An Industry-Academia Collaborative Approach to Curriculum Design: Adaptation to the Modified Delphi Method Process in Manufacturing Engineering

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Abstract

This methods full paper presents the adaptation of the Modified Delphi Method in the context of curriculum development of a new Master of Engineering degree in Manufacturing, Design, and AI. This project is conducted by the Massachusetts Institute of Technology (MIT) in the USA in collaboration with the New Age Makers' Institute of Technology (NAMTECH) in India. MIT adopted a participatory curriculum design approach for the development of the curriculum framework. One of the core components of the design process consists of the identification of the set of competencies for a master's-level manufacturing engineering graduate to possess that align with industry needs and future trends in advanced manufacturing. Industry representatives from the USA and India and faculty from MIT and Indian academic partners were recruited to participate in this study.

A Modified Delphi method was adopted and adapted to conduct this study, with adaptations informed by literature and participants' feedback throughout the process. Our approach consisted of four steps: literature review, survey, separate industry and faculty panels, and a reconciliation "mixed panel". The novelty of our approach consisted in a final reconciliation panel between the two stakeholders' groups, industry and faculty, to address and align the differing competency expectations between academia and industry.

An initial review of the literature was conducted to compile a comprehensive list of competencies expected of manufacturing engineering graduates upon completion of the program. A survey was designed and distributed to a group of industry representatives from multiple sectors, selected based on their involvement in the hiring of new graduates, experience supervising recent hires, and managerial-level responsibilities. An identical survey was also sent to faculty. The results from the surveys were the starting point for a series of in-person and online consensus-building panels with industry representatives and faculty to reach consensus on the list of competencies, their definition and the mastery level that new graduates are expected to achieve in the selected competency at degree completion. Analysis of the panel data revealed notable differences between faculty and industry perspectives, which were important to address in the final "mixed panel", where representatives from both groups were recruited to participate.

The analysis of the panels, performed blending quantitative ratings with qualitative interpretation, highlighted rich conversations enabling participants to collectively refine and prioritize competencies, finalize the specific taxonomy for each of them and reflect on their content and mastery level. This approach afforded the benefit of a structured, iterative consensus-building process designed to facilitate multi-sector participation to minimize bias from dominant voices and promote industry-academia reconciliation/collaboration to reach a shared understanding of the competencies that graduates are expected to possess when completing their degree. Adjustments were made to reduce participants' attrition and fatigue, minimize the risk of superficial consensus and adjust to the online and in-person formats. In this paper, we describe the methodology adopted, the adaptations and adjustments that were made

and the approach to data analysis. We also present evaluation data from the analysis of qualitative data and end-of-the-panel surveys to share lessons learned for future implementations.

Introduction

This is a methods full paper. Engineering education programs increasingly face the challenge of preparing graduates for professional practice in contexts characterized by rapid technological change, interdisciplinary problem-solving, and evolving societal expectations. In manufacturing engineering, advances in automation, data-driven decision-making, and artificial intelligence are reshaping working environments and professional roles, creating the need for forward-looking curricula that are responsive to evolving industry needs. Addressing this challenge requires a systematic approach to curriculum design informed by diverse perspectives and expertise. In response to these challenges, the Massachusetts Institute of Technology (MIT) in collaboration with the New Age Makers' Institute of Technology (NAMTECH) is developing a new curriculum framework for a Master of Engineering in Manufacturing, Design, and AI through a participatory curriculum design approach [1]. This approach positions curriculum development as a collaborative process involving stakeholders who influence, possess expertise in, or are affected by educational outcomes [2, 3]. In this project, multiple stakeholder groups were engaged, including faculty, industry, MIT alumni of a well-established manufacturing Master of Engineering, and students enrolled in a comparable manufacturing program in India. Each group contributed unique perspectives, collectively shaping a curriculum that responds to evolving professional, technological, and societal needs.

A central component of this study involved identifying and prioritizing the critical competencies that graduates of a Master of Engineering in Manufacturing, Design, and AI are expected to demonstrate upon completion of the program, from the perspectives of academia and industry. The process also intended to foster collaboration between academia and industry representatives from diverse sectors within manufacturing. This study employed a consensus-building methodology adapted from the Modified Delphi method that comprises seven stakeholder-specific panels (industry-only and academia-only), to surface within-group judgments, followed by a mixed industry-academia panel composed of panelists who participated in the earlier panels and had expressed interest in further engagement in the project. This sequential design represents a methodological novel contribution, enabling structured cross-sector interpretation and reconciliation informed by prior stakeholder-specific deliberation. The Delphi method [4, 5] and its variants [6, 7] are well-established approaches in engineering education research for eliciting expert judgment when multiple perspectives must be reconciled [8, 9, 10]. The present study builds on this literature by describing and evaluating adaptations to the Modified Delphi tailored to an international, participatory curriculum development project. The paper contributes to engineering education research by documenting these adaptations, presenting qualitative and quantitative evidence of their effectiveness, and reflecting on how such approaches can strengthen industry-academia collaboration. This study aims to provide methodological insights for engineering educators engaged in participatory curriculum design.

Background

The Modified Delphi Method in Engineering Education

The Delphi method was first developed in the early 1950s by researchers at the RAND Corporation as a systematic approach for eliciting and refining expert judgment [4, 5]. Originally conceived as a forecasting tool, the method has been widely adopted to achieve informed consensus through multiple iterative rounds of anonymous questionnaires with controlled feedback [7, 11]. These features are intended to reduce dominance effects, encourage independent thinking, and promote convergence of expert opinions. However, traditional Delphi applications have also revealed limitations, including time intensity, participant attrition, and rigidity in process design [7, 12, 13]. In response, the Modified Delphi method emerged as a practical adaptation that preserves core Delphi principles while allowing greater methodological flexibility, such as the use of literature-informed item lists, fewer rounds, and the integration of qualitative components including focus groups [6, 12, 14].

The Delphi and Modified Delphi methods have been applied across various fields, including health sciences, education, public policy, engineering, and technology forecasting [8, 9, 11, 15, 16, 17, 18, 19]. Within engineering/STEM education, it has become an established methodology for defining and validating competencies, program goals and outcomes, and professional roles. Buelin [20] used a three-round Modified Delphi to identify and prioritize opportunities to integrate the Engineering Grand Challenges into K-12 engineering curricula. Rossouw et al. [18] conducted an international Delphi study involving experts in engineering and technology education to define key concepts and contexts in technological literacy. Their study began with a predefined list of concepts derived from prior research followed by successive rounds of feedback to refine expert judgments and reach consensus. Strimel et al. [21] adopted a Modified Delphi method to address the lack of a foundational framework for engineering concepts and practices in the K-12 engineering curriculum. This study implemented a series of survey and panel rounds with experts selected across multiple fields of K-12, industry and higher education.

In higher education, Eskandari et al. [15] applied a three-round Modified Delphi process with industry and academic experts to identify desired characteristics and emerging topics in undergraduate industrial engineering curricula. Their approach adopted an initial literature informed survey, reducing participant burden while anchoring the expert’s feedback in prior scholarly work. Craps et al. [8] employed a Modified Delphi approach to identify engineering roles and associated professional competencies, integrating literature review, and multiple Delphi rounds with industry experts in sector-specific and multi-sectoral contexts. Gesun et al. [22] used a three-round Delphi method to construct a conceptual model to better understand undergraduate students’ thriving in engineering. This study involved multiple academic institutions and engineering disciplines with experts selected among administrators, faculty and staff to collect a multitude of perspectives. Ragusa et al. [9] applied a large-scale Modified Delphi process to identify core competencies for advanced manufacturing engineering. Their study combined an initial brainstorming session with subsequent anonymous survey rounds involving a broad set of industry participants. Tuyaerts et al. [10] applied a three-round Delphi method to identify lifelong learning competencies for engineers from an industry perspective. Collectively, these studies attest to the established use of the Delphi and Modified Delphi methods in engineering higher education as rigorous but flexible approaches for engaging cross-sectoral stakeholders.

Building on this body of work, the present study introduces and evaluates further adaptations of the Modified Delphi method to support curriculum development, in international context, focusing on the contributions of industry and faculty participation, and the impact of consensus-building panels on opportunities for dialogue and collaboration in engineering curriculum development. These adaptations were guided by the specific needs of the study while maintaining the core methodological principles of iteration, structured feedback, and expert-driven consensus. While prior studies have demonstrated the established role of Delphi approaches in education, this study intends to focus on how specific design choices within the Modified Delphi method guidelines, specifically stakeholder-specific panels and a mixed industry-academia panel shape sense-making and collaboration between industry and academia.

Industry-Academia Collaboration

Industry-academia collaboration is widely recognized as a critical mechanism for fostering innovation, enabling knowledge exchange, and ensuring mutual responsiveness between educational programs and evolving workforce needs, with applications in curriculum development, research partnerships, and technology transfer [23, 24, 25, 26]. Despite these benefits, tensions persist in such collaborations, stemming in particular from differences in goals and time horizons: academic institutions typically emphasize long-term learning outcomes, academic rigor, and foundational knowledge, whereas industry partners often prioritize short-term applicability, rapid response to market changes, and immediate workforce readiness [25, 27, 28]. These divergent priorities can lead to differing interpretations of curriculum relevance and competency importance. Co-design approaches, rooted in structured iterative cycles, have been applied to curriculum design to integrate diverse stakeholders' insights [29, 30, 31]. However, they often aggregate stakeholders' inputs rather than explicitly negotiate cross-sector differences. Structured consensus methods, such as the Delphi and Modified Delphi methods have also proven effective in synthesizing expert perspectives while mitigating dominance effects in group decision-making [6, 7, 11, 12, 14]. Yet traditional Delphi applications often treat expert panels as homogeneous groups, potentially masking meaningful differences in stakeholders' priorities. In contexts where academic and industry incentives diverge, aggregated consensus may reflect compromise rather than informed reconciliation. To address this issue, the adapted Modified Delphi adopted in this study incorporates a sequential panel structure consisting of industry-only, faculty-only that allows participants to articulate and refine group-specific priorities, preserving the authenticity of each group's perspectives and a subsequent mixed panel that creates a structured opportunity for dialogue, enabling stakeholders to recognize and reconcile differences through transparent deliberation. This can enhance mutual understanding, strengthening the resulting competency framework. By explicitly embedding cross-sector interaction within the consensus process, the approach models a collaborative process that can contribute to more sustainable curriculum partnerships.

Research Questions

RQ1: How does the adapted Modified Delphi design facilitate collective sense-making around graduate-level competencies across industry and academic participants?

RQ2: What methodological affordances, if any, emerge from implementing a mixed industry-academia panel in an engineering curriculum development context?

Study Design

This study was designed to elicit structured experts' feedback on the relevant competencies that graduates of a Master of Engineering degree in Manufacturing, Design, and AI are expected to acquire during their studies. It employed a Modified Delphi approach comprised four phases (Fig. 1): 1) Competency list developed through literature review and expert feedback; 2) Separate industry and faculty survey to prioritize competencies; 3) Stakeholder-specific and country-specific panels (industry-only and faculty-only, in India and in the USA); 4) A mixed industry-faculty panel to reconcile differences and support cross-sector understanding.

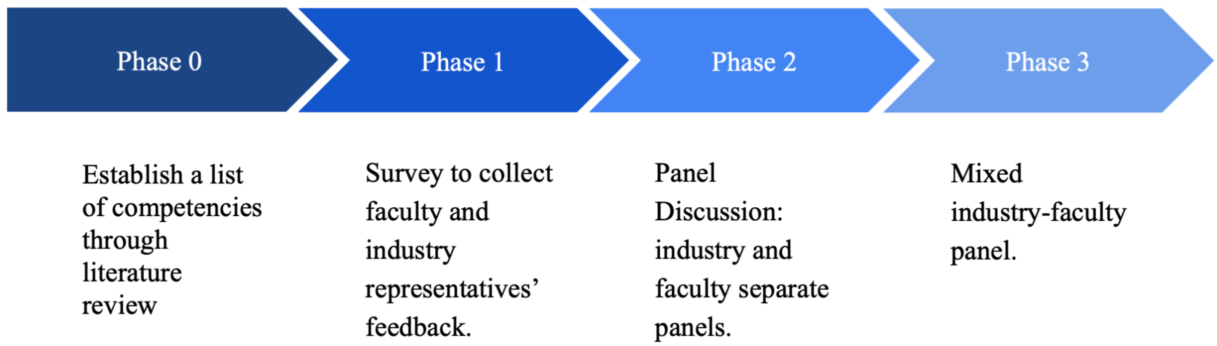

Figure 1: Multi-phase adapted Modified Delphi method

Survey and panel participants were selected among industry representatives and faculty in the US and in India. As the degree under development is not sector-specific (e.g., semiconductors, automotive) but designed to prepare graduates for manufacturing broadly defined, significant effort was placed to select industry representatives from different sectors to help ensure that the identified competencies reflected cross-cutting manufacturing capabilities rather than sector-bound priorities. Industry representatives were selected among mid- and high-level managerial engineers with direct experience in the hiring of new graduates and experience working with them. Faculty from MIT and from Indian institutions participated in the survey and panels. Participants' composition aimed to preserve balance across stakeholder type (industry/faculty) and national context (India/U.S.) to avoid dominance of any single perspective. While final ratios were influenced by voluntary participation, efforts were made to maintain balance across groups to support equitable dialogue. The participants' selection is in line with existing literature that emphasizes the critical role of the expert's selection based on the relevance of their experience [14]. The study, as designed, allowed to preserve independent stakeholder perspectives while progressively increasing integration across groups.

Phase 1: Development of the Initial Competency List

An extensive review of the literature was conducted to identify competencies relevant to manufacturing engineering at the graduate level, as well as broader engineering, professional, and leadership competencies commonly associated with Master of Engineering programs. Competencies were organized in four categories (knowledge, technical skills, professional skills, and attributes), consistent with prior engineering education frameworks [32]. To strengthen content validity and clarity, Subject Matter Experts (SMEs) from the Department of Mechanical Engineering at MIT reviewed this initial list. Their role was to assess the relevance and comprehensiveness of the competencies, refine language, merge, split or remove competencies more appropriate for undergraduate education, and develop concise definitions for each of them. This expert review phase replaced the first open-ended Delphi round, a common adaptation intended to reduce participant burden and focus subsequent stages on prioritization and revisions.

Phase 2: Survey

Following finalization of the competency list, two parallel surveys were developed and distributed separately among industry and faculty representatives in India and in the USA. Respondents were asked to rank competencies within each category according to their importance for a newly graduated Master of Engineering student in manufacturing. The surveys also included an open-ended question asking participants to suggest additional competencies not captured in the initial list, thereby preserving opportunities for emergent input. In addition, the surveys collected background information on participants' professional roles and sectors, enabling the research team to verify stakeholders' representation in each group.

The industry survey received a total of 32 responses (13 from India and 19 from the USA). A variety of manufacturing sectors and companies' sizes were represented in the USA and in India. The faculty survey received a total of 13 responses, seven from India and six from the USA, with most faculty from the Manufacturing and Mechanical Engineering department of their respective university, ranging from Associate Professor to Full Professor and Research Professors. The survey results were analyzed for industry and faculty separately. Competencies were distributed in four priority placements according to the mean of the ranked responses (Fig. 2). The priority placement indicated the emphasis that the curriculum should place on that competency, from Priority 1 indicating the highest emphasis to Priority 4 indicating the lowest emphasis. Open-ended survey responses were reviewed to identify additional competencies; these items were retained as unranked inputs for subsequent panel deliberation. This pre-ranking technique is commonly used to prioritize discussion and reduce redundancy during panels.

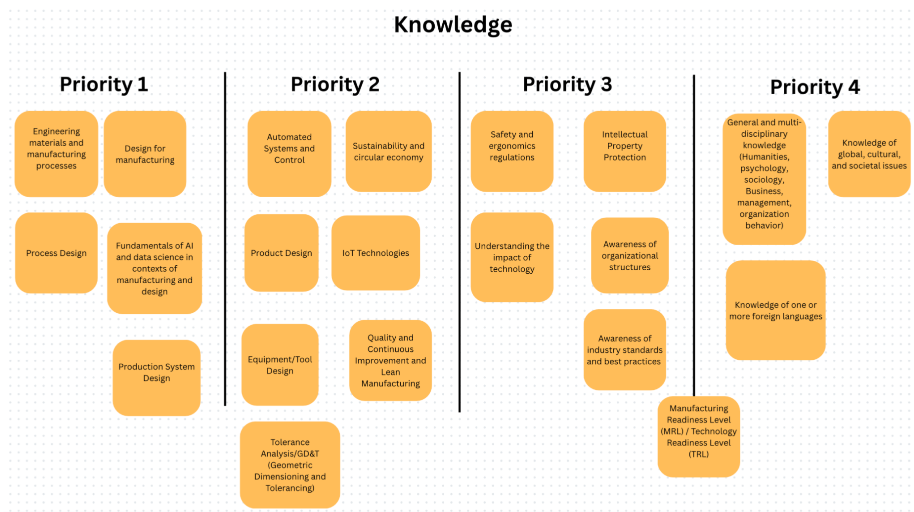

Figure 2: Example of visual board (Competencies in the "Knowledge" category)

Phase 3: Stakeholder-Specific Consensus-Building Panels

Four industry-only (1 with USA representatives, 3 with representatives from India) and three faculty-only (1 with MIT faculty and 2 with faculty from Indian institutions) panels were conducted to support consensus-building within each stakeholder group, with panel sizes ranging from 4 to 12 participants, consistent with consensus methodologies that prioritize depth of expertise and meaningful discussion over large sample sizes [6]. Panels were intentionally structured as stakeholder- and country-specific to facilitate consensus within homogeneous groups, reducing the potential for power imbalances and conformity pressures while also allowing culturally and nationally influenced interpretations and prioritization of competencies to surface. The decision to conduct separate panels is aligned with prior Delphi applications in engineering contexts, including Craps et al. [8], where sector-specific panels were employed. While some Delphi studies recommend panels of approximately 10-15 experts for heterogeneous groups, methodological guidance emphasizes that appropriate size depends on the degree of panel homogeneity and the level of expertise represented [14]. Because panels in this study were intentionally structured as homogeneous expert groups, smaller panel sizes were considered appropriate. Panels were conducted both in person and online, depending on participant availability. A total of 31 panelists participated in the study; the size of our study is consistent with previous studies employing a Modified Delphi method in education [10, 18, 21].

Panelists were shown visual summaries of the preliminary priority placement of competencies within each category (Fig. 2). The priority levels were initially labeled as "Essential", "Important", "Less Important", "Not a Priority". However, during the first faculty panel, panelists' feedback indicated that these priority labels were interpreted inconsistently. In response, the labels were revised to a numerical priority scale (Priority 1- 4) for the first and subsequent panels. Additionally, in order to identify and focus the discussions where disagreement or uncertainty existed, panelists were given a few minutes to review the visual material and indicate competencies for which the priority placement needed further discussion. During the panel discussion, participants could collectively agree to retain, modify, or reassign priorities; revise competency definitions; add or remove competencies; or identify areas where consensus could not be reached. Consensus was defined as agreement among 75% of panel members. Thresholds in Delphi studies commonly range from 70% to 80%, with no universally prescribed standard [14]. A 75% criterion was selected to reflect substantial agreement while remaining feasible for smaller expert panels. In panels with four participants, this threshold required agreement from at least three members. Moderators served as non-voting facilitators, ensuring that discussion remained focused and all participants had opportunities to contribute. One of the biggest challenges encountered, particularly among faculty, was a noticeable resistance to shifting from a course-based thinking to a competency-based perspective. Moderators frequently reminded panelists that the activity focused on competencies rather than specific courses, emphasizing that a single competency might be developed across multiple courses. This perspective was more easily grasped when discussing professional skills, which often cut across disciplinary boundaries. To support clarity, the moderators developed an introductory presentation outlining the goals, structure, and norms of the panel activity. This presentation was continuously refined as feedback and questions emerged during subsequent panels, proving essential for establishing shared understanding on the intended panel outcomes.

Panel discussions were recorded and notes were created to capture both consensus decisions and key discussion points. To enhance analytic rigor, two researchers collaboratively conducted a two-stage qualitative analysis of the panel data to ensure analytical rigor and reliability. In the first round of coding, each researcher independently reviewed the panels' audio to identify emergent themes and to document discussion points using their preferred reporting formats. The researchers then met to compare interpretations, reconcile discrepancies, and co-develop a shared coding framework comprising a standardized set of reporting activities. This process supported consistent interpretation of panel data and informed the design of the mixed industry-faculty panel. Heat maps displaying the assigned priority level for each competency within each panel were generated, with blank cells indicating instances where consensus was not reached.

Phase 4: Mixed Industry-Faculty Panel

Analysis of the stakeholder-specific panels revealed areas of alignment and differences between industry and faculty perspectives. To address these differences, a mixed industry-faculty panel was convened as a reconciliation step. Participants in this panel were selected from those who had already participated in prior panels. A total of seven industry and faculty representatives participated in this panel. Although a similar approach of multi-sectoral panels was taken by

Craps et al. [8], the mixed panel organized in this study focused explicitly on competencies for which disagreement remained, newly introduced competencies, and areas where qualitative data suggested the need for deeper discussion. Visual materials were used to highlight differences in priority placement between industry and faculty panels, including heat maps and summary of qualitative findings. This information provided a basis for discussion and supported focused deliberation. Unlike the earlier panels, the primary goal of the mixed panel was not only to reach consensus but also to surface and negotiate underlying rationales behind differing perspectives.

Methods

Positionality Statement

The first author is a Research Scientist with a background in engineering education research. The second author is a Postdoctoral Fellow with expertise in manufacturing engineering. The third author is an undergraduate student who participated in this project through an undergraduate research program. The fourth author is a Research Professor with expertise in manufacturing engineering education and a co-PI on this project. All authors are affiliated with MIT. The first and fourth authors served as moderators during the panels. The first and third authors conducted the primary analysis of panel data. The second and fourth authors, acting as SMEs, contributed to the development of the initial competency list and provided guidance during the panel data analysis. This study was conducted by researchers with professional commitments to engineering education and industry-academia collaboration. While this positionality informed the study design, the authors took deliberate steps to mitigate bias through structured facilitation, and collaborative data analysis across researchers with different roles and expertise.

Data Collection and Analysis

At the conclusion of each stakeholder-specific panel, participants were asked to complete a brief evaluation survey administered on Qualtrics. The survey consisted of two matrix-style 5-point Likert questions (1= Strongly disagree to 5=Strongly agree) and one open-ended question designed to capture participants' perceptions of the activity's organization and value. The survey was designed to require no more than five minutes to complete, in order to maximize the time for panel discussion and reduce fatigue. A total of 19 faculty responses and 26 industry responses were collected across panels and combined mean and median were calculated. Following the mixed industry-faculty panel, a separate short Qualtrics survey was administered to capture participants' perceptions of the value of engaging in cross-sector dialogue to explore differing perspectives. This survey consisted of one matrix-style 5-point Likert (from 1= Strongly disagree to 5=Strongly agree) questions and one open-ended question designed to capture participants' perceptions of the value of the mixed panel. This survey also required less than five minutes to complete and yielded seven responses (all the panelists in the mixed panel completed the survey). The mean and median of responses were calculated. In addition to survey data, moderators collected informal feedback immediately after each panel through structured debriefing memos, and researchers recorded analytic notes during the review of the recordings. These reflections documented facilitation challenges, participant sense-making, and iterative adaptations to the study design. These notes served as complementary sources of data. All participants signed a consent form. An institutional IRB was approved for this study.

Results

RQ1: How does the adapted Modified Delphi design facilitate collective sense-making around graduate-level competencies across industry and academic participants?

Panelists demonstrated strong engagement in the process, contributing thoughtful insights. Panelists recognized the diversity of manufacturing sectors and the resulting variability in required competencies. In response, they were asked to reflect on the essential competencies that all graduates should possess upon completing a Master of Engineering program in Manufacturing, Design, and AI. Indeed, as the discussion unfolded and participants began sharing examples, and comparing practices, we observed a noticeable shift from a sector-specific focus toward a broader, cross-sectoral understanding of graduate competencies. This evolution was exemplified when one panelist reflected on the value of the discussion, remarking, "We all have a blind spot, and we are helping each other." Throughout the process, participants displayed collaboration, openness, and mutual learning, as illustrated when one panelist recognized the value of another panelists' response by saying, "We are learning from you," signaling a collective shift toward a more holistic perspective on graduate preparedness. The forced ranking served as a critical component, prompting structured prioritization and collaborative decision-making by requiring participants to make deliberate choices among competing priorities and clarifying trade-offs. This process prevents overgeneralization where every competency is important. While all panels debated the relative positioning of individual competencies, some panelists also proposed to vote collectively on the entire board to capture the full picture.

Panel evaluation survey results indicate positive perceptions of the organization and value of the panel activity. Participants reported that the goals of the panel were clearly stated (M = 4.40, Md = 5) and that the activity was well explained (M = 4.56, Md = 5). They strongly agreed that the discussion was engaging (M = 4.52, Md = 5), that they enjoyed participating (M = 4.57, Md = 5), and that they felt comfortable asking questions (M = 4.61, Md = 5). Panelists did not perceive the sessions as rushed (M = 2.09, Md = 2), suggesting that the format allowed adequate time for discussion, and they generally felt that contributions were balanced across participants (M = 4.45, Md = 4). Survey responses also reflect the strong perceived value of the activity for shared understanding and collaboration between industry and academia. Participants expressed high interest in hearing perspectives from others (M = 4.64, Md = 5) and in the final outcomes of the study (M = 4.61, Md = 5). Panelists reported that their perspectives were valued (M = 4.56, Md = 5) and that they were given meaningful opportunities to contribute industry viewpoints to curriculum development (M = 4.45, Md = 5). The overall time commitment was perceived as appropriate (M = 4.30, Md = 4), and participants agreed that the study would strengthen industry-academia collaboration (M = 4.34, Md = 4). Open-ended responses reinforced these findings, with one participant describing the panels as "a nice interaction, having diverse opinions and still coming to consensus with logic and understanding." One participant suggested that sharing competency definitions in advance could further improve future implementations.

RQ2: What methodological affordances, if any, emerge from implementing a mixed industry-academia panel in an engineering curriculum development context?

Participants strongly agreed that the mixed panel was essential for reaching shared understanding between academia and industry regarding both the competencies and their priority levels (M = 4.43, Md = 4). They also reported that the panel provided meaningful opportunities to better understand the challenges faced by the other group, whether related to industry hiring expectations or students' academic preparation (M = 4.14, Md = 5) and the differing industry and academic perspectives on curriculum development (M = 4.71, Md = 5). Participants perceived that the outcomes of this panel may have a positive impact on the curriculum development process (M = 4.86, Md = 5). These results suggest that sequencing stakeholder-specific consensus-building prior to cross-stakeholder dialogue may have enhanced the depth and quality of the mixed-panel discussion. For example, during the mixed panel, industry and faculty engaged in a meaningful exchange related to the knowledge that graduates of this program should have related to AI. This sequence appears to have enabled participants to enter the mixed panel with openness to negotiation and refinement.

Discussion

This study examined adaptations of a Modified Delphi method to support participatory curriculum development for a Master of Engineering program in Manufacturing, Design, and AI. The paper focuses on the methodological design, implementation, and implications of the consensus-building process used to identify graduate competencies and their prioritization. This study shows that the primary contribution of industry and faculty participation in the adapted Modified Delphi process occurred through collective sense-making and alignment. Participants initially framed competencies through sector- or role-specific lenses shaped by their professional contexts, reflecting the diversity and fragmentation characteristic of manufacturing practice. The forced-ranking mechanism required participants to articulate trade-offs among competing priorities, discouraging the tendency to treat all competencies as equally important. This design choice aligns with established Delphi principles emphasizing independent judgment followed by controlled feedback to promote convergence without suppressing dissent [7, 11, 13]. As discussion progressed, participants increasingly engaged in comparative reasoning across sectors, resulting in a shift toward more generalizable, cross-sectoral framings of graduate competencies. These findings reinforce the view that Delphi-based approaches in engineering education function as effective qualitative research methodology for collaborative knowledge-construction, rather than instruments for extracting static expert opinions [12, 33]. Early panel discussions also surfaced challenges associated with transitioning from course-based thinking to a competency-based framing, particularly among faculty participants, a well-documented difficulty in the literature on competency-based curriculum reform [15, 34]. An additional methodological contribution lies in the study's ability to surface national and cultural contextual influences. In the Indian panels, discussions of professional competencies, particularly communication, were framed in relation to cross-cultural engagement with Western partners and differing communication norms. Panelists also referenced national policy directions, including India's 2070 net-zero commitment, as shaping industry trajectories and competency expectations. These culturally and policy-informed distinctions emerged because panels were structured within national contexts prior to integration. This design choice demonstrates how Modified Delphi approaches can support curriculum frameworks that are responsive to national, cultural, and economic ecosystems.

The mixed industry-faculty panel, composed of participants who had already engaged in stakeholder-specific and country-specific deliberations, emerged as a pivotal integration stage. By the time this panel convened, competencies had been grounded in literature, ranked via survey, and refined within homogeneous groups. Consequently, the mixed session functioned less as an exploratory phase and more as a negotiation and alignment mechanism. While prior Delphi studies rarely isolate the structural role of mixed panels, this sequencing aligns with

Delphi theory emphasizing structured discussion to surface assumptions and negotiate meaning following independent deliberation [7]. This sequencing represents a meaningful extension of prior practice, suggesting that mixed panels may serve as an effective final integration phase. Evaluation data further indicate that the mixed panel strengthened mutual understanding between industry and academia. Participants reported clearer awareness of differing constraints, priorities, and implementation realities across sectors. This bidirectional dialogue aligns with models of manufacturing engineering curriculum co-design that emphasize iterative interaction between industry and academia as a mechanism for bridging professional practice and academic implementation [29], developing trust [27], and enhancing shared curriculum ownership, graduate employability, and professional skills development in specialized engineering domains [30, 31]. By embedding industry participation within a Modified Delphi framework, this approach supported shared ownership of outcomes, reduced perceptions of disconnect, and enabled a more holistic articulation of graduate competencies appropriate for a general manufacturing engineering program. This contribution is particularly relevant for engineering education programs seeking to move beyond advisory input toward a co-design approach. Finally, the Modified Delphi approach enabled to produce a finalized list of competencies and their priority levels related to curricular emphasis. This finding is particularly valuable for curriculum design, as it supports decisions related to depth of coverage, sequencing, etc. Prior engineering education Delphi studies have similarly highlighted the importance of moving toward prioritization of competencies to inform actionable curricular change [8, 9, 10, 15, 21].

Conclusions, Limitations and Recommendations for Future Implementations

The methodological approach adopted in this study supported collective sense-making, prioritization of competencies, and agreement around graduate expectations while preserving independent judgment and minimizing power imbalances. Findings suggest that the mixed panel provided a meaningful space for real-time dialogue and mutual learning, reinforcing trust and shared ownership of outcomes. Although the findings are context-specific, the study contributes a transferable methodological framework for engineering educators seeking to engage industry in curriculum co-design. Future implementations across institutional and disciplinary settings may further refine and strengthen the approach. The process was time- and labor- intensive, requiring coordination of surveys, multiple panels, and synthesis of qualitative and quantitative data. While this investment contributed to rich data, it may limit feasibility in settings with fewer resources or tighter timelines. Recommendations can be offered to improve feasibility and efficiency of implementation. Narrowing panel discussions to competencies exhibiting high variance or disagreement guaranteed a more efficient use of panel time, allowing areas of strong consensus to be accepted without extensive deliberation. Providing panel material to panelists in advance may further efficiency of discussion time. Emerging tools such as large language models (LLMs) could be used to support analysis of panel recordings, reducing researcher workload. Scheduling constraints emerged as a significant challenge; offering in-person and online options was essential to securing expert involvement. The full list of competencies and phase-by-phase results will be reported in a separate manuscript.

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