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Vivek Ramachandran, Kate Roach and Emanuela Tilley

Centre for Engineering Education, Faculty of Engineering Sciences,

University College London, United Kingdom

v.ramachandran@ucl.ac.uk

Abstract

Engineering education faces mounting pressure to address accreditation requirements and prepare students to tackle complex societal and environmental challenges. Universities are responding by incorporating sustainability frameworks such as the United Nations Sustainable Development Goals (UNSDGs) and related Education for Sustainable Development (ESD) competencies into their curricula. Despite these efforts, there are significant gaps in the integration of sustainability and ethics into engineering courses, particularly in disciplinary content. This paper explores the challenges and opportunities of integrating Responsible Innovation (RI) — which includes ethics, sustainability, safety, and equity, diversity, and inclusion (EDI) — into "Scenarios," a one-week, project-based learning initiative within the Integrated Engineering Programme (IEP) at University College London (UCL). The IEP Scenarios are aimed at transcending the boundaries of modular learning and fostering individual students' skill development. The report provides an in-depth analysis of semi-structured interviews conducted with 22 Scenario Leads across seven engineering departments at UCL. These interviews explored the design, implementation, and assessment of Scenarios, including their alignment with the Accreditation of Higher Education Programmes 4th edition (AHEP4) framework. Key findings revealed several barriers, including a lack of motivation, time, and knowledge among faculty. Departmental resistance to prioritizing sustainability, coupled with constraints on resources and expertise, further hindered the explicit integration of responsible innovation topics. To address these challenges, the IEP proposes a three-tier support framework tailored to empower faculty in embedding RI into their Scenarios. The first tier involves clear signposting of SDGs through existing lecture content that aligns with Scenario learning objectives, minimising additional effort for faculty. The second tier provides curated toolkits and resources, offering practical strategies and case studies for incorporating sustainability and ethics into teaching. The third tier emphasizes seamless integration, including contextualised resources, curriculum development support, assessment design, and teaching hours dedicated to responsible innovation. By analysing the findings, this paper highlights the importance of approaches to engineering education embedded in care ethics – an ethical framework emphasizing empathy, relationships, and responsiveness – where sustainability and real-world contextualisation are woven throughout the curriculum. The integration of dedicated modules, experiential learning opportunities, and collaboration with external stakeholders enhances students' understanding of their professional responsibilities. Additionally, the IEP's scenario-based approach provides a replicable model for fostering critical transversal skills such as teamwork, communication, and project management alongside technical expertise. Ultimately, this research underscores the urgent need for higher education institutions to evolve their curricula to meet societal demands for sustainable and socially responsible engineering practices. By implementing structured support frameworks and leveraging proven methodologies, such as the IEP's Design and Professional Skills modules within employ the scenario-based learning approach, universities can better prepare future engineers to address global challenges. Most importantly, this paper offers actionable recommendations for embedding responsible innovation principles into engineering education in a context-specific manner.

1 Introduction

Engineers have long played a crucial role in shaping societies, wielding a tremendous amount of power and influence in determining the built environments we reside in, the machines we use on a daily basis, and the technological systems we have grown increasingly reliant upon. These endeavours have been completely dependent on extractive practices that take from nature, through materials resources and human labour.

These practices have been underpinned by a worldview that treats nature as something to be used rather than as an entity within which we reside and engage with respectfully. It is this instrumental logic that has resulted in and continues to contribute to the ecological crisis confronting the planet today. Engineers, and engineering as a discipline and profession must confront its historical legacy and ongoing entanglements with fostering the problems that numerous species face today. Within this context, there is a growing recognition amongst engineers of the urgent need to confront their professional and ethical responsibilities as key stakeholders in addressing the climate crisis and contributing to the development of sustainable solutions (Perkins, 2013). While many engineers are motivated to make a meaningful contribution to sustainability, they may place undue faith in technological solutions alone, risking a techno-optimism that overlooks the systemic changes sustainability requires (Ribeiro & Soromenho-Marques, 2022). On the other hand, some engineers express uncertainty or anxiety about how to act, while others feel disempowered or sceptical about whether their efforts can make a meaningful difference — risking a slide into technological determinism that further disconnects agency from responsibility (Khalaim & Budziszewska, 2024).

Part of the problem lies in the framing of climate change as a discrete problem to be solved, a threat to be neutralised, or even a battle to be won. Such a combative orientation casts nature as an adversary, reinforcing an oppositional and extractive relationship with the natural world. Engineers are not neutral actors operating outside of society; they are both shaped by socio-political forces and actively participate in shaping them. Recognising this mutual constitution is essential for cultivating a more reflexive and socially attuned engineering practice – one that understands itself as embedded within, rather than separate from, the ecological and social systems it affects. What is required, therefore, is not merely a reassessment of engineering outputs but a fundamental rethinking of the identity and societal role of the engineer.

One of the persistent challenges in engineering education lies in the lack of clear guidance on how these socio-ecological dimensions ought to be integrated into the curriculum (Zandvoort, 2008; Riley & Lambrinidou, 2015; Bielefeldt, 2018). While accreditation bodies have begun to emphasise the inclusion of environmental and social responsibilities of engineers in the curriculum, there is still ambiguity regarding operationalisation in teaching practice (Engineering Council, 2020). Engineering programmes are encouraged to be intentional in addressing the role of the engineer within society, yet the absence of pedagogical frameworks, resources, and institutional support often leaves individual educators without the tools necessary to implement this guidance effectively (Bowen, 2009). In this context, consistent support is essential—not only in terms of content, but in how sustainability-oriented thinking is embedded within engineering education. In response to the pressures from society and accreditation bodies, engineering programmes have begun embedding sustainability into their curricula through frameworks such as the United Nations Sustainable Development Goals (UNSDGs) and Education for Sustainable Development (ESD) (Kasinathan et al., 2022; Scoones et al. 2020). However, integration often remains fragmented and superficial, with sustainability occupying the margins rather than the core of engineering education. One key barrier to meaningful integration is the structural constraint of an overloaded curriculum – simply adding content is not a viable solution. What is needed is not more content, but a reconfiguration of how content is taught and experienced.

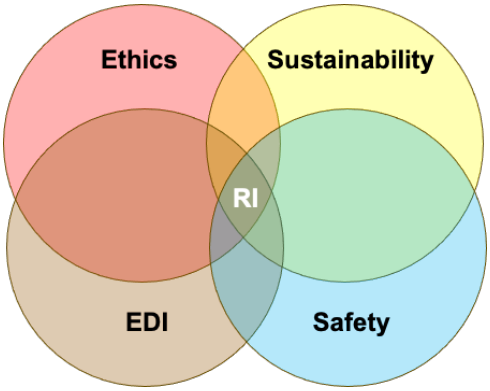

Figure 1: Responsible Innovation defined as the intersection of Ethics, Sustainability, Safety, and Equity, Diversity, and Inclusion in Engineering Practice

For the work presented here, we have relied on *Responsible Innovation* (RI) as a valuable theme. While RI has numerous definitions (Roach et al., 2022), broadly speaking, it refers to the processes that anticipate and address the broader impacts of innovation, aiming to minimise harm, reduce barriers to adoption, and improve social and environmental outcomes. Taking inspiration from the AHEP4 section on "The Engineer and Society" (Engineering Council, 2020; Truslove et al. 2023), we have created a framework for RI – a system of interrelated lenses that encourages educators and students to consider reflexivity and responsiveness in the development and deployment of technology. The four lenses are 1) Ethics & Social Sustainability, 2) Climate Justice & Environmental Sustainability, 3) Safety & Risk Mitigation, and 4) Equity, Diversity, & Inclusion.

While the *lens* metaphor helps to analyse how RI is understood, the pedagogical integration can be addressed through the metaphor of *weaving*. Drawing inspiration from numerous Indigenous Knowledge Systems that consider weaving as a practice central to livelihood as well as a philosophy, this metaphor emphasises the interlacing of technical skills with cultural, ethical, and environmental wisdom (Henri et al., 2021). This approach ensures that the focus is not on introducing new content, but rather on highlighting and connecting existing material, fostering deeper, more meaningful relationships between knowledge areas that are already present in the curriculum.

What connects these two crucial aspects are the stories – the aforementioned experiences of faculty members. We need to better understand the experiences of faculty members who are tasked with the educational responsibility of including sustainability in the curricula. This requires listening to the ways in which they relate to the topics, their needs, their difficulties, and the institutional conditions under which they operate. This is essential if we are to design support systems and pedagogical frameworks that are contextually grounded, responsive, and sustainable over time. Our work relies on centring their experiences with empathy, attentiveness, and relational responsibility, key principles of the Care Ethics framework developed by Joan Tronto (Tronto, 2020).

This paper examines how such a model of sustainability integration is currently being pursued in the UCL Integrated Engineering Programme (IEP) through *Scenarios*. We propose a supportive framework for embedding Responsible Innovation (RI) into disciplinary contexts, offering practical guidance for weaving ethical and sustainable thinking throughout engineering curricula.

2 Scenario-based Learning

Since its inception over a decade ago, the Integrated Engineering Programme at UCL has been actively, including the integration of SDGs across engineering curricula (Hailes et al., 2021; Mitchell at al., 2021; Roach et al., 2022). One avenue through which this integration occurs is via the modules that teach and give time in the curriculum for students to explore and develop their own engineering design practice whilst learning professional skills in their disciplinary and engineering contexts. These modules are specifically designed for Bachelor of Engineering and Integrated Master of Engineering (BEng/MEng) students in Biochemical, Biomedical, Chemical, Civil, Electronic & Electrical, and Mechanical Engineering, as well as Bachelor of Science and Integrated Master of Engineering (BSc/MEng) students in Computer Science.

Throughout these specific modules which span across the first and second years of the undergraduate curricula, students develop crucial transversal skills such as communication, academic research, ethics, teamwork, critical and creative thinking, sustainability, project management, the engineering design cycle, and various technical and digital skills pertinent to their chosen discipline. An integral and significant part of the assessment and student experience of the Design & Professional Skills modules are the Scenarios - week-long team projects where regular lectures pause, allowing students to focus solely on a collaborative technical engineering design endeavour (Mitchell et al., 2014). Led by the department and scheduled as a series of six projects across the first and second years of the degree programmes, Scenarios provide a platform to apply the disciplinary knowledge from the module lectures, offering students invaluable insights into engineering practices. Participation in Scenarios is designed to offer UCL engineering students a first-hand glimpse into real-world engineering challenges in the context of their own discipline.

Expressed by student feedback both whilst they are enrolled at UCL and as graduates in workplace, the profound influence that Scenarios have in shaping students' educational pathways, they are ideal to explore opportunities within the curricula for the inclusion of topics pertaining to social responsibility within engineering.

3 Listening with Care – Perspectives of Scenario leads

In the spirit of gathering stories to inform our work, we conversed with 22 Scenario Leads who represented seven departments of the Faculty of Engineering Sciences at University College London (UCL). The conversations took place through individual semi-structured interviews, unconstrained by time, and lasting anywhere between 30 and 90 minutes. Following a path shaped by open questions and shared curiosity, each Lead described their personal experiences, perspectives, and challenges in designing and delivering content in their Scenarios.

The conversations were guided by a set of questions aimed at learning and understanding the different facets of Scenarios, including the intended learning outcomes, the real-world context in which they are framed, the strategies used to assess learning, and the connections with other disciplinary modules and Scenarios in the IEP. While the leads were describing their narratives, we asked them to analyse the Scenarios through the lenses of RI to understand how deeply woven these values and ideas already were in their designs. In relation to this, we enquired whether the centrality of these themes was made explicit to the students. We also asked the leads to share their beliefs and suggestions regarding the way these topics are taught and the connections with departmental and institutional expectations. Importantly, the interviews also explored the

Leads' familiarity with and interpretation of the AHEP4 criteria, as well as their understanding of ESD competencies and UNSDGs. These conversations helped identify gaps in current scenario design and delivery and allowed us team to assess how these pedagogical tools supported or fell short of fostering sustainable and responsible engineering practices.

Given the diversity of experiences among the Scenario Leads, we wanted to consciously avoid imposing our own biases, particularly regarding the importance of including Responsible Innovation within the Scenarios. At the same time, we were fully transparent about our motivations for inviting them into dialogue, making it clear that the decision to incorporate any tangible outcome from the conversation would be entirely theirs to make.

We chose *Care Ethics* as a guiding framework for grounding these conversations because care ethics with its focus on attentiveness, responsibility, competence, and responsiveness offered a powerful vocabulary for engaging with the leads' reflections in a way that respected their unique perspectives. Each stage of the interview process was informed by this approach, ensuring that we listened carefully, responded thoughtfully, and worked collaboratively to surface the ways Responsible Innovation was already present, or could be more deeply woven into, their educational practices:

- **Attentiveness (Caring about)** involved giving close attention to the underlying concerns, tensions, and aspirations of the Scenario Leads. We listened for what was said, but also for what remained unsaid. An open, curious attitude helped us to listen carefully and notice what mattered to them.
- **Responsibility (Taking care of)** is shown by inviting the Scenario Leads to engage in conversations aimed at improving educational practices around Responsible Innovation. This action reflects a sense of moral obligation toward colleagues, students, the Faculty community, and the broader socio-ecological systems we are part of and affect.
- **Competence (Care-giving)** is demonstrated through the knowledge and skills applied in framing questions that respect our colleagues' practices and experiences, creating a space that enables constructive reflection on their approaches to Scenario design and delivery, free from fear of judgment.
- **Responsiveness (Care-receiving)** involved actively engaging with the feedback and interpretations shared by participants throughout the process. We sought to honour the relational nature of the exchange by allowing their experiences to meaningfully inform the emerging framework for Responsible Innovation integration, ensuring that the resulting support was co-constructed from the ground up rather than externally imposed.

Ultimately, the conversations we had with the Scenario Leads highlighted not only their passion and commitment but also the structural and cultural challenges that need to be addressed to meaningfully weave Responsible Innovation into engineering education. This paper responds by proposing a locally situated, ethically grounded, and practically applicable framework for advancing RI.

4 Embedding Responsible Innovation – Best Practices and Persisting Barriers

We begin by describing the experiences of the Scenario Leads — including how they perceive the lenses of Responsible Innovation, the extent to which the principles underlying the lenses are currently integrated within the Scenarios, the best practices that support this integration, and the challenges they continue to encounter.

The four lenses themselves revealed several key themes, highlighting both the promise and the complexity of integrating Responsible Innovation into scenario-based learning. Indeed, many Scenarios in the IEP already offer fertile ground for weaving RI principles because they engage students with real-world

challenges that have implicit ethical issues and/or sustainability goals, and foster ESD competencies such as critical thinking and systems thinking:

- **Environmental Impact**: Scenarios focused on *Ice Cream Production*, *Cellular Agriculture*, and *Ammonia Production* enable students to engage with complex industrial processes and their environmental implications, prompting consideration of lifecycle assessment, material choices, emissions, and other sustainability constraints.
- **Human-Centred Design**: Scenarios such as *Bio-signal Based Human-Machine Interaction*, *Developing a Healthcare App*, and *Living Aid* place ethical reflection and social impact at the centre of engineering design. These scenarios promote inclusivity, accessibility, and empathy, highlighting the social responsibilities engineers hold in shaping technology.
- **Social Justice and Safety**: Scenarios like the *Grenfell Memorial* and *High Speed Two (HS2)* highlight the deeply interventionist nature of engineering within social, built, and ecological systems. They require students to reflect on safety, justice, and risk, fostering an understanding of engineering as both a technical and ethical endeavour.
- **Sustainable Innovation**: Scenarios such as *Returnable Reusable Packaging* and *Peristaltic Pump – Design for Manufacture* focus on sustainability and circular design principles. Students are encouraged to develop engineering solutions that meet environmental and societal needs in tandem, embedding ethical reflection within the design process.

Additionally, the Design and Professional Skills modules, which host the Scenarios on Moodle across most departments, also deliver lectures on one or more of the principles underlying Responsible Innovation. At the same time, these alignments with RI themes are not sufficient to bridge the systemic and structural challenges that impede deeper integration:

- **Motivational Barriers**: Some of the Leads reported encountering resistance from their departments as well as from some of their own students, who tended to adopt a "traditionalist" stance prioritising technical content over socio-ecological dimensions — a view that a few Leads themselves also expressed.
- **Time Constraints**: Leads also cited limited time as a major barrier — both the time needed to prepare material and the time required to meaningfully integrate RI themes within the existing curriculum. The demands of covering core technical content, combined with staffing and/or resource limitations further compound this issue.
- **Knowledge Gaps**: Among the leads who were motivated and felt they could allocate time to prepare and facilitate content on RI, a common theme was a lack of confidence and expertise in teaching Responsible Innovation—particularly in contextualizing the socio-ecological aspects alongside the technical content in a manner that felt natural and cohesive.

These challenges reflect the broader tensions within engineering education regarding the purpose and scope of teaching societal and environmental responsibilities. The pressures of covering core technical content without sufficient support limits the capacity to deliberately embed inter- and/or transdisciplinary socio-ecological dimensions. Further challenges include contextualising ethical concepts that might seem abstract to students, mapping learning outcomes to accreditation requirements (e.g., AHEP4), and ensuring coherence across different learning levels. In light of these difficulties, there is a clear need for capacity-building, peer support, and practical guidance to support the integration of Responsible Innovation in a way that aligns with both academic expectations and real-world application.

5 Tiered Support Framework

To support the inclusion of Responsible Innovation into the IEP Scenarios, we propose a structured, three-tiered framework. Each tier offers varying levels of engagement and support, allowing flexibility for Scenario Leads while progressively deepening the integration of social and environmental responsibility into the curriculum.

- **Tier 1 - Signposting**: *Foundation* – The first tier weaves a clear, foundational layer of knowledge into the curriculum, threading connections with existing educational content by signposting relevant Sustainable Development Goals (SDGs) and lectures on Responsible Innovation themes already embedded within the Design and Professional Skills modules. These reference points are intended to minimise the effort required by Scenario Leads. By carefully stitching these connections, this tier seeks to heighten ethical awareness amongst students and normalise sustainability as part of their practice.
- **Tier 2 – Resource Provision**: *Depth* - The second tier weaves deeper textures and layers onto the foundational fabric through an array of resources and toolkits created by diverse communities and expert networks. This tier provides Scenario Leads with curated materials — including case studies, frameworks, and guidance from organisations such as the Engineering Professors' Council (EPC). These resources are not intended as rigid prescriptions, but as flexible threads that educators can select and adapt according to the particular needs and contexts of their Scenarios.
- **Tier 3 – Seamless Integration**: *Cohesion* - The third tier weaves cohesion throughout the curricular tapestry, with the IEP team stepping into the role of co-weavers alongside Scenario Leads. Here, Responsible Innovation is not simply an added thread but becomes an integral part of the design, delivery, and assessment of learning. Together with the Leads, we re-work content, resources, and evaluation practices into an interconnected fabric where sustainability, ethics, and social responsibility are woven deeply into the structure of students' educational journeys. We reinforce the weave by offering tangible support in terms of teaching hours or support sessions.

Case Study – Ice Cream Production Scenario

To illustrate the practical application of the three-tier framework for weaving Responsible Innovation into the Scenario, we piloted it with the *Ice Cream Production* Scenario – it involves student teams acting as engineering consultants tasked with addressing quality and scalability challenges in artisanal ice cream manufacturing, by investigating ingredient sourcing practices, refining processing methods, and analysing the economic trade-offs of proposed improvements.

Tier 1: The first tier involves connecting the Scenario to relevant global frameworks, specifically four United Nations Sustainable Development Goals (SDGs): SDG 6: Clean Water and Sanitation, SDG 9: Industry, Innovation, and Infrastructure, SDG 12: Responsible Consumption and Production, SDG 13: Climate Action. These links can be reinforced through lecture signposting on Engineering Ethics, Professional Standards, and Teamwork, in the Design and Professional Skills Module, ensuring students can readily link technical content to broader social and environmental concerns.

Tier 2 : In the second tier, a curated set of toolkits and resources are provided to support the Scenario Lead in embedding RI principles. Materials are organised according to the four RI lenses: *Ethics & Social Sustainability* (e.g., activities on ethical sourcing and fair-trade practices), *Climate Justice & Environmental Sustainability* (e.g., case studies on carbon footprint analysis of dairy production), *Safety & Risk* (e.g., real-world examples of foodborne illness outbreaks and risk mitigation), *Equity, Diversity & Inclusion* (e.g.,

inclusive product development for allergen-sensitive consumers). Scenario Leads are free to adapt and select resources that best suited the context and their teaching style, promoting ownership while ensuring depth of engagement with RI.

Tier 3: The third tier integrates RI throughout curriculum delivery, including *Curriculum Enhancement* - students engage with real-world dilemmas, such as balancing sustainability with economic feasibility. Role-based activities ensure inclusive participation. *Assessment and Feedback* - new rubrics explicitly evaluate projects against RI themes. Students can receive feedback on the ethical implications of their designs and a reflective component on team dynamics. *Teaching Support* - supervision sessions to emphasise the intersection of technical and social dimensions in production, while additional opportunities for signposting RI principles are identified.

This example demonstrates how the framework not only supports Scenario Leads in scaffolding Responsible Innovation but also fosters a holistic and inclusive learning environment that equips students with the competencies to navigate the ethical and societal dimensions of engineering practice.

6 Conclusion

This paper highlights the successes and challenges encountered by Scenario Leads in integrating Responsible Innovation into engineering education. The findings demonstrate a strong recognition of the importance of embedding sustainability, ethics, and social impact awareness within engineering curricula. Moreover, Scenario Leads from departments across the Faculty expressed a clear interest in building a community of practice to share strategies and experiences, alongside a demand for practical tools and support to scaffold sustainability education effectively. These insights align closely with existing research emphasising the critical role of instructors in weaving sustainable development principles into engineering frameworks. However, successful integration requires not only individual commitment but also institutional support through professional development opportunities, access to resources, and curriculum design assistance.

The introduction of the IEP's three-tier framework—focused on signposting, resource provision, and seamless integration—offers a practical model for overcoming the barriers identified. By providing structured yet flexible support, the framework empowers educators to meaningfully embed Responsible Innovation without overwhelming their teaching load. The three-tier framework moves beyond patchwork interventions, helping to cultivate a seamless, living curriculum – one that demonstrates shared care, responsiveness, and a deep commitment to preparing future engineers for an interdependent and evolving world.

This initiative reflects a broader imperative: as global challenges such as climate change, resource scarcity, and social inequality intensify, engineering education must evolve accordingly. It is no longer sufficient to focus solely on technical proficiency; universities must actively cultivate students' competencies in sustainability, ethics, and interdisciplinary collaboration. Moving forward, it is essential to prioritise ongoing collaboration, professional development, and continuous refinement of teaching practices to remain responsive to societal and industry needs. By fostering a dynamic and socially engaged learning environment, engineering education can better equip future engineers to address the complex, interconnected challenges of the 21st century with both technical excellence and a strong sense of social responsibility.

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