Integrating Nanoparticle Research into Engineering Education for Environmental Sustainability and Public Health

Grace Yemisi Balogun, Morgan State University

Grace Yemisi Balogun is a Ph.D. student in Bio-Environmental Sciences at Morgan State University. She received her Bachelor's and Master's degrees in Plant Biology from the University of Ilorin, Nigeria, with specializations in food safety and environmental biology. With a professional background in environmental, health & safety (EHS) consultancy and ISO 14001:2015 auditing, she blends research with impact. Her passion lies in ESG strategy, nanoparticle applications to mitigate environmental challenges, as well as microplastic studies. She continues to explore the intersection of science and policy for a global sustainable future.

Grace's research on the use of nanoceria as a foliar application offers promising strategies to reduce toxic stress and promote sustainable agriculture. https://orcid.org/my-orcid?orcid=0009-0005-7248-5013

Abiodun Taofeeq Adedoyin, Morgan State University

Adedoyin Abiodun is a second-year PhD student at the School of Architecture and Planning, Morgan State University. He hails from Nigeria, had his Bachelor of Technology in Estate Management from the Federal University of Technology, Akure, Nigeria, and his master's degree in Housing Development and Management at the University of Ibadan, Nigeria. His research interests include housing quality, sustainable housing, and nanomaterials.

Dr. Oludare Adegbola Owolabi P.E., Morgan State University

Dr. Oludare Owolabi, a professional engineer in Maryland, joined the Morgan State University faculty in 2010. He is the director of the Sustainable Infrastructure Development, Smart Innovation and Resilient Engineering Research Lab, Department of Civil Engineering at Morgan State University.

Oluwafemi Samuel Ifesanmi, Morgan State University

Oluwafemi Samuel Ifesanmi is a passionate graduate researcher, and social impact advocate. He holds a Bachelor's degree in Environmental Science and Resource Management and is currently pursuing his M.Sc. in Advanced Computing at Morgan State University. His background covers software development, data analytics, AI applications, environmental sustainability and intelligent computing, and this fusion is at the heart of his current research: Smart AI-Based Waste Bin Monitoring and Collection Optimization. The project leverages AI and IoT to create efficient, sustainable urban waste management systems.

David Olusogo Owolabi, Morgan State University

David Owolabi is a PhD student in civil engineering at Morgan State University, specializing in resilience and sustainable engineering for critical infrastructure. His academic journey focuses on advancing his knowledge in structural engineering and construction management, with the goal of becoming a leading expert in these fields. David's primary research area is on the development of innovative sustainable materials, such as self-healing concrete known as bioconcrete. David's work explores the integration of green materials, lifecycle assessment, and resilient engineering practices in construction. In his other research areas, he also seeks to address key challenges in infrastructure sustainability while promoting long-term resilience in construction.

Integrating Nanoparticle Research into Engineering Education for Environmental Sustainability and Public Health

Abstract

Today's engineers must tackle the intertwined problems of environmental contamination, sustainable technology deployment, and responsible nanotechnology innovation. This work-in-progress paper describes a design-based instructional framework that integrates authentic nanoparticle-related environmental research data into environmental engineering education to enhance sustainability literacy, public health reasoning, and ethical decision-making. Using a previously published set of environmental data on nanoparticles only as a teaching case, the framework addresses how research data on nanoparticles can be effective pedagogical tools, not new scientific contributions. The proposed model uses a three-module structure consisting of environmental data analysis, sustainability and systems thinking, and public health, ethics, and communication. Students work with real environmental datasets based on real atomic absorption spectrophotometry (AAS) data and reflect on pollutant interpretation, sustainability trade-offs, and socio-technical engineering responsibilities. We perform initial validation with an IRB-approved expert survey of engineering faculty, students, and sustainability professionals (n = 20) with Likert-scale and qualitative measures. Descriptive statistics, Cronbach's alpha, and thematic analysis support iterative refinement. The results demonstrate the pedagogical clarity, feasibility, and educational relevance of the framework while aligning with ABET outcomes and providing a transferable model to incorporate nanotechnology, sustainability, and responsible innovation into current engineering curricula.

Keywords: Nanoparticle, Engineering Education, Sustainability Literacy, Public Health, Environmental Systems.

1.0 Introduction

Engineering practice is increasingly influenced by sustainability requirements, public health considerations, and the ethical use of new technologies. Today, engineers are expected to do more than just design technically sound systems. They must assess environmental impacts, manage risk, and communicate implications to a diverse array of stakeholders. However, despite this expectation, sustainability and ethical reasoning are often poorly integrated in the core engineering curricula as isolated topics rather than integrated components of technical learning [1] – [4]. The teaching challenge of nanotechnology is particularly urgent. Engineered nanoparticles are intensively researched today for environmental remediation, pollution abatement, and materials innovation. Meanwhile, concerns of environmental, health, and safety (EHS), regulatory uncertainty, and long-term risk have increased the call for risk-informed and responsible innovation approaches in engineering education [7] - [11].

To prepare students to navigate these tensions, we need instructional strategies that link technical data analysis with systems thinking around sustainability and ethical judgment. Engineering education research has demonstrated that using real research settings and real data sets can help students to improve their ability to reason under uncertainty, interpret environmental measurements, and make evidence-based decisions [4], [5]. However, there are a few instructional models that explicitly embed data from nanoparticle research to integrate sustainability reasoning and perspectives on public health in environmental engineering courses. When nanotechnology is discussed, teaching is often focused on material properties or laboratory synthesis, with insufficient attention to downstream impacts, governance, or societal relevance [9] – [11].

This Work-in-Progress paper seeks to address this gap by proposing an instructional framework that integrates nanoparticle research data in environmental engineering education for sustainability and public health reasoning. The framework is based on the principles of design-based research [5], [6], and repurposes a pre-existing environmental dataset as a pedagogical case rather than a source of new scientific claims. The teaching sequence is structured into three modules: (i) data analysis and environmental interpretation, (ii) sustainability and systems thinking, and (iii) public health, ethics, and communication.

The paper makes three contributions. First, it offers a modular pedagogy that integrates sustainability and ethical reasoning as part of the technical data analysis. Second, it shows an ethically grounded approach to using existing data on nanoparticle research as a teaching tool in the real world. Third, it provides preliminary validation evidence on clarity, feasibility, and educational value from the feedback of experts and stakeholders. Together, these contributions address the call for more integrated, socio-technical approaches to sustainability education in engineering programs [1], [3], [7].

2.0 Background and Related Work

2.1 Sustainability in Engineering Education

Sustainability has been a key concern in engineering education in the last decade due to environmental challenges around the globe, health hazards to the public, and changing professional expectations. A growing body of literature has documented a persistent gap between the sustainability skills expected of engineering graduates and the content emphasized in traditional engineering curricula [1] – [4]. Sustainability concepts are increasingly being recognized in accreditation standards and institutional mission statements, but their integration into core technical coursework is inconsistent.

Systematic literature reviews show that *"sustainability instruction is usually provided as stand-alone courses or elective modules, rather than as an integral part of the technical problem-solving and data analysis activities of engineering education"* [1], [2]. This decoupling may hinder students' ability to apply sustainability reasoning to real-world engineering situations where environmental, social, and technical considerations are tightly coupled. Recent empirical research has also demonstrated that the extent to which sustainability concepts are embedded within disciplinary content, rather than learned in isolation, has a significant effect on students' sustainability learning outcomes [3].

Experiential and data-driven pedagogical approaches are found to be effective for sustainability education in engineering education [4]. Engaging students in authentic problems, datasets, and decision-making scenarios has been shown to support a deeper understanding of environmental systems, trade-offs, and long-term impacts, according to reviews of experiential learning strategies [4]. Yet, even with these findings, many instructional models still use hypothetical or simplified examples that do not represent the complexity of real environmental data.

2.2 Authentic Data and Experiential Learning in Engineering Education

The use of authentic data is gaining increasing attention as a way of bridging theory and practice in engineering education. Studies in engineering disciplines indicate that exposure to real research data helps students to: interpret uncertainty, evaluate the quality of evidence, and make informed decisions under constraints [4], [5]. Such competencies are especially important in environmental engineering, where variability of measurements, system complexity, and incomplete information are commonplace.

Design-based research (DBR) has been acknowledged as a methodological framework for developing and refining instructional interventions that involve authentic data and iterative feedback [5,6]. DBR emphasizes the co-development of theory and practice through a series of design, implementation, evaluation, and redesign cycles. DBR has been used to design instructional frameworks based on theory and sensitive to realities of the classroom in the context of engineering education [5].

Although the importance of authentic data is well known, previous work has highlighted challenges in incorporating real research datasets into instruction. Such challenges include cognitive overload, a mismatch between student preparation and data complexity, and uncertainty about the ethical reuse of previously published data [6]. Thus, there is a need for structured frameworks that guide the pedagogical exploitation of authentic datasets with clarity, feasibility, and ethical integrity.

2.3 Nanotechnology, Environmental Risk, and Responsible Innovation

Nanotechnology is playing an increasingly important role in environmental engineering research, especially in pollution control, materials performance, and environmental remediation. Along with these prospects, concerns regarding environmental, health, and safety (EHS) risks have resulted in extensive research on nanomaterial risk assessment and governance [9]–[11]. Frameworks for the assessment of fate, exposure pathways, and potential ecological impacts of nanoparticles are now well established in the scientific literature [9].

Policy and regulatory studies emphasize the persistent challenges in translating nanomaterial risk assessment into engineering practice and education. Analyses of regulatory frameworks such as the REACH regulation point out the need for engineers to understand not only material performance but also uncertainty, precaution, and lifecycle considerations [10]. REACH (Registration, Evaluation, Authorization and Restriction of Chemicals) is the main EU legislation to protect human health and the environment from the risks that can be posed by chemicals [17].

These findings have strengthened calls for “safer-by-design” and risk-informed innovation approaches that integrate EHS considerations early in the design process [11]. In engineering education, scholars have contended that responsible innovation and ethics should be treated as socio-technical competencies, not as abstract or external constraints [7], [8]. Reviews of ethics education in engineering suggest that good instruction situates ethical reasoning within technical contexts so that students can grapple with real trade-offs and consequences [7]. Anticipation, reflection, and stakeholder engagement are also emphasized as key elements of professional engineering practice in responsible innovation frameworks [8].

2.4 Gaps in Existing Instructional Approaches

While prior work has advanced sustainability education, experiential learning, and nanotechnology risk assessment as separate domains, few instructional models have combined these strands into a single framework. Most existing nanotechnology education efforts are limited to the synthesis of materials or their applications, with little sustained attention to the systems of sustainability, implications for public health, or the ethical responsibility [9]– [11]. However, the sustainability education frameworks are often not based on the emerging technological data, and, therefore, are less relevant to the current engineering challenges [1], [3].

This gap presents an opportunity for instructional designs employing authentic data from nanoparticle research to address technical analysis, sustainability reasoning, and public health considerations concurrently. Such integration is consistent with calls for socio-technical engineering education to prepare students to navigate complex, interdisciplinary problems [1], [7]. This Work-in-Progress study builds upon this body of literature by presenting an instructional framework that repurposes existing nanoparticle research data as an educational case, connecting environmental measurement, sustainability systems thinking, and ethical communication in environmental engineering education.

3.0 Instructional Framework Design

3.1 Design Rationale and Pedagogical Orientation

The instructional framework, as shown in Figure 1, was developed using a design-based research (DBR) approach to ensure alignment between theoretical grounding, instructional feasibility, and iterative validation [5], [6]. DBR is particularly suited to engineering education contexts where instructional innovations must balance disciplinary rigor with practical classroom constraints. In this study, DBR principles guided the articulation of learning objectives, module sequencing, and assessment alignment before classroom implementation.

The framework responds directly to calls for integrating sustainability and ethical reasoning into core engineering instruction rather than treating these topics as peripheral or add-on content [1], [3], [7]. By embedding sustainability and public health considerations within technical data analysis tasks, the framework supports socio-technical learning outcomes consistent with contemporary expectations for environmental engineering graduates.

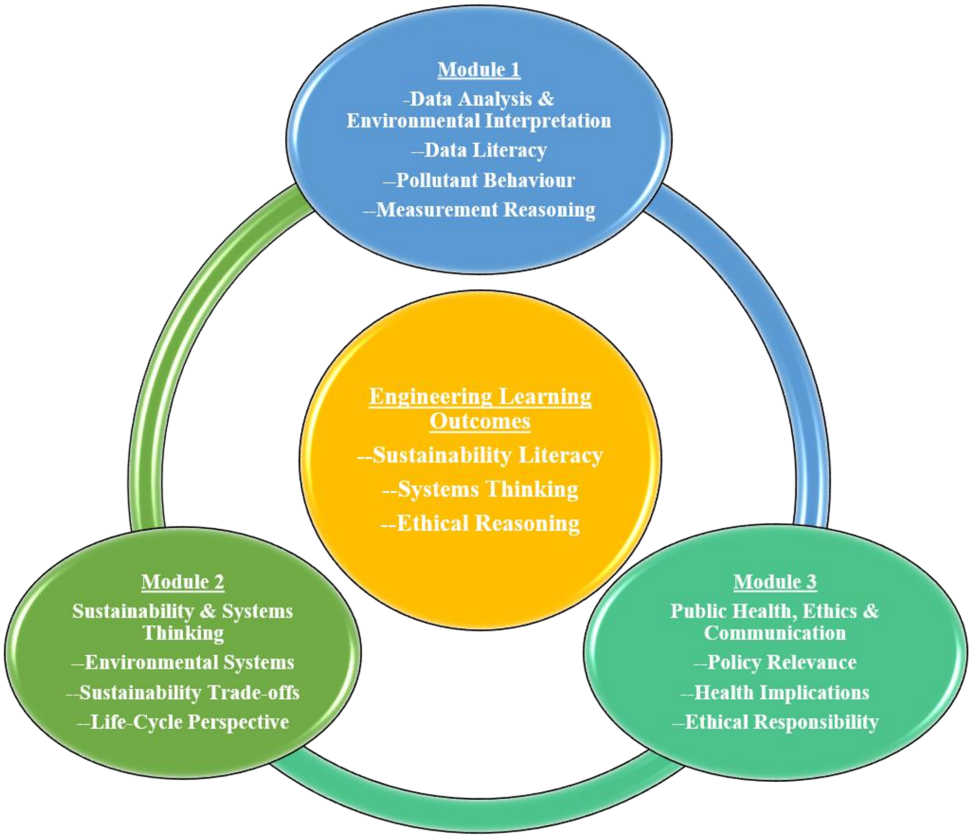

Figure 1. Instructional framework integrating nanoparticle research into environmental engineering education

3.2 Framework Overview and Modular Structure

The instructional framework consists of three sequential modules, designed to guide learners from technical data interpretation to broader sustainability and public health reasoning. The modules are represented visually in the framework diagram and are intended to be implemented over multiple instructional sessions or adapted to fit existing course structures.

Each module builds on the outputs of the previous one, reinforcing conceptual continuity while expanding the scope of analysis. This progression reflects prior findings that scaffolded learning sequences support deeper engagement with complex environmental and sustainability topics [4], [5].

3.3 Module 1: Data Analysis and Environmental Interpretation

The first module is designed to develop students' skills in interpreting real data obtained from environmental measurements. Learners are introduced to an authentic data set from environmental research on nanoparticles and guided through structured activities focusing on data literacy, measurement reasoning, and interpretation of the behavior of pollutants. Teaching activities in this module include: Identifying trends, assessing variability, and Interpreting results in an environmental context.

For example, students will analyze real-world environmental monitoring data sets to determine trends in pollutant concentration, assess variability across environmental conditions, interpret patterns in measurement using descriptive statistical tools, and evaluate environmental implications using evidence-based reasoning. Students will interpret aggregated AAS metal concentration profiles, compare contaminant distributions, interpret pollutant behavior based on sustainability and remediation contexts, and develop data-based conclusions that increase quantitative literacy, environmental interpretation, and engineering judgment, but do not make new scientific claims. Rather than replicating experimental procedures, the emphasis is on reasoning with data. This approach is consistent with research that demonstrates working with real data improves students' ability to handle uncertainty and assess the quality of evidence in engineering contexts [4], [5].

Critically, the dataset is presented as a teaching case, not as a site for new scientific claims. This distinction allows for ethical reuse and maintains the authenticity required to learn well.

3.4 Module 2: Sustainability and Systems Thinking

Building on the technical interpretation developed in Module 1, the second module situates the dataset within broader environmental systems. Learners are prompted to consider sustainability trade-offs, system boundaries, and lifecycle perspectives relevant to environmental engineering decision-making.

Activities in this module encourage students to connect technical findings to environmental sustainability metrics and systems-level impacts. This design reflects evidence that sustainability learning is strengthened when students engage with real-world constraints and interconnected systems rather than abstract principles alone [1], [3], [4].

By linking data interpretation to systems thinking, the module reinforces the integration of technical and sustainability competencies, addressing a persistent gap identified in engineering education literature [1], [2].

3.5 Module 3: Public Health, Ethics, and Communication

The third module extends analysis beyond technical and environmental systems to include public health implications, ethical responsibility, and communication. Students are tasked with translating technical findings into forms accessible to non-technical stakeholders, such as policy briefs or advisory summaries.

This module draws on responsible innovation and engineering ethics frameworks that emphasize anticipation of societal impacts, reflection on uncertainty, and accountability to affected communities [7], [8]. In the context of nanoparticle-related environmental applications, such considerations are particularly salient given ongoing debates surrounding environmental and health risks [9]– [11].

By situating ethical reasoning within a technical case, the framework avoids treating ethics as an abstract exercise and instead presents it as an integral component of professional engineering practice [7].

3.6 Alignment with Assessment and Validation Instruments

The instructional framework was designed to align directly with the evaluation instruments used in this Work-in-Progress study. Survey items were structured to assess perceptions of clarity, feasibility, coherence, and educational value across all three modules.

Each module corresponds to specific constructs measured in the survey instrument, enabling targeted feedback on instructional design elements. This alignment supports early-stage validation of the framework before classroom deployment, consistent with DBR practices in engineering education research [5], [6].

3.7 Ethical Considerations in Framework Design

Ethical considerations were central to the design of the framework shown in Figure 2. The use of a pre-existing research dataset was strictly limited to teaching purposes only, and there was no intention to re-analyze for new scientific conclusions. This approach is consistent with the principles of responsible innovation and reinforces transparency in pedagogical reuse [7], [8]. Authentic environmental nanoparticle data sets previously published are pedagogically adapted for classroom analysis by reorganizing, simplifying, and educationally contextualizing to form instructional case materials.

This process emphasizes teaching usability, sustainability interpretation, and ethical reasoning with attention to scientific integrity and unambiguous boundaries between educational use and original experimental research. The framework models risk-informed engineering practice and supports the development of professional judgment for emerging technology contexts by explicitly addressing environmental, public health, and ethical dimensions in the instructional sequence [9]–[11].

Figure 2. Transformation of previously published nanoparticle data into an instructional teaching case

4.0 Data Source and Ethical Pedagogical Reuse of Prior Research

4.1 Origin and Scope of the Dataset

The teaching framework is based on a real data set of environmental measurements from previously published research on nanoparticles. The data set presented in Figure 3 is a set of quantitative observations obtained using standard environmental analytical methods. It is used solely as a teaching tool to help students learn how to interpret data, analyze pollutants, reason about sustainability, and make engineering decisions in realistic environmental settings. In the current Work-in-Progress study, the dataset is used merely as an instructional artifact. No novel experimental procedures were used, no new variables were introduced, and no scientific hypotheses were tested. The dataset provides a context case to promote learning activities that are interpretation, reasoning, and decision making rather than scientific discovery.

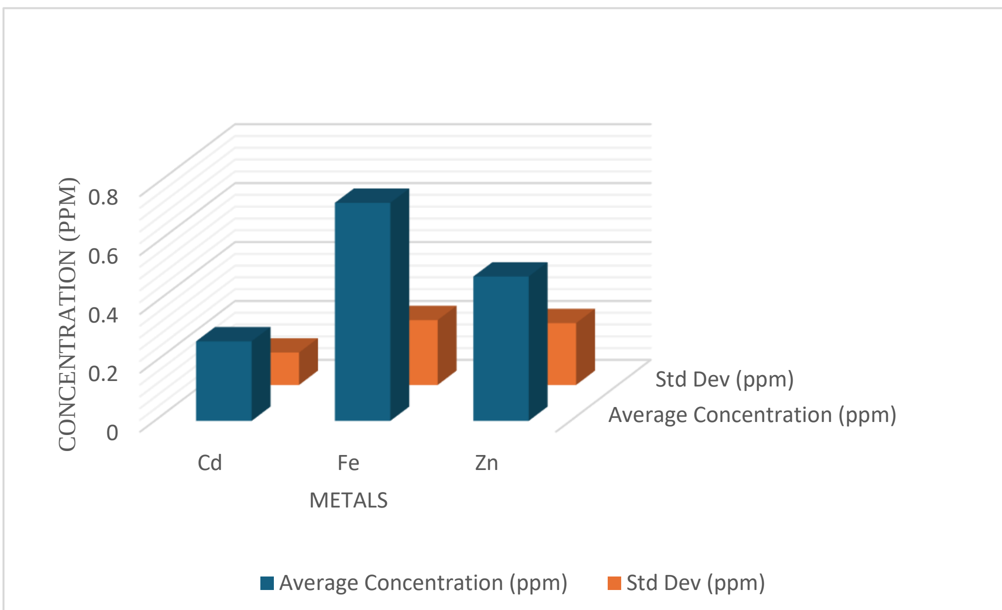

Figure 3: Pedagogical Environmental Dataset Used for Instruction (AAS Metals)

This is consistent with previous directions in engineering education research that authentic research data can be a valuable instructional material when used transparently and within well-defined pedagogical boundaries [5], [6]. Figure 3 presents a representative subset of aggregated environmental measurements, curated by the instructor from the larger published data set, and provided to students as the primary analytical resource for Module 1 activities. Students utilize these structured quantitative profiles directly within an instructional setting for descriptive analysis, interpretation of pollutant behaviour, variability assessment, and development of evidence-based conclusions in environmental engineering.

4.2 Rationale for Using an Authentic Research Dataset

Original datasets have distinct pedagogical benefits for engineering education, especially in areas involving uncertainty, variability, and complex system interactions. Previous research has demonstrated that exposure to authentic research data enhances learners' capacity to interpret evidence, assess limitations, and make informed decisions within the boundaries typically experienced in professional practice [4], [5].

These competencies are particularly important in the education of environmental engineers because environmental systems seldom provide clean or deterministic data. The selected data set is appropriate for educational purposes in the three modules of the framework, as it captures realistic variability in measurements and environmental complexity. Importantly, the dataset was chosen not for its scientific novelty but for its pedagogic relevance. With this design, students can participate in environmental interpretation, trade-offs in sustainability, and public health considerations in a meaningful way without duplicating laboratory methods.

4.3 Ethical Framework for Pedagogical Reuse

Reuse of previously published research data leads to important ethical questions, especially regarding transparency, attribution, and not publishing the same thing twice. This study explicitly designed the dataset as a teaching case, not as new scientific evidence, to ensure ethical reuse. Responsible innovation frameworks emphasize the need for clarity about the purpose and limitations of technological and scientific outputs [7], [8]. Consistent with these principles, the data set is presented as an example to learners and survey respondents in support of instructional objectives, not as a basis for making new environmental claims.

Moreover, the instructional activities do not involve reanalysis to generate novel scientific interpretations. Instead, students are prompted to engage in data interpretation, systems reasoning, and communication with specific prompts and criteria for evaluation. This distinction maintains the integrity of the original research while allowing for meaningful educational engagement.

4.4 Alignment with Risk-Informed and Safer-by-Design Principles

The pedagogical reuse of environmental data related to nanoparticles is especially relevant in the context of risk-informed and safer-by-design engineering education. The vast literature on nanomaterial governance emphasizes the importance of engineers' knowledge of uncertainty, exposure pathways, and lifecycle considerations associated with emerging technologies [9]– [11]. The framework presents learners with the sorts of evidence and ambiguity they will face when making judgments about environmental and public health risks by placing authentic data in a structured instructional sequence. Such a design also allows for early development of professional judgment and is consistent with calls to incorporate risk awareness and ethical responsibility in engineering curricula [7], [9].

4.5 Transparency and Boundary Setting in Instructional Design

To avoid ambiguity regarding the scope of the dataset's use, the instructional framework explicitly delineates the boundaries of pedagogical reuse. These boundaries are communicated through instructional materials, survey documentation, and the framework overview diagram.

Such transparency is consistent with best practices in design-based research and supports trust among educators, students, and reviewers [5], [6]. By clearly separating scientific contribution from instructional innovation, the framework ensures compliance with ethical standards while maximizing educational value.

5.0 Evaluation Design and Survey Instrument

5.1 Evaluation Purpose and Work-in-Progress Scope

The evaluation is meant to provide initial validation evidence for the clarity, feasibility, and perceived educational value of the proposed instructional framework before it is implemented in the classroom. The evaluation does not measure student learning outcomes consistent with the Work-in-Progress (WIP) designation. Instead, it considers the perceptions of experts and stakeholders on the framework as an instructional design artifact.

This approach is in line with engineering education design-based research (DBR) practices that emphasize validating instructional concepts early in the design process before full implementation or experimental testing [5], [6]. This early appraisal enables iterative refinement and mitigates the risk of misalignment between instructional intent and classroom realities.

5.2 Participant Recruitment and Ethical Oversight

Participants (n = 20) were purposively recruited from university-affiliated and broader professional networks to ensure informed evaluation of the instructional framework across relevant educational and sustainability contexts, as summarized in Figure 4. The sample consisted of engineering faculty, graduate students, and environmental sustainability practitioners, whose disciplinary expertise contributed to the evaluation of the pedagogical feasibility, curricular relevance, and alignment with current engineering education and professional practice expectations of the framework.

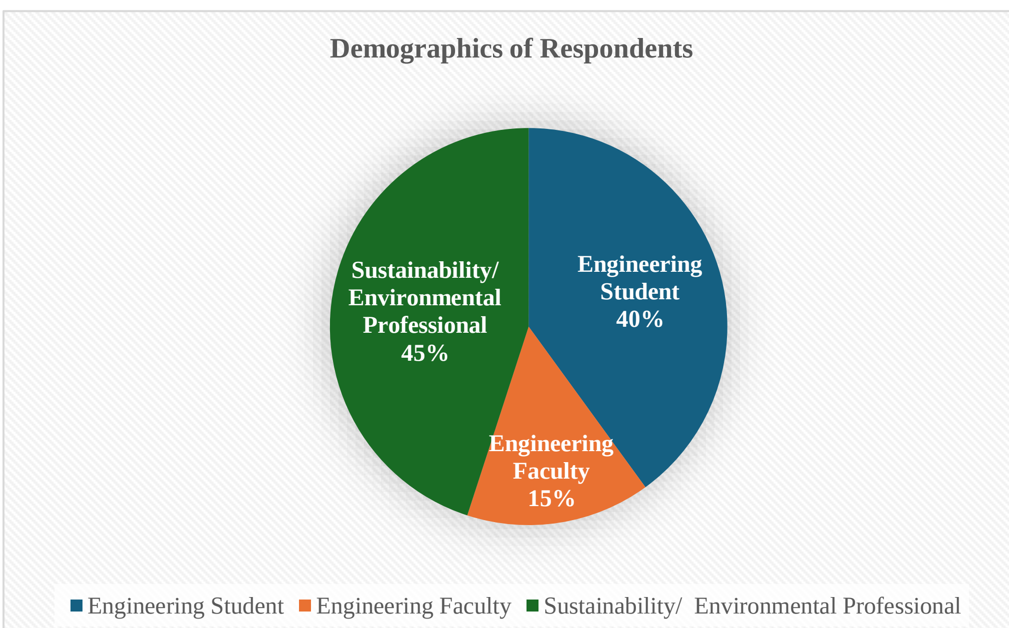

Figure 4: Survey Participant Demographics

Figure 4 depicts the professional composition of survey participants (n = 20), illustrating the proportional distribution of engineering students, engineering faculty, and sustainability or environmental professionals who contributed to framework evaluation. This diverse respondent profile strengthened the assessment by incorporating perspectives from emerging engineers, academic educators, and experienced practitioners across educational and professional sustainability contexts.

Participation was voluntary, and all data collection procedures were conducted under an approved Institutional Review Board (IRB) protocol. Respondents were informed that the study concerned instructional framework evaluation and did not involve assessment of scientific efficacy or biological outcomes. This framing ensured transparency and minimized potential misinterpretation of the study's purpose.

5.3 Survey Instrument Design

The survey instrument was designed to assess key constructs associated with instructional quality and adoption potential. Instrument development followed established guidelines for online survey design and deployment [12], [13]. Items were organized into four primary constructs:

1. **Clarity**: the extent to which the framework's goals, modules, and progression were understandable;
2. **Feasibility**: perceived practicality of implementing the framework within existing engineering courses;
3. **Educational Value**: perceived contribution to sustainability, systems thinking, ethics, and communication outcomes; and
4. **Adoption Potential**: likelihood of future use or adaptation by instructors.

Each construct was measured using multiple five-point Likert-scale items (1 = strongly disagree to 5 = strongly agree). Open-ended prompts were included to solicit qualitative feedback on strengths, limitations, and suggested improvements.

The survey was administered online to facilitate broad participation and reduce logistical barriers, consistent with best practices for web-based survey research [12].

5.4 Data Analysis Procedures

Descriptive statistics were used to analyze quantitative survey findings to summarize overall trends in constructs. Cronbach's alpha was used to determine the internal consistency of Likert scale items for each construct. This reliability measure is commonly used in education research and is suitable for early stage instrument validation [14], [15].

We measured the internal consistency of the expert survey with 12 items using Cronbach's alpha. The expert survey exhibited acceptable reliability ($\alpha > 0.70$), suggesting that the survey items coherently measured the constructs of instructional clarity, sustainability relevance, ethical integration, and implementation feasibility. The reliability attests to the appropriateness of the survey instrument for the initial design-based validation of the proposed instructional framework.

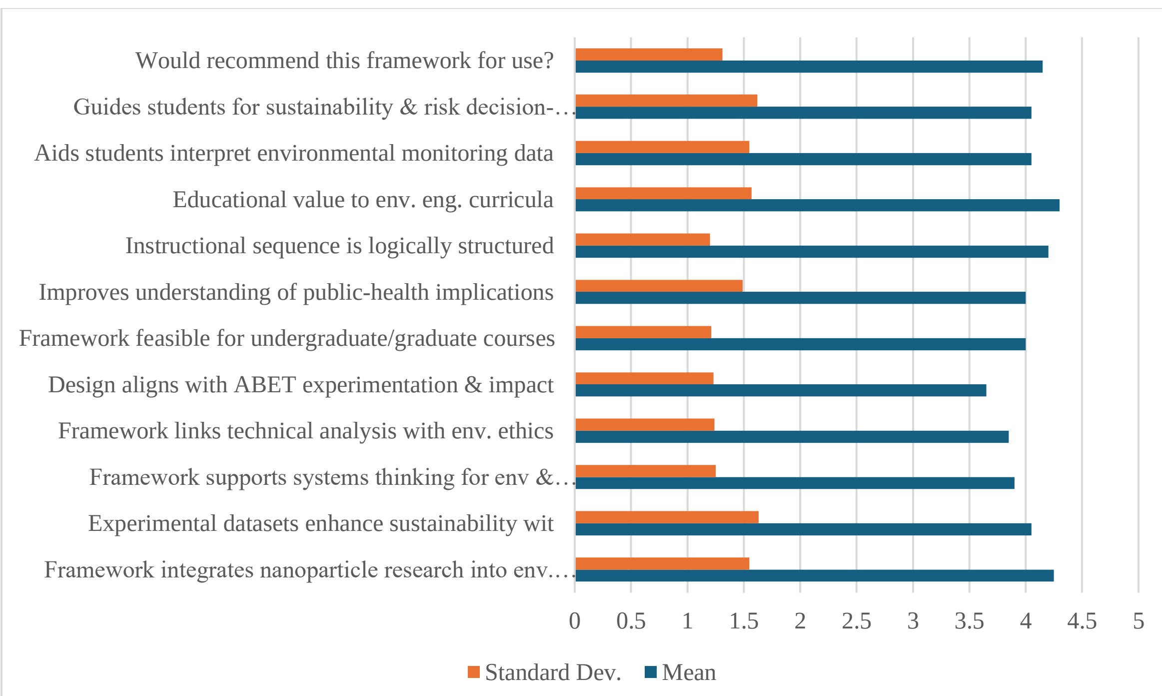

Figure 5: Mean & Standard Deviation Likert-Scale Responses Evaluation Results

Qualitative responses from open-ended items were analyzed using thematic analysis. An inductive coding approach was employed to identify recurring themes related to instructional clarity, coherence, and improvement opportunities. This approach follows established qualitative analysis guidelines emphasizing transparency, reflexivity, and systematic coding [16].

Given the exploratory nature of the study and the modest sample size, inferential statistical testing was not conducted. Instead, quantitative and qualitative findings were triangulated to inform iterative refinement of the instructional framework.

5.5 Alignment Between Framework and Evaluation Measures

The survey instrument was designed to match the instructional framework's modular structure. Items were mapped to features of Modules 1–3 to ensure that feedback covered all aspects of the design. The survey instrument was developed to systematically assess each instructional module by targeting specific construct areas. The survey items were organized into three categories: Module 1 (data analysis and environmental interpretation), Module 2 (sustainability and systems thinking), and Module 3 (public health, ethics, and communication). This modular mapping enabled participant feedback to directly assess the coherence, feasibility, and educational value of each framework component, facilitating iterative refinement in line with design-based research principles that stress alignment between instructional design, assessment, and continuous improvement. This alignment allows for targeted refinement and reflects DBR principles that emphasize coherence between instructional design and evaluation [5, 6].

The evaluation provides practical insights into the strengths and limitations of the framework, with a focus on perceptions of experts and stakeholders, and is suitable for a WIP study. Table 1 also shows the alignment of the instructional framework with ABET (Accreditation Board for Engineering and Technology) student outcomes, reflecting the outcomes-based accreditation approach that is at the core of modern engineering education literature for integrating sustainability and professional responsibility into engineering curricula.

Table 1: Alignment of instructional framework modules with ABET student outcomes

Instructional Module	ABET Outcome Addressed	ABET Description (Condensed)	How the Framework Addresses It
Module 1: Data Analysis & Environmental Interpretation	**ABET Outcome 6**	Ability to develop and conduct appropriate experimentation, analyze	Students analyze real environmental monitoring datasets (AAS metals profiles), interpret pollutant behavior, and

		and interpret data, and use engineering judgment	justify conclusions using measurement reasoning rather than hypothesis testing.
	ABET Outcome 1	Ability to identify, formulate, and solve complex engineering problems	Students frame environmental contamination challenges using quantitative data and contextual constraints drawn from real-world datasets.
Module 2: Sustainability & Systems Thinking	**ABET Outcome 2**	Ability to apply engineering design considering public health, safety, welfare, and sustainability	Students extend dataset interpretation to system-level sustainability trade-offs, life-cycle considerations, and environmental system interactions.
	ABET Outcome 4	Ability to recognize ethical and professional responsibilities in engineering situations	Students evaluate sustainability decisions using environmental, social, and regulatory perspectives, including unintended consequences.
Module 3: Public Health, Ethics & Communication	**ABET Outcome 3**	Ability to communicate effectively with a range of audiences	Students translate technical findings into policy briefs and public-facing summaries addressing environmental and health implications.
	ABET Outcome 4	Ethical responsibility and impact of engineering solutions in societal contexts	Students assess public health implications, ethical responsibilities, and regulatory relevance of nanotechnology-enabled environmental solutions.

The accreditation process is also focused on outcome-based education, requiring programs to define and evaluate specific student outcomes such as problem solving, ethical responsibility, communication, and the capacity to analyze and interpret data, all of which prepare graduates for engineering practice while ensuring the protection of public health, safety, and welfare [18]. The engineering education literature on sustainability integration points to the need to align curricular design with accreditation requirements, such as those from ABET. This is because such outcomes-focused frameworks incentivize programs to integrate sustainability thinking, ethics, and systems reasoning as part of the core coursework rather than as add-on topics. The evolving expectations of engineering accreditation and professional competencies are mirrored in the literature.

6.0 Preliminary Results

6.1 Overview of Response Characteristics

The participants of the preliminary evaluation, comprising 20 participants from the engineering faculty, graduate students, and sustainability or environmental professionals, are depicted in Figure 4. The diversity of disciplines represented among respondents also offered balanced perspectives on clarity of instruction, feasibility, and curricular relevance for both academic and applied contexts. The sample size is enough for the stage of instructional framework development, which is in the early stages of expert validation and is a work in progress, prioritizing design iteration rather than testing of hypotheses or generalizability.

Response patterns showed high levels of engagement with both Likert-scale items and open-ended prompts, suggesting that participants were able to interpret the description of the framework and associated visual materials in meaningful ways. In engineering education research, response to survey instruments has been found to be an important indicator of construct clarity in early validation stages [12], [13].

6.2 Quantitative Results: Perceived Clarity, Feasibility, and Educational Value

A descriptive analysis of the Likert-type ratings indicated consistently positive perceptions of each of the four assessed constructs: clarity, feasibility, educational value, and adoption potential. The highest average scores were given to items related to framework clarity, indicating that respondents perceived the modular structure and progression as comprehensible. Perceived feasibility scores indicated that respondents believed the framework could be incorporated into existing environmental engineering or sustainability-related courses with minimal disruption to the curriculum. The finding is consistent with previous research that modularity is an important factor affecting instructors’ adoption of instructional innovations [5], [6].

The internal consistency analysis (Cronbach's alpha) indicated acceptable reliability for the main constructs of the survey, indicating coherent measurement of instructional clarity, feasibility, sustainability, relevance, and ethical integration in the evaluation instrument. These reliability results are consistent with the appropriateness of the survey for preliminary framework validation and are consistent with methodological expectations for early-stage design-based research in engineering education [14], [15].

6.3 Qualitative Results: Thematic Insights from Open-Ended Responses

Thematic analysis of the open-ended responses identified several recurring themes. First, respondents emphasized the value of authentic data in supporting realism and relevance in sustainability instruction. Many pointed out that the use of a real environmental data set reinforced the link between the technical analysis and larger societal implications, in line with findings from previous experiential learning studies [4], [5].

Second, respondents emphasized the importance of the framework's sequenced progression, particularly the transition from technical interpretation to systems thinking on sustainability and ethical communication. This sequence was mirroring professional engineering workflows and was consistent with calls for socio-technical integration in engineering education [7], [8]. Third, participants offered constructive suggestions related to instructional scaffolding and time allocation. These comments highlight the need for iterative refinement before deployment in the classroom, a core principle of design-based research [5], [6].

6.4 Interpretation within a Work-in-Progress Context

The preliminary results would be taken as evidence for instructional design features, not as evidence of student learning gains or instructional effectiveness. Findings suggest that the framework is considered clear, relevant, and feasible by stakeholders with expertise in engineering education and sustainability practice. Such perception-based validation is an accepted and valuable step in the development of instructional interventions, particularly when used to inform subsequent pilot testing and refinement [5, 6].

The overall response patterns within participant groups uniformly indicated favorable perceptions of clarity, feasibility, and relevance, but this work-in-progress evaluation was purposefully intended to establish baseline stakeholder confidence and inform iterative refinement before eventual classroom implementation, comparative subgroup analysis, and outcome-based educational assessment. The results also justify the transition to classroom implementation and more rigorous outcome-based assessment in future work.

7.0 Discussion

7.1 Interpretation of Preliminary Findings

Early indications from initial survey data suggest that expert stakeholders received the proposed instructional framework positively in terms of clarity, logical structure, and educational value. This interpretation is supported by high mean Likert-scale ratings on constructs related to instructional clarity, curricular feasibility, sustainability relevance, and framework recommendation, indicating that the modular design was consistently viewed as understandable and appropriate for inclusion in environmental engineering educational contexts. Especially the strong agreement in terms of framework structure, educational value, and feasibility of implementation shows that the framework is effective in communicating its pedagogical objectives and promises practical implementation in instruction, both of which are necessary characteristics for adoption of educational innovations within engineering curricula [5], [6].

The results further provide direct support for the framework's central premise that sustainability, public health, and ethical reasoning can be intentionally embedded within technical environmental data analysis rather than treated as isolated curricular supplements. Positive respondent ratings of survey items related to systems thinking, sustainability decision-making, environmental ethics, and public health implications indicate that stakeholders perceived value in embedding socio-environmental reasoning directly in quantitative engineering teaching. Such perception-based findings are consistent with existing sustainability education research indicating that integrating environmental and societal considerations into disciplinary problem-solving activities better prepares students for complex engineering practice [1], [3], [4].

7.2 Importance of Nanoparticle-Centered Datasets for Sustainability and Risk Reasoning

Although real data are generally useful in the teaching of engineering, data sets involving environmental issues associated with nanoparticles provide uniquely valuable pedagogical benefits as they expose students to the interdisciplinary complexity, uncertainty, and regulation issues surrounding emerging technologies. While traditional environmental data sets might focus on pollutant concentrations or system performance, nanoparticle-centric data sets are intrinsically linked to sustainability innovation, toxicological uncertainties, lifecycle trade-offs, public health concerns, and changing governance structures [9]–[11].

The use of nanotechnology for environmental remediation, sustainable materials engineering, pollution mitigation, green building technologies, and advanced infrastructure systems is increasing. However, these innovations are associated with unsolved environmental health and safety challenges, ambiguous exposure routes, and complicated regulatory responsibilities under frameworks such as REACH and safer-by-design governance [10], [11]. This means that nanoparticle datasets provide a particularly rich educational platform that requires students to engage not only with technical interpretation but also with precautionary reasoning, sustainability trade-offs, and principles of responsible innovation.

The framework leverages environmental data related to nanoparticles to provide students with authentic engineering contexts in which technological development is tightly coupled with social responsibility. This focus adds relevance to the framework beyond being a generic data analysis method, by training learners to assess emerging environmental technologies in real-world professional contexts that are uncertain, interdisciplinary, and involve public accountability [7]–[11].

7.3 Socio-Technical Integration and Ethics Education

The evolution of the framework from quantitative data interpretation to sustainability systems analysis, and then to public health, ethics, and communication, represents a deliberate socio-technical model of engineering education. Previous research has consistently demonstrated that ethical reasoning is best taught in technical decision-making contexts that require students to struggle with real trade-offs, uncertainty, and societal consequences instead of abstract ethical scenarios [7].

The responses of the participants reveal that the third module of the framework has been able to integrate public health and ethical communication into the natural extension of technical environmental analysis. This is particularly true of engineering that is related to nanotechnology, where the pace of technological innovation often outstrips societal concerns for long-term environmental exposure, safety, and governance that are not being addressed [8]–[11]. In that sense, the framework supports responsible innovation by explicitly linking technical competence with broader societal accountability, reinforcing the idea that the practice of professional engineering must consider environmental performance, sustainability, ethics, and public welfare concomitantly.

7.4 Implications for Environmental Engineering Education

From an educational perspective, the results indicate that the framework could tackle several perennial shortcomings in environmental engineering curricula. First, it offers a systematic and modular approach to incorporating sustainability, public health, and ethical reasoning into technical courses of study without requiring a complete curricular change. Second, the framework exposes students to current technological and regulatory challenges by focusing on nanoparticle-related environmental datasets that are increasingly important in modern environmental engineering practice.

This instructional model fits within broader efforts to reform engineering education to prepare graduates to address interdisciplinary sustainability challenges, emerging technology risks, and societal obligations in addition to technical problem solving [1], [4], [19]. The flexibility of the framework also suggests possible importance to other fields outside of environmental engineering such as civil, chemical and materials engineering, where nanotechnology and sustainability are increasingly converging.

While this work-in-progress study does not yet evaluate direct student learning outcomes, the positive perception of feasibility, clarity, and educational value by stakeholders provides sufficient justification for future classroom implementation and more rigorous outcome-based evaluation.

7.5 Positioning within the Work-in-Progress Context

Because this is a Work-in-Progress study, the results are intentionally limited to a preliminary validation of the instructional framework, not to claims of proven educational effectiveness. The results obtained here should therefore be read as evidence of stakeholder-supported design promise, methodological coherence, and pedagogical feasibility.

This positioning aligns with the design-based research methodologies that highlight iterative refinement, phased validation, and progressive implementation before large-scale educational deployment [5], [6]. Thus, the discussion situates the framework within contemporary scholarship, articulates its unique contribution to nanoparticle-informed sustainability education, and provides a warranted basis for future classroom implementation, longitudinal evaluation, and broader educational validation.

8.0 Limitations and Future Work

8.1 Study Limitations

The present investigation is a Work-in-Progress study, and therefore, several limitations should be considered when interpreting the findings. First, the evaluation was limited to expert and stakeholder perceptions of the instructional framework rather than direct measures of student learning outcomes. Perceptual validation is a recognized and helpful step in early instructional design research, but it does not offer evidence of instructional effectiveness or learning gains [5], [6].

Second, the sample of participants was small and used voluntary response sampling. Hence, the findings may be suggestive of the views of those already predisposed to sustainability or engineering education innovation. Such limitations have been described in earlier exploratory studies of instructional interventions targeting sustainability [1], [4]. Third, the framework was tested on descriptive materials (i.e., a visual overview and written descriptions of the modules) rather than in a live classroom implementation. This approach provides little insight into instructional pacing, student workload, facilitation challenges, and contextual constraints that may arise in actual deployment [5], [6].

Finally, the study did not investigate how variation in students' prior technical preparation may influence engagement with the dataset or learning activities. Research in engineering education indicates that authentic data use may require differentiated scaffolding based on learners' backgrounds and experience levels [4].

8.2 Planned Classroom Implementation

The next step will be to pilot the instructional framework in undergraduate and graduate engineering courses. Classroom deployment will allow direct measurement of student learning outcomes for sustainability literacy, systems thinking, ethical reasoning, and technical communication.

Assessment plans include pre- and post-instruction measures, rubric-based student artifact assessment, and analysis of reflective writing. These approaches are in line with best practices in engineering education research for assessing complex socio-technical competencies [1], [3].

8.3 Expansion of Assessment and Validation

Future studies will include larger sample sizes as well as multi-institutional participation to provide a stronger empirical basis for the framework. More widespread implementation will allow for comparison across instructional settings and increase the generalizability of findings, addressing a common limitation of early-stage instructional research [5], [6].

Future work will also investigate inter-rater reliability of rubric-based assessments and consider the longitudinal impacts on students' sustainability perspectives and professional identity development. Longitudinal assessment has been identified as a major gap in sustainability education research in engineering programs [1], [4].

8.4 Opportunities for Framework Extension

The instructional framework can also be adapted for use in related fields of study such as civil, chemical, and materials engineering, where emerging technologies intersect with sustainability and public health concerns, in addition to environmental engineering. Because of the modular nature of the design, it can be flexibly integrated without significant curricular restructuring, which is a factor in the adoption of instructional innovations [4], [5].

Additional extensions could include policy analysis activities, community-based case contexts, or alignment with capstone design projects. Such extensions are in accordance with calls for approaches in engineering education that make the connection between technical education and societal impact and responsible innovation more explicit [7], [8].

9.0 Conclusion

This Work-in-Progress paper describes the design and initial validation of an instructional framework that integrates nanoparticle research data into environmental engineering education to promote sustainability and public health reasoning. The framework addresses persistent gaps in engineering curricula where sustainability, ethics, and emerging technology risk are often covered separately from technical analysis [1]– [4].

The framework shows how technical data interpretation can be explicitly linked to systems-level sustainability thinking and ethical communication by its use of a real-world environmental dataset and a sequenced, modular approach to learning. This is consistent with previous work highlighting the importance of socio-technical integration in engineering education and the benefits of experiential, data-driven learning environments [4], [5].

Preliminary results from the evaluation indicate that faculty, graduate students, and practitioners view the framework as clear, feasible, and educationally valuable. These results provide initial evidence that the proposed design might support instructor adoption and curricular integration, consistent with design-based research approaches to instructional innovation [5], [6]. Importantly, the study illustrates an ethical approach to using previously published nanoparticle research data as an educational tool without repeating scientific claims or overextending experimental results.

While the study does not measure student learning outcomes, it provides a validated foundation for future classroom implementation and assessment. As environmental engineers are increasingly called upon to navigate sustainability tradeoffs, public health implications, and emerging technology risks, instructional frameworks that embed such considerations within technical learning are likely to play an important role in preparing graduates for professional practice [7]–[9].

This paper contributes to research on engineering education by providing a transferable, risk-informed instructional framework that links research data on nanoparticles with reasoning on sustainability and public health. Future work includes deployment in the classroom, outcome-based assessment, and cross-institutional validation to further assess the educational impact of the framework.

References

[1] L. Gutierrez-Bucheli, G. Kidman, and A. Reid, "Sustainability in engineering education: A review of learning outcomes," *Journal of Cleaner Production*, vol. 330, Art. no. 129734, 2022, doi: 10.1016/j.jclepro.2021.129734.

[2] D. K. Narong and P. Hallinger, "Traversing the evolution of research on engineering education for sustainability: A bibliometric review (1991–2022)," *Sustainability*, vol. 16, no. 2, Art. no. 641, 2024, doi: 10.3390/su16020641.

[3] T. S. Henderson, A. Carrero, and J. O. Michel, "Engineering students' sustainability learning: Examining opportunities to learn about sustainability and their role in student outcomes," *Journal of Engineering Education*, vol. 114, no. 3, 2025, doi: 10.1002/jee.70010.

[4] J. Sundman, X. Feng, A. Shrestha, A. Johri, O. Varis, and M. Taka, "Experiential learning for sustainability: A systematic review and research agenda for engineering education," *European Journal of Engineering Education*, pp. 1-31, 2025, doi: 10.1080/03043797.2025.2532591.

[5] A. Minichiello and L. Caldwell, "A narrative review of design-based research in engineering education: Opportunities and challenges," *Studies in Engineering Education*, vol. 1, no. 2, pp. 31-54, 2021, doi: 10.21061/see.15.

[6] C. Hoadley and F. C. Campos, "Design-based research: What it is and why it matters to studying online learning," *Educational Psychologist*, vol. 57, no. 3, pp. 207–220, 2022, doi: 10.1080/00461520.2022.2079128.

[7] D. A. Martin, E. Conlon, and B. Bowe, "A multi-level review of engineering ethics education: Towards a socio-technical orientation," *Science and Engineering Ethics*, vol. 27, 2021.

[8] E. Fisher, "Reinventing responsible innovation," *Journal of Responsible Innovation*, vol. 7, no. 1, pp. 1–5, 2020, doi: 10.1080/23299460.2020.1712537.

[9] D. Hristozov, S. Gottardo, E. Semenzin, A. G. Oomen, A. Bos, A. Peijnenburg, and A. Marcomini, “Frameworks and tools for risk assessment of manufactured nanomaterials,” *Environment International*, vol. 95, pp. 36–53, 2016, doi: 10.1016/j.envint.2016.07.016.

[10] K. Schwirn, D. Voelker, W. Galert, J. Quik, and L. Tietjen, “Environmental risk assessment of nanomaterials in the light of new obligations under the REACH regulation: Which challenges remain and how to approach them?,” *Integrated Environmental Assessment and Management*, vol. 16, no. 5, pp. 706–717, Sep. 2020, doi: 10.1002/ieam.4267.

[11] A. G. Oomen, K. G. Steinhäuser, E. A. J. Bleeker, F. van Broekhuizen, A. Sips, S. Dekkers, S. W. P. Wijnhoven, and P. G. Sayre, “Risk assessment frameworks for nanomaterials: Scope, link to regulations, applicability, and outline for future directions in view of needed increase in efficiency,” *NanoImpact*, vol. 9, pp. 1–13, Jan. 2018, doi: 10.1016/j.impact.2017.09.001.

[12] P. R. Regmi, E. Waithaka, A. Paudyal, P. Simkhada, and E. van Teijlingen, “Guide to the design and application of online questionnaire surveys,” *JMIR Public Health and Surveillance*, vol. 2, no. 2, e186, 2016.

[13] R. Sammut, O. Griscti, and I. J. Norman, “Strategies to improve response rates to web surveys,” *International Journal of Nursing Studies*, vol. 123, Art. no. 104058, 2021.

[14] D. G. Bonett and T. A. Wright, “Cronbach’s alpha reliability: Interval estimation and sample size planning,” *Journal of Organizational Behavior*, vol. 36, no. 1, pp. 3–15, 2015.

[15] K. S. Taber, “The use of Cronbach’s alpha when developing research instruments,” *Research in Science Education*, vol. 48, pp. 1273–1296, 2018.

[16] V. Braun and V. Clarke, “Toward good practice in thematic analysis,” *Qualitative Research in Sport, Exercise and Health*, 2022.

[17] E. S. Williams, J. Panko, and D. J. Paustenbach, “The European Union’s REACH regulation: A review of its history and requirements,” *Critical Reviews in Toxicology*, vol. 39, no. 7, pp. 553–575, 2009, doi: 10.1080/10408440903036056.

[18] ABET, *Criteria for Accrediting Engineering Programs, 2023–2024*, Accreditation Board for Engineering and Technology, Baltimore, MD, USA, 2023. [Online]. Available: https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs

[19] E. P. Byrne, “The evolving engineer: Professional accreditation sustainability criteria and societal imperatives and norms,” *Education for Chemical Engineers*, vol. 43, pp. 23–30, 2023, doi: 10.1016/j.ece.2023.01.004.