Engineering for Tomorrow : A Systematized Literature Review of Essential Future Engineering Competencies

Mr. Abdul Wasay Khan Laghari, Utah State University

Abdul Wasay Khan Laghari is a graduate researcher in the Department of Engineering Education at Utah State University. Abdul's research endeavors are primarily dedicated to the critical analysis of engineering competencies, the formulation of engineering education policy, and the advancement of accreditation standards.

Dr. Yashin Brijmohan, Utah State University

Yashin Brijmohan is a faculty member at Utah State University in the Department of Engineering Education. He is executive Committee member of the Commonwealth Engineers Council, Board Member of the UNESCO International Center for Engineering Education, and Chair of the Africa Asia Pacific Engineering Council.

He was the founding Executive Dean of Business, Engineering and Technology at Monash South Africa, former Vice President of the World Federation of Engineering Organizations, and led several committees in the engineering profession.

Yashin has both leadership and specialist experience within the engineering power industry and education sectors and is known for his thought leadership in capacity building and engineering education.

Mr. Foeday Zinnah, Utah State University

Foeday Zinnah is a graduate researcher and a second-year Ph.D. student in the Department of Engineering Education at Utah State University. He holds a master's degree in soil and water sciences from the Hebrew University of Jerusalem and a bachelor's degree in civil engineering from the University of Liberia. His research interests focus on engineering workforce development, particularly the role of non-degree credentials and work-based learning in shaping STEM career pathways. He is also interested in e-learning management and the use of diverse learning methods to enhance learning outcomes for both traditional and non-traditional learners. Additionally, Foeday brings professional experience in youth and community development, nonprofit leadership, and online learning management in higher education.

Engineering for Tomorrow: A Systematized Literature Review of Essential Future Engineering Competencies

Abstract

As engineering education evolves to meet the demands of emerging technologies and global workforce shifts, there is a critical need to understand the competencies required for future engineers. Identifying those future competencies has become a strategic priority for engineering educators, researchers, policymakers, and industry leaders. This study presents a systematized literature review that synthesizes 33 peer-reviewed studies on engineering competencies published between 2000 and 2025, focusing on future-oriented skills and attributes from industrial and educational perspectives. Drawing on the methodological framework of Borrego and colleagues, the systematized review investigates research methods, geographical area, publication types, and competency dimensions as classified through the universal competency taxonomy.

Research findings reveal a significant misalignment between university curricula, which emphasize STEM fundamentals, and industry requirements, which prioritize technical practice, interpersonal competencies, and meta-competencies such as adaptability, analytical thinking, and systems thinking. A systematized review of the literature indicates that while the publications has increased significantly since 2020, most existing studies have utilized qualitative or literature review methodologies, suggesting a critical need to employ quantitative and mixed methods approaches. Furthermore, an analysis of 541 competencies extracted from 33 reviewed articles demonstrates that practice-technical, people, and meta-competencies are the most highly emphasized in the literature, whereas STEM fundamentals and learning competencies are comparatively underrepresented.

Our study will contribute to engineering education by offering a synthesized framework of future competencies that can inform curriculum design, accreditation standards, and professional development initiatives (i.e., non-degree credentialing). Our paper also advocates for a more dynamic and responsive educational model that equips engineers with technical expertise and the flexible, human-centered skills necessary to thrive in uncertain and rapidly evolving environments.

This paper serves as a foundational reference for stakeholders seeking to align engineering education with the demands of the 21st-century workforce. By bridging insights from both academia and industry, it provides actionable guidance for shaping the next generation of engineers who are not only technically competent but also socially responsive and innovation driven.

Keywords: *Systematized literature review; future engineering competencies; emerging technology skills; engineering education research; industry 4.0; industry 5.0*

Introduction and Background

The industrial landscape of the modern world is being reshaped by the rapid advancements of the fourth industrial revolution and the emerging paradigm of the fifth industrial revolution [1], [2], [3], [4]. Technologies such as artificial intelligence (AI), internet of things (IoT), and large-scale automation have transformed production systems and significantly altered the competencies required of engineers [5], [6]. As a result, engineers today must not only be proficient in modern technological tools but also capable of analyzing and solving complex engineering problems using advanced, data-driven approaches [1]. Building on these technological shifts, the European Commission introduced Industry 5.0, which extends beyond automation by emphasizing human-centric, ethical, and sustainable approaches to engineering practice [7], [8], [9], [10], [11]. This shift underscores that engineering competencies can no longer be limited to technical proficiency; engineers must also demonstrate interdisciplinary collaboration, ethical judgment, and awareness of environmental and societal impacts. Together, the transformations associated with Industry 4.0 and 5.0 demand a rethinking of the knowledge, skills, and attitudes required of future engineers, prompting renewed attention to the competencies that will be essential in the years ahead [12], [13], [14].

Building on this need to redefine engineering preparation, past research has attempted to classify future engineering competencies into personal, technical, cognitive, and social categories [1], [5], [10], [14] underscoring the importance of lifelong learning, adaptability, creative problem-solving, and ethical responsibility [15], [16], [17], [18], [19], [20], [21], [22], [23]. These competencies reflect the escalating expectations for modern engineers in an era of rapid technological advancement, where technical progress intersects with environmental and social complexities. However, despite existing findings, the literature remains fragmented, also making it unclear which engineering competencies should be prioritized within engineering curricula.

Persistent gaps between engineering education and industry expectations further underscore the need to clarify which competencies future engineers require. Numerous studies report that engineering graduates often lack the modern competencies demanded by rapidly evolving technological environments, particularly skills related to emerging technologies such as AI, IoT, and robotics [24], [25], [26], [27], [28], [29], [30], [31], [32], [33], [34], [35], [36], [37], [38], [39], [40], [41], [42]. Academic programs, meanwhile, continue to emphasize traditional technical content, leaving limited space for interdisciplinary, adaptive, and future-oriented competencies. At the same time, some researchers highlight that industry professionals themselves are not adequately trained to mentor or upskill new engineers, creating a dual gap in both preparation and professional development [36]. Together, these findings point to a significant misalignment between the competencies taught in universities and those expected in contemporary engineering practice. Despite these challenges, there are various common competencies prioritized by both industry and academia such as problem solving, STEM fundamentals, and core information technology skills [43], [44]. However, the consensus between industry practitioners and academic researchers diverges significantly regarding competencies extending beyond the foundational core.

Addressing these practical challenges is essential because much of the existing research has focused on current engineering competencies, and the few studies that examine future competencies were conducted before the major technological and societal shifts of the past five years. Moreover, no recent systematized or systematic literature review has synthesized the evolving conversation on future engineering competencies, limiting the field's ability to identify emerging skills and research gaps. Given the rapid pace of technological advancement, understanding future engineering competencies has become increasingly critical. Policymakers, educators, and industry stakeholders require clear and up-to-date guidance to design curricula that align with the demands of the future engineering workforce. A systematized literature review provides the structured synthesis needed to consolidate existing research, identify emerging competency trends, and inform future educational and workforce development efforts.

To close these gaps, this study conducts a systematized literature review on future engineering competencies. Its aim is to identify, analyze, and synthesize research from the past 25 years on this topic. The study specifically explores how researchers have investigated and expressed future competencies, and how past research has evolved and emerged globally. Therefore, this work seeks to answer the following research question:

1- How have future engineering competencies been studied and expressed by research scholars over the past 25 years?

    a. What methods have been used to study future engineering competencies?

    b. Where have future engineering competencies been researched (geographical area)?

    c. How has the research evolved over the years (by type of publication)?

    d. What future engineering competencies dimensions are expressed by scholars?

Theoretical and Conceptual Frameworks on Engineering Competencies

To guide RQ1d, this section investigates past engineering competency frameworks. There are frameworks that highlight the shift from industry 4.0 to human centric industry 5.0. The holistic engineering competency model is a framework that is proposed to address the changes from industry 4.0 to 5.0 [10]. This model groups the 30 classified competencies into four categories, namely, cognitive competencies, functional competencies, social competencies, and meta-competencies. Another competency model that is presented is Kauffeld's competency model that is related to logistics and manufacturing for industry 4.0 [1]. This model classifies the competencies into four categories, namely, professional competencies, social competencies, methodological competencies, and personal competencies. Another competency model that is presented in literature is the Shaping Skills Dynamic Taxonomy [45], [46]. This framework combines the skills and occupations; however, it introduces a dynamic element by introducing machine learning and regularly updating the competencies as per the need of varying times. The framework categorizes the competencies into three clusters, namely, object-related skills, individual skills, and organization-related skills.

There are some frameworks that are based on the 21st century and broad learning frameworks. They are foundational and fundamental layer of engineering education; however, they are broad in scope. One such frameworks is P21 framework [47]. This framework focuses on 4C's, specifically creativity, collaboration, critical thinking, and communication. These skills are covered with essential competencies and evolving themes such as global awareness. Additional framework that is presented in the same research study is national research council framework. This framework classifies the competencies based on the bloom's taxonomy. The clusters of competencies include intrapersonal, interpersonal, and cognitive competencies. Additional framework that is presented in the past literature includes the OECD Learning Compass 2030 [48]. This framework focuses on transformative competencies such as taking responsibility, resolving dilemmas, and creating value. The framework focuses on utilizing the problem-solving and critical thinking skills that are essential for enhancing the social skills.

Moreover, there are frameworks that are focused on specific engineering disciplines and the engineering accreditation bodies. RICS competency framework divides the competencies into three categories, explicitly, technical core, technical optional, and mandatory [49]. Additional model presented in the literature is the structural engineering cluster model [50]. This model classifies the competencies into seven categories; explicitly; management, engineering practice, communication, core technical, sustainability, technology and digitalization, and societal and ethical responsibilities.

Despite the existing engineering competency frameworks, there are gaps in the present literature that justify the need for a new framework to analyze the engineering competencies. Various frameworks fail to keep up to pace with the changes in rapid engineering and IT technologies [3]. There is a need for a framework that can analyze and forecast the changes in the engineering domain and respond to emerging needs as compared to just developing a framework that could satisfy the challenges of current engineers. Emergence of industry 5.0 demands human-centric solutions; however, the current frameworks focus heavily on the industry 4.0 skills such as automation, robotics, and machine learning and fail to recognize skills such as sustainability and ethics as essential competencies [9], [10], [50]. Engineers need a framework that can fuse hard and soft skills and provide hybrid intelligence to our current engineers. Frameworks such as P21 and national research council framework are broad for the application of the engineering disciplines and frameworks such as DOL advanced manufacturing model do not emphasize the cognitive element of the competency framework and therefore, they may not be a good fit for an innovative engineer [5], [51]. In light of the fragmented nature of existing engineering competency frameworks, this study utilizes the Universal Competency Taxonomy (UCT), which offers a more comprehensive and future-aligned structure for evaluating the competencies required of modern engineers [52]. The UCT model has the following dimensions, namely, STEM fundamentals, practice, value, people, meta-competencies, learning, and community of practice.

Unlike other frameworks, the UCT was chosen for three main reasons. First, it incorporates elements of previously proposed competency frameworks. Second, it was developed for the engineering environment through a rigorous process that incorporated various worldviews from organizations that represent engineers worldwide (e.g., the World Federation of Engineering Organizations) [53], [54], [55]. Third, its alignment has been successfully tested in recent years against acknowledged competency frameworks from four countries, including ABET and the recently updated Washington Accord requirements [52].

Methods

This study follows the established process for conducting a systematized literature review in engineering education. A systematized literature review was conducted given its methodological fit with the aims of this study, which aim to yield valuable knowledge contributions in the field of future engineering competencies, within the constraints of available human and time resources [56]. The review procedures were informed by prior methodological guidance on systematic and systematized reviews [57]. The steps adopted for this review include deciding to conduct the review, developing review-specific research questions, defining inclusion and exclusion criteria, identifying and cataloging sources, screening studies, critiquing and appraising study quality, synthesizing findings, and identifying limitations.

The literature identification and screening process was guided by the PRISMA 2020 chart [58] to enhance transparency and methodological rigor.

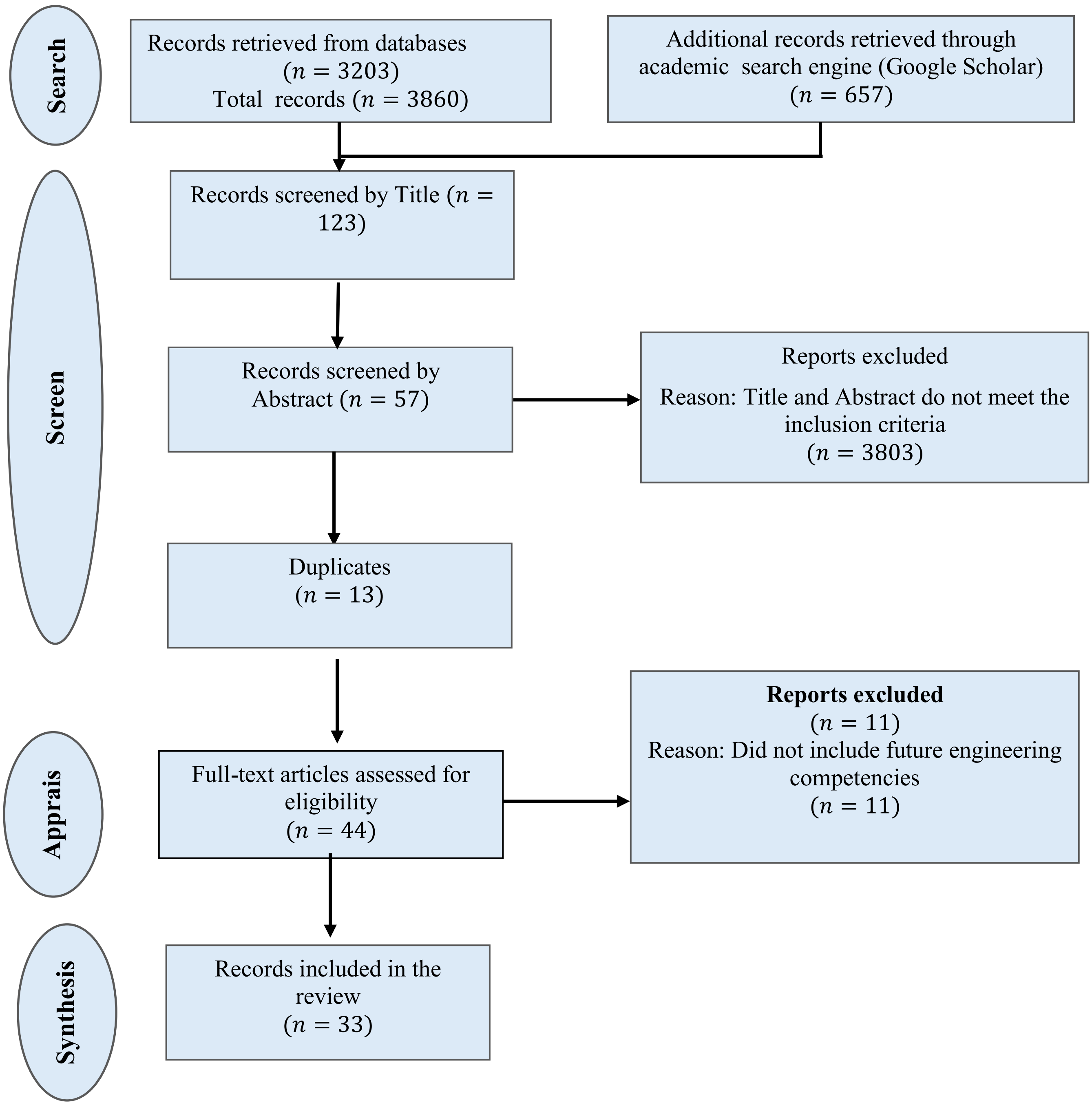

Figure 1. PRISMA 2020 flow diagram for the systematized literature review of future engineering competencies

As shown in Table 1, multiple databases were selected to capture engineering education and disciplinary research related to future-oriented engineering competencies. These databases included a university library discovery system, Scopus, IEEE Xplore, ASEE PEER, and Google Scholar. The selection of databases aligns with recommended practices for systematic reviews in interdisciplinary fields, incorporating subject-specific, general, professional society, and gray-literature sources [59].

The search strategy was developed collaboratively by the research team in consultation with an academic librarian at a public university in the western United States. Search terms were iteratively refined and included combinations of *future competencies*, *future engineering competencies*, *future skills*, *emerging skills*, *emerging technology skills*, *engineering*, and *engineers*. Inclusion criteria required that studies be published in English between 2000 and 2025 and explicitly address engineering competencies within engineering disciplines or engineering education contexts. Studies that did not focus on engineering competencies or were situated outside engineering contexts were excluded.

The database and search engine queries yielded a total of 3,860 records before duplicate removal, including 657 records retrieved through Google Scholar. All records were exported in BibTeX format into reference management software. The titles and abstracts screening were assessed by the lead author. 123 articles were included after title assessment after which the abstracts were screened. 57 articles were selected after the abstract review. Articles that clearly did not meet the inclusion criteria were excluded. The duplicates were removed and 44 articles were assessed for eligibility. 33 articles were included in the review.

Table 1: Database Searches

Database/Search Engine	**Syntax**	**Results**
USU Library	(“Future Competencies” and “Future Engineering Competencies” and “Future skills” AND “Engineering” and “Emerging capabilities” AND “Engineers” and “Emerging Technology Competencies” and “Emerging Technology Skills” and “Emerging skills” and “Future Skills” and “Future development” AND “Engineers” and “Future Engineering Expertise”)	560
Scopus	(“Future Competencies” and “Future Engineering Competencies” and “Future skills” AND “Engineering” and “Emerging capabilities” AND “Engineers” and “Emerging Technology Competencies” and “Emerging Technology Skills” and “Emerging skills” and “Future Engineering Expertise”)	418
IEEE Xplore	(“Future Competencies” and “Future Engineering Competencies” and “Future skills” AND “Engineering” and “Emerging capabilities” AND “Engineers” and “Future Engineering skills” and “Emerging Technology Competencies” and “Emerging Technology Skills” and “Emerging skills” and “Future Skills” and “Future	2045

	development" AND "Engineers" and "Future" AND "Engineering" AND "Competencies" and "Emerging" AND "Technology" AND "Competencies" and "Emerging" AND "Technology" AND "Skills")	
ASEE PEER	("Future Competencies" and "Future Engineering Competencies" and "Future skills" AND "Engineering" and "Emerging capabilities" AND "Engineers" and "Future Engineering skills" and "Future Engineering abilities" and "Future Engineering innovation" and "Emerging Technology Competencies" and "Emerging Technology Skills" and "Emerging skills" and "Future Skills")	180
Google Scholar	("Future Competencies" and "Future Engineering Competencies" and "Future Engineering skills" and "Emerging Technology Competencies" and "Emerging Technology Skills" and "Emerging skills" and "Emerging STEM Skills" and "Future STEM Skills")	657

The lead author conducted an initial full-text review of the 33 retained articles and extracted preliminary descriptive information, including year of publication, publication venue (journal or conference proceedings), research methodology, and reported competencies. Formal inter-rater reliability has not yet been conducted and will be addressed in subsequent phases of the study. In the completed review, all authors will independently screen full texts, assess study quality, and conduct a reliability analysis prior to synthesis. Discrepancies will be resolved through discussion until consensus is achieved. Data extraction and synthesis will be used to address the review research questions in the final systematic literature review.

Results

The publications are categorized according to the year of publication to demonstrate the development in the scholarly work related to future engineering competencies. As shown in Figure 2, publications on future engineering competencies increased after 2020 [60], [61]. Although the data from this review cannot establish a direct causal relationship, this rise coincides with the disruptive effects of the COVID-19 pandemic, during which industries and educational institutions accelerated their adoption of emerging technologies and re-evaluated required engineering competencies (e.g., digital literacy, adaptability, and interdisciplinary work) [44]. Figure 2 shows a steady growth in the publications from 2020 onwards, with 2024 and 2025 being the years with the highest publications. There were 10 articles published in the archival journals from 2020 to 2025 focusing on competencies such as industry 4.0 and industry 5.0 integration [2], [7], [21], [46], [49], [62], [63], [64], [65], [66]. Moreover, there were 20 conference proceedings between 2020 and 2025 showing the evolving nature of the field [1], [3], [4], [5], [9], [10], [14], [45], [47], [50], [67], [68], [69], [70], [71], [72], [73], [74], [75], [76]. There was one report published in 2022 that focused on future engineering competencies showing an implication of future competencies in the engineering workforce development [77].The upwards trend in the journal and conference publications in the area of future engineering competencies shows that the field has become a central concern for both the academia and the industry. This trend resonates with the emergence of industry 5.0 which prioritizes human-centric approach and integrating sustainable approaches into the engineering curricula so that the engineers are equipped with technical, environmental, social, and meta-competencies. The amount of conference and journal publications in the past few years shows that there is a growing consensus among the academic and industrial community that engineers must be equipped with competencies such as critical thinking, adaptability, digital literacy, and ethical decision-making to handle the challenges of the 21st century.

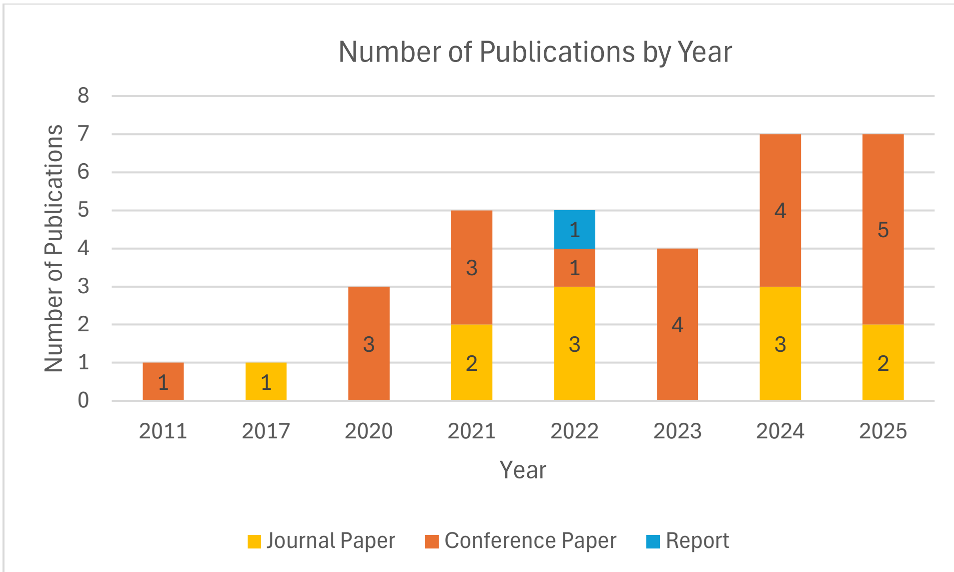

Figure 2: Number of Publications by Year

As shown in Figure 3, most of the reviewed articles have employed either qualitative or literature review methods, which collectively account for the bulk of the 33 publications. Out of 33 reviewed articles and report, 13 have employed qualitative methods using qualitative approaches such as focus groups, open ended interviews, semi-structured interviews, and thematic analysis to explore the future engineering competencies in-depth [1], [3], [46], [47], [50], [60], [61], [63], [65], [70], [73], [76], [77]. These in-depth qualitative approaches provide an insight to the understanding of the competency needs from various stakeholders such as academic faculty, industry professionals, and students. 12 review articles have used literature review methodologies to synthesize the existing sustainability frameworks and proposing future directions in this field by revealing the gaps in this research domain [4], [5], [9], [14], [21], [45], [62], [64], [67], [68], [69], [71]. The dependence on qualitative approach and literature review methodology demonstrates an exploration and evolving nature of the research in this area. Additionally, only four studies employed quantitative methods such as surveys and statistical analyses to examine the effectiveness of engineering curricula [7], [49], [74], [75], three papers utilized mixed-methods approach by integrating the qualitative in-depth exploration with the quantitative rigor to provide a more comprehensive analysis of the data [2], [10], [72], while one research article used descriptive survey method [66]. The reviewed articles demonstrated limited use of quantitative and mixed methods approaches suggesting that the empirical validation of the future engineering competencies remains underdeveloped. Figure 3 demonstrates an imbalance where past research has focused on qualitative inquiry with lack of quantitative data driven methods in discussion on future engineering competencies.

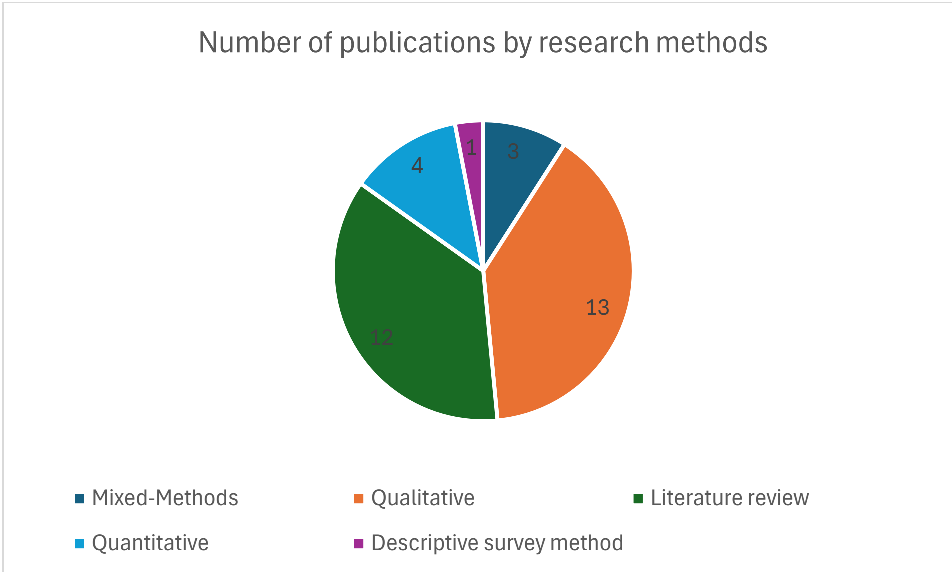

Figure 3: Research Methods

Table 2 classifies the competencies found from the data into seven dimensions of the UCT namely, STEM fundamentals, practice, value, people, meta-competencies, learning, and community of practice. The practice competencies are sub-divided into technical and engineering management. The classification helps in providing a structured approach to analyze the holistic competencies required by engineers, ensuring the engineers possess both technical and adaptive competencies. Table 2 shows the competency dimensions and their frequencies indicating the prioritization of the competencies within the reviewed literature. A total of 541 competencies were identified across the 33 reviewed articles. Two of the articles reported more than 20 competencies each [60], [70], while the remaining articles had between 4 and 19 competencies. The data reveals that practice-technical (160), people (152), and meta-competencies (121) are the most dominant dimensions. This high prioritization of these competencies indicates high emphasis placed on the competencies such as technical IT and engineering skills, communication and interpersonal skills, and meta-cognitive abilities that are highly significant in the current industry 4.0 and evolving industry 5.0 era. The high emphasis on technical competencies demonstrates that these competencies are non-negotiable; however, the high emphasis on people's skills shows a paradigm shift towards human-centric approaches. However, what is surprising is the low focus on the STEM-fundamentals competencies. The STEM fundamentals appear twice in the data, indicating low priority on fundamental mathematical and scientific knowledge. The industries and the educational sectors have not focused on the fundamentals of sciences as a require competency for future engineers. The practice-engineering management (58) and value competencies (39) are evolving as indicated by their emerging importance. Competencies such as supply chain management, finance, human resource management, sustainability, and ethical responsibility are emerging skills needed by engineers in the human-centric industry 5.0 era. The low representation of the learning and community of practice competencies shows that they have not yet received proper attention in the engineering competency frameworks.

Table 2: Competency Dimensions and their Frequencies

Competency Dimensions	Frequency
Learning	9
Meta-competency	121
People	152
Practice -Technical	160
Practice-Engineering management	58
STEM Fundamentals	2
Value	39
Grand Total	**541**

Table 3 shows the geographical distribution of the reviewed literature, revealing significant insights into the global nature of the future engineering competencies. There were 4 studies conducted in Asia, Europe, and North America. There was one study that was conducted in both Asia and North America (China and USA) and the remaining one research study was conducted in Australia. The existence of articles from diverse regions and countries such as Sweden, Australia, Ireland, Norway, Mexico, Indonesia, China, Philippines, Malaysia, and India validate that the interest in future engineering competencies is increasing across diverse landscapes; however, in an uneven manner. One research study was a joint effort among various European countries that aimed to align the industry 5.0 principles with engineering education. 19 of the reviewed articles did not specify a country where the data was collected that confines the scope of the study to understanding the policy, economic, and cultural factors influencing the competency development. For example, the competencies prioritized in technologically advanced countries may vary from developing regions where the financial and educational constraints may shape their priorities differently. Table 3 suggests that although the research on future engineering competencies is global; however, empirical research is limited to few developing regions and is highly based on the literature reviews.

Table 3: Publications by Continents

Continents	Frequency
Asia	4
Australia	1
Europe	4
North America	4
Asia and North America	1
Not mentioned	19

Discussion

The findings of the systematized literature review mark a significant shift from the automation-based industry 4.0 to the human-centric and sustainability driven industry 5.0. One of the key findings of this paper is the imbalance/divergence between education and industry. The universities emphasize basic science and mathematical skills with a large focus on basic engineering courses such as statics and fundamentals of electronics; however, the industry focuses on interdisciplinary skills such as teamwork, communication, leadership, ethical decision-making, and negotiation [14], [62], [63]. The data in Table 2 shows that the practice-technical (160) and people skills (152) are the most focused competencies in the recent literature, whereas the STEM fundamentals (2) had a much lesser emphasis in the recent literature. The results from the systematized literature review demonstrate that practice-technical remains a non-negotiable competency for future engineers; however, the future graduate engineers are expected to demonstrate proficiency in their ability to solve complex engineering problems in different social and ethical landscapes.

Furthermore, the review indicates that scholarly attention to future engineering competencies increased notably after 2020, with the highest number of publications appearing in 2024 and 2025, as shown in Figure 2. This upward trend underscores the growing importance of integrating Industry 4.0 technologies such as artificial intelligence, robotics, and machine learning into contemporary engineering curricula.

The emergence of industry 5.0 has increased the significance of the meta-competencies. Meta-competencies were cited 121 times in the systemized literature review. These were competencies such as adaptability, agility, analytical thinking, creativity, critical thinking, decision-making, design thinking, flexibility, problem solving, systems thinking, and transdisciplinary thinking. Industry 5.0 demands not only technical and technological skills, but it focuses on the moral implications and environmental impact of the engineering projects. However, the current frameworks fail to merge the meta-competencies as essential technical skills; however, they are just focused and taught as soft skills.

There are challenges in the implementation of these competencies. The industry frequently mentions the engineering curricula as outdated; however, the industry professionals and engineers are not well equipped to mentor the engineering graduates once they enter the workforce. Therefore, this creates a situation where neither the academia nor the industrial professionals are well prepared to fulfill the demands of the rapid technological process.

The UCT [52] aims to bridge the gap between the engineering technical and professional skills moving towards a cross intelligence model, that moves past the frameworks such as P21 to provide the future graduate engineers with innovative skills to compete and excel in their work. The UCT combines technical and professionals' skills under seven dimensions, namely, STEM fundamentals, practice, people, meta-competencies, learning, value, and community of practice. This aligns with the post Covid-19 environment where resilience and adaptability are essential competencies to survive the significant 21st century engineering challenges.

This synthesis reveals new insights that extend beyond existing engineering competency frameworks. The increase in publications after 2020 and the strong reliance on qualitative methodologies indicate a shift toward more exploratory research. This could suggest that past models may not have adequately captured emerging trends of newly envisaged future engineering competencies. Furthermore, the results show an imbalance in the prioritization of competency dimensions, with practice-technical, people, and meta-competencies receiving greater emphasis, while STEM fundamentals and learning competencies appear far less frequently. This pattern has not been reported in previous research.

Conclusion

This systematized literature review focuses on the essential change in the field of engineering education driven by industry 4.0 and the emerging paradigm of human-centric industry 5.0. The findings of the study reveal that the future competencies extend far beyond the technical-engineering competencies to holistically include the competencies such as environmental and social dimensions of sustainability, ethical decision-making, and meta-cognition. While technical skills remain non-negotiable, the inclusion of competencies such as critical thinking, analytical thinking, adaptability, and creativity signal a shift towards a human-centric and sustainable methods driven by industry 5.0. The shift towards industry 5.0 emphasizes the growing importance of value competencies such as social awareness, environmental awareness, and ethics to address various challenges faced by our communities. The results of the study revealed that there were some converging competencies demanded by both the industry and the education professionals such as problem solving, IT skills, and learning to learn; however, they diverge on various competencies such as academia focuses on the STEM fundamentals, while industry prioritizes proficiency in modern technology and skills such as interdisciplinary knowledge to compete in the rapidly evolving engineering world. Ultimately, the UCT model used in this review provides a robust framework to measure the competencies of the future engineers to ensure they are not only technically capable but also socially and environmentally responsible.

Implications and Future Research

The findings of this study have several implications for engineering educators, curriculum designers, and researchers. For engineering educators, the shift toward human-centric Industry 5.0 indicates the need to adopt pedagogical approaches that integrate technical engineering competencies with higher-order cognitive skills. For curriculum designers, the low emphasis on STEM fundamentals and learning competencies highlights the need to rebalance curricular structures. Strengthening curricular agility will better prepare undergraduate engineering students for the evolving industrial landscapes of the twenty-first century. For researchers in engineering education, the strong reliance on qualitative and literature-review methodologies reveals a gap in mixed-methods and quantitative approaches. Further research should examine the empirical validation of engineering competency frameworks and incorporate longitudinal studies. Future research may also explore the factors that limit the ability of engineers in industry to mentor new engineers effectively.

Limitations

The systematized literature review has several limitations. First, the search strategy was developed solely by the lead author, which may introduce bias due to the researcher's close proximity to the data. Additionally, the literature synthesis was conducted in October 2025; therefore, given the rapid increase in publications in recent years, relevant studies published after this period may not have been captured. The review also relied on only five databases, which raises the possibility that some pertinent articles were not identified. Moreover, most articles were excluded during the title-screening stage by the lead author; however, titles do not always accurately reflect the content of scholarly work, and this may have resulted in the unintended omission of relevant studies. 19 papers in our synthesis did not specify the country for the data collection. This could limit us drawing conclusions based on the country's specific factors. Most of the papers in our synthesis utilized either a qualitative or a literature review approach with few reviewed studies using quantitative, mixed-methods, and descriptive survey method. The reliance on the qualitative data may restrict the results of the frequency-based conclusions. Moreover, the research study highlights that the industry professionals are not properly trained to mentor the engineering graduates once they enter the workforce; however, the barriers to training among the industry professionals were not thoroughly studied and explained in the research study.

Acknowledgement

The author wants to acknowledge the use of AI (Gemini, Co-Pilot, and Grammarly) to assist with clarity in grammar, spelling, researcher-led brainstorming, and structuring.

References

[1] H. Dahl, N. Tvenge, C. S. A. Assuad, and K. Martinsen, “A Learning Approach for Future Competencies in Manufacturing using a Learning Factory,” *Procedia CIRP*, vol. 118, pp. 1039–1043, 2023, doi: 10.1016/j.procir.2023.06.178.

[2] K. S. P. N. Kannan and A. Garad, “Competencies of quality professionals in the era of industry 4.0: a case study of electronics manufacturer from Malaysia,” *IJQRM*, vol. 38, no. 3, pp. 839–871, Sep. 2020, doi: 10.1108/IJQRM-04-2019-0124.

[3] J. D. Azofeifa, V. Rueda-Castro, L. Gonzalez-Gomez, M. Zaragoza, J. Noguez, and P. Caratozzolo, “Future Skills Taxonomies in Engineering Continuing Education Shaping Lifelong Learning: An Integration Proposal,” in *2025 ASEE Annual Conference & Exposition Proceedings*, Montreal, Quebec, Canada: ASEE Conferences, Jun. 2025, p. 56627. doi: 10.18260/1-2--56627.

[4] T. Chowdhury and H. Murzi, “The Evolution of Teamwork in the Engineering Workplace from the First Industrial Revolution to Industry 4.0: A Literature Review,” in *2020 ASEE Virtual Annual Conference Content Access Proceedings*, Virtual On line: ASEE Conferences, Jun. 2020, p. 35318. doi: 10.18260/1-2--35318.

[5] S. Sapper, M. Kohl, and J. Fottner, “Future Competency Requirements in Logistics Due to Industry 4.0: A Systematic Literature Review,” in *2021 10th International Conference on Industrial Technology and Management (ICITM)*, Cambridge, United Kingdom: IEEE, Mar. 2021, pp. 94–105. doi: 10.1109/ICITM52822.2021.00025.

[6] L. C. Nnadi, D. Ding, E. D. Godwin-Ojukwu, Y. Watanobe, and K. Naruse, “Strategic Human Resource Development for Emerging Technologies: A Scoping Review in ICT, Robotics, Data Science, and CPS,” *IEEE Access*, vol. 13, pp. 133994–134013, 2025, doi: 10.1109/ACCESS.2025.3592301.

[7] A. KUS, “Competencies of the future in the context of the Industry 5.0 – challenges and prospects,” *SPSUTOM*, vol. 2024, no. 199, 2024, doi: 10.29119/1641-3466.2024.199.24.

[8] M. I. Ciolacu, C. Marghescu, B. Mihailescu, M. Sorecau, E. Sorecau, and P. Bechet, “Education 5.0: Transforming Engineering Education in the Age of Generative AI,” in *2024 IEEE 30th International Symposium for Design and Technology in Electronic Packaging (SIITME)*, Sibiu, Romania: IEEE, Oct. 2024, pp. 303–308. doi: 10.1109/SIITME63973.2024.10814745.

[9] M. I. Ciolacu *et al.*, “Developing Future Skills in Engineering Education for Industry 5.0: Enabling Technologies in the Age of Digital Transformation and Green Transition,” in *Open Science in Engineering*, vol. 763, M. E. Auer, R. Langmann, and T. Tsiatsos, Eds., in Lecture Notes in Networks and Systems, vol. 763. , Cham: Springer Nature Switzerland, 2023, pp. 1019–1031. doi: 10.1007/978-3-031-42467-0_94.

[10] A. R. Fernando, N. E. Ghazali, F. Phang, and N. F. Abdul Rahman, “Validating Future Engineering Competencies: An Innovation System Approach in Competency Modeling through Delphi Method,” in *2025 ASEE Annual Conference & Exposition Proceedings*, Montreal, Quebec, Canada: ASEE Conferences, Jun. 2025, p. 57324. doi: 10.18260/1-2--57324.
[11] “IDEAS_23_CEIE_Journal_Oct2025.”
[12] C. Pacher, M. Woschank, and B. M. Zunk, “The role of competence profiles in industry 5.0-related vocational education and training: exemplary development of a competence profile for industrial logistics engineering education,” *Applied sciences*, vol. 13, no. 5, p. 3280, 2023.
[13] L. Li, “Reskilling and upskilling the future-ready workforce for industry 4.0 and beyond,” *Information Systems Frontiers*, vol. 26, no. 5, pp. 1697–1712, 2024.
[14] L. Zare, M. Ben Ali, and E. Rauch, “Industry 5.0 and SMEs Future Work Competency Fields: A Literature Review,” in *Latest Advancements in Mechanical Engineering*, vol. 1125, F. Concli, L. Maccioni, R. Vidoni, and D. T. Matt, Eds., in Lecture Notes in Networks and Systems, vol. 1125. , Cham: Springer Nature Switzerland, 2024, pp. 200–208. doi: 10.1007/978-3-031-70465-9_20.
[15] M. Zhanna and V. Nataliia, “Development of engineering students competencies based on cognitive technologies in conditions of industry 4.0,” *International Journal of Cognitive Research in Science, Engineering and Education*, vol. 8, no. S, pp. 93–101, 2020.
[16] S. R. Brunhaver and S. Sajadi, “CAREER: Ready for change: Fostering adaptability along the engineering pathway,” presented at the 2021 ASEE Virtual Annual Conference Content Access, 2021.
[17] K. Froehle, L. Dickman, A. R. Phillips, H. Murzi, and M. Paretti, “Understanding lifelong learning and skills development: Lessons learned from practicing civil engineers,” *Journal of Civil Engineering Education*, vol. 148, no. 4, p. 04022007, 2022.
[18] O. K. Sabri, “Lifelong Learning for Engineers: A Literature Review.,” *International Society for Technology, Education, and Science*, 2023.
[19] H. Li *et al.*, “Individual sustainability competence development in engineering education: Community interaction open-source learning,” *Plos one*, vol. 18, no. 11, p. e0294421, 2023.
[20] K. Subrahmanyam, M. A. Kumar, N. V. Rao, A. R. Murthy, and B. Varma, “Innovative Teaching and Learning Methods in Engineering Education: A Review.,” *Library of Progress-Library Science, Information Technology & Computer*, vol. 44, no. 3, 2024.
[21] H. Q. Ang and B. Domingo, “An Innovative and Universal Teaching Model in Engineering Education to Foster Industry 5.0 Skills—EPIC Principles,” *Education Sciences*, vol. 15, no. 9, p. 1096, Aug. 2025, doi: 10.3390/educsci15091096.
[22] S. C. Brink *et al.*, “Curriculum Agility principles for transformative innovation in engineering education,” *European Journal of Engineering Education*, vol. 50, no. 3, pp. 455–471, 2025.
[23] A. Lourenço, J. S. Navarro-Loli, and S. Dominguez-Lara, “Technological Innovation in Engineering Education: A Psychopedagogical Approach for Sustainable Development,” *Sustainability*, vol. 17, no. 14, p. 6429, 2025.
[24] J.-B. R. Souppez, “Engineering employability skills: Students, academics, and industry professionals perception,” *International Journal of Mechanical Engineering Education*, vol. 53, no. 1, pp. 125–142, 2025.

[25] K. Alboaouh, “The gap between engineering schools and industry: A strategic initiative,” presented at the 2018 IEEE Frontiers in Education Conference (FIE), IEEE, 2018, pp. 1–6.
[26] C. Arlett, F. Lamb, R. Dales, L. Willis, and E. Hurdle, “Meeting the needs of industry: the drivers for change in engineering education,” *engineering education*, vol. 5, no. 2, pp. 18–25, 2010.
[27] S. R. Brunhaver, R. F. Korte, S. R. Barley, and S. D. Sheppard, “Bridging the gaps between engineering education and practice,” in *US engineering in a global economy*, University of Chicago Press, 2017, pp. 129–163.
[28] C. Ferreira, B. Gabriel, R. Valente, and C. Figueiredo, “Engineering education challenges and strengths: reflecting on key-stakeholder’s perspectives,” presented at the Frontiers in Education, Frontiers Media SA, 2024, p. 1297267.
[29] D. Gope and A. Gope, “Students and academicians views on the engineering curriculum and industrial skills requirement for a successful job career,” *Open education studies*, vol. 4, no. 1, pp. 173–186, 2022.
[30] X. Yinglun, S. Hao, and C. Xiang, “Bridging the Gap between University Engineering Education and Enterprise Requirements,” *Mobile Networks and Applications, online first*, 2022.
[31] R. Malhotra, M. Massoudi, and R. Jindal, “Shifting from traditional engineering education towards competency-based approach: The most recommended approach-review,” *Education and Information Technologies*, vol. 28, no. 7, pp. 9081–9111, 2023.
[32] J. Leoste, L. Jõgi, T. Õun, L. Pastor, J. San Martín López, and I. Grauberg, “Perceptions about the future of integrating emerging technologies into higher education—the case of robotics with artificial intelligence,” *Computers*, vol. 10, no. 9, p. 110, 2021.
[33] V. Sanchez Padilla, A. Espinal, J. Cordova-Garcia, and L. Schibelius, “Barriers to Integrating Low-Power IoT in Engineering Education: A Survey of the Literature,” *arXiv e-prints*, p. arXiv-2510, 2025.
[34] I. Mosly, “Artificial intelligence’s opportunities and challenges in engineering curricular design: A combined review and focus group study,” *Societies*, vol. 14, no. 6, p. 89, 2024.
[35] A. D. Salisu, “Robotics and artificial intelligence in STEM curriculum development: Preparing learners for emerging security and technological frontiers,” *International Journal of Innovative Information Systems & Technology Research*, vol. 21, pp. 1–12, 2025.
[36] S. R. Brunhaver, B. K. Jesiek, R. F. Korte, and A. C. Strong, “The early career years of engineering: Crossing the threshold between education and practice,” *Engineering Studies*, vol. 13, no. 2, pp. 79–85, 2021.
[37] C. Ferreira *et al.*, “In search of a more balanced engineering curriculum: The perspective of students, teachers, alumni and employers,” *Trends in Higher Education*, vol. 3, no. 1, pp. 142–154, 2024.
[38] M. Cheang and G. L. Yamashita, “Employers’ Expectations of University Graduates as They Transition into the Workplace.,” *European Journal of Education (EJED)*, vol. 6, no. 2, pp. 22–32, 2023.
[39] M. Itani and I. Srour, “Engineering students’ perceptions of soft skills, industry expectations, and career aspirations,” *Journal of professional issues in engineering education and practice*, vol. 142, no. 1, p. 04015005, 2016.
[40] K. Saira Banu and T. K. Lakshmi, “A Comprehensive Review of Soft Skills Training: Enhancing Employability and Impact on Job Market,” presented at the International

Conference on Computers, Management & Mathematical Sciences, Springer, 2023, pp. 93–103.
[41] E. Koromyslova, C. Steinlicht, and M. K. Peter, “Closing the professional skills gap for engineering graduates: Recent trends in higher education,” presented at the 2023 ASEE Annual Conference & Exposition, 2023.
[42] Y. Kuleshov and A. Lucietto, “Soft and hard skills balance among engineering & engineering technology graduates,” presented at the 2022 ASEE Annual Conference & Exposition, 2022.
[43] T. Richter and B. Kjellgren, “Comparing peer-reviewed competence frameworks for engineers: a systematic review and critical discussion of backgrounds, development, and content,” *Australasian Journal of Engineering Education*, pp. 1–22, 2025.
[44] N. Z. Muzulon, L. M. Resende, G. C. L. Leal, and J. Pontes, “Beyond Technical Skills: Competency Framework for Engineers in the Digital Transformation Era,” *Societies*, vol. 15, no. 8, p. 217, 2025.
[45] P. Caratozzolo *et al.*, “Board 67: A guide for Generation Z students to meet the Future Skills requirements of Industry 4.0,” in *2023 ASEE Annual Conference & Exposition Proceedings*, Baltimore , Maryland: ASEE Conferences, Jun. 2023, p. 42895. doi: 10.18260/1-2--42895.
[46] J. D. Azofeifa, V. Rueda-Castro, C. Camacho-Zuñiga, G. M. Chans, J. Membrillo-Hernández, and P. Caratozzolo, “Future skills for Industry 4.0 integration and innovative learning for continuing engineering education,” *Front. Educ.*, vol. 9, p. 1412018, Jul. 2024, doi: 10.3389/feduc.2024.1412018.
[47] J. Qadir, K.-L. A. Yau, M. Ali Imran, and A. Al-Fuqaha, “Engineering Education, Moving into 2020s : Essential Competencies for Effective 21st Century Electrical & Computer Engineers,” in *2020 IEEE Frontiers in Education Conference (FIE)*, Uppsala, Sweden: IEEE, Oct. 2020, pp. 1–9. doi: 10.1109/FIE44824.2020.9274067.
[48] J. Zheng and K. T. Kim, “The Driving Force for Sustaining Future Competencies for University Students in the Digital Era: Learning Strategies,” *JCT*, vol. 14, no. 1, p. 19, Jan. 2025, doi: 10.5430/jct.v14n1p19.
[49] J. B. H. Yap, M. Skitmore, Y. W. Lim, S.-C. Loo, and J. Gray, “Assessing the expected current and future competencies of quantity surveyors in the Malaysian built environment,” *ECAM*, vol. 29, no. 6, pp. 2415–2436, Jun. 2022, doi: 10.1108/ECAM-01-2021-0091.
[50] A. Byrne *et al.*, “THE IDENTIFICATION OF FUTURE PROFESSIONAL SKILLS FOR THE GRADUATE STRUCTURAL ENGINEER AND THE COCREATION OF THEIR DEFINITIONS.,” 2021, doi: 10.21427/R82K-YA38.
[51] D. Pahuja, M. Mardis, and F. Jones, “What is Advanced Manufacturing? Exploring the Topography of Definitions,” in *2019 ASEE Annual Conference & Exposition Proceedings*, Tampa, Florida: ASEE Conferences, Jun. 2019, p. 33554. doi: 10.18260/1-2--33554.
[52] A. W. K. Laghari and Y. Brijmohan, “A Comparative Analysis of Engineering Accreditation Bodies Expressions of Curriculum Outcome Requirements: Proposal for the Universal Competency Taxonomy,” in *2025 World Engineering Education Forum - Global Engineering Deans Council (WEEF-GEDC)*, Daegu, Korea, Republic of: IEEE, Sep. 2025, pp. 1–9. doi: 10.1109/WEEF-GEDC66748.2025.11256187.
[53] Y. Brijmohan, “Balanced Perspective of International and National Accreditation and Pedagogical Approaches: A call for change,” presented at the International Conference on Engineering Education Accreditation, Myanmar, Jul. 2023.

[54] Y. Brijmohan, "What does preparedness mean in the context of engineering education in an inclusive and sustainable world?," presented at the International Conference on Engineering Education Accreditation, Jul. 2024.
[55] "IEA-Graduate-Attributes-and-Professional-Competencies-2021.1-Sept-2021."
[56] A. Jackson, A. Godwin, S. Bartholomew, and N. Mentzer, "Learning from failure: A systematized review," *International Journal of Technology and Design Education*, vol. 32, no. 3, pp. 1853–1873, 2022.
[57] M. Borrego, M. J. Foster, and J. E. Froyd, "Systematic literature reviews in engineering education and other developing interdisciplinary fields," *Journal of Engineering Education*, vol. 103, no. 1, pp. 45–76, 2014.
[58] A. Liberati *et al.*, "The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate healthcare interventions: explanation and elaboration," *Bmj*, vol. 339, 2009.
[59] W. M. Bramer, M. L. Rethlefsen, J. Kleijnen, and O. H. Franco, "Optimal database combinations for literature searches in systematic reviews: a prospective exploratory study," *Systematic reviews*, vol. 6, no. 1, p. 245, 2017.
[60] I. Penesis, R. Barnes Katersky, S. Kilpatrick, M. Symes, and B. A. León De La Barra, "Reskilling the manufacturing workforce and developing capabilities for the future," *Australasian Journal of Engineering Education*, vol. 22, no. 1, pp. 14–22, Jan. 2017, doi: 10.1080/22054952.2017.1338228.
[61] A. Macalalag and C. Jurado, "Grade 3-8 Teachers' Initial Ideas about 21st Century Skills in the Context of a Science and Engineering Professional Development Program," in *2011 ASEE Annual Conference & Exposition Proceedings*, Vancouver, BC: ASEE Conferences, Jun. 2011, p. 22.755.1-22.755.19. doi: 10.18260/1-2--18036.
[62] K. Z. Akhilla, A. Sukmawati, and B. Sartono, "Identifying the Types of Future Skills Needed in The Manufacturing Industry: A Systematic Literature Review," *jabm*, vol. 11, no. 3, p. 1099, Sep. 2025, doi: 10.17358/jabm.11.3.1099.
[63] E. I. Daniel, O. S. Oshodi, and J. Marte Gomez, "Developing future skills for the engineering sector: evidence from the UK," *Proceedings of the Institution of Civil Engineers - Management, Procurement and Law*, vol. 178, no. 2, pp. 65–75, Apr. 2025, doi: 10.1680/jmapl.24.00005.
[64] S. C. Gurbuz and M. Celik, "Serious games in future skills development: A systematic review of the design approaches," *Comp Applic In Engineering*, vol. 30, no. 5, pp. 1591–1612, Sep. 2022, doi: 10.1002/cae.22557.
[65] M. E. West, A. L. Carrel, and R. L. Kajfez, "Future Skill Requirements in Transportation Engineering and Implications for Graduate Curriculum Design," *J. Civ. Eng. Educ.*, vol. 147, no. 3, p. 04021002, Jul. 2021, doi: 10.1061/(ASCE)EI.2643-9115.0000042.
[66] "EBSCO-FullText-11_03_2025 (1)."
[67] A. Huderson, E. Peiffer, S. Shamsi, F. Plaza, and E. Collins, "FUTURE OF MECHANICAL ENGINEERING, MANUFACTURING ENGINEERING, AND MACHINIST ROLES FOR INDUSTRY 4.0," in *2022 ASEE Annual Conference & Exposition Proceedings*, Minneapolis, MN: ASEE Conferences, Aug. 2022, p. 41625. doi: 10.18260/1-2--41625.
[68] J. Membrillo-Hernández, E. L. Caudana, and P. Vázquez-Villegas, "Challenge-Based Learning: An Essential Tool for Fostering Future Engineering Competencies," in *2023 World Engineering Education Forum - Global Engineering Deans Council (WEEF-GEDC)*,

Monterrey, Mexico: IEEE, Oct. 2023, pp. 1–7. doi: 10.1109/WEEF-GEDC59520.2023.10344051.

[69] A. S. Araújo, R. P. Do Nascimento, D. A. C. Barone, and H. Lindemann, "Soft Skills and Ethics: A Different Perspective on Engineering Competencies and the Future of AI Development," in *2025 34th Annual Conference of the European Association for Education in Electrical and Information Engineering (EAEEIE)*, Cluj-Napoca, Romania: IEEE, Jun. 2025, pp. 1–5. doi: 10.1109/EAEEIE65428.2025.11136273.

[70] Y. Cao *et al.*, "Visions of Engineers for the Future: A Comparison of American and Chinese Policy Discourses on Engineering Education Innovation," in *2021 ASEE Virtual Annual Conference Content Access Proceedings*, Virtual Conference: ASEE Conferences, Jul. 2021, p. 38030. doi: 10.18260/1-2--38030.

[71] A. Coroiu, A. Călin, R. Găceanu, and A. Vescan, "Advancements, Challenges, and Emerging Trends in Computer Science Education: A Systematic Literature Review of Academic and Professional Learning: Editorial," in *2024 IEEE International Conference on Software Analysis, Evolution and Reengineering - Companion (SANER-C)*, Rovaniemi, Finland: IEEE, Mar. 2024, pp. 1–12. doi: 10.1109/SANER-C62648.2024.00006.

[72] T. Eppes, I. Milanovic, and D. Shetty, "The Future of Things: Simulations and Next Generation Manufacturing," in *2020 IEEE Global Engineering Education Conference (EDUCON)*, Porto, Portugal: IEEE, Apr. 2020, pp. 442–446. doi: 10.1109/EDUCON45650.2020.9125282.

[73] E. Karapidakis, M. Markaki, S. Apostolakis, B. Canizes, R. Androulakis, and F. Castro, "Smart and Advanced Electrical Skills: Identifying Current Gaps and Emerging Trends," in *2024 5th International Conference on Communications, Information, Electronic and Energy Systems (CIEES)*, Veliko Tarnovo, Bulgaria: IEEE, Nov. 2024, pp. 1–6. doi: 10.1109/CIEES62939.2024.10811239.

[74] S. Maricic, A. Kovac, and M. Peric, "Innovative Technologies in Computer Education: Integration VR, CAD/CAM and 3D Modeling with Gamification," in *2024 47th MIPRO ICT and Electronics Convention (MIPRO)*, Opatija, Croatia: IEEE, May 2024, pp. 659–662. doi: 10.1109/MIPRO60963.2024.10569466.

[75] O. Ogunrinde, I.-K. Pena, T. Rider, and B. Gray, "The Integration of Emerging Technologies into University Education," in *2025 ASEE Annual Conference & Exposition Proceedings*, Montreal, Quebec, Canada: ASEE Conferences, Jun. 2025, p. 57242. doi: 10.18260/1-2--57242.

[76] S. Qiu, M. Natarajarathinam, M. Johnson, and E. Roumell, "The Future of Work: Identifying Future-ready Capabilities for the Industrial Distribution Workforce," in *2021 ASEE Virtual Annual Conference Content Access Proceedings*, Virtual Conference: ASEE Conferences, Jul. 2021, p. 37864. doi: 10.18260/1-2--37864.

[77] T. Wickland, "Needed Skills in the Transportation Workforce, in the Context of New and Emerging Technologies and Approaches," 2022, doi: 10.17610/T6GG6H.