimal or unclear argument; missing structure.
Use of Evidence	Strong and relevant evidence; sources cited as needed.	Adequate evidence; some lacking detail.	Limited or weak evidence.	No evidence or unsupported claims.
Reasoning & Analysis	Deep analysis; clear connection between evidence and claim.	Some reasoning present; partially developed.	Reasoning is weak or inconsistent.	Little or no reasoning provided.
Engagement in Replies	Two thoughtful, critical replies made with insight.	Replies made but lack critical engagement.	Only one reply or minimal engagement.	No replies or irrelevant comments.

4. Results

4.1 Exploratory Discourse Themes (Word Cloud)

Exploratory lexical analysis revealed that students' discussions centered primarily on material use and waste-related considerations associated with 3D printing. The most frequently occurring terms across initial discussions and replies were 'materials', 'PLA', 'waste', 'printing', 'plastic', and 'recycling'; with printing appearing most frequently at 204 uses. These dominant terms suggest that students framed the sustainability issue largely through a materials and waste management lens rather than through broader systems or lifecycle perspectives. Less frequently used but notable terms included 'air', 'biodegradable', 'pollution', 'emissions', and 'microplastics'. Although these terms appeared less often, their presence indicates that some students extended their reasoning beyond immediate material waste to consider downstream environmental and health impacts. Overall, the word cloud reflects a discourse grounded in tangible engineering concerns, with emerging attention to broader environmental implications.

4.2 Sentiment Analysis

Automated sentiment analysis indicated a greater prevalence of negative sentiment than positive sentiment within the discussion posts. Specifically, negative sentiment codes outnumbered positive sentiment codes (150 negative compared to 83 positive), with negative sentiment representing 14.3% of the coded discussion text and positive sentiment accounting for approximately 8.6%. Negative sentiment was most often associated with environmental concerns related to plastic waste, pollution, and long-term ecological impacts of 3D printing materials. In contrast, positive sentiment tended to appear in statements emphasizing innovation, emerging biodegradable materials, and potential solutions to mitigate waste. Rather than indicating disengagement, this distribution suggests that students predominantly framed the issue as a serious environmental challenge while still acknowledging opportunities for technological improvement and responsible design.

4.3 Argument Positioning and Discourse Patterns

Analysis of argument positioning revealed that most students maintained consistent stances throughout the discussion. Of the fifteen students in this class, four students originally discussed how "3D Printing is not a significant sustainability issue," while ten framed "3D printing as a significant sustainability issue." In nearly all cases, students' replies to peers reinforced their original positions rather than signaling shifts in perspectives. Only one student demonstrated a change in stance across the discussion, moving from framing 3D printing as a significant issue in the initial post to a more tempered position in peer responses. This shift appeared to result from engagement with alternative viewpoints and evidence presented by classmates. This suggests that structured peer discourse may prompt reconsideration of assumptions in some cases, even when overall positions remain stable.

4.4 Rubric-Based Sustainability Reasoning Outcomes

Rubric-based analysis revealed meaningful variation in the depth and quality of students' sustainability reasoning across discussion contributions. Total rubric scores ranged from 11 to 19 out of 20, with the majority of students scoring in the mid-to-high range (15-18). Higher-scoring responses were characterized by explicit CER structures, strong integration of quantitative or peer-reviewed evidence, and clear connections between technical design decisions and broader sustainability considerations. Across the class, *argument quality* and *use of evidence* tended to be stronger than *reasoning and analysis*. While many students articulated clear positions and cited relevant sources, reasoning was often descriptive rather than analytical. What led to this conclusion was the limited examination of trade-offs, counterevidence, and downstream implications. Lower-scoring posts frequently exhibited implicit or incomplete CER structures, weak linkage between claims and evidence, and minimal systems-level framing.

5. Discussion and Conclusion

This study examined how structured classroom debate influenced engineering students' short-term sentiment and systems-level sustainability reasoning related to plastic waste from 3D printing. In response to the first research question, results indicate that participation in structured debate elicited measurable affective engagement with sustainability issues. Sentiment analysis revealed a predominance of negative sentiment associated with environmental concerns, alongside positive sentiment linked to innovation and mitigation strategies. Consistent with prior research, these short-term sentiment patterns appear to reflect heightened engagement and seriousness rather than disengagement, suggesting that debate-based discourse can prompt students to grapple meaningfully with complex, value-laden engineering challenges [7, 8].

With respect to the second research question, findings suggest that structured debate supported students' ability to articulate sustainability-related arguments and engage with evidence, but more limited development of systems-level reasoning. Rubric-based analysis showed that most students demonstrated clear positions and relevant evidence use, aligning with prior work on the effectiveness of argumentation and CER frameworks in STEM education [2, 6]. However, reasoning and analysis scores were generally lower than argument quality and evidence use, indicating that while students could defend claims, fewer consistently integrated life cycle thinking, trade-off analysis, or broader social and ethical implications. This pattern reflects challenges noted in the sustainability education literature, where systems thinking and ethical responsibility remain difficult to operationalize in technically focused courses [3, 4].

These findings suggest that structured debate represents a promising instructional strategy for embedding sustainability into engineering courses in ways that align with the EOP framework. The activity supported competencies related to evidence-based reasoning, ethical awareness, and engagement with sustainability challenges, while also revealing areas where additional scaffolding may be needed to deepen systems-level integration. In particular, more explicit prompts or assessment criteria tied to life cycle impacts, stakeholder considerations, and environmental justice may help students move beyond descriptive reasoning toward more holistic sustainability framing, as emphasized in recent EOP-focused work [5, 10, 11].

This study is limited by its small sample size, single-course context, and reliance on asynchronous discussion posts rather than live discourse. Additionally, sentiment analysis and rubric-based evaluation introduce interpretive constraints despite consistent application. Future work should examine structured, in-class debates to capture real-time reasoning, peer interaction, and perspective shifts, as well as compare live and asynchronous debate formats. Such work would further clarify how different modes of civil discourse support sustainability learning and systems thinking in engineering education.

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