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Fostering Values Thinking in Engineering Students through a Game-Based Sustainability Intervention

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Abstract

This paper presents the findings from a cross-institutional study investigating how a game-based educational intervention can foster values thinking and normative competence among engineering students. Implemented across seven programmes at three universities in Sweden and the UK, the intervention aimed to develop students' ability to engage with complex sustainability issues by providing a structured space for discussing ethical dilemmas and competing perspectives.

The study employed pre- and post-session surveys combining quantitative Likert-scale items and qualitative open-ended questions. Students were asked to self-assess their comfort with discussing divergent viewpoints, their ability to work with ill-defined problems, and their perception of the relevance of sustainability to their future careers. The analysis revealed statistically significant improvements in the first two areas, suggesting that the seminar contributed meaningfully to the development of key competencies for sustainability. While students' perception of sustainability's importance remained high, no significant post-session change was observed in this dimension.

The results indicate that structured, game-based interventions can support sustainability-related learning outcomes in engineering education. The format encourages critical dialogue, reflection, and peer engagement, making it particularly well-suited to addressing the normative and systemic dimensions of sustainable development. These findings underscore the potential of experiential, values-driven pedagogies in preparing engineers to navigate the ethical and complex challenges of sustainability practice.

1 Introduction

The integration of sustainable development into engineering education presents both opportunities and challenges. Engineers are uniquely positioned to drive sustainability transitions by shaping infrastructure, technology, and systems, yet many sustainability issues are inherently ill-structured, value-laden, and complex – qualities that contrast with the traditionally reductionist focus of engineering education (Mulder et al., 2012; Leifler & Dahlin, 2020). As the engineering profession continues to grapple with the ecological, social, and ethical implications of technological development, educators face increasing pressure to cultivate not only technical skills but also the key competencies required for a sustainable future (Wiek et al., 2011; Brundiers et al., 2021). These include systems thinking, values thinking, strategic and anticipatory competence, as well as the interpersonal abilities necessary for communication, collaboration, and negotiation in contexts marked by uncertainty and pluralism. Delivering such a transformative educational

agenda poses significant pedagogical challenges, not least due to the abstract, value-laden, and complex nature of sustainability itself (Seager et al., 2012).

These key competencies for sustainability transcend disciplinary boundaries and require learning approaches that reflect the interconnected, contested, and uncertain nature of sustainability challenges. Yet integrating such competencies into engineering curricula remains difficult. Institutional barriers, disciplinary silos, limited faculty training, and inadequate assessment tools persist (O'Brien et al., 2013; Barth & Rieckmann, 2012). Recent evaluations, such as the Swedish Higher Education Authority (UKÄ) review (2017), concluded that most universities still struggle to embed sustainability meaningfully in engineering programmes (Leifler & Dahlin, 2020).

Over the past decade, educational games and simulations have emerged as powerful tools in the sustainability educator's toolbox. Game-based learning can simulate messy, real-world decision-making scenarios that require players to navigate multiple stakeholder perspectives, grapple with ethical trade-offs, and consider long-term consequences (Dahlin et al., 2015; Dieleman & Huisingh, 2006). Studies have shown that such approaches promote deeper learning, improve knowledge retention, and increase student engagement by drawing on experiential, social, and reflective modes of learning (Fenner et al., 2014). A variety of games, each addressing different specific learning outcomes and key competences for sustainability, have proven effective for teaching sustainability in engineering contexts (Dahlin, 2023). These games provide a safe environment to experience and debate sustainability dilemmas, helping students to develop normative reasoning and systems-oriented perspectives.

This paper continues this line of inquiry by presenting new evidence from a recent intervention using the *Dilemma game* in seminar settings across seven engineering programmes at three universities in the UK and Sweden. An effort was made to keep the classroom experience as similar as possible across institutions, but some details still varied across. For example, one of the learning outcomes of one module was expressed as '*Demonstrate understanding of the engineer's role in society and the social context of engineering*,' which was partly assess be students writing a reflection on an engineering dilemma associated with their group project could be articulated in a way similar to what they experience during the game session. In another module, there was a learning outcome expressed as '*Demonstrate knowledge of the role of biotechnology in the development of a sustainable society*,' which was assessed in a similar reflection report. Most modules had similar constrictive alignment between the game seminar, one of the learning outcomes, and assessment. However, this alignment was somewhat weaker in some of the modules. From a broader programme-wide perspective, this learning intervention was considered one of many touchpoints including sustainability-relevant content and competences with some variety across the sample modules in regards to whether this was the introduction to sustainability or forming a subsequent intervention.

Building on earlier work that demonstrated the value of combining structured lectures with small-group gaming sessions (Dahlin et al., 2015), the current study explores the effects of a targeted values-based intervention on students' sustainability thinking. The goal was to examine whether participation in the game seminar could lead to measurable changes in students' comfort discussing divergent viewpoints, their ability to engage with ill-defined problems, and their perceived importance of sustainability in relation to future professional practice.

2 Methods

In line with previous studies (Dieleman & Huisingh, 2006; Dahlin et al., 2015; Dahlin, 2016; Dahlin, 2023), we hypothesise that structured game-based seminars can serve as an effective catalyst for fostering key competencies for sustainability. Unlike traditional didactic teaching methods, which may struggle to address the emotional, ethical, and integrative demands of sustainability education, games offer a dialogic and participatory learning space where complexity and values are not only acknowledged but embraced. This paper offers both quantitative and qualitative evidence on the educational outcomes of the intervention, with implications for broader curriculum development in engineering education.

The intervention took place during seminar sessions where students played a board game designed to stimulate values thinking and facilitate dialogue around complex sustainability challenges. Structured around ethically charged dilemmas, the game requires players to articulate positions, consider trade-offs, and debate possible courses of action in teams.

2.1 Participants and Programmes

The intervention was implemented across seven engineering programmes at three universities: King's College London (KCL), KTH Royal Institute of Technology, and Uppsala University (UU). The participating programmes varied in level and disciplinary focus, including both undergraduate (UG) and postgraduate (PG) students. The cohorts included:

- **Biotechnology MSc PG [n ≈ 25]:** postgraduate programme at KTH, focusing on advanced biotechnological methods and applications
- **Biotechnology 1st year UG [n ≈ 100]:** five-year BSc and integrated MSc programme at KTH, focused on biotechnological applications
- **Engineering 2nd year UG [n ≈ 160]:** joint general engineering and electrical engineering cohort at (KCL), multidisciplinary UG programme(s)
- **Engineering 4th year [n ≈ 25]:** joint general engineering and electrical engineering cohort at (KCL), multidisciplinary UG programme(s)
- **Engineering Foundation Year [n ≈ 25]:** foundation-level programme at KCL for students preparing to enter engineering degrees
- **Robotics MSc PG [n ≈ 40]:** postgraduate programme in robotics at KCL
- **Engineering Physics 1st year UG [n ≈ 125]:** five-year BSc and integrated MSc programme at UU, with a strong focus on applied physics and mathematics

Circa 500 students participated in the seminars, with pre- and post-session survey responses received from 313 individuals. Participation in the survey was voluntary, and ethical consent was implied by completion.

2.2 Game Seminar Structure

Seminars were between 90 and 120 minutes and facilitated by an academic or a teaching assistant. Students were divided into small groups of 4-6 participants and played the board game, which combines two types of cards: 'step-by-step' cards containing knowledge questions, and 'dilemma' cards presenting complex ethical scenarios. During the game, teams answered sustainability-related quiz questions to progress, but when encountering a dilemma, they engaged in structured debates. Examples of dilemmas included questions such as whether "economic growth and sustainable development are compatible." Discussions followed a structured flow, with players reflecting individually, debating collectively, and voting on a preferred course of action. This format encouraged critical thinking, values articulation, and peer learning.

Prior to the session, students were given brief readings or introductory lectures on sustainability, ensuring they had the contextual grounding necessary for meaningful engagement. After gameplay, a facilitated debrief took place to encourage reflection and synthesis. In several programmes, students were also assigned short reflective essays or discussion forum tasks to extend the learning experience.

2.3 Survey Instruments

Students completed pre-session and post-session surveys designed to measure changes in key dimensions of sustainability thinking. Three constructs were operationalised using 7-point Likert scale items:

a. **Comfort discussing divergent viewpoints**
   "How comfortable are you discussing issues with people who have a different viewpoint than you?"
b. **Comfort with ill-defined problems**
   "How comfortable are you working with problems that don't have a clear solution?"
c. **Perceived importance of sustainability**
   "How important do you think your future employer will regard skills for sustainability?"

A score of '1' on the scale indicated "very uncomfortable/unimportant" whereas '7' indicated "very comfortable/important". The surveys included open-ended questions on students' understanding of sustainability and their reflections on the relevance of sustainability to their discipline. Responses were analysed thematically to identify shifts in conceptual framing before and after the intervention.

2.4 Data Analysis

Quantitative data were cleaned, merged across Swedish and English versions, and matched by programme and session type. Paired t-tests assessed statistically significant changes in mean Likert scores from pre- to post-session, and descriptive statistics were calculated per programme. Comparisons were visualised using bar charts to illustrate differences in learning outcomes between cohorts. Qualitative responses were subjected to inductive thematic analysis to identify changes in the way students defined and discussed sustainability. Themes related to complexity, stakeholder perspectives, and ethical reasoning were noted, and illustrative quotes were extracted to support interpretation.

3 Results

To assess the impact of the game seminar on students' sustainability competencies, we analysed pre- and post-session survey data from seven engineering programmes across three European universities. The results, summarised in Table 1 and visualised in Figures 1–3, provide insight into the intervention's effectiveness across diverse educational contexts.

Students demonstrated a significant improvement in their comfort discussing issues with individuals holding different viewpoints, an ability closely linked to values thinking and normative competence. This competency requires learners to confront ethical dilemmas, articulate their positions, and engage with challenging perspectives. As shown in Table 1 and Figure 1, all programmes experienced positive shifts, with an average increase of 0.32 points on a 7-point Likert scale, a statistically significant change ($t(4) = 9.28$, $p < .001$). The largest gains were observed in the Robotics MSc, Engineering Physics (1st year UG), and Engineering (2nd year GE/EE) programmes, each showing a mean increase of 0.44 points or greater.

Table 1: Mean pre- and post-session scores by programme

	Viewpoints			Ill-defined problems			Importance		
Education programme	**Pre:**	**Post:**	**Change:**	**Pre:**	**Post:**	**Change:**	**Pre:**	**Post:**	**Change:**
Biotechnology MSc PG	6.07	6.43	0.36	5.86	5.86	0.00	6.14	5.86	-0.28
Biotechnology 1st year UG	5.86	6.06	0.20	5.60	5.88	0.28	6.09	5.96	-0.13
Engineering 2nd year UG	5.88	6.32	0.44	5.16	5.68	0.52	5.69	5.92	0.23
Engineering 4th year	6.00	6.33	0.33	5.29	6.00	0.71	6.14	6.33	0.19
Engineering Foundation Year	6.00	6.25	0.25	5.71	6.00	0.29	6.14	6.75	0.61
Robotics MSc PG	5.62	6.08	0.46	5.00	5.69	0.69	5.68	6.23	0.55
Eng. Physics 1st year UG	5.89	6.33	0.44	5.82	6.06	0.24	5.5	5.71	0.21

In parallel, the intervention significantly increased students' comfort with engaging in problems lacking clear solutions. This dimension reflects a key aspect of systems thinking, requiring students to navigate ambiguity, complexity, and trade-offs characteristic of sustainability challenges. Across programmes, the mean score rose by 0.36 points, a statistically significant change ($t(4) = 3.97$, $p = .007$). As shown in Figure 2, all cohorts except one exhibited gains, with particularly strong improvements in the Engineering (4th year GE/EE) and Robotics MSc programmes. These findings highlight the game's effectiveness in helping students tolerate ambiguity and engage in critical problem-solving even when definitive answers are absent.

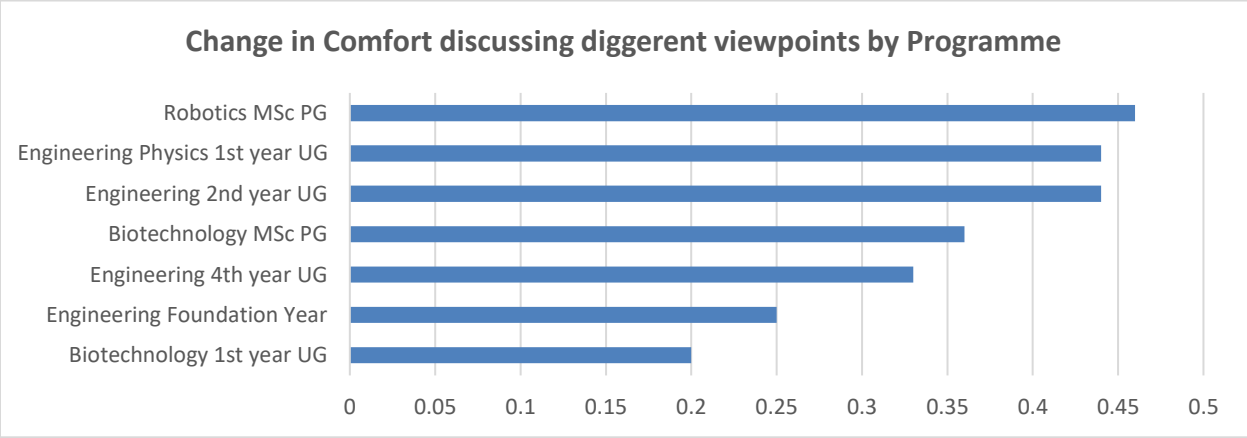

Figure 1. Mean change in students' comfort with discussing divergent viewpoints before and after participating in the seminar-based game intervention. Improvements were observed across all cohorts, indicating enhanced normative and interpersonal competence.

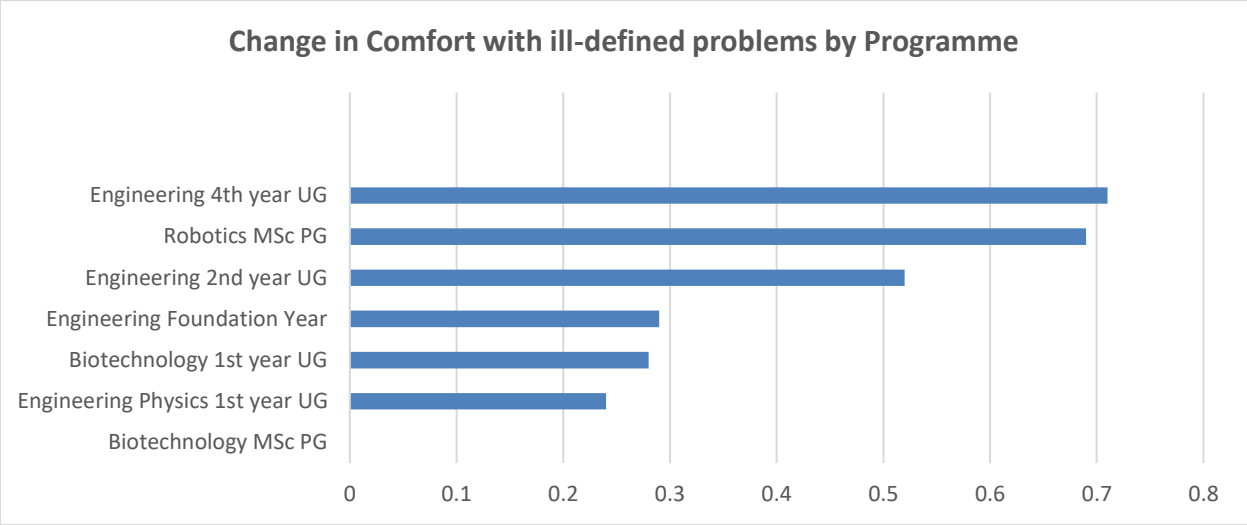

Figure 2. Mean change in students' comfort working with ill-defined or ambiguous problems, comparing pre- and post-session survey responses. Results reflect increased ability to engage with complexity and uncertainty.

In contrast to the other two constructs, students' perceptions of the importance of sustainability to future employers showed no statistically significant change. Pre-session scores were already high across most cohorts, reflecting existing awareness and value alignment. Although the average post-session score rose slightly, the change was not significant ($t(4) = 1.61$, $p = .159$). Figure 3 shows variation across programmes: while groups like the Engineering Foundation Year demonstrated some increases, others remained static or showed slight declines. This suggests a potential ceiling effect and highlights the need to integrate industry perspectives more deeply into interventions to further reinforce sustainability's career relevance.

When taken together, the overall findings underscore the effectiveness of the game seminar in supporting core sustainability competencies, particularly those linked to values thinking and the ability to operate within complex, ambiguous systems.

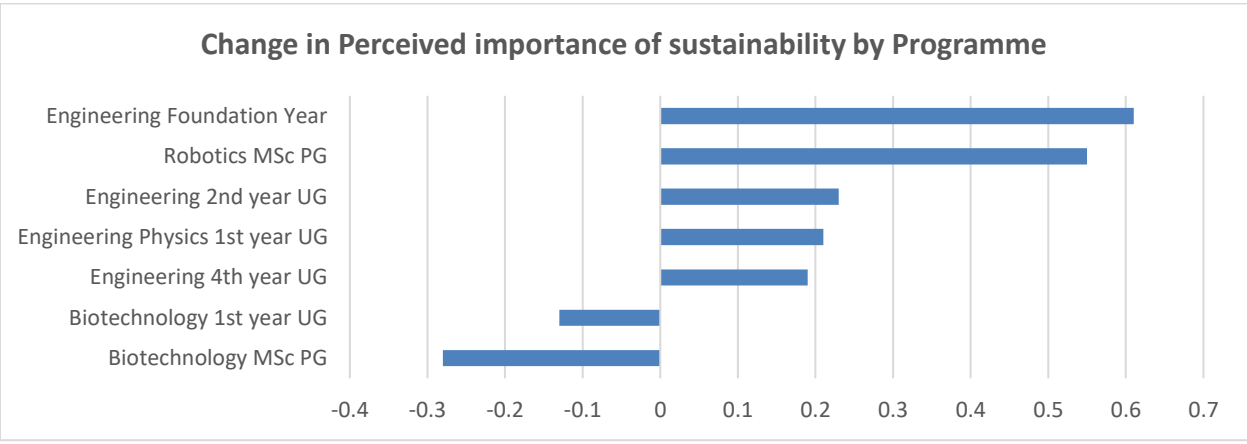

Figure 3. Mean change in students' perception of how important sustainability skills will be to future employers. While pre-session scores were already high, some variation was observed between cohorts, with no statistically significant overall change.

These findings, while derived from a specific intervention using a specific educational game, point to broader implications for the design of learning environments that aim to foster competencies for sustainability in engineering education. The observed improvements in students' comfort with divergent viewpoints and ill-defined problems suggest that educational formats which incorporate structured dialogue, ethical reflection, and collaborative decision-making – particularly those situated in experiential, participatory contexts – can be highly effective. Such characteristics are not unique to the Dilemma game and can be embedded in a variety of pedagogical formats, including role-playing, scenario-based simulations, case discussions, and co-creation workshops. The success of the intervention therefore underscores the value of intentionally designed learning situations that create space for students to engage with complexity, confront normative tensions, and practice reflective judgement, key ingredients for developing the competencies needed to address real-world sustainability challenges.

4 Discussion

The findings of this study provide encouraging evidence that game-based learning, specifically through this specific intervention, can foster sustainability-related competencies among engineering students. Participation led to significant improvements in comfort with discussing divergent viewpoints and handling ill-defined problems, supporting the development of normative and systems thinking competencies (Wiek et al., 2011).

The intervention's design, rooted in dialogic and experiential learning, aligns with prior research highlighting the benefits of active, participatory pedagogies in sustainability education (Seager et al., 2012; Dahlin, 2016). Rather than offering simplified solutions, the game provided a structured environment in which students navigated ethical complexity and articulated reasoned arguments, a skill set essential for engineering practice for sustainability.

The lack of significant change in perceived importance of sustainability likely reflects a saturation effect, especially among cohorts already valuing sustainability highly, such as Engineering Physics students. Observations from course assignments support this interpretation, suggesting that many students had already internalised the relevance of sustainability to their future careers.

Variation in outcomes across programmes points to the influence of academic maturity and prior exposure to sustainability topics. Furthermore, as the current findings are based on self-reported survey data, it is important to acknowledge the limitations of such instruments in capturing complex competence development. Future work will therefore explore the impact of the intervention through complementary methods such as focus groups, providing deeper insights into students' learning experiences. This highlights the need for carefully scaffolding sustainability interventions across curricula, ensuring that learners are adequately prepared to benefit from discussion-driven pedagogical formats.

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