Leveraging Artificial Intelligence in Industrial and Mechanical Engineering Education: An Umbrella Mapping Review

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Abstract—This comprehensive research examines the impact of Artificial Intelligence (AI) on industrial and mechanical engineering education by synthesizing insights from 12 review papers published between 2023 and 2025. The study employed CiteSpace software for co-citation and keyword co-occurrence analysis to identify key intellectual structures and thematic clusters shaping the field. The co-citation analysis of authors highlights three main research areas: the use of generative AI tools (e.g., ChatGPT) for personalized education; data-driven models for predicting academic success; and, not least, immersive technologies such as robotics and virtual reality for experiential learning. The clustering of co-cited literature reveals two primary domains: (1) practical AI integration aimed at improving curriculum and exam assessments, and (2) the future potential of generative and immersive AI technologies to promote creativity and skill development among next-generation professionals. The co-citation networks of authors emphasize two distinct but overlapping scholarly communities: one focused on system-level educational technologies and the other on ethical, curricular, and institutional reform needs. The keyword co-occurrence patterns indicate convergence around two main themes: on the one hand, AI-powered analytics and simulations, while on the other, learner-centered adaptive systems. Overall, the findings of this umbrella study suggest a paradigm shift toward AI-enhanced, student-centered, and policy-driven engineering education, as this interdisciplinary field rapidly develops and widens its application, with critical societal relevance for the future.

Keywords—Artificial Intelligence, Umbrella Mapping Review, Industrial and Mechanical Engineering, Emerging Educational Technologies, CiteSpace Mapping

I. Introduction

In the last five years, the impact of artificial intelligence (AI) on the teaching of engineering disciplines, particularly industrial and mechanical engineering, has been remarkable, [1], [2]. Worldwide, university educators leverage AI for teaching and personalized learning, as well as for curriculum alignment with Industry 4.0 demands. Recent scholarly studies highlight the applications of AI technologies to increase students' active participation and provide real-time feedback, thereby optimizing the overall learning process and outcomes. However, incorporating AI technologies raises new challenges related to academic integrity, revising pedagogical practices, and the administration of exams and assessments, [3].

Thus, as demonstrated in the literature to date, integrating AI into industrial and mechanical engineering education shows several distinct trends. First, the breadth of AI applications across these two education sectors is expanding from AI-based instructors in classroom lectures to a range of AI-enhanced instructional tools in laboratories. The theme of AI as a means to customize education remains prevalent in the context of such a backdrop, as a multitude of programs have instituted intelligent systems that allow for the customization of content and feedback to meet the unique requirements of individual learners, [4], [5], [6], [7]. Secondly, engineering programs have begun to transform by incorporating AI not only as a subject but also as a pedagogical tool across several other disciplines, [8], [9], [10], [11]. The need for "AI-aware" engineers is increasing in the workforce, driven by greater collaboration with contemporary AI technologies across many sectors and by the growing need for engineers with these skills. Third, the adoption of sophisticated, hands-on AI technologies such as simulations, VR/AR, and robotics is increasing, signaling a shift towards technology-driven experiential learning, [12]. This fact aligns with the paradigm of mechanical and industrial engineering education, in which AI technology facilitates student engagement with simulation equipment that emulates the real world through a range of physical and virtual instruments.

Finally, the most recent literature identifies a significant trend toward the growing popularity of generative AI in teaching across various engineering disciplines, [13]. From explaining theoretical concepts through intelligent tutoring systems to scaffolding coding tasks and supporting visualization design, AI systems can now provide engineering educators with substantial assistance, [14].

However, alongside the rapid integration of generative AI systems into engineering education, there are conflicting perspectives on ChatGPT's pedagogical utility. While some authors propose that the system supports formative assessment and feedback, others highlight potential limitations concerning academic integrity and the need for novel exam and assessment methodologies, [15], [16], [17]. Therefore, there is a strong tendency to incorporate AI technology into teaching and learning in engineering disciplines at higher education institutions in more complex and innovative ways that enhance efficiency and user experience, while integrating with contemporary technological practices.

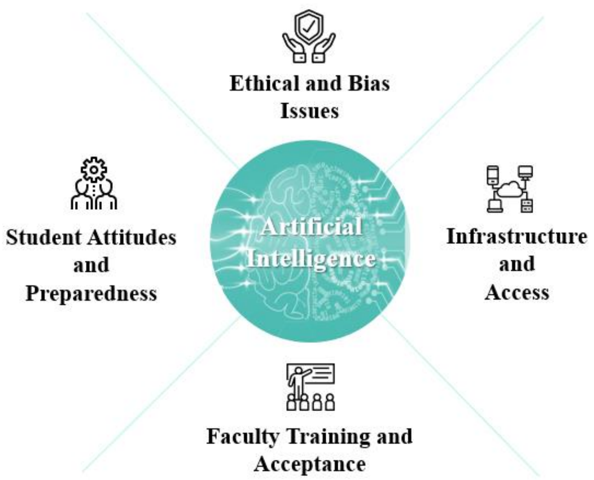

Fig. 1 AI in Engineering Education: Key Challenges
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In addition to the aforementioned issues, four primary concerns, commonly noted by university educators and researchers, must be addressed for the successful and responsible integration of AI into engineering education. These key issues are graphically illustrated in Figure 1 and briefly explained below.

Ethical and Bias Issues: Artificial Intelligence systems may display irrational, inequitable, or biased behavior. The data sets used to train AI tutors and the algorithms used for grading might be inequitable, leading to discriminatory outcomes that may adversely affect students, [11], [18]. Such an appearance raises an ethical dilemma about AI's potential to perpetuate existing societal prejudices, particularly among students. Several scholars have stated that, regarding the ethical issues of integrating AI into education, there is a need for research focused on ethical principles that facilitate the use of AI in enhancing educational outcomes and equity, [19]. Hence, the issue of academic integrity also needs to be considered, in the sense that responsible guidelines and ethical boundaries must be defined to prevent AI-assisted aid from being abused as a form of cheating, [20].

Infrastructure and Access: The widespread use of AI in education requires robust infrastructure, including proprietary software and hardware, reliable computing devices, and fast internet connections. Particularly at small colleges or universities, education providers are struggling to acquire the resources needed to adopt AI, as the cost of AI platforms, the maintenance of VR labs and associated cloud services, and the continual updates required can be prohibitive. Thus, it can result in asymmetrical access, where some programs are AI-enabled and equipped with advanced facilities, while others are left with basic tools, exacerbating disparities in educational quality. This challenge will likely require targeted investments and some degree of resource-sharing, considering the possible use of collaborative or open-source AI software, to address the gap in access to AI-integrated education for many potential students.

Faculty Training and Acceptance: Embedding artificial intelligence into teaching and curriculum design requires staff adoption and a willingness to engage with this shift. Currently, many engineering educators have not received training in pedagogical teaching of AI and are therefore ill-prepared to deploy the related tools. Without appropriate guidance and professional development, educators may fail to realize AI's full potential. A significant challenge, hence, lies in educators' AI training literacy, which may be addressed through more focused training seminars, effective dissemination of AI pedagogical practices, and the development of AI educational teaching tools. Industrial and mechanical engineering university educators do not need to become AI specialists, but they do need a pedagogical understanding of AI's potential and limitations to deploy and guide students in its use. As the literature suggests, well-trained educators increase the likelihood of addressing students' concerns and of using AI in instruction to elevate rather than supplant their critical thinking, [21], [22], [23].

Student Attitudes and their Preparedness: The willingness of students to integrate Artificial Intelligence into learning varies considerably. Some students are willing to integrate AI tools into their learning activities, while others are hesitant due to the perceived threat AI poses to the learning process and future employment. Research has shown the importance of student acceptance, as disengagement from the learning process is likely when students dislike and distrust an AI-based tool used in learning activities, [24], [25]. Therefore, students need instructions on the effective use of available AI tools. In contemporary education, teaching students AI skills, such as expected chatbot responses and AI tutor feedback analysis, is indispensable. Students will always need to view AI as an aid and not a replacement. Some studies based on surveys and focus groups have shown that student participation in discussions about the purpose of AI in their learning and the clear articulation of the goals of associated tools helped achieve alignment between their attitudes and learning goals, [26], [27], [28].

Over the past five years, advances in AI for Industrial and Mechanical Engineering Education (IMEE) have been significant. Recent AI literature highlights AI's potential to personalize and improve teaching methods, streamline curriculum elements, develop innovative skills-training approaches, and possibly boost student learning across various content areas. However, ethical, technical, and interpersonal challenges related to full AI implementation still need to be addressed. Future AI integration should support traditional teaching methods and skill development in engineering and critical thinking, as researchers have noted AI's hesitance to bypass these approaches. As engineering education evolves, collaboration among educators, AI practitioners, and industry stakeholders will be crucial for creating effective, fair AI-enhanced educational systems that align with the professional environment students will face.

Nonetheless, there remains a need for an umbrella review that synthesizes findings from various reviews on the topic under analysis. As some authors have already pointed out, without a synthesis of the literature, the field risks the community “running in cycles," producing siloed studies and redundant research, [29]. More comprehensive integrations, such as the one proposed in this paper, enable a broader view, capturing convergent lines and recurring findings, as well as the blind spots that individual reviews may overlook. So far, the use of generative artificial intelligence (AI) in engineering education is an understudied area with a chronic lack of research, [30]. Transitions within engineering education to incorporate AI are still primarily discussed in literature, with little real-world guidance on how to implement such drastic changes. In the case of meta-syntheses of review papers, these are the types of problems to be examined. By doing so for various articles, it is possible to create an outlined schema with prominent issues, such as the lack of review and longitudinal studies on the outcomes of learning with AI, to say the literature on the application of AI to the education of specific disciplines, such as thermal engineering, is extensive.

This article continues the previously noted gap in the literature by providing an umbrella review of the application of AI in IMEE. Thus, the information from existing reviews and primary studies on major IMEE domains is systematically integrated and interpreted through a qualitative review and a bibliometric analysis. Such a methodology provides the most comprehensive current overview of the field's advancements, whose scope surpasses the underlying aim of independent reviews. Most notably, the present synthesis provides novel bibliometric insights by employing CiteSpace to visualize co-citation networks and keyword co-occurrence. Furthermore, it allows for the revelation of deeper patterns and emerging topics in the field, insights that would be challenging to extract from standalone reviews.

II. METHODS AND TOOLS

A comprehensive, methodical strategy was developed and implemented across the Web of Science (WoS) Core Collection and Scopus databases to identify relevant papers with maximal accuracy and reproducibility. These databases are renowned for their extensive and meticulous indexing of significant peer-reviewed articles and conference proceedings in engineering and education. The search keywords were crafted to be sufficiently expansive and comprehensive, encompassing a diverse array of pertinent subfields while maintaining a focus on the use of artificial intelligence in the teaching and learning methodologies of industrial and mechanical engineering. Such a goal was accomplished through a searching process that combined controlled vocabulary, discipline-specific terms, and Boolean operators, enabling the achievement of sufficient breadth and conceptual precision.

TABLE 1. SEARCH PROTOCOL FOR THE WOS CORE COLLECTION DATABASE

Field tag	Conceptual block	Keywords query	
TS	Artificial Intelligence and Educational Technologies	"artificial intelligence" OR "AI" OR "machine learning" OR "deep learning" OR "neural network*" OR "natural language processing" OR "NLP" OR "language model*" OR "large language model*" OR "chatbot*" OR "intelligent tutoring system*" OR "adaptive learning system*" OR "generative AI" OR "ChatGPT" OR "educational technology" OR "intelligent system*" OR "automated feedback" OR "learning analytics"	
	Mechanical Engineering Education and Learning Contexts	AND	"mechanical engineering education" OR "mechanical engineering students" OR "mechanical engineering curriculum" OR "mechanical engineering curricula" OR "mechanical engineering instruction" OR "teaching mechanical engineering" OR "learning mechanical engineering" OR "mechanical engineering pedagogy" OR "mechanical engineering course" OR "mechanical engineering classroom"
AB	Review-Oriented Publications	AND	"review" OR "literature review" OR "systematic review" OR "scoping review" OR "state of the art" OR "meta-analysis" OR "bibliometric analysis" OR "umbrella review"

Source: Created by the authors

The search methodology was structured around three interrelated conceptual blocks, as shown in Table 1. Each of these encapsulates an aspect of the subject to be examined: (1) Artificial Intelligence and Educational Technologies, encompassing the application of AI and its related tools and methodologies in education, including machine learning, expert systems, and intelligent tutoring systems; (2) IMEE along with the related Learning Contexts, referring to the literature concerning the pedagogy, curriculum, and practices of teaching and learning these fields across all university levels; and (3) Review-Oriented Publications, restricted to works employing systematic, scoping, bibliometric, or meta-analytical review methodologies that synthesize evidence rather than present primary empirical research.

No restrictions were placed on the publication year, geographical region, or the journal's academic scope, ensuring a diverse, inclusive, and historically extensive coverage of the literature. This initiative sought to assess the development, global impact, and interdisciplinary aspects of research on the application of AI in industrial and mechanical engineering education. However, to ensure consistency and clarity, the assessment was limited to publications written in English. The data search and collecting procedure concluded in June 2025, confirming that all studied datasets were relevant and comprehensive throughout the considered timeframe.

The review adhered to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines to ensure clarity and rigor in conducting a meticulous search of the WoS Core Collection and Scopus databases, [31]. Figure 2 illustrates the sequence of actions undertaken, encompassing identification, screening, eligibility, inclusion, and data preparation for analysis.

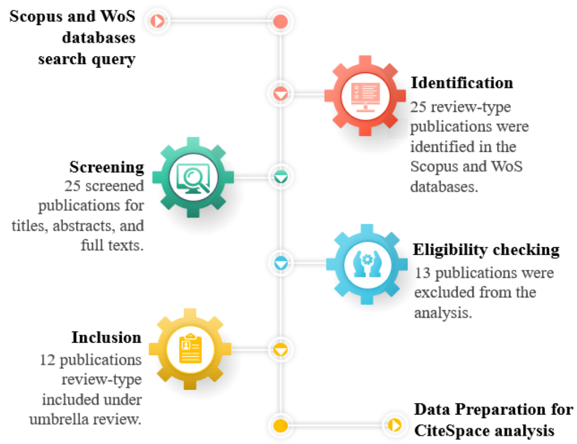

Fig. 2 The PRISMA plan followed in this study
Source: Created by the authors

The preliminary identification round yielded 25 review-type articles, all identified using the aforementioned searching approach. These recordings were chosen for their potential significance at the convergence of artificial intelligence (AI) with the instruction of Industrial and Mechanical Engineering fields. The screening procedure comprised two consecutive stages. Initially, titles and abstracts were evaluated to determine whether the articles met the theme inclusion criteria and the study's methodological standards. Thereafter, each article underwent a comprehensive examination to determine its relevance and verify its inclusion. The eligibility checking phase employed clearly defined inclusion and exclusion criteria. Inclusion was limited to peer-reviewed articles employing review methodologies, such as narrative, systematic, scoping, and bibliometric reviews. The research was tasked to focus on the integration and impact of Artificial Intelligence in Industrial and Mechanical Engineering Education. The exclusion criteria included studies that (a) concentrated on the incorporation of Artificial Intelligence in engineering practices without an educational aspect, (b) reported primary research without utilizing review methodology, (c) addressed general educational technologies unrelated to artificial intelligence, or (d) lacked peer review, encompassing editorials, commentaries, and book chapters. Thirteen papers were excluded based on the specified criteria, leaving a final count of 12 acceptable review-type publications.

The final step involved preparing data for CiteSpace analysis. Metadata was exported from Scopus in CSV format, whereas it was exported from the WoS Core Collection in plain text format. Before analysis, the dataset underwent careful preprocessing to ensure consistency and compatibility with CiteSpace. Special attention was directed to the Cited References (CR) list, emphasizing the standardization of author name formatting, particularly with the use or exclusion of commas after initials. The degree of laxity poses a risk of inaccuracies in the citation data, hence compromising the reliability of co-citation and author co-occurrence analysis. Consequently, all records were meticulously verified and standardized to guarantee the comprehensiveness of the present bibliometric study.

A methodological concern encountered during the data preparation phase was the inconsistency and lack of semantic accuracy in the Keywords Plus (i.e., WoS) and Indexed Keywords (i.e., Scopus) inside the database metadata. These keywords generally failed to address the primary objective of the papers under examination, therefore reducing their relevance to the subject matter. As Clarivate Analytics, [32] noted, "the data in Keywords Plus are words or phrases that frequently appear in the titles of an article's references but do not appear in the title of the article itself." In fact, Keywords Plus are automatically generated using a proprietary algorithm specific to Clarivate databases, designed to improve cited-reference searches by identifying frequently co-occurring terms across references, particularly in interdisciplinary articles. Meanwhile, Indexed Keywords in Scopus are terms assigned by database curators that use controlled vocabularies to describe the contents of a scientific paper, such as MeSH (Medical Subject Headings), Emtree (for life sciences and health sciences), or Compendex (for engineering), [33]. However, as [34] pointed out, although Indexed Keywords can be as effective as Author Keywords in bibliometric analyses for mapping a scientific field's knowledge structure, they often provide a less precise view of an article's actual content. Indeed, upon achieving the objectives of this study, it was found that Keywords Plus, Indexed Keywords, and even Author Keywords are surprisingly limited in describing the content of the reviewed articles.

Therefore, to address this limitation and improve thematic accuracy, a Methodological Framework for Key Terms Mapping (MFKTM) is proposed, as illustrated in Figure 3. Such a framework was specifically designed to enhance topical clarity by extracting and categorizing key keywords from the body of each article (excluding the Abstract and Introduction), thereby enabling more effective thematic clustering.

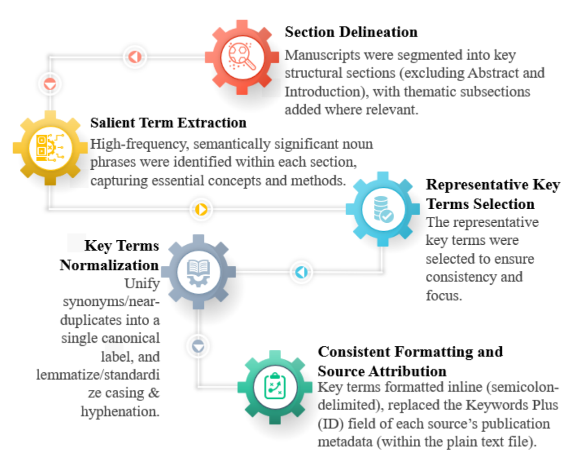

Fig. 3 The workflow of MFKTM approach
Source: Created by the authors

To incorporate the key methodological components, the analysis phase of the study used CiteSpace software, [35], as the primary tool for conducting the bibliometric umbrella review. CiteSpace enables the identification and visualization of hidden intellectual structures in the literature through network-based visualizations such as co-citation networks, keyword co-occurrence maps, and temporal trend analyses across large amounts of scholarly data. These visualizations facilitate the exploration of thematic connections, scholarly research influence, and the evolution of research areas over time with greater accuracy and interpretive insight, [36].

The final dataset included 12 peer-reviewed studies published between 2023 and 2025 that explored the integration, application, or impact of artificial intelligence in industrial and mechanical engineering education. The present bibliometric study used a time-slicing approach with 1-year intervals to analyze how ideas and topics have evolved, thereby pinpointing trends and changes in research focus over the specified period.

III. Results and Discussion

This study uses bibliometrics through four integrated dimensions to build a scholarly overview of the analyzed domain. First, the bibliometric co-citation analysis identifies the key studies and the core of the research, highlighting the academic consensus and essential developments. Next, the co-citation block analysis displays the main topic areas and subfields, clarifying the domain's fundamental and specialized structures. Third, analyzing co-citation among leading authors helps identify the key scholars and the complex academic network and relationships that support the domain's knowledge creation and dissemination. Finally, the co-occurring keywords analysis maps the relationships and connection strengths among the main concepts, shedding light on the current scholarly work's focus and how the concepts interrelate.

These evaluations encompass cross-conditions and principal areas of concern, significant milestones in the discipline, and deficiencies in the potential for future inquiries intersecting with AI in the instruction of mechanical engineering.

A. Co-citation analysis of references

The co-citation analysis of references indicates a structured and burgeoning corpus influenced by recent scholarly research developments. Table 2 outlines the five most commonly co-cited works. Each of these articles is located relatively close to the others in the dataset. To put it differently, they collectively suggest a consensus regarding the digitalization of education, the innovation of pedagogy, and the preparedness of institutions. As such, these publications can be regarded as conceptual anchors, providing theoretical insights and connecting to the broader discussion on the application of Artificial Intelligence in IMEE.

The article with the highest co-citations is [37], which gives a detailed bibliometric and content analysis of Generative Artificial Intelligence (GAI) in education. It describes GAI with a solid conceptual framework, positioning ChatGPT's application as a game-changer in the field. The authors argue ethical and pedagogical aspects in a range of uses like personalized learning, intelligent tutoring, and autonomous AI evaluation, which grant them the GAI's overwhelmingly touted capabilities.

TABLE 2. FIVE REFERENCES WITH THE HIGHEST CO-CITATION FREQUENCY

Core ID in CiteSpace-style	No. of co-citations	Cluster ID in Figure 3
Bahroun Z, 2023, SUSTAINABILITY-BASEL, V15, P12983	3	#2
Pham T, 2023, AUSTRALAS J EDUC TEC, V39, P1	2	#2
Garcés JM, 2021, SENSORS-BASEL, V21, P1398	2	#2
Kuzilek J, 2021, FUTURE GENER COMP SY, V125, P661	2	#1
Kahangamage U, 2020, INT J TECHNOL DES ED, V30, P799	2	#1

Source: Created by the authors

Its pivotal position in the co-citation network shows the rapid pace at which scholars are tracking the educational prospects of GAI. In addition, article [38] is highly co-cited, especially for the use of ChatGPT in developing AI-integrated instructional tools for engineering teaching. The objective is to demonstrate the efficacy of generative tools in enhancing student engagement and assessment, and the necessity of preparing students for interactions with AI. The two publications mentioned above contribute to the expanding literature on the role of conversational AI in engineering education. Article [39] contributes to the discourse by introducing the MiniCERNBot platform, an educational robot designed to engage students in collaborative problem-solving in STEM fields. Although centered on mechatronics and robotics, the co-citation pattern with AI literature reveals fundamental principles of experiential pedagogy, engagement, and multimodal instruction. This indicates a developing trend in engineering education: the utilization of AI-driven technology to impart practical skills.

Other highly co-cited references highlight the relevance of AI methods in gauging and refining performance and curriculum. In the research published in [40], machine learning algorithms were developed to predict students' academic performance by analyzing their performance on several examinations. The study demonstrates the AI's predictions, highlighting the need for prompt, accurate academic support, which is becoming increasingly essential for engineering faculties amid rising dropout rates. The research [41] demonstrates that redesigning courses based on active learning, although not AI-centered, intersects with many AI discourses, particularly those advocating active learning and student-centered instruction in course design. Its relevance to AI curriculum reform, especially concerning its predictive analytics and generative studies, explains its frequent co-citation with AI curriculum studies.

The co-citation analysis points to a unification of three primary lines of inquiry with respect to the use of AI in the teaching of industrial and mechanical engineering education: the pattern of use of generative AI tools (e.g., ChatGPT) for adaptive and responsive learning; the forecasting of academic performance and the analytics-led intervention framework; and the use of robotics and simulation for the development of virtual realities in deep and rich learning.

B. Clustering of co-cited literature

In contrast to the co-citation analysis of references, co-citation analysis of references involves clustering co-cited pieces of literature into distinct thematic groups. The objective of clustering extends beyond merely understanding the location of each element within the domain; it also seeks to capture the overall configuration and structure of the discipline. The clustering of cited works from various source publications reveals fresh research opportunities, related sub-disciplines, and hidden areas of academia.

As shown in Figure 4, the largest cluster (#1), which could be titled "*AI Integration in Mechanical Engineering Education*" with 50 members and a high silhouette score of 0.914, demonstrates strong internal consistency in its thematic focus. This cluster is anchored by the reference [12], which, published in Frontiers in Education, offers a comprehensive overview of AI applications in mechanical engineering education. The study delineates several nascent educational instruments, specifically, personalized learning systems, sophisticated tutoring platforms, AI-enhanced evaluation tools, and generative AI applications in pedagogy. This research clearly demonstrates the significance of AI in transforming instructional methodologies to align with Industry 4.0 requirements.

The principal co-cited reference in this cluster is [42], which investigated the use of online educational resources during the COVID-19 pandemic and their impact on the academic achievement of engineering students. This research confirmed the efficacy of digital educational platforms such as Microsoft Teams and Zoom in maintaining high-quality education, as well as the essential role of AI-assisted remote learning systems. In particular, the study [41], which focuses on remodeling an engineering design subject, emphasizes the use of active learning strategies to enhance student engagement and learning outcomes in mechanical engineering education. The research, [40], introduced machine learning (ML) to predict student success by analyzing exam behavior patterns. The research, [40], employed ML approaches to forecast student achievement by analyzing their behavioral patterns during tests. This reinforces and contributes to the growing application of AI in engineering curricula for academic performance forecasting and early intervention. The study [43], utilized bandit algorithms to create a personalized instructional automaton for self-training systems in mathematics instruction. This demonstrates the utilization of reinforcement learning in adaptive instruction, applicable to various fields within STEM, including mechanical engineering education. This cluster offers a novel perspective on educational frameworks that leverage AI tools to augment student-centered, evidence-based adaptive learning systems.

The second-largest cluster (i.e., #2) in Figure 4 focuses on "*Generative AI, Immersive Technologies, and Skill Alignment*" and includes 23 members, with a perfect silhouette score of 1.0. This cluster centers on the work of [44], highlighting the transformative potential of Generative Artificial Intelligence (GAI) within the framework of mechanical engineering education. Thus, one proposal for utilizing GAI in this context is to incorporate more braiding into the curriculum to improve instructional efficacy and foster students' creative thinking.

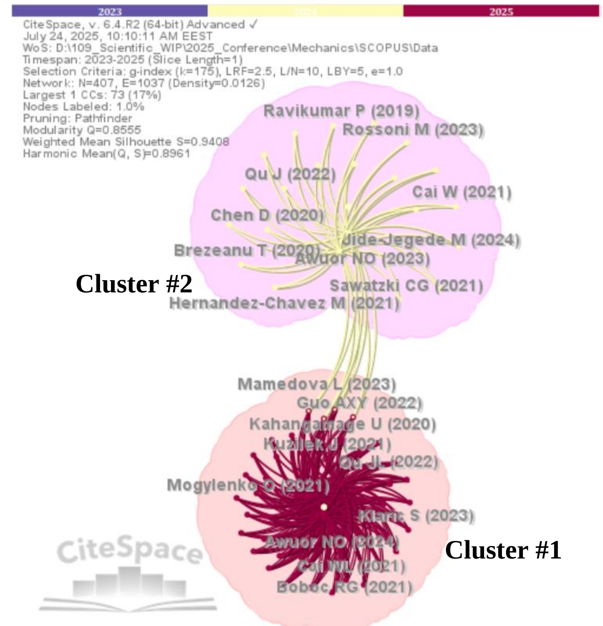

Fig. 4 Clustering visualization of co-cited literature
Source: Created by the authors

Co-cited literature in this cluster emphasizes immersive and multidisciplinary methods, as shown in reference [45], which investigated the use of Virtual Reality (VR) to support active learning in product design education. The study found that VR tools effectively help students grasp 3D modeling, technical drawings, and assembly procedures, thereby filling gaps in mechanical knowledge among students from various backgrounds. Similarly, the reference [46] discusses how educational robotics kits, such as Arduino platforms, are supporting project-based learning in engineering. As a matter of fact, such educational kits promote interdisciplinary skills and practical understanding of AI and mechatronics. Likewise, the study [47] identified fundamental competency criteria for artificial intelligence in finite element analysis using the Delphi method. As a result of their findings, professional training programs in technical education focused on artificial intelligence are being developed. Within the same framework, the research study [48], advocates updating engineering programs' curricula to emphasize critical thinking, problem-solving, and innovation, skills that are greatly enhanced by integrating AI. It also positions artificial intelligence and digital skills within Industry 4.0's priorities.

This study identifies two separate, yet interconnected routes shown by the clustering analysis. The initial cluster addresses the methodical incorporation of artificial intelligence (AI) tools into mechanical engineering education, supported by learning outcomes and predictive analytics. The second cluster, conversely, is future-oriented and investigates the influence of emerging AI technologies (including generative AI, virtual and augmented reality, and robotics) on experiential and competency-based learning. Collectively, these clusters constitute a burgeoning, interdisciplinary research field that perceives AI as a synthesis of sophisticated pedagogy and a catalyst for transformative change in engineering education.

C. Co-citation patterns of authors

Co-citation analysis of authors is a meaningful addition to reference co-citation analysis, detecting patterns of scholarly influence and the alignment of authors whose works are often cited together. The examination of these prominent figures, academic communities, and collaborative networks goes beyond mere document citation counts. Mapping patterns of author co-citation within and across sub-disciplines facilitates a better understanding of their scholarly outputs. In other words, it essentially facilitates constructive bibliometric mapping and enhances the author's analysis by focusing on citations to the authors rather than the publications cited. Because these areas are dynamic and interdisciplinary, the effects of artificial intelligence (AI) on industrial and mechanical engineering, for instance, often extend beyond education, technology, and professional practice. Figure 5 illustrates that the authors' co-citation networks bifurcate into two clusters of researchers whose collective contributions propel advancements in this nascent field.

The first largest cluster (#1), which is nearly entirely centered on *Pedagogical Innovation and Intelligent Systems in Engineering Education*, includes 76 authors and has a silhouette value of 1.0, indicating strong internal thematic coherence. This cluster primarily focuses on reference [49], which may have been the first study intended to carefully examine the literature regarding the application of AI in education. In this regard, the paper identifies numerous key themes, including virtual experiments, intelligent tutors, educational learning analytics, and educational robotics, perceiving AI as a means to enhance learning and teaching environments.

The most co-cited authors in this cluster, [50], are acknowledged as the pioneers in developing project-based learning modules for biologically inspired robotics. They illustrate the use of multidisciplinary, constructive methods to help students understand the intricacies of engineering systems. The reference [51], sheds light on the use of learning analytics to capture deliberate practice through auto-graded digital assessments in chemical engineering. This study illustrates the capability of AI-driven analytics to enhance learning. The research proposed in [52] on AI-driven simulation environments in transportation engineering demonstrates the use of game design and AI as tools to promote active learning of engineering abstraction principles. The authors of references [53] and [54] expanded on AI-assisted remote labs, robotic contests, and face recognition for learning. Furthermore, they established remote-access laboratories, including an artificial intelligence lab. This combination of methodologies facilitates adaptable, genuine, and technologically augmented training, applicable in both physical classrooms as well as entirely online learning environments.

The cluster highlights the efforts of an academic community focused on the design, implementation, and evaluation of learning systems that integrate interactivity with AI-driven project-based learning, enhanced by intelligent assessment mechanisms, to improve teaching and learning and facilitate the incorporation of AI into the curricula of industrial and mechanical engineering programs.

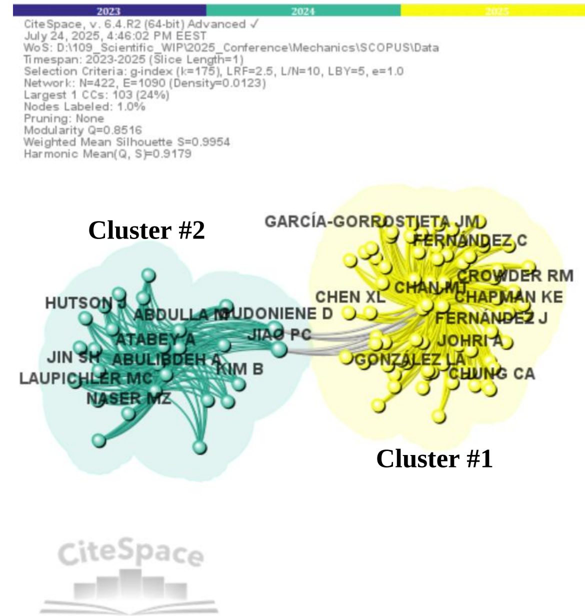

Fig. 5 Visualization patterns of co-cited authors
Source: Created by the authors

The second-largest cluster (#2), which could be called Curriculum Integration, Equity, and the Ethical Dimensions of AI in Education, includes 27 authors and has a silhouette value of 0.982, showing strong thematic cohesion. It is mainly guided by reference [11], which conducts a mixed-methods study on the benefits and challenges of integrating AI into engineering education, emphasizing the ethics, infrastructure, and pedagogy needed for the sustainable and fair adoption of AI.

Among the most significant contributors to this group is reference [55], which examined the use of artificial intelligence-generated wireframes in engineering education. They emphasized inclusion, flexibility, and the potential of machine learning to enhance the user experience in instructional design. The research outlined in [56] focuses on creating an AI-driven model to predict academic achievement, aiming to amalgamate process and outcome data and present it as a tool to deliver targeted support to online engineering students. The research, [22], offered a perspective focused on sustainability and ethics, linking AI adoption in education to the broader goals of Industry 4.0 and Education for Sustainable Development (ESD), while also addressing the transformative potential and ethical concerns of ChatGPT. The research study [57] provided a valuable faculty-oriented case study addressing issues related to the implementation of AI in civil engineering education and advocates for proactive and transformative curriculum modifications, including the early integration of AI, the revision of teaching and learning methodologies, and the enhancement of professional development for AI-enabled instruction for all graduates. Such an investigation contends that educational methods must broaden to ensure that all learners, even those beyond computer science and engineering, are equipped with AI competencies and can effectively engage with and utilize these systems. The reference [58], proposes a transformative concept of AI literacy that ought to be incorporated into secondary and higher education curricula.

The first group emphasizes the concepts of change and intelligent systems, whereas the second group advocates a more contemplative perspective, promoting a robust approach to 'responsible, inclusive innovation' in engineering education.

D. Co-occurrence of Key Terms

The co-occurrence analysis of keywords performed using CiteSpace software has revealed two primary thematic clusters. These clusters encapsulate the nascent research domains at the convergence of artificial intelligence (AI) and education within industrial and mechanical engineering. The clusters in Figure 6 illustrate the convergence of two research fields and represent the progression of the research landscape from 2023 to 2025.

Fig. 6 Keywords co-occurrence network visualization
Source: Created by the authors

The first cluster, *Learning Assessment and Analytics*, dominates the network with 28 co-occurring keywords and a silhouette score of 0.98, suggesting a high degree of thematic cohesion. This cluster has significant relevance to machine learning (ML) with assessment and learning analytics, indicative of the growing adoption of AI-driven evaluation systems in engineering education. This cluster encompasses simulation and modeling (VR/AR), deep learning and artificial neural networks (ANNs), Industry 4.0, output analysis and forecasting, as well as skill development and professional competency. The utilization of keywords indicates the application of data, neural networks, and deep learning methodologies to enhance feedback systems, adaptive learning, and the alignment of students' competencies with industry standards. The application of VR/AR underscores the growing importance of immersive simulations for talent assessment and concept visualization. The connections to Industry 4.0 and additive manufacturing signify the introduction of AI technology in advanced production.

The second cluster, Personalized & Intelligent Learning Systems, includes 17 keyword nodes and has a perfect silhouette score of 1.0, indicating a transparent yet interconnected research area. It emphasizes the growing significance of personalized learning technologies and AI-driven educational systems, with key related terms including: personalized & intelligent learning systems, interdisciplinary collaboration, education strategy & policy, collaboration & feedback loops, student motivation & engagement, and critical thinking and problem-solving.

More specifically, this cluster highlights the community's interest in adaptive AI systems that go beyond simple performance monitoring, as these systems actively influence learners' educational experiences. The emphasis on feedback, evolving policy, and relationship cultivation underscores the necessity for significant and systematic incorporation of AI tools within businesses. The incorporation of concepts such as student motivation, critical thinking, and problem-solving demonstrates that the fundamental objectives of education are central to the use of AI.

Both the above-mentioned clusters, when viewed together, highlight a twofold evolution in the body of literature. The technical infrastructure dimension, also known as the first cluster, is situated at one end of the spectrum. This dimension focuses on machine learning applications, simulation tools, and automated assessments. The second cluster at the opposite end adopts a learner-centered and policy-sensitive orientation. This viewpoint emphasizes tailored instruction, program reconfiguration, and inter-institutional collaboration.

Crucially, there is a confluence of technological innovation with educational techniques, as seen in the use of shared components such as infrastructure, learning assessment, and analytics. Although scholars and educators implement innovative AI methodologies in diverse engineering education and engagement, multidisciplinary collaboration indicates that these matters are also current and evolving. This is especially pertinent now, given that these topics are receiving heightened attention.

IV. Conclusion

The co-citation analysis indicates the convergence of three primary and emerging lines of research for the application of AI technology in teaching and learning of Industrial and Mechanical Engineering: the use of generative AI systems like ChatGPT for individualized and adaptive learning; the application of predictive analytics to academic performance data for proactive and reactive intervention planning and data-informed decision making; and the creation of robotics and simulation-based immersive and interactive learner-centered environments. These patterns indicate that the field is beginning to embrace robust, scalable, learner-oriented, AI-powered instructional design. Findings reflect the field's increasing plurality and maturity and point to the need for a more thorough empirical examination, as well as to the integration of AI into course design and curricular frameworks.

The cluster visualization of co-cited literature provides insight into the discipline’s intellectual structure, including the predominant themes, nascent themes, associated subtopics, and other knowledge gaps that shape the future of AI in the teaching of industrial and mechanical engineering.

In the context of scholarly research trends, the co-citation scene reveals two distinct areas of focus:

Cluster #1 (i.e., *AI Integration in Mechanical Engineering Education*) investigates the primary focal areas of artificial intelligence in the educational process of mechanical engineering, including personalized learning, intelligent tutoring, and performance forecasting. The cited materials in this direction show a movement away from conventional educational approaches and toward the integration of AI to optimize engagement and learning, while analytics systems are used to improve student retention.

Cluster #2 (i.e., Generative AI, Immersive Technologies, and Skill Alignment) emphasizes the application of Generative Artificial Intelligence in conjunction with virtual reality, robotics, and simulation training to augment design and creative competencies. In other words, it underscores the development of more advanced methods in engineering education that combine GAI with experiential and problem-based teaching.

It follows that there is a movement within these two clusters from the practical integration of AI tools to more sophisticated, advanced suppositional applications of artificial intelligence technologies, indicating greater research maturity. While thematically distinct, these clusters are interconnected by regularly co-cited references, suggesting three interdisciplinary subtopics, which are briefly summarized below:

The first focus of learning analytics is on modeling academic performance, which promotes cross-domain efforts and highlights a shared goal of predicting students' success using AI. The second area, curriculum innovation and instructional design, acts as another link, as many references emphasize AI's role in aligning curriculum and educational outcomes with Industry 4.0, reflecting a common pedagogical concern about intersections. Third, digital tools responding to COVID-19 appear in both groups, pointing to a subtopic on maintaining the resilience and continuity of engineering education through AI-supported online learning.

Such intersections indicate an emerging integration of adapted instruction, learner modeling, and educational technology design, forming a sophisticated, entangled web of subtopics bound by a common aim: AI-augmented education.

The clustering analysis reveals that the field is developing along two main paths: one integrating AI into engineering education and the other exploring AI domains such as GAI, VR, and robotics. These routes have common issues related to personalized learning and instruction, curriculum modification, and skills development. Additionally, the interdisciplinary research landscape is defined by tacit knowledge communities that form around peripheral yet closely connected areas. All these communities, along with the co-citation structure, indicate anticipation of a research agenda that extends beyond defining intellectual boundaries, including necessary ethnographic studies of GAI and design education, ongoing research into AI-enabled learning outcomes, and the responsible, fair integration of AI into global engineering curricula.

The two co-cited author groups demonstrate the dynamic research agenda of AI in industrial and mechanical engineering education. Group #1 centers on using teaching-by-learning strategies that incorporate AI to enhance student engagement and formative assessment. Group #2 advocates change over the status quo, adopts a more transformational and ethical approach to systemic curriculum change, and supports greater AI in the teaching process. The integration of these groups represents a more sophisticated field of scholarship, one that embraces the integration of advancement and critical instructional content.

Analysis of keyword co-occurrences reveals two new research areas: one focused on assessment and simulation technology driven by Artificial Intelligence (AI) (such as machine learning, virtual (VR) and augmented (AR) reality, and neural networks), and the other on personalized, learner-centered pedagogical methods enhanced by cross-disciplinary collaboration and feedback. Together, these areas demonstrate a balanced emphasis on advancing technology and strengthening pedagogy, pointing toward a future where artificial intelligence not only enhances the measurement of learning outcomes but also fosters more adaptive, engaging, and inclusive engineering education.

DECLARATION OF GENERATIVE AI AND AI-ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

The authors wrote, reviewed and edited the content as needed and verifies that none utilized artificial intelligence (AI) tools were used. The authors take full responsibility for the content of the publication.

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