Defining Human-Centered Engineering: A Multidisciplinary Delphi Approach

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Abstract

This paper reports on the design and initial implementation of a modified Delphi study examining how academic experts across disciplines conceptualize Human-Centered Engineering (HCE). Although HCE has gained visibility in engineering education as a way to foreground human experience, ethical responsibility, and sociotechnical context, the term remains inconsistently defined across disciplinary, institutional, and pedagogical settings. This conceptual ambiguity poses challenges for multidisciplinary engineering education, where shared language is necessary to support curricular integration, assessment, and cumulative research. In multidisciplinary engineering programs and courses, this lack of shared language complicates curricular integration, assessment, and collaboration across disciplinary boundaries.

To address this gap, the study employs a three-round modified Delphi method to surface and refine expert-informed understandings of HCE. This paper focuses specifically on the study design and the preliminary qualitative findings from Round 1, which included 15 completed expert responses at the time of analysis. The first round consisted of an open-ended online survey inviting experts to define HCE in their own words, articulate its guiding principles and values, distinguish it from related frameworks, and reflect on its pedagogical implications. The study adopts several methodological adaptations, including inductive construct emergence, a flexible interdisciplinary expert-inclusion framework, and an analytic stance that treats persistent divergence as theoretically meaningful rather than a methodological failure.

Thematic analysis of Round 1 responses reveals early convergence around HCE encompassing empathetic and iterative design practices, intentional reflexivity on the role and positionality of the engineer, and explicit attention to the sociotechnical, ethical, and contextual dimensions of engineering work. At the same time, expert responses reflect variation in how these elements are emphasized and integrated, highlighting HCE as a multidimensional and context-sensitive construct rather than a singular approach.

By documenting the methodological architecture and deployment of a multidisciplinary Delphi study, the expert recruitment strategy, and early analytic patterns, this paper contributes transparency to early-phase findings and helps develop an expert-informed framework for Human-Centered Engineering. The findings offer initial insights relevant to multidisciplinary engineering education and lay the groundwork for subsequent Delphi rounds focused on statement refinement, stability analysis, and framework development to inform curriculum design, assessment, and future empirical research.

Keywords: Human-Centered Engineering (HCE); Delphi method; multidisciplinary engineering education.

Introduction

Human-Centered Engineering (HCE) has gained increasing attention in engineering education and practice as a way to foreground human experience, ethical responsibility, and social context in engineering work. Across accreditation criteria, funding priorities, and diversity, equity, and inclusion initiatives, there is a growing expectation that engineers attend to human needs and societal impacts as integral to professional competence [1], [2]. Notably, these expectations increasingly span disciplinary boundaries, positioning HCE as a site of convergence among engineering, design, social sciences, humanities, and education. Despite this momentum, HCE remains inconsistently defined across curricula, research, and professional discourse. The term is often invoked without shared conceptual grounding, limiting its usefulness for instructional design, assessment, and cumulative research.

Engineering problems are widely recognized as sociotechnical in nature—ill-structured, value-laden, and shaped by human, environmental, institutional, and cultural factors [3], [4]. Addressing such problems often requires collaboration across disciplinary traditions with distinct epistemologies, methods, and norms. While related constructs such as human-centered design, participatory design, engineering for social good, and user-centered approaches have been examined within specific disciplinary or pedagogical contexts, far less attention has been given to how Human-Centered Engineering itself is understood across disciplines. As a result, educators working in multidisciplinary spaces lack a shared language to articulate what HCE entails, how it differs from adjacent constructs, and how it can be meaningfully integrated into programs that bridge engineering with design, computing, education, or the social sciences.

This lack of conceptual clarity poses a particular challenge for multidisciplinary engineering education, where faculty and students must navigate divergent assumptions about what counts as engineering knowledge, legitimate expertise, and appropriate forms of human engagement. Without clearer cross-disciplinary understanding, curriculum design, learning outcome alignment, and assessment efforts risk becoming fragmented or superficial.

This study addresses this gap by presenting preliminary findings from a modified Delphi study designed to surface and refine expert-informed understandings of Human-Centered Engineering across disciplinary and institutional contexts. Rather than advancing a single prescriptive definition, the study seeks to map areas of convergence, divergence, and productive tension among expert perspectives. In doing so, it aims to support multidisciplinary dialogue around HCE and to lay the groundwork for more coherent curricular, pedagogical, and research approaches in engineering education.

Guided by this aim, the study addresses the following research questions:

1. How do experts across engineering education and related disciplines conceptualize Human-Centered Engineering, and where do their perspectives converge and diverge?
2. What dimensions of Human-Centered Engineering emerge as stable, contested, or context-dependent across expert perspectives?

For multidisciplinary engineering programs, this lack of conceptual clarity carries particular consequences. General engineering degrees, integrated curricula, and cross-listed courses often rely on shared learning goals and coordinated instructional approaches across disciplinary boundaries. When Human-Centered Engineering is invoked without a common understanding, instructors may emphasize divergent practices, values, or outcomes under the same label, complicating curriculum design, assessment, and collaboration. As multidisciplinary engineering education continues to expand, there is a growing need for expert-informed language that can support coherence without erasing disciplinary nuance. This study responds to that need by examining how experts across disciplines conceptualize Human-Centered Engineering and by identifying areas of convergence and productive tension that can inform multidisciplinary teaching and program design.

Rather than advancing a finalized definition, this paper contributes methodological transparency and early conceptual dimensions intended to inform subsequent Delphi rounds and support multidisciplinary dialogue. The findings offer initial, expert-informed dimensions of HCE that are particularly relevant to multidisciplinary engineering curricula, integrated programs, and cross-disciplinary teaching teams. The objectives of this study are threefold: (1) to systematically document how experts across engineering and related disciplines define and frame Human-Centered Engineering; (2) to identify areas of convergence, divergence, and productive tension in those conceptualizations; and (3) to establish a transparent methodological foundation for subsequent Delphi rounds aimed at statement refinement and consensus analysis. This paper focuses specifically on the design architecture of the study and the preliminary qualitative findings from Round 1.

Literature Review

Engineering education has increasingly recognized the need to move beyond narrowly technical conceptions of engineering competence toward approaches that explicitly account for human experience, ethics, and social context. Accreditation frameworks, such as ABET student outcomes, and funding priorities, such as the National Science Foundation's Broader Impacts criterion, signal an institutional shift toward integrating communication, ethical reasoning, and societal awareness as core elements of engineering practice [1], [2]. In parallel, diversity, equity, and inclusion initiatives have further emphasized the importance of centering people, communities, and lived experience in engineering education.

Within this landscape, Human-Centered Engineering (HCE) has emerged as a term for approaches that foreground human needs and values in engineering work. However, the literature reflects considerable variation in how human-centeredness is defined and operationalized. Some work emphasizes empathy and user needs within engineering design processes, while other strands focus on broader sociotechnical considerations such as justice, sustainability, power, and historical context. This diversity suggests that HCE functions less as a single, settled construct and more as an umbrella term encompassing multiple, possibly competing, orientations.

Much of the existing scholarship engages constructs adjacent to HCE rather than HCE itself. Research on human-centered and user-centered design often focuses on usability, accessibility, and iterative user engagement, yet may not explicitly address broader social or ethical implications. Other bodies of work, such as engineering for social good, service learning, and sociotechnical systems thinking, foreground community impact, social responsibility, and structural inequities [5], [6]. While these traditions overlap with HCE, they do not consistently articulate how technical engineering knowledge, human experience, and ethical responsibility are integrated within a single framework.

Prior studies have also shown that engineering problems are frequently ill-structured, involve competing constraints, and entail human consequences that cannot be resolved solely through technical optimization [3], [4]. Despite this recognition, the field lacks a shared vocabulary for describing what it means to engage with such complexity in a human-centered way. As a result, educators may invoke HCE rhetorically while enacting substantially different pedagogical practices, and researchers may operationalize HCE inconsistently across studies.

The absence of a shared, empirically grounded understanding of HCE has practical and scholarly consequences. Without conceptual clarity, it is challenging to design curricula that intentionally cultivate human-centered competencies, to develop assessment tools aligned with HCE learning outcomes, or to compare findings across studies. Prior research suggests that when engineering students are explicitly supported in connecting technical work with human and social dimensions, they experience increased motivation, stronger professional identity, and greater persistence [7], [8]. However, such outcomes depend on a clear articulation of what human-centeredness entails in engineering contexts. Calls for definitional clarity are not unique to HCE. Engineering education research has increasingly turned to structured consensus-building methods to define emergent, value-laden constructs that resist straightforward operationalization. In this context, empirical approaches that foreground expert judgment offer a promising path forward.

The Delphi method has been widely used to develop shared definitions and frameworks in fields characterized by conceptual ambiguity and interdisciplinary complexity. Initially developed by the RAND Corporation for technological forecasting, Delphi studies rely on iterative rounds of anonymous expert input and controlled feedback to surface convergence while preserving diversity of perspective [9], [10]. Recent engineering education research has successfully employed Delphi methods to articulate constructs such as engineering thriving, professional competencies, and curricular priorities [11]. Delphi approaches are particularly well-suited for examining HCE because they allow for inductive emergence of meaning rather than imposing predefined theoretical models. By engaging experts across disciplinary and methodological traditions, Delphi studies can reveal shared foundations and persistent tensions, insights that are critical to the development of constructs in engineering education research. Importantly, the intent of this paper is not to claim consensus, but to surface early patterns, tensions, and conceptual boundaries emerging from expert responses.

Methodology

This paper focuses on the design rationale, deployment, and first-round analytic outcomes of a three-round modified Delphi method [12], [13] to elicit, refine, and ultimately converge expert perspectives on Human-Centered Engineering (HCE). The Delphi approach is well-suited to this inquiry given HCE's interdisciplinary character, conceptual ambiguity, and the absence of a widely accepted definition across engineering domains. Although the full study consists of three iterative rounds, this paper reports exclusively on the methodological design and the preliminary qualitative findings from Round 1.

Overview of the Three-Round Delphi Design

The overall study consists of three iterative rounds:

- **Round 1 (Exploratory, Open-Ended):** Elicitation of expert definitions, principles, distinctions, examples, and tensions related to HCE.

- **Round 2 (Structured Rating):** Synthesis of Round 1 themes into declarative statements for expert evaluation using Likert-scale ratings and qualitative feedback.
- **Round 3 (Stability and Refinement):** Re-rating of revised statements to assess stability, convergence, and persistent divergence across expert perspectives.

This paper reports findings exclusively from Round 1.

Several deliberate modifications distinguish this study from a classical Delphi approach. First, rather than using the Delphi technique for forecasting or decision-making, the method is employed for conceptual articulation and refinement of *Human-Centered Engineering* as an emergent construct. Second, the first round is intentionally open-ended, with no predefined definitions or constructs, enabling expert perspectives to surface inductively without premature conceptual closure. Third, expert selection follows a flexible, interdisciplinary inclusion framework that recognizes diverse forms of scholarly, pedagogical, and leadership expertise relevant to HCE. Fourth, consensus is operationalized not as uniform agreement, but as interpretive stability across rounds, with sustained divergence treated as analytically meaningful rather than as methodological failure. Finally, qualitative analysis will be supported by AI-assisted sensemaking tools that organize and surface thematic patterns while preserving researcher-led interpretation.

Data Collection

Round 1 consists of an open-ended online survey administered via Qualtrics, designed to elicit experts' conceptualizations, assumptions, and lived interpretations of Human-Centered Engineering (HCE). The survey begins with brief participant identification items (disciplinary background, sector, and years of experience) to contextualize responses without using these variables for exclusion or stratification. The core of Round 1 comprises a series of open-ended prompts that invite participants to: define HCE in their own words and within their professional context; articulate the principles, values, and goals that guide their understanding or application of HCE; distinguish HCE from other forms of engineering and from related frameworks such as user-centered design, social impact engineering, and sociotechnical approaches; describe concrete examples (e.g., projects, courses, initiatives) that reflect their approach to HCE; identify the forms of knowledge and ways of knowing they view as central to HCE (e.g., experiential, cultural, technical, embodied); surface common misunderstandings, misapplications, tensions, or tradeoffs encountered when implementing HCE; and reflect on how HCE should be taught, how it varies across disciplinary and institutional contexts, and what core themes should anchor an expert-informed HCE framework.

Survey prompts were informed by prior conceptual work examining HCE through ontological, epistemological, ethical, and learning-oriented discussions, ensuring coverage of the construct's multidimensional character while avoiding predefined definitions or analytic categories. This design allows expert perspectives to surface inductively, preserving conceptual diversity at the initial stage of the Delphi process. Subsequent rounds will involve synthesizing Round 1 themes into structured statements for expert rating, feedback, and refinement, following standard Delphi procedures. At the time of manuscript preparation, 20 experts had accessed the Round 1 survey, and 15 completed responses were included in the preliminary analysis. Five partially completed submissions were excluded due to insufficient substantive content. Recruitment and data collection remain ongoing, with additional experts expected to participate prior to initiating subsequent Delphi rounds.

Expert Selection and Recruitment
Expert selection is a central methodological contribution of this study. Experts were identified using a flexible, multi-criteria inclusion framework designed to reflect the interdisciplinary and evolving nature of HCE. Participants qualified for inclusion if they met at least one of the following criteria:

1. Disciplinary alignment with engineering education, engineering design, human–computer interaction, or closely related human-centered fields;
2. Demonstrated intellectual, pedagogical, or leadership contributions, evidenced through peer-reviewed publications, curriculum design, program leadership, or community-engaged projects related to HCE or adjacent frameworks; or
3. Peer recommendation as individuals with sustained engagement in HCE-related scholarship or practice.

All invited experts work primarily in academic contexts and represent a wide range of disciplinary and professional backgrounds relevant to Human-Centered Engineering. At the time of manuscript preparation, following data cleaning (e.g., removal of incomplete entries and consolidation of closely related self-reported areas), the invited expert pool comprised 55 identifiable individuals. Based on participants' self-reported primary areas of expertise, disciplinary representation included engineering education; mechanical engineering; engineering, design, and society–oriented fields; design and design education, including human-centered design and design thinking; human-centered engineering as an explicitly named area; information science or human-centered computing; and broader or interdisciplinary engineering fields (e.g., integrated engineering, polytechnic studies, engineering fundamentals, innovation and society. Table 1 presents the disciplinary distribution of the invited experts.

Table 1. Disciplinary Distribution of Invited Experts (n = 55).

Primary Area of Expertise	**n**
Engineering Education	15
Mechanical Engineering	7
Engineering, Design, and Society–Oriented Fields	6
Design and Design Education	6
Human-Centered Engineering (explicitly named)	2
Information Science / Human-Centered Computing	1
Interdisciplinary Engineering Fields	18

Participants occupied a range of academic roles, including assistant, associate, and full professors; teaching-focused faculty; professors of practice; and academic administrators or center directors. Recruitment followed a purposive and snowball-based strategy, initially targeting scholars with established contributions to engineering education, design, and human-centered approaches, and subsequently expanding through peer recommendations to incorporate adjacent and interdisciplinary perspectives shaping contemporary understandings of HCE.

At the time of writing, recruitment and data collection are ongoing. Consistent with the Delphi literature, the target sample for the completed study is 25–30 experts [13]. The current Round 1 completion count (n = 15) represents an initial analytic subset, with additional recruitment planned prior to subsequent rounds.

Data Analysis

For this paper, analysis is intentionally limited to a preliminary thematic analysis of Round 1 definitions of HCE. Responses were analyzed using a qualitative coding process supported by NotebookLM to assist with pattern identification and thematic clustering. The tool was used to support the researcher's interpretation by organizing textual data, identifying recurrent language, and surfacing conceptual groupings. At this stage, analysis focuses exclusively on how experts define HCE, rather than on consensus-building or quantitative agreement. The findings presented should therefore be interpreted as exploratory and illustrative, offering an early window into the conceptual diversity and emerging commonalities surrounding HCE. At the same time, the entire Delphi process continues.

For the complete study, Round 1 responses will be analyzed using inductive thematic analysis to identify recurring concepts, values, assumptions, and tensions related to HCE. These themes will be synthesized into declarative statements for evaluation in subsequent rounds. In Rounds 2 and 3, participants will rate statements using a 5-point Likert scale, with controlled feedback provided between rounds. Quantitative analyses will examine levels of agreement and stability across rounds, while qualitative comments will be used to refine statements and interpret areas of persistent divergence. Following established Delphi guidelines, consensus will be defined as at least 75% agreement [14].

Methodological Considerations and Limitations

As with all Delphi studies, several limitations warrant consideration. Expert selection may reflect sampling bias based on professional networks and visibility within the field. Attrition across rounds may influence stability estimates in later phases. Additionally, the synthesis of open-ended responses into structured statements introduces interpretive decisions that may shape how convergence is assessed. While the study treats persistent divergence as analytically meaningful rather than as failure, consensus thresholds (e.g., 75% agreement) remain convention-based rather than absolute indicators of construct validity. These limitations are acknowledged as inherent to structured consensus-building approaches.

Phase 1 Findings: Expert Conceptualizations of HCE

The themes below are presented not as finalized categories, but as emerging dimensions of Human-Centered Engineering that will be refined, tested, and potentially contested in subsequent Delphi rounds. Representative quotations illustrating these themes will be incorporated in a future manuscript to provide additional contextual depth.

The 15 experts included in the preliminary Round 1 analysis articulated definitions of Human-Centered Engineering (HCE) that coalesced around several overlapping themes, reflecting practical design orientations and broader philosophical commitments. While terminology varied, responses consistently emphasized the centrality of humans, reflexivity, and sociotechnical awareness in engineering practice.

A prominent theme defined HCE as an *empathetic, iterative, design-oriented problem-solving approach*. Several experts described HCE as a process driven by empathy and iteration, in which stakeholder needs are intentionally prioritized throughout the engineering design process. This includes designing solutions that address diverse backgrounds, abilities, needs, and preferences, and ensuring that outcomes are usable and provide meaningful value to intended users. Within this framing, HCE is seen as extending beyond technical know-how or economic optimization to foreground human experience as a core design criterion.

Another recurring theme emphasized *intentional reflexivity and the humanity of the engineer*. Experts highlighted that HCE involves applying a human-centered lens to one's own engineering practice by recognizing engineers as human actors whose values, subjectivities, imperfections, and positionalities shape design decisions. Reflexivity was described as an intentional practice throughout the engineering process, challenging notions of engineer neutrality and objectivity. In this view, acknowledging the influence of personal identity, bias, and irrationality is not a limitation but a defining feature of human-centered engineering.

Experts also framed HCE as a form of *sociotechnical and contextual integration,* rejecting the idea that engineering exists in a vacuum. Responses emphasized that technical decisions, such as choices related to materials, components, or system configurations, carry social, cultural, historical, political, and environmental implications. Human-centered engineering was described as explicitly attending to issues of justice, power dynamics, sustainability, oppression, and privilege to mitigate harm and promote equity and well-being. Engineering work, from this perspective, is inherently embedded within broader human and societal systems.

Several experts articulated HCE as a *holistic, ethical, and civic philosophy* rather than a discrete set of tools or methods. Within this framing, HCE emphasizes pro-social and pro-environmental engineering practice and positions the public interest as central to decisions about what should and should not be built. This orientation highlights epistemic humility, ethical responsibility, and the evaluation of non-technical inputs and outcomes alongside technical requirements. HCE is thus understood as a reframing of what constitutes "good engineering," expanding evaluation criteria beyond performance metrics to include social and environmental consequences.

Finally, some experts described HCE through *multi-directional human engagement*, characterizing engineering work as occurring *with*, *as*, and *for* humans. This includes collaborating with non-engineers and communities, acknowledging one's own humanity as an engineer, and considering the long-term impacts of engineering work on people and ecosystems. Within this perspective, engineering is closely aligned with design as a process for addressing complex, open-ended problems situated within interconnected social and environmental contexts.

Across themes, HCE emerges as a multidimensional construct encompassing design practice, reflexivity, sociotechnical awareness, and ethical orientation. While early convergence is evident, persistent variation suggests that HCE may function less as a single framework and more as a family of related orientations—an insight with direct implications for multidisciplinary engineering education.

Implications and Future Work

The methodological architecture documented in this study offers a replicable model for researchers seeking to clarify emergent, interdisciplinary constructs. It is possible to adapt the three-round Delphi structure to define locally relevant interpretations of Human-Centered Engineering or related constructs. The open-ended first round allows disciplinary nuance to surface without imposing premature consensus, while subsequent rounds provide structured opportunities for convergence and refinement. Importantly, institutions adopting similar approaches should remain attentive to expert diversity, interpretive transparency, and the treatment of divergence as informative rather than problematic.

The next phases will along four interrelated directions: expert consensus development, analytic refinement, methodological extension, and educational application. First, the study will complete expert recruitment and conduct subsequent Delphi rounds to refine and evaluate synthesized statements derived from Round 1 responses. These rounds will focus on assessing levels of agreement, identifying points of convergence and divergence, and iteratively refining statements toward an expert-informed framework of Human-Centered Engineering (HCE).

Second, future analyses will examine the internal structure of HCE as articulated by experts. This includes identifying stable dimensions that persist across rounds, articulating unresolved tensions or competing orientations, and distinguishing core commitments from context-dependent interpretations. Additional analyses will explore how definitions of HCE vary across disciplinary backgrounds, institutional roles, and professional contexts, providing insight into how human-centeredness is enacted differently across engineering subfields and educational settings.

Third, subsequent rounds extend this work beyond expert consensus to include methodological extensions. Findings from the Delphi study will inform the development of empirically testable constructs and instruments, including refined survey measures and analytic frameworks that capture multiple orientations toward HCE. These instruments will enable future studies to examine the prevalence, coherence, and educational impacts of HCE across student, faculty, and practitioner populations.

Finally, the expert-informed framework will guide future research on curriculum design, pedagogical interventions, and assessment practices aligned with Human-Centered Engineering. This includes designing learning experiences that integrate reflexivity, sociotechnical reasoning, and ethical responsibility alongside technical content and developing and validating HCE-related learning outcomes. Subsequent empirical work can examine how different instructional approaches support students' engagement with HCE and how these orientations influence students' professional identity development, decision-making, and sense of responsibility as engineers.

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