Mapping the Evolution of Engineering Design Thinking: A Systematic Review and Bibliometric Analysis of Scopus Publications (2020 – 2025)

Eva Rahayu Putri[1*], Dewanto Harjunowibowo[2], Sri Budiawanti[3]

[1,2,3]Program Study of Physics Education, Faculty of Teacher Training and Education, Universitas Sebelas Maret, Indonesia

----
Corresponding Author:
Author Name*: Eva Rahayu Putri
Email*: evarahayu79@student.uns.ac.id

ABSTRACT

Engineering Design Thinking (EDT) has become a critical framework in contemporary engineering education by integrating creativity, human-centered perspectives, and systems thinking to address complex problems. This study aims to map the evolution of EDT research, identify dominant thematic structures, and indicate future research directions through a hybrid approach combining a Systematic Literature Review (SLR) and Bibliometric Analysis. Using the Scopus database, 893 publications published between 2020 and 2025 were analyzed following the PRISMA protocol and VOSviewer was used to visualize co-authorship, citation, and keyword networks. The results reveal a substantial increase in EDT-related publications after 2015, with the United States, China, and Indonesia emerging as leading contributors, indicating a growing global research landscape. Thematic analysis identifies five core and interrelated dimensions of EDT: technology integration, collaboration and communication, ideation and creativity, human-centered design, and systems and sustainability thinking. Despite this growth, empirical investigations and cross-regional collaborations remain limited. By integrating systematic and large-scale bibliometric perspectives and contextualizing recent studies within a broader historical trajectory (1957–2025), this research provides the first comprehensive mapping of EDT's intellectual development and offers a unified conceptual model to guide future research and educational practice.

Keywords: bibliometric analysis, engineering design thinking, scopus, STEM Education

INTRODUCTION

In recent years, Engineering Design Thinking (EDT) has emerged as one of the most influential approaches to integrating creativity and analytical reasoning within engineering education [1],[2]. The increasing interest in EDT reflects a global effort to prepare future engineers who can think critically, design responsibly, and address complex, real-world problems through innovation [3], [4].

Engineering Design Thinking (EDT) can be understood as a human-centered and iterative process that merges analytical reasoning, creativity, and systems thinking to address real-world engineering challenges [5], [6]. It serves both as a pedagogical framework, guiding the teaching of design, and as a cognitive process that shapes how engineers approach problem-solving [7], [8]. Rather than following a rigid, linear sequence, EDT encourages flexible thinking, constant reflection, and continuous prototyping [9], [10].

The roots of EDT lie in broader Design Thinking (DT) traditions that emerged from the fields of industrial and cognitive design. While design thinking focuses on creativity and empathy in innovation, EDT adapts those same principles to engineering by integrating scientific reasoning and technological awareness [11], [12]. This makes EDT not just a way to generate ideas, but also a method for validating them with evidence and functionality.

EDT combines the flexibility of design thinking with the structure of engineering methods. It guides learners and practitioners through iterative stages of empathizing, ideating, prototyping, and testing, encouraging them to move beyond technical efficiency and toward socially meaningful design [5],[6]. As universities adopt design-based and problem-oriented learning models, understanding how EDT has developed as a field of study becomes essential for improving both teaching and curriculum design [15], [16].

From a broader systems perspective, EDT also aligns with systems thinking and sustainable design paradigms [17], [18]. These perspectives encourage future engineers to consider the social and environmental impacts of their work, understanding design as part of an interconnected system rather than as an isolated task [19], [20], [21]. Modern approaches such as regenerative design push this even further by positioning sustainability not as a constraint, but as a creative opportunity. Consequently, EDT provides an intellectual framework that balances innovation, ethics, and social responsibility in engineering [22], [23].

A systematic literature review offers a powerful way to capture this evolution. By mapping past and present trends, researchers can identify how EDT has influenced engineering pedagogy and pinpoint its remaining gaps [9],[10]. Moreover, a bibliometric approach adds a quantitative layer to this understanding by uncovering patterns of authorship, collaboration, and citation networks that traditional reviews might overlook [26].

Previous work has recognized that EDT involves multiple dimensions, ranging from contextual and procedural aspects to cognitive and affective outcomes [4]. However, despite these insights, few studies have combined systematic and bibliometric methods to examine how EDT research has evolved across time and geography [12],[13]. Previous reviews on design thinking in engineering education have primarily emphasized pedagogical implementation or limited bibliometric snapshots of the field [29]. However, none have systematically integrated both perspectives across a historical continuum. The novelty of this study lies in combining a PRISMA-guided Systematic Literature Review with bibliometric visualization to capture the evolution, distribution, and thematic structure of EDT from 2020 to 2025. This dual approach enables a multi-layered understanding of how EDT research has evolved from conceptual foundations to applied and interdisciplinary domains. This paper fills that gap by providing a long-term overview of how the field has grown from its early conceptual foundations in the 1950s to its contemporary intersections with sustainability, digital technologies, and interdisciplinary education.

In education, EDT serves as a pedagogical bridge, helping students connect theory to practice [15],[16]. By engaging in authentic, open-ended projects, students learn not only to solve technical problems but also to empathize with users, negotiate team decisions, and assess the impact of design [17],[18]. Such learning aligns directly with constructivist and experiential theories that emphasize knowledge building through hands-on experience, reflection, and iterative learning [34], [35]. Additionally, EDT supports the broader vision of the United Nations' Sustainable Development Goals (SDGs), especially those related to quality education and responsible innovation [36], [37].

Given its growing significance, this study was guided by three main research questions:
1. RQ1: Is Engineering Design Thinking Still Relevant for Future Research?
2. RQ2: What Is the Global Distribution of EDT Research?
3. RQ3: What Are the Theoretical and Practical Implications of EDT Research?

To answer these questions, we conducted a hybrid Systematic Literature Review and Bibliometric Analysis using the Scopus database, following the PRISMA framework for selection and VOSviewer for visualization. This combined approach enables us not only to quantify publication patterns but also to interpret their conceptual meanings.

Ultimately, this study aims to offer a structured and comprehensive picture of EDT's development over nearly seven decades. By synthesizing historical and thematic perspectives, we contribute to a clearer understanding of how EDT supports innovation in engineering education and how it can evolve to meet future social, technological, and environmental demands.

RESEARCH METHODS
1. Research Design

This study employed a hybrid research design, combining a Systematic Literature Review (SLR) with a Bibliometric Analysis to capture both the qualitative depth and quantitative patterns of Engineering Design Thinking (EDT) research. The SLR approach provided a structured framework for collecting and evaluating literature, while the bibliometric component allowed us to identify publication trends, citation networks, and emerging themes in the field [3], [27].

The integration of these two methods offered a balanced analysis; the SLR ensured transparency and rigor in the review process, whereas the bibliometric analysis revealed large-scale patterns that could not be captured through qualitative synthesis alone. This methodological combination is increasingly recognized as an effective strategy for mapping knowledge development in interdisciplinary fields such as engineering education [38].

2. Data Source

Data for this study were collected exclusively from the Scopus database, chosen for its extensive coverage of peer-reviewed journals and conference proceedings across engineering, education, and multidisciplinary domains. Scopus was preferred over other databases, such as Web of Science, due to its of engineering education and technology-related studies [39]. The search was conducted on December 27, 2025, using the keyword *"Engineering Design Thinking"*

The query was applied to article titles, abstracts, and keywords. This search yielded 26.549 records published between 1957 and 2025, with 1957 marking the earliest mention of the term "design thinking" in engineering contexts [40]. Although the initial Scopus search retrieved publications spanning from 1957 to 2025, the analytical scope of this study was deliberately restricted to articles published between 2020 and 2025. This time window was selected to capture the most recent and empirically mature phase of Engineering Design Thinking (EDT) research. Earlier publications were used solely to provide historical and contextual background, particularly for illustrating long-term publication trends, and were not included in the bibliometric mapping or thematic analyses.

3. Inclusion and Exclusion Criteria

To ensure data quality and relevance, a set of inclusion and exclusion criteria was systematically

applied. Eligible studies were required to be written in English, explicitly reference Engineering Design Thinking (EDT) in the title, abstract, or keywords, and be published as peer-reviewed journal articles, review papers, or conference proceedings indexed in Scopus. The data collection covered all available publications up to December 27, 2025. Publications written in languages other than English were excluded, along with non-scholarly works such as editorials, notes, errata, or retracted articles. Duplicate records, incomplete bibliographic entries,

and non-peer-reviewed materials, including books or reports without full-text access, were also removed from the dataset.

After applying these criteria, the total dataset was reduced from 26.549 to 10.207 records. A further round of manual screening identified 893 documents that met all inclusion criteria and were included in the full analysis. To maintain a multi-stage selection process was employed to filter eligible studies. The corresponding selection stages and criteria are summarized in Table 1.

Table 1. Inclusion and Exclusion Criteria

| Criteria	Inclusion	Exclusion
Research Focus	Studies explicitly addressing *Engineering Design Thinking (EDT)* in the title, abstract, or keywords	Studies not related to EDT or lacking explicit relevance
Data Source	Peer-reviewed publications indexed in the Scopus database	Non-Scopus indexed sources
Period	All available years up to December 27, 2025	Publications outside the defined retrieval scope
Document Type	Journal articles, review articles, and conference papers	Editorials, notes, errata, retracted articles, books, book chapters, reports
Language	English	Non-English publications (e.g., Chinese, Spanish, German)
Publication Status	Final published articles	Incomplete bibliographic records
Data Quality	Complete metadata (authors, title, abstract, keywords, affiliations)	Duplicate records or incomplete bibliographic information
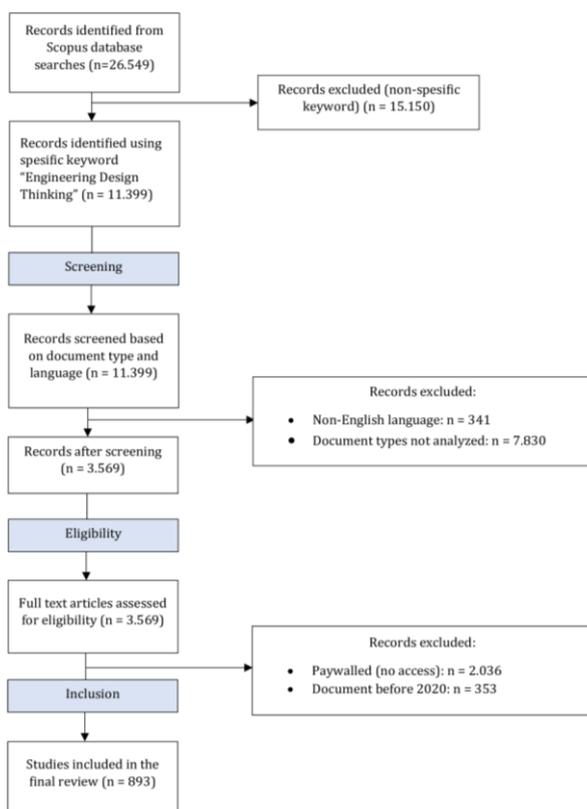
Figure 1. PRISMA Flow Diagram of the Article Selection Process

Figure 1 provides the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) diagram, which outlines the step-by-step

filtering process from identification to final inclusion, ensuring transparency and reproducibility. From an initial pool of 26,549 records, the application of specific keywords related to Engineering Design Thinking (EDT) reduced the dataset to 11,399 records, indicating that a substantial portion of the literature broadly related to engineering and design does not explicitly engage with EDT as a defined framework. Subsequent screening based on document type and language further narrowed the dataset to 3,569 records, reflecting the study's emphasis on peer-reviewed and accessible English-language sources. The eligibility assessment revealed additional structural barriers in the literature, with a notable number of articles excluded due to paywall restrictions (n = 2,036) and publications predating the defined analytical window (n = 533). The final inclusion of 893 studies reflects a rigorous multi-stage selection process that enhances the methodological robustness of the review while also revealing practical limitations related to database accessibility.

After applying the PRISMA protocol, 893 publications on *Engineering Design Thinking (EDT)* from 2020 to 2025 were analyzed. The bibliometric and thematic analyses provide insights into three key aspects of EDT research:

a. Its temporal growth and continued relevance,
b. Its global and institutional distribution, and
c. The conceptual and thematic structure emerging from the literature.

4. Data Extraction and Cleaning

Bibliographic information was exported from Scopus in CSV format, including metadata such as authors, titles, publication years, abstracts, keywords, citations, and affiliations. The following data-cleaning steps were undertaken:

a. Duplicate Removal: Entries with identical DOIs or titles were removed using Microsoft Excel.

b. Keyword Standardization: Variants such as *design-thinking* and *engineering design thinking* were unified.

c. Affiliation Standardization: Institution names were normalized (e.g., "Purdue Univ." and "Purdue University" were merged).

d. Manual Verification: Two reviewers independently checked inclusion decisions to maintain consistency and reduce bias.

The data extraction and cleaning procedures described above represent the operational implementation of the inclusion and exclusion criteria summarized in Table 1. These procedures ensured that the final dataset was accurate, coherent, and ready for bibliometric mapping ensured that both the SLR and bibliometric analyses adhered to recognized standards of scientific transparency [28], [41].

5. Bibliometric Analysis

To visualize and quantify relationships within the dataset, this study employed VOSviewer (version 1.6.20), a widely used software for constructing and visualizing bibliometric networks. VOSviewer was selected due to its effectiveness in mapping large-scale bibliographic data and its established use in Scopus-indexed bibliometric studies [42], [43]. Four types of bibliometric analyses were conducted:

a. Co-authorship Analysis to identify collaboration networks among authors, institutions, and countries.

b. Co-citation Analysis to capture the intellectual structure of the field by identifying frequently co-cited authors and sources.

c. Keyword Co-occurrence Analysis to map conceptual themes and thematic clusters based on the co-occurrence of author keywords.

d. Country and Institutional Analysis to examine the geographical and organizational distribution of Engineering Design Thinking (EDT) research output.

The bibliometric networks were visualized using the Visualization of Similarities (VOS) mapping technique. In these maps, nodes represent authors, institutions, countries, or keywords, while node size reflects publication frequency or occurrence. Link strength indicates the intensity of collaboration or co-occurrence relationships. Clusters of closely related nodes were automatically generated, revealing dominant research themes and illustrating the expansion and structural development of the EDT research field over time. RStudio or bibliometrix-based statistical analysis was not employed, as the study focused on mapping relational structures through network-based visualization using VOSviewer.

6. Thematic Synthesis

In addition to quantitative mapping, a thematic synthesis was conducted to interpret the underlying meanings and relationships behind the identified bibliometric patterns. Firstly, an open coding process was applied to extract recurring concepts and keywords from article titles and abstracts. Secondly, these concepts were organized through axial coding into broader analytical categories, such as technology integration and sustainability. Thirdly, selective coding was employed to integrate these categories into a cohesive framework that captures the conceptual essence of Engineering Design Thinking (EDT) research. This synthesis confirmed that EDT scholarship is structured around five interrelated domains: Technology Integration, Collaboration and Communication, Ideation and Creativity, Human-Centered Design, and Systems and Sustainability Thinking. These domains were subsequently examined in relation to the research questions.

7. Ethical Considerations

Because this study relied exclusively on publicly available bibliographic data, no human participants or personal information were involved. Ethical approval was therefore not required. Nonetheless, all data were handled responsibly, and each source was cited appropriately to maintain academic integrity.

RESULT AND DISCUSSION

1. RQ1 – Is Engineering Design Thinking Still Relevant for Future Research?

The analysis confirms that *Engineering Design Thinking* has evolved from an abstract pedagogical idea into a well-defined research field. Its early stages (1950s–1990s) focused primarily on defining design processes and problem-solving frameworks. By the mid-2000s, interest shifted toward educational applications, culminating in a post-2015 boom driven by digital transformation and global sustainability initiatives.

The historical publication trend presented in Figure 2 clearly indicates that EDT remains a vibrant and expanding area of inquiry. It should be noted that the historical trend is intended to contextualize the field's evolution, whereas all detailed analyses in this section are based exclusively on publications from 2020 to 2025. Between 1957 and 2010, research output was minimal, consisting mainly of conceptual discussions and methodological proposals. However, from 2015 onward, the number of publications grew exponentially with continued growth between 2020 and 2025. This pattern demonstrates that EDT has transitioned from a conceptual approach into a mature and expanding research domain within engineering education.
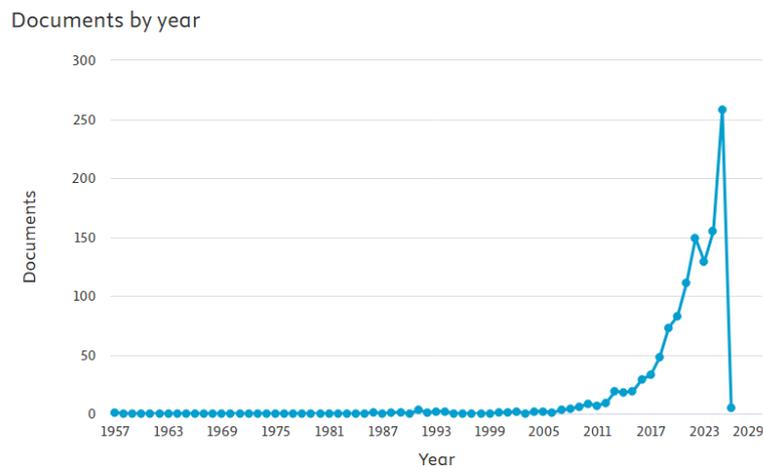
Documents by year

Figure 2. Growth of Engineering Design Thinking Publications (1957–2025)

The bibliometric data from Scopus shows a consistent upward trend in the number of publications on EDT. Starting from 19 articles in 2015, the volume reached its peak in 2025 with 181 documents. This trend is not merely a statistical increase but a reflection of the global educational shift toward Industry 4.0 requirements. The primary factor driving this growth is the urgent need for engineers with both technical process and soft skills, such as empathy and creativity [44], [45].

This surge corresponds with global educational reforms emphasizing innovation, STEM integration, and sustainability-driven learning. Three key drivers appear to underpin this growth:

a. Curricular Transformation: Engineering programs worldwide began embedding design thinking principles into their curricula to foster creativity and real-world problem-solving [32].

b. Technological Advancements: The emergence of AI, digital modeling, and virtual laboratories expanded opportunities for applying design-thinking methodologies [46], [47].

c. Global Sustainability Agendas: The alignment of EDT with the Sustainable Development Goals (SDGs) encouraged research exploring ethical, social, and ecological dimensions of engineering [36].

This evolution reflects broader shifts in engineering education, transitioning from knowledge transmission to experiential learning [48]. Recent studies have emphasized the empirical validation of EDT, exploring how it enhances student creativity, teamwork, and systems thinking [5], [49]. Such research demonstrates the transition from theoretical advocacy to measurable educational outcomes.

This longitudinal analysis extends beyond previous reviews by tracing the transformation of EDT from isolated pedagogical concepts into a mature, interdisciplinary framework [50], [51]. It is the first to document how Asian countries, particularly Indonesia and Malaysia, have emerged

as active contributors in global EDT research networks. This shift illustrates the democratization of innovation scholarship, where developing regions are no longer passive adopters but are increasingly shaping the global discourse on design thinking in engineering.

While research activity is increasing, it still lags behind the broader 'design thinking' literature in terms of publication volume and empirical diversity, suggesting that EDT, although conceptually mature, remains a developing field with ample room for empirical expansion. Its relevance is reinforced by its direct contribution to the core objectives of modern engineering education: innovation, systems awareness, and human-centeredness. These findings align with prior studies on the internationalization of EDT, which highlight its growing adoption across diverse educational contexts [52]. However, this study provides a more updated perspective than earlier studies that predicted a potential plateau in EDT research growth [53]. The implication is that EDT is becoming a mandatory competency rather than an elective pedagogical choice.

A key strength of this study lies in its integration of systematic literature review and large-scale bibliometric analysis, allowing for a comprehensive and data-driven assessment of EDT's research relevance. However, the study is not without limitations. The analysis is limited to Scopus-indexed publications, which may underrepresent regional or practice-based studies published in local or non-indexed outlets. Moreover, the focus on publication trends may not fully capture the depth of classroom-level implementation of EDT.

The findings of this study are largely consistent with previous research that identifies design thinking as an increasingly influential framework in engineering education. For example, earlier studies by [42] emphasize the growing scholarly attention toward design-oriented and interdisciplinary research approaches. However, this study extends prior work by demonstrating that EDT research is no longer concentrated solely in Western

contexts but has expanded significantly in Asia, particularly in emerging economies.

Overall, these findings confirm that EDT remains highly relevant for future research. The sustained growth and global diversification of EDT scholarship suggest that it will continue to play a critical role in shaping engineering education research, particularly in addressing ethical, social, and sustainability challenges that characterize 21st-century engineering practice [20], [54], [55].

2. RQ2 – What Is the Global Distribution of EDT Research?

a. Distribution by Country

Bibliometric mapping revealed that EDT scholarship is geographically diverse but concentrated within a few leading countries. The top ten countries with EDT publications are visually shown in Figure 3.
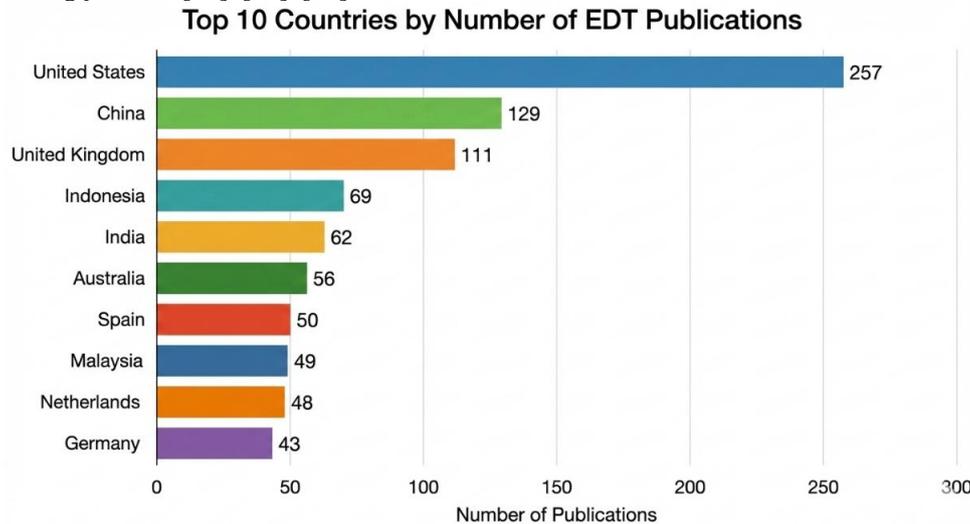
Top 10 Countries by Number of EDT Publications

Country	Number of Publications
United States	257
China	129
United Kingdom	111
Indonesia	69
India	62
Australia	56
Spain	50
Malaysia	49
Netherlands	48
Germany	43

Figure 3. Top Ten Countries by EDT Publications

The United States leads research on Engineering Design Thinking (EDT), reflecting long-term investment in design-oriented engineering pedagogy. China and the United Kingdom follow closely, with both countries actively integrating design-thinking approaches into national education initiatives. Notably, Indonesia, Malaysia, and India also rank among the top ten contributors, indicating increasing engagement from developing regions. This geographical distribution reveals two key patterns: established nations continue to shape the theoretical foundations and methodological directions of EDT research, while emerging economies are rapidly adapting and contextualizing EDT principles to address local educational priorities and innovation challenges.

Beyond publication volume, the bibliometric networks reveal an increasing trend in international collaboration, particularly between the Global North and South. These partnerships allow for localized adaptation of design-thinking practices while maintaining theoretical alignment with global standards [56]. For example, Indonesia's rise in EDT publications reflects government-backed innovation programs that connect engineering with sustainability education. However, collaboration intensity remains uneven. Many developing countries participate primarily as data contributors rather than research leaders. Expanding equitable partnerships and co-authorship initiatives could enhance diversity and innovation in EDT scholarship.

Such diversification strengthens the field's global impact, though it also reveals a need for more *cross-regional collaboration* and *knowledge exchange* between developed and developing contexts. This distribution pattern supports prior findings on the decentralization of engineering research, which highlight the increasing contribution of non-Western countries [57]. A weakness found in the distribution is the lack of cross-continental collaboration; most Indonesian papers are authored by local teams, missing the opportunity for global knowledge exchange.

b. Distribution by Institution

Institutional analysis identified Purdue University (United States) as the most prolific contributor, followed by Delft University of Technology (Netherlands) and Universitas Negeri Yogyakarta (Indonesia).
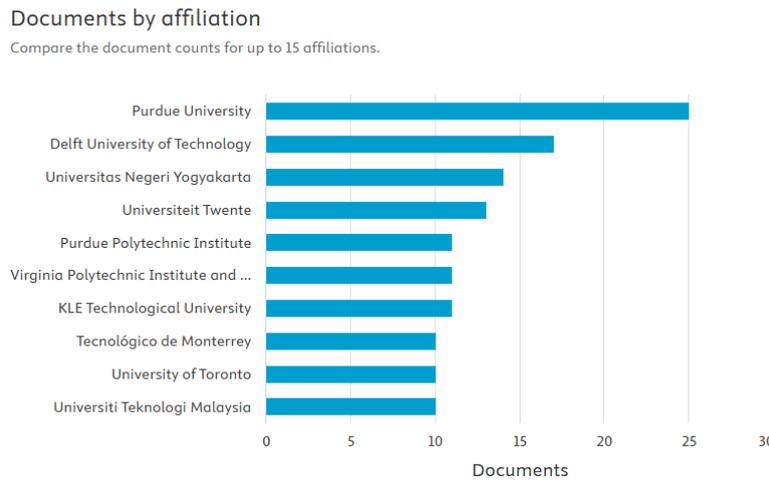
Documents by affiliation

Compare the document counts for up to 15 affiliations.

Figure 4. Top Contributing Institutions in EDT Research

The strong representation of Southeast Asian institutions suggests that the region has become an emerging hub for integrating design thinking in engineering education. Collaborations between Western and Asian universities, as reflected in the VOSviewer co-authorship networks shown in Figure 4, indicate a growing global research ecosystem centered on design-based pedagogy.

Purdue University emerges as the most prolific institution, followed by Delft University of Technology and Universitas Negeri Yogyakarta, indicating both strong representation from established Western engineering institutions and growing contributions from Southeast Asia. The presence of institutions such as KLE Technological University, Tecnológico de Monterrey, and Universiti Teknologi Malaysia further reflects the expanding geographic diversity of EDT scholarship. However, the overall distribution suggests that EDT research leadership remains concentrated in a small group of institutions, pointing to an uneven institutional landscape. This concentration underscores the need to broaden institutional participation to strengthen global knowledge production and reduce regional and institutional disparities in EDT research.
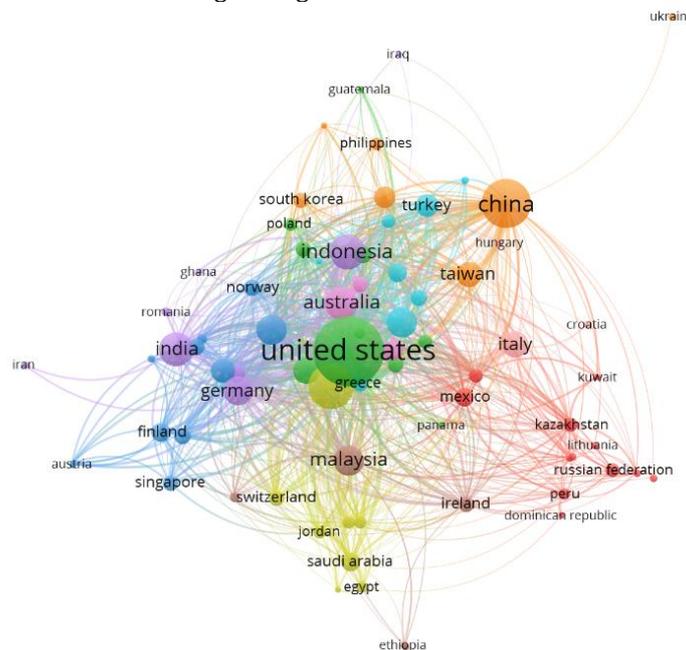

Figure 5. International Collaboration Network (VOSviewer Visualization)

The network visualization shown in Figure 5 reveals that authors from the United States and Europe frequently serve as central connectors, bridging smaller regional research communities. These actors occupy structurally central positions in the network, indicating their role as key knowledge brokers who facilitate the flow of theoretical frameworks, methodological standards, and collaborative practices across regions. The dense clustering around the United States suggests its function as a primary hub, linking research groups from Asia, Australia, and

parts of the Global South, thereby shaping dominant research agendas and citation pathways in EDT scholarship.

Emerging regional clusters, particularly in Southeast Asia (e.g., Indonesia, Malaysia, and the Philippines) and East Asia (e.g., China and Taiwan), demonstrate increasing internal collaboration as well as selective integration into global networks. This pattern reflects a dual structure in which global centers maintain agenda-setting influence, while peripheral and semi-peripheral regions are progressively strengthening their regional research ecosystems. Overall, the network structure highlights both the integrative role of transnational collaboration in advancing EDT and the persistent asymmetries in global knowledge production, underscoring the importance of fostering more balanced, multi-directional partnerships to enhance inclusivity and contextual diversity in EDT research.
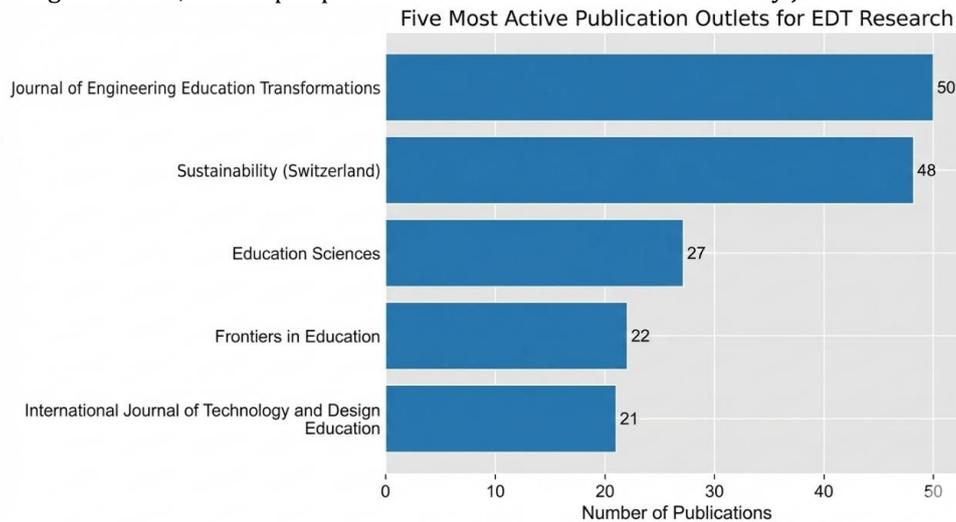
c. Distribution by Journal Source

Figure 6. The five most active publication outlets for EDT research

Figure 6 visually shows the distribution of research across various publication outlets, revealing a strong concentration in journals focused on pedagogical transformation and sustainability. The Journal of Engineering Education Transformations leads as the most prolific venue with 50 publications, followed closely by Sustainability (Switzerland) with 48 publications. These two journals serve as the primary hubs for the current discourse. There is a secondary tier of active outlets consisting of Education Sciences (27 publications), Frontiers in Education (22 publications), and the International Journal of Technology and Design Education (21 publications). This spread underscores an interdisciplinary research landscape that bridges specific engineering education methodologies with broader themes of sustainable development and technological design.

The prominence of journals such as Sustainability (Switzerland) and Frontiers in Education, which have global author pools and open-access models, facilitates wider participation from researchers in Asia, Latin America, and other emerging research regions. This helps partially mitigate geographic barriers and supports the diffusion of EDT research beyond traditional Western centers. However, the dominance of a limited number of outlets also suggests potential structural asymmetries, where scholars from developing regions may need to align with the thematic priorities and standards of these journals to gain visibility. In this sense, outlet concentration not only reflects where EDT research is published, but also indirectly shapes whose perspectives are amplified in the global EDT landscape, reinforcing the uneven global distribution observed in country and collaboration level analysis.

A strength of this global distribution analysis lies in its ability to capture how pedagogical emphases are represented across regions through publication patterns. However, although many of the reviewed studies report direct pedagogical evaluations such as classroom experiments and pre–post assessments, the present analysis captures how pedagogical effectiveness is represented in the literature rather than assessing learning outcomes across countries directly. As a result, variations in educational contexts and implementation practices may influence how these findings translate into practice.

These findings align with prior studies that highlight the global diffusion of design thinking in engineering education [1],[2]. However, this study extends previous research by empirically demonstrating how these dimensions co-evolve and reinforce one another at a global scale, rather than treating them as isolated instructional elements.

The global distribution of EDT research has important implications for both research and policy. The concentration of publications in established research nations highlights their continued influence in shaping EDT frameworks, while the growing contribution from emerging economies suggests increasing localization and contextual adaptation of EDT practices. For future research, this uneven distribution underscores the need for stronger cross-regional collaboration and comparative studies to better understand how EDT is implemented across diverse educational systems.

3. RQ3 – What Are the Theoretical and Practical Implications of EDT Research?

The theoretical implications of EDT are further supported by recurring conceptual patterns identified in prior definitions, including iteration, human-centeredness, systems thinking, and collaborative engagement. Across these definitions five recurring ideas stand out:

Iteration and reflection – framing,

a. design as a recursive and feedback-driven process of continuous improvement [58].
b. Human-centeredness – solutions guided by empathy and user understanding [32].
c. Integration of technology and creativity – merging analytical and imaginative processes [46], [59].
d. Systems perspective – considering design within broader ethical and ecological contexts [60].
e. Collaborative engagement – viewing design as a team-based, communicative process [61].

Keyword Co-occurrence and Thematic Mapping

Keyword co-occurrence analysis identified 20 highly connected terms within the EDT literature. The ten most frequent are listed in Table 2, and the VOSviewer Co-occurrence Map is captured in Figure 7.

Table 2. Top Keywords and Total Link Strength (Adapted from VOSviewer Output)

Rank	Keyword	Total Link Strength
1	Engineering Education	2031
2	Curricula	957
3	Education Computing	881
4	Education	728
5	Design	727
6	Learning System	720
7	Design Thinking	632
8	E-learning	628
9	Engineering	622
10	Systems Thinking	493

Table 2 indicates that EDT research is theoretically grounded in the core domains of engineering education and curriculum design, as reflected by the highest total link strengths for Engineering Education and Curricula. This pattern suggests that EDT functions not merely as an instructional technique but as a curriculum-level paradigm that reshapes learning objectives, competency frameworks, and instructional structures. The strong association with Design Thinking and Systems Thinking further implies a theoretical shift toward holistic, systems-oriented reasoning, positioning EDT as a response to complex, socio-technical challenges that cannot be addressed through linear problem-solving alone.

Practically, the prominence of Education Computing, Learning System, and E-learning demonstrates that EDT is increasingly operationalized through digital and technology-enhanced learning environments. This reflects a transition toward hybrid ecosystems that support iterative design, rapid prototyping, and collaborative feedback. The implication for institutions is that successful EDT implementation requires not only pedagogical change but also investment in digital infrastructure and faculty capacity. Collectively, these trends indicate that EDT research is shaping both the theoretical foundations of engineering education and the practical conditions under which future engineers are trained.
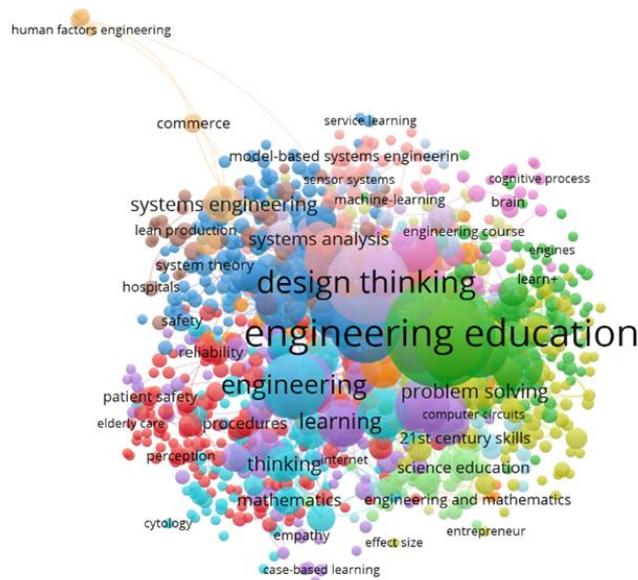
Figure 7. Keyword Co-occurrence Map (VOSviewer Output)

The bibliometric visualization reveals that the theoretical and practical implications of Engineering Design Thinking (EDT) center on an essential transition from technical reductionism to a multidimensional, human-centric paradigm. Theoretically, the strong convergence of engineering education, systems thinking, and cognitive processes suggests that EDT is no longer a peripheral toolkit but a core epistemological bridge that integrates psychological empathy with structural rigor, redefining how engineering knowledge is constructed. Practically, the dense mapping of 21st-century skills and problem solving underscores a critical shift for industry and academia to move beyond siloed expertise toward interdisciplinary agility. This necessitates the adoption of hybrid frameworks where technical solutions are validated through the lens of human factors and social impact, ensuring that future engineering outputs are not only functional but also systemically resilient and ethically aligned with complex global challenges.

These keywords formed five dominant conceptual clusters, confirming EDT's multidimensional nature:

a. Curricular Innovation in Engineering Education integrating design thinking into instructional design [62], [63].

b. Technology-Enhanced Learning linking e-learning, AI, and computational tools to design education [64], [65], [66].

c. Human-Centered and Sustainable Design embedding ethics and social responsibility into technical curricula [20], [53], [67].

d. Systems Thinking and Decision Processes addressing complexity and uncertainty in design environments [20].

e. Creativity and Ideation emphasizing divergent thinking, imagination, and problem reframing [68], [69], [70].

The synthesis of 893 articles reveals two major implications. Theoretically, EDT is evolving into Systems-Design Thinking, merging linear engineering logic with non-linear design cycles. The theoretical shift to a systems-oriented approach is a response to the wicked problems of the 21st century, where often generates unintended social and ethical consequences. Practically, the transformation of the engineer's identity is from a problem solver to a problem seeker [71], [72]. This shift is facilitated by low-fidelity prototyping, which reduces students' fear of failure.

Within higher education, EDT has proven to be an effective framework for developing both technical and non-technical competencies [73], [74]. Universities worldwide are shifting from lecture-based instruction to problem-based, project-based, and inquiry-driven learning, where students actively construct solutions to open-ended challenges [56]. Through these approaches, students not only learn engineering concepts but also develop critical thinking, adaptability, and teamwork skills [5], [75].

For example, when design thinking principles are applied in physics or mathematics courses, students report higher engagement and better conceptual understanding. This occurs because they can directly connect theory to practical contexts [76]. Moreover, when embedded in robotics, renewable energy, or sustainability projects, EDT helps learners integrate knowledge from multiple disciplines while fostering innovation and environmental awareness [60], [77]. Overall, EDT supports a shift from teacher-centered instruction to learner-centered construction of knowledge, aligning closely with 21st-century skill development and global education reform [78], [79].

These implications align with prior studies that emphasize EDT's role in developing resilient engineering graduates [80]. Our study adds a new contribution by identifying "Digital Prototyping (VR/AR)" as a practical game-changer in the

iteration phase [81]. A strength of this discussion is its direct link to graduate employability [82], while a weakness is the difficulty in standardizing EDT assessment across different engineering disciplines [83].

Integrating Core EDT Dimensions

Scholars have consistently highlighted five foundational attributes that define successful implementation of EDT:

a. Technology Integration – using digital tools and AI-driven systems to enhance design and prototyping [84], [85].

b. Collaboration and Communication – developing teamwork and interdisciplinary dialogue [61], [86].

c. Ideation and Creativity – encouraging flexible thinking and imaginative problem-solving [87], [88].

d. Human-Centered Design – prioritizing empathy and usability in design processes [9], [14].

e. Systems and Sustainability Thinking – incorporating ethical, social, and ecological awareness [89], [90].
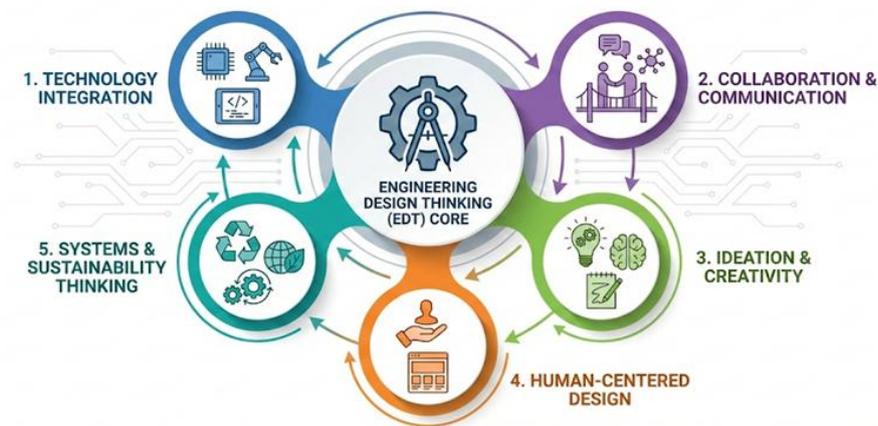

Figure 8. Conceptual Model of Engineering Design Thinking Attributes

The five attributes of Engineering Design Thinking (EDT) as illustrated in Figure 8, constitute a holistic and interconnected model rather than isolated competencies. Technology Integration supports visualization, simulation, and rapid prototyping processes [91], while Collaboration and Communication ensure that problem-solving remains inclusive and interdisciplinary [92]. Ideation and Creativity enable both divergent and convergent thinking essential for innovation [93], whereas Human-Centered Design anchors engineering practices in empathy and user experience [79]. Systems and Sustainability Thinking further embeds social responsibility and long-term considerations into technical decision-making [94]. Collectively, these dimensions form an integrative framework that aligns technical excellence with ethical awareness and societal values, reflecting competencies increasingly emphasized in 21st-century engineering education [95], [96].

Recent technological advancements have revolutionized how design thinking is taught and practiced in engineering. The integration of *Artificial Intelligence (AI)*, *Augmented Reality (AR)*, and *computational modeling* has created new opportunities for simulation, rapid prototyping, and collaborative experimentation [97], [98]. The adoption of *TRIZ* (the Theory of Inventive Problem Solving) has further strengthened EDT by introducing structured creative techniques that help

students break mental barriers and generate innovative ideas [84]. Similarly, AI-assisted modeling now supports ideation by automatically generating multiple design alternatives, allowing learners to focus on evaluating and refining the best ones [85].

Collaboration is a cornerstone of effective engineering design. EDT encourages cross-disciplinary teamwork that brings together technical, social, and creative perspectives [61]. In project-based settings, students engage in discussions, share feedback, and collectively refine their ideas on mirroring how professional engineering teams work [99], [100]. Communication skills complement collaboration by ensuring that complex ideas can be articulated clearly to diverse audiences [101]. As digital tools evolve, virtual platforms are increasingly used for documentation, visualization, and discussion, making remote or hybrid design collaboration feasible [102], [103].

Human-Centered Design (HCD) has become a defining pillar of EDT. It focuses on empathy, inclusion, and usability, ensuring that engineering solutions genuinely respond to human needs [104], [105]. Designers often begin by engaging with users through interviews or participatory workshops, allowing them to gain deep insights into user experiences and constraints [106]. Iterative prototyping then helps to validate these insights, ensuring functionality and satisfaction [14].

At the same time, sustainability thinking extends EDT's relevance to global challenges. By integrating life-cycle assessment and ethical reflection into the design process, engineers can minimize environmental impact and promote long-term well-being [89], [90]. The convergence of HCD and sustainability represents a shift from *problem-solving* to *problem-framing,* encouraging engineers to question what should be designed and why. Ultimately, EDT nurtures a mindset that combines empathy with responsibility. It empowers future engineers to create solutions that are not only technically sound but also socially meaningful and environmentally just.

Research Gaps and Future Directions

Despite its growth, EDT research faces several gaps:

a. Regional Concentration: Most studies come from developed nations, while local applications in developing contexts remain underexplored [107].
b. Empirical Evidence: Many works remain conceptual; more longitudinal and experimental designs are needed [108].
c. Measurement Tools: There is no standardized framework for assessing EDT learning outcomes [109].
d. Interdisciplinary Integration: Limited work connects EDT with cognitive science, environmental systems, or digital ethics [110].

Future studies should address these gaps through cross-cultural comparisons, multi-method research, and AI-assisted analysis. Such directions would deepen understanding of how EDT shapes not only learning but also professional identity and innovation capacity.

CONCLUSION

This study aimed to map the evolution of Engineering Design Thinking (EDT) research by combining a Systematic Literature Review (SLR) and a Bibliometric Analysis of publications indexed in Scopus from 2020 to 2025. Through this hybrid approach, we examined publication trends, global contributions, and conceptual structures that define EDT as both a pedagogical framework and a field of inquiry. The analysis revealed a steady and significant rise in EDT publications, particularly after 2015, reflecting the growing emphasis on creativity, sustainability, and human-centered learning in engineering education. The United States, China, and Indonesia emerged as the leading contributors, demonstrating a shift toward more globalized research collaboration.

The bibliometric results identified five interrelated attributes that characterize successful EDT implementation: Technology Integration, Collaboration and Communication, Ideation and Creativity, Human-Centered Design, and Systems and Sustainability Thinking. These dimensions form a coherent model that connects technical problem-solving with ethical awareness and social responsibility. To our knowledge, this is the first comprehensive and time-bounded synthesis of Engineering Design Thinking research that integrates systematic and bibliometric perspectives. By mapping publications across 68 years and introducing a five-attribute conceptual model, this study offers a new perspective on EDT's intellectual development. It not only highlights shifts in thematic focus and global participation but also establishes a foundation for future empirical and comparative studies in engineering education.

ACKNOWLEDGMENTS

REFERENCES

[1]   J. A. Sánchez Muñoz, G. Flores-Eraña, J. M. Silva-Campos, R. Chavira-Quintero, and J. M. Olais-Govea, "GenAI as a cognitive mediator: a critical-constructivist inquiry into computational thinking in pre-university education," *Front. Educ.*, vol. 10, 2025, doi: 10.3389/feduc.2025.1597249.

[2]   N. Phuseengoen and J. Singhchainara, "Effects of STEM-integrated movement activities on movement and analytical thinking skills of lower secondary students," *J. Phys. Educ. Sport*, vol. 22, no. 2, pp. 511–517, 2022, doi: 10.7752/jpes.2022.02064.

[3]   A. Bhandari, "Design Thinking: from Bibliometric Analysis to Content Analysis, Current Research Trends, and Future Research Directions," *J. Knowl. Econ.*, vol. 14, no. 3, pp. 3097–3152, 2023, doi: 10.1007/s13132-022-00920-3.

[4]   N. Rösch, V. Tiberius, and S. Kraus, "Design thinking for innovation: context factors, process, and outcomes," *Eur. J. Innov. Manag.*, vol. 26, no. 7, pp. 160–176, 2023, doi: 10.1108/EJIM-03-2022-0164.

[5]   M. Tramonti, A. M. Dochshanov, and A. S. Zhumabayeva, "Design Thinking as an Auxiliary Tool for Educational Robotics Classes," *Appl. Sci. Switz.*, vol. 13, no. 2, 2023, doi: 10.3390/app13020858.

[6]   K.-Y. Lin, Y.-T. Wu, Y.-T. Hsu, and P. J. Williams, "Effects of infusing the engineering design process into STEM project-based learning to develop preservice technology teachers' engineering design thinking," *Int. J. STEM Educ.*, vol. 8, no. 1, 2021, doi: 10.1186/s40594-020-00258-9.

[7]   Y.-L. Chang and H.-H. Wu, "A case study of increasing vocational high school teachers practices in designing interdisciplinary use of scientific inquiry in curriculum design," *Eurasia J.*

Math. Sci. Technol. Educ., vol. 11, no. 1, pp. 37–51, 2015, doi: 10.12973/eurasia.2015.1304a.

[8] N. Osman, S. N. D. Mahmud, and N. M. Arsad, "A systematic review of metacognitive dynamics in secondary physics education," *Int. J. Eval. Res. Educ.*, vol. 14, no. 5, pp. 3859–3871, 2025, doi: 10.11591/ijere.v14i5.32722.

[9] K. A. Bello, R. Wilson Maladzhi, M. G. Ntunka, L. Khumalo, and J. A. Adedeji, "A Framework for Embedding Design Thinking in Engineering Education and Practice," presented at the 2025 Annual IEEE Conference on Information Communication Technology and Society, ICTAS 2025 - Proceedings, 2025. doi: 10.1109/ICTAS64866.2025.11155662.

[10] M. Ravi and M. Besharat, "A holistic consideration of authentic assessments: student perception of assessment design, delivery, flexibility and creativity," *Eur. J. Eng. Educ.*, 2025, doi: 10.1080/03043797.2025.2480116.

[11] J. Milovanovic, T. Shealy, and A. Katz, "Higher perceived design thinking traits and active learning in design courses motivate engineering students to tackle energy sustainability in their careers," *Sustain. Switz.*, vol. 13, no. 22, 2021, doi: 10.3390/su132212570.

[12] N. Unkelos-Shpigel, "Elicit, specify, require, revise: enhancing requirements engineering process using gamification," *Softw. Qual. J.*, vol. 33, no. 3, 2025, doi: 10.1007/s11219-025-09721-8.

[13] R. M. Clark, L. M. Stabryla, and L. M. Gilbertson, "Use of active learning and the design thinking process to drive creative sustainable engineering design solutions," presented at the ASEE Annual Conference and Exposition, Conference Proceedings, 2018. [Online]. Available: https://www.scopus.com/inward/record.uri?eid=2-s2.0-85051235587&partnerID=40&md5=607c7f400868bbaa3f35e3a751ff1516

[14] R. Harte *et al.*, "A Human-centered design methodology to enhance the usability, human factors, and user experience of connected health systems: A three-phase methodology," *JMIR Hum. Factors*, vol. 4, no. 1, 2017, doi: 10.2196/humanfactors.5443.

[15] Y. Deng and W. Liu, "How to Develop Engineering Students as Design Thinkers: A Systematic Review of Design Thinking Implementations in Engineering Education," presented at the ASEE Annual Conference and Exposition, Conference Proceedings, 2023. [Online]. Available: https://www.scopus.com/inward/record.uri?eid=2-s2.0-85172137952&partnerID=40&md5=c63794bb291136befb3ea1224293ea83

[16] A. Mardiah, I. Irwanto, and A. Afrizal, "Taking Design Thinking to Classroom: A Systematic Literature Review Over a Past Decade," *J. Eng. Educ. Transform.*, vol. 36, no. 3, pp. 18–27, 2023, doi: 10.16920/jeet/2023/v36i3/23094.

[17] K. Sandhu, P. Sarkar, and K. Karupppasamy, "Entrepreneurial thinking in engineering design education: a comparative study of cognitive paradigms with insights from industry and academia," *Entrep. Educ.*, 2025, doi: 10.1007/s41959-025-00158-5.

[18] C. Rotondi, "How the informed relations between physical, digital and biological dimensions are changing the design practice, as well as the sustainability paradigm," *Front. Bioeng. Biotechnol.*, vol. 11, 2023, doi: 10.3389/fbioe.2023.1193353.

[19] C. L. Gargalo, H. Yu, N. Vollmer, A. Arabkoohsar, K. V. Gernaey, and G. Sin, "A process systems engineering view of environmental impact assessment in renewable and sustainable energy production: Status and perspectives," *Comput. Chem. Eng.*, vol. 180, 2024, doi: 10.1016/j.compchemeng.2023.108504.

[20] A. Gerosa, "Work in Progress: Systems Thinking as a Foundation for Sustainability Awareness and Ethical Use of Technologies," presented at the IEEE Global Engineering Education Conference, EDUCON, 2024. doi: 10.1109/EDUCON60312.2024.10578931.

[21] A. Abdurrahman, H. Maulina, N. Nurulsari, I. Sukamto, A. N. Umam, and K. M. Mulyana, "Impacts of integrating engineering design process into STEM makerspace on renewable energy unit to foster students' system thinking skills," *Heliyon*, vol. 9, no. 4, 2023, doi: 10.1016/j.heliyon.2023.e15100.

[22] V. C. Peligro, E. D. S. Antivo, M. E. Cañeda, M. P. Eviota, R. N. Verdeflor, and J. R. Sintos, "Training designs that affect motivation and intellectual progression of science, Engineering, and mathematics teachers," *Environ. Soc. Psychol.*, vol. 10, no. 6, 2025, doi: 10.59429/esp.v10i6.3308.

[23] T. Humphries-Smith and A. Adrian, "Intellectual property education - Thinking outside the box meets colouring within the lines," *Int. J. Learn. Intellect. Cap.*, vol. 9, no. 3, pp. 337–350, 2012, doi: 10.1504/IJLIC.2012.047292.

[24] J. K. L. Leung, D. T. K. Ng, and C.-Y. Tsui, "A Primer for Design and Systems Thinkers: A First-Year Engineering Course for Mindset Development," *Educ. Sci.*, vol. 14, no. 1, 2024, doi: 10.3390/educsci14010086.

[25] K. B. Christian, A. M. Kelly, and M. F. Bugallo, "NGSS-based teacher professional development to implement engineering practices in STEM instruction," *Int. J. STEM Educ.*, vol. 8, no. 1, 2021, doi: 10.1186/s40594-021-00284-1.

[26] B. G. Agazu, C. A. Kero, and K. L. Debela, "Transformational leadership and firm performance: a systematic literature review," *J. Innov. Entrep.*, vol. 14, no. 1, p. 29, Mar. 2025, doi: 10.1186/s13731-025-00476-x.

[27] T. Risal, D. Lie, and F. R. A. Lubis, "Agile Coaching: A Hybrid Systematic Literature Review and Bibliometric Analysis," *J. Bus. Manag.*, vol. 3, no. 1,

pp. 85–96, Aug. 2025, doi: 10.47134/jobm.v3i1.156.

[28] W. O. F. Annur and I. Saflia, "Healthcare Access : A Hybrid Systematic Literature Review and Bibliomertic Analisis," vol. 6, no. 3, 2025.

[29] P. E. E. Napitupulu, Y. Dananjaya, and H. M. Gunawan, "Green Human Resource Management Research Landscape: Trends, Gaps, and Future Directions from a Systematic Literature Review".

[30] A. N. Bhatt and A. Chakrabarti, "Gamification of design thinking: a way to enhance effectiveness of learning," *Artif. Intell. Eng. Des. Anal. Manuf. AIEDAM*, vol. 36, 2022, doi: 10.1017/S0890060422000154.

[31] A. Chou and L. H. Shu, "Using analogies to explain versus inspire concepts," *Artif. Intell. Eng. Des. Anal. Manuf. AIEDAM*, vol. 29, no. 2, pp. 135–146, 2015, doi: 10.1017/S0890060415000025.

[32] N. Mentzer, W. Lee, and S. R. Bartholomew, "Examining the Validity of Adaptive Comparative Judgment for Peer Evaluation in a Design Thinking Course," *Front. Educ.*, vol. 6, 2021, doi: 10.3389/feduc.2021.772832.

[33] S. Narayana Namasivayam, A. S. M. Al-Obaidi, and M. H. Hosseini Fouladi, "A Conceptual Curriculum Design Approach for Educating Engineers of and for the Future," *Indones. J. Sci. Technol.*, vol. 8, no. 3, pp. 381–396, 2023, doi: 10.17509/ijost.v8i3.59580.

[34] Y.-T. Huang, C.-L. Li, C.-C. Chang, and W. Tarng, "Enhancing Computational Thinking and Programming Logic Skills with App Inventor 2 and Robotics: Effects on Learning Outcomes, Motivation, and Cognitive Load," *Sensors*, vol. 25, no. 22, 2025, doi: 10.3390/s25227059.

[35] P. Wiltshier and M. Edwards, "Managing knowledge transfer partnership for a rural community: The outcomes at Wirksworth, UK," *Kybernetes*, vol. 43, no. 3, pp. 629–651, 2014, doi: 10.1108/K-07-2013-0128.

[36] M. Martínez Casanovas, "Exploring Design Thinking Methodologies: A Comprehensive Analysis of the Literature, Outstanding Practices, and Their Linkage to Sustainable Development Goals," *Sustain. Switz.*, vol. 17, no. 15, 2025, doi: 10.3390/su17157142.

[37] M. D. L. O. Cuevas-Cancino, M. Peña-Becerril, E. Mondragon-Estrada, and C. Camacho-Zuñiga, "Incorporating vertical collaboration to address sustainable development goals: the Monarch Route Project," *Front. Educ.*, vol. 9, 2024, doi: 10.3389/feduc.2024.1246889.

[38] N. Chotisarn and T. Phuthong, "Place Branding as a Soft Power Tool: A Systematic Review, Bibliometric Analysis, and Future Research Directions," *Int. Rev. Manag. Mark.*, vol. 15, no. 4, pp. 123–142, Jun. 2025, doi: 10.32479/irmm.18519.

[39] K. Sandhu, P. Sarkar, and K. Karupppasamy, "Understanding entrepreneurial thinking for designers: Perspectives from entrepreneurs, academicians, product designers, and students," *Think. Ski. Creat.*, vol. 56, 2025, doi: 10.1016/j.tsc.2024.101728.

[40] D. B. Breedon, "Analog versus digital techniques for engineering design problems," *IRE Trans. Ind. Electron.*, vol. PGIE-4, pp. 86–89, 1957, doi: 10.1109/IRE-IE.1957.5007789.

[41] L. Leydesdorff, L. Bornmann, J. A. Comins, and S. Milojević, "Citations: Indicators of Quality? The Impact Fallacy," *Front. Res. Metr. Anal.*, vol. 1, Aug. 2016, doi: 10.3389/frma.2016.00001.

[42] N. Donthu, S. Kumar, D. Mukherjee, N. Pandey, and W. M. Lim, "How to conduct a bibliometric analysis: An overview and guidelines," *J. Bus. Res.*, vol. 133, pp. 285–296, Sep. 2021, doi: 10.1016/j.jbusres.2021.04.070.

[43] F. Naqsyahbandi, E. Rohaeti, and A. K. Prodjosantoso, "Trends engineering design process in chemistry learning on databases: A bibliometric analysis," *Multidiscip. Rev.*, vol. 9, no. 3, 2026, doi: 10.31893/multirev.2026134.

[44] S.-Y. Qu, T. Hu, J.-L. Wu, and X.-M. Hou, "Experimental teaching centre platform 'new engineering' practice teaching mode," *Eurasia J. Math. Sci. Technol. Educ.*, vol. 13, no. 7, pp. 4271–4279, 2017, doi: 10.12973/eurasia.2017.00810a.

[45] T. Blanco, I. López-Forniés, and F. J. Zarazaga-Soria, "Deconstructing the Tower of Babel: a design method to improve empathy and teamwork competences of informatics students," *Int. J. Technol. Des. Educ.*, vol. 27, no. 2, pp. 307–328, 2017, doi: 10.1007/s10798-015-9348-6.

[46] J. Ji and T. Lucas, "The Role of Digital Intangible Culture Heritage Resources in Promoting Students' Innovative Ability in Higher Education Courses," *J. Trends Comput. Sci. Smart Technol.*, vol. 7, no. 4, pp. 658–677, 2025, doi: 10.36548/jtcsst.2025.4.003.

[47] Y. Li, "The use of educational psychology-based STEAM education concept in the development of English curriculum resources," *Sci. Rep.*, vol. 15, no. 1, 2025, doi: 10.1038/s41598-025-25007-2.

[48] C. Passoni, M. Caruso, A. Marini, R. Pinho, and R. Landolfo, "The Role of Life Cycle Structural Engineering in the Transition towards a Sustainable Building Renovation: Available Tools and Research Needs," *Buildings*, vol. 12, no. 8, 2022, doi: 10.3390/buildings12081107.

[49] J. A. Ramírez Masferrer, J. H. Herrera, and P. K. Echevarría, "Innovative Development of Student Skills in Raw Materials Engineering Programs," *UPorto J. Eng.*, vol. 8, no. 1, pp. 23–33, 2022, doi: 10.24840/2183-6493_008.001_0004.

[50] M. Goos, S. Carreira, and I. K. Namukasa, "Mathematics and interdisciplinary STEM education: recent developments and future directions," *ZDM - Int. J. Math. Educ.*, vol. 55, no. 7, pp. 1199–1217, 2023, doi: 10.1007/s11858-023-01533-z.

[51] J. W. Willison, "Research skill development spanning higher education: Critiques, curricula

and connections," *J. Univ. Teach. Learn. Pract.*, vol. 15, no. 4, 2018, doi: 10.53761/1.15.4.1.

[52] S. M. Pfotenhauer, D. Wood, D. Roos, and D. Newman, "Architecting complex international science, technology and innovation partnerships (CISTIPs): A study of four global MIT collaborations," *Technol. Forecast. Soc. Change*, vol. 104, pp. 38–56, 2016, doi: 10.1016/j.techfore.2015.12.006.

[53] B. Mazur and A. Walczyna, "Sustainable Development Competences of Engineering Students in Light of the Industry 5.0 Concept," *Sustain. Switz.*, vol. 14, no. 12, 2022, doi: 10.3390/su14127233.

[54] S. S. Guzey, T. J. Moore, and M. Harwell, "Building up stem: An analysis of teacher-developed engineering design-based stem integration curricular materials," *J. Pre-Coll. Eng. Educ. Res.*, vol. 6, no. 1, 2016, doi: 10.7771/2157-9288.1129.

[55] J. Tharakan, "Using educational technology to enhance creative and critical thinking skills through open ended design projects," *J. Eng. Educ. Transform.*, vol. 33, no. Special Issue, pp. 225–232, 2020, doi: 10.16920/jeet/2020/v33i0/150150.

[56] R. F. Colmenares-Quintero, D. M. Caicedo-Concha, N. Rojas, K. E. Stansfield, and J. C. Colmenares, "Problem based learning and design thinking methodologies for teaching renewable energy in engineering programs: Implementation in a Colombian university context," *Cogent Eng.*, vol. 10, no. 1, 2023, doi: 10.1080/23311916.2022.2164442.

[57] C. E. Coltman *et al.*, "The Biomechanics Research and Innovation Challenge: Development, Implementation, Uptake, and Reflections on the Inaugural Program," *J. Appl. Biomech.*, vol. 40, no. 2, pp. 155–165, 2024, doi: 10.1123/jab.2023-0056.

[58] A. Jackson, "'Does that mean it's a success?': Beginning Designers' Forethought and Self-Reflection in Engineering Design Thinking," *J. Technol. Educ.*, vol. 36, no. 2, pp. 61–88, 2025, doi: 10.21061/jte.v36i2.a.4.

[59] Z. Z. Li, H. Wang, D. Gašević, J. Yu, and J. K. Liu, "Enhancing Blockchain Adoption through Tailored Software Engineering: An Industrial-grounded Study in Education Credentialing," *Distrib. Ledger Technol.*, vol. 2, no. 4, 2023, doi: 10.1145/3632532.

[60] A. del Mastro, G. Garofalo, and P. Veragouth, "Terrestrial Education and Marine Structural Design: A Post-Sustainability Framework for Ocean Engineering Innovation," *Sustain. Mar. Struct.*, vol. 7, no. 3, pp. 88–100, 2025, doi: 10.36956/sms.v7i3.2084.

[61] M. Mendini, L. Bitetti, and P. C. Peter, "how to use co-creation in design thinking to promote and enhance healthy food experience among vulnerable populations," in *Design Thinking for Food Well-Being: The Art of Designing Innovative Food Experiences*, 2021, pp. 53–69. doi: 10.1007/978-3-030-54296-2_4.

[62] C. Castaño *et al.*, "Developing Sustainability Competencies Through Active Learning Strategies Across School and University Settings," *Sustain. Switz.*, vol. 17, no. 19, 2025, doi: 10.3390/su17198886.

[63] Z. Güney, "Visual literacy and visualization in instructional design and technology for learning environments," *Eur. J. Contemp. Educ.*, vol. 8, no. 1, pp. 103–117, 2019, doi: 10.13187/ejced.2019.1.103.

[64] M. N. H. Z. Zainal Alam and Z. Y. Zakaria, "Application of Computational Tools to Support Cooperative Learning in Bioreactor Design Course," *Int. J. Emerg. Technol. Learn.*, vol. 16, no. 15, pp. 46–61, 2021, doi: 10.3991/ijet.v16i15.23697.

[65] I. H. Y. Yim and J. Su, "Artificial intelligence literacy education in primary schools: a review," *Int. J. Technol. Des. Educ.*, vol. 35, no. 5, pp. 2175–2204, 2025, doi: 10.1007/s10798-025-09979-w.

[66] M. Lynch, U. Kamovich, K. K. Longva, and M. Steinert, "Combining technology and entrepreneurial education through design thinking: Students' reflections on the learning process," *Technol. Forecast. Soc. Change*, vol. 164, 2021, doi: 10.1016/j.techfore.2019.06.015.

[67] C. Hass, "Understanding the Human-Centered Design Process," in *Consumer Informatics and Digital Health: Solutions for Health and Health Care*, 2019, pp. 145–162. doi: 10.1007/978-3-319-96906-0_8.

[68] N. Nguyen, P. Pham, and N. T. Tu, "The Impact of Design Thinking on Problem Solving and Teamwork Mindset in A Flipped Classroom.," *Eurasian J. Educ. Res.*, vol. 2021, no. 96, pp. 30–50, 2021, doi: 10.14689/ejer.2021.96.3.

[69] A. Davletova, A. Nazarova, A. Alzhanova, and Y. Lazareva, "How does student creativity depend on teaching methods at the institute? Modern information technologies for education and creativity as manifestations of the specifics of the psyche," *Cogent Educ.*, vol. 12, no. 1, 2025, doi: 10.1080/2331186X.2025.2482502.

[70] M. D. Wolcott and J. E. McLaughlin, "Promoting creative problem-solving in schools of pharmacy with the use of design thinking," *Am. J. Pharm. Educ.*, vol. 84, no. 10, pp. 1271–1276, 2020, doi: 10.5688/ajpe8065.

[71] D. Case, E. Shirl Donaldson, and T. Ferreira, "Crossing Boundaries: How Technology and Occupational Therapy Students Create Solutions Together," *IEEE Access*, vol. 13, pp. 166695–166703, 2025, doi: 10.1109/ACCESS.2025.3612836.

[72] A. S. Putri, Z. K. Prasetyo, L. A. Purwastuti, A. K. Prodjosantoso, and H. Putranta, "Effectiveness of STEAM-based blended learning on students' critical and creative thinking skills," *Int. J. Eval.*

Res. Educ., vol. 12, no. 1, pp. 44–52, 2023, doi: 10.11591/ijere.v12i1.22506.

[73] Y. G. Sahin and U. Çelikkan, "Information technology asymmetry and gaps between higher education institutions and industry," *J. Inf. Technol. Educ. Res.*, vol. 19, pp. 339–365, 2020, doi: 10.28945/4553.

[74] M. Greene, R. Gonzalez, P. Papalambros, and A.-M. McGowan, "Design thinking vs. systems thinking for engineering design: What's the difference?," presented at the Proceedings of the International Conference on Engineering Design, ICED, 2017, pp. 467–476. [Online]. Available: https://www.scopus.com/inward/record.uri?eid =2-s2.0-85029752659&partnerID=40&md5=9b25301ac9 6a237a964c71261da5164f

[75] L. Ladachart, V. Radchanet, and W. Phothong, "Design Thinking Mindsets Facilitating Students' Learning of Scientific Concepts in Design-Based Activities," *J. Turk. Sci. Educ.*, vol. 19, no. 1, 2022, doi: 10.36681/tused.2021.106.

[76] D. Kazimova, S. Sadykova, A. Kostangeldinova, G. Tazhigulova, and A. Shertser, "Developing geometric thinking through culturally contextualized mathematical modeling: a yurt-building lesson for middle-school students in Kazakhstan," *Front. Educ.*, vol. 10, 2025, doi: 10.3389/feduc.2025.1622697.

[77] A. Ambiyar, U. Usmeldi, and R. Fadillah, "Developing and Assessing the Impact of an Integrated STEM Project-Based Learning Model in Vocational Education for Enhanced Competence and Employability," *Salud Cienc. Tecnol.*, vol. 5, 2025, doi: 10.56294/saludcyt20251786.

[78] I. de Vere, G. Melles, and A. Kapoor, "Product design engineering - a global education trend in multidisciplinary training for creative product design," *Eur. J. Eng. Educ.*, vol. 35, no. 1, pp. 33–43, 2010, doi: 10.1080/03043790903312154.

[79] S. Brink, Å. Wikberg Nilsson, M. de Hei, E. Sjoer, and W. Admiraal, "Student personas and their learner journeys in co-creative curriculum innovation," *Discov. Educ.*, vol. 4, no. 1, 2025, doi: 10.1007/s44217-025-00980-y.

[80] C. Lazou and A. Tsinakos, "A Framework for Participatory Creation of Digital Futures: A Longitudinal Study on Enhancing Media Literacy and Inclusion in K-12 Through Virtual Reality," *Inf. Switz.*, vol. 16, no. 6, 2025, doi: 10.3390/info16060482.

[81] F. Li *et al.*, "Application of Sustainable Development of Teaching in Engineering Education: A Case Study of Undergraduate Course Design of Raman Spectroscopy Based on Virtual Reality (VR) Technology," *Sustain. Switz.*, vol. 15, no. 3, 2023, doi: 10.3390/su15031782.

[82] F. D. Bacalso, C. J. B. Orquia, C. P. Paclipan, F. E. Villamor, E. C. Rellin, and A. L. Cutillas, "Curricular feedback from technology-based workforce: Assessment of soft skills among CTU graduates," *Environ. Soc. Psychol.*, vol. 10, no. 5, 2025, doi: 10.59429/esp.v10i5.2557.

[83] T. Vedhathiri, "Self-regulated learning (Srl) strategies on engineering faculty members, executives, and students," *J. Eng. Educ. Transform.*, vol. 35, no. 2, pp. 18–28, 2021, doi: 10.16920/jeet/2021/v35i2/22068.

[84] P. Panikar, C. Milligan, A. H. Al-Bulushi, S. M. Rizwan, and N. Al Balushi, "Empowering Future Innovators: A TRIZ-Integrated Design Thinking Approach to Engineering Prototyping and Entrepreneurship in Oman," *Int. J. Learn. Teach. Educ. Res.*, vol. 24, no. 2, pp. 322–351, 2025, doi: 10.26803/ijlter.24.2.17.

[85] C. V. Suresh Babu, M. R. Sekhar, A. Sachin, and B. Brindha, "Leveraging artificial intelligence techniques in design thinking tools for software engineering," in *Innovative Design Thinking Approaches in Software Engineering*, 2025, pp. 27–52. doi: 10.4018/979-8-3693-9531-8.ch002.

[86] S. Leem and S. W. Lee, "Fostering collaboration and interactions: Unveiling the design thinking process in interdisciplinary education," *Think. Ski. Creat.*, vol. 52, 2024, doi: 10.1016/j.tsc.2024.101520.

[87] T. K. Sahu, "Exploring the Role of Cognitive Processes in Design Ideation," presented at the Lecture Notes in Mechanical Engineering, 2025, pp. 435–446. doi: 10.1007/978-981-96-5495-6_35.

[88] S. Avsec and V. F. Savec, "Creativity and critical thinking in engineering design: The role of interdisciplinary augmentation," *Glob. J. Eng. Educ.*, vol. 21, no. 1, pp. 30–36, 2019, [Online]. Available: https://www.scopus.com/inward/record.uri?eid =2-s2.0-85063322653&partnerID=40&md5=c1495346b 60d53d3aaf58d7933102735

[89] E. A. Sanders, M. H. Goldstein, and J. L. Hess, "Course experiences that promote and inhibit human-centered design," *Int. J. Technol. Des. Educ.*, vol. 34, no. 2, pp. 783–808, 2024, doi: 10.1007/s10798-023-09834-w.

[90] H. Barbouch, "Nudge at the Service of Design for a Better World: Perspectives and Challenges," presented at the Advances in Science, Technology and Innovation, 2025, pp. 77–82. doi: 10.1007/978-3-031-76025-9_5.

[91] S. A. Soomro, H. Casakin, and G. V. Georgiev, "Sustainable design and prototyping using digital fabrication tools for education," *Sustain. Switz.*, vol. 13, no. 3, pp. 1–17, 2021, doi: 10.3390/su13031196.

[92] R. Belkbir, "Integrating the 6Cs in Moroccan Higher Education: A Framework for Inclusive AI Learning Design," *Arab World Engl. J.*, vol. 15, no. 3, pp. 217–234, 2024, doi: 10.24093/awej/vol15no3.13.

[93] S. R. Daly, E. A. Mosyjowski, and C. M. Seifert, "Teaching creativity in engineering courses," *J. Eng. Educ.*, vol. 103, no. 3, pp. 417–449, 2014, doi: 10.1002/jee.20048.

[94] J. Tharakan, "Sustainable Development Needs a Transformed Engineering Education," *J. Eng. Educ. Transform.*, vol. 36, no. Special Issue 2, pp. 173–178, 2022, doi: 10.16920/jeet/2023/v36is2/23024.

[95] I. Ram, R. Rosenberg-Kima, D. R. Lewin, A. Barzilai, O. Chumtonov, and I. Roll, "Active Learning and the Development of 21st Century Skills in Online STEM Education: A Large-Scale Survey," *Online Learn. J.*, vol. 29, no. 1, pp. 4–31, 2025, doi: 10.24059/olj.v29i1.3533.

[96] H. Hussin, P. Y. Jiea, R. N. R. Rosly, and S. R. Omar, "Integrated 21st century science, technology, engineering, mathematics (STEM) education through robotics project-based learning," *Humanit. Soc. Sci. Rev.*, vol. 7, no. 2, pp. 204–211, 2019, doi: 10.18510/hssr.2019.7222.

[97] L. C. Nguyễn, H. Q. Hoa, and L. H. P. Hien, "Integrating design thinking into STEM education: Enhancing problem-solving skills of high school students," *Eurasia J. Math. Sci. Technol. Educ.*, vol. 21, no. 4, pp. 1–11, 2025, doi: 10.29333/ejmste/16084.

[98] G. Murari Upadhyay, M. Joshi, S. Kumar, and P. Vats, "The Synergy of Design Thinking and Agile Methodologies: Implications and Applications Across Industries," presented at the Lecture Notes in Networks and Systems, 2025, pp. 329–338. doi: 10.1007/978-981-96-4139-0_28.

[99] J. S. Rossmann, "Engineering design as a liberal art: A first-semester introduction to design thinking," presented at the International Journal of Engineering Education, 2016, pp. 1502–1507. [Online]. Available: https://www.scopus.com/inward/record.uri?eid=2-s2.0-84974602914&partnerID=40&md5=8b9c06b7f42c19284e837a8c01100073

[100] P. Hirsch *et al.*, "Collaborating with design professionals and industry to build a design course for freshmen," presented at the International Journal of Engineering Education, 2003, pp. 103–109. [Online]. Available: https://www.scopus.com/inward/record.uri?eid=2-s2.0-0037221285&partnerID=40&md5=4b572c12e5cba0f79fe826dad124e8cc

[101] M. Aurisicchio, R. Bracewell, and G. Armstrong, "Supporting communication in the supply chain with design rationale maps," presented at the Proceedings of the International Conference on Engineering Design, ICED, 2013, pp. 335–344. [Online]. Available: https://www.scopus.com/inward/record.uri?eid=2-s2.0-84897596733&partnerID=40&md5=ae558bd4153ee10e5566f3c1d1ab8e06

[102] S. Lukosch and G. Kolfschoten, "Towards effective collaborative design and engineering," presented at the CEUR Workshop Proceedings, 2011. [Online]. Available: https://www.scopus.com/inward/record.uri?eid=2-s2.0-84890867189&partnerID=40&md5=5c93f7d396a764c420d09b1df0e4c882

[103] A. M. Maier, C. M. Eckert, and P. J. Clarkson, "Factors influencing communication in collaborative design," *J. Eng. Des.*, vol. 32, no. 12, pp. 671–702, 2021, doi: 10.1080/09544828.2021.1954146.

[104] S. L. Grau and T. Rockett, "Creating Student-centred Experiences: Using Design Thinking to Create Student Engagement," *J. Entrep.*, vol. 31, no. 2_suppl, pp. S135–S159, 2022, doi: 10.1177/09713557221107443.

[105] A. Vagal *et al.*, "Human-Centered Design Thinking in Radiology," *J. Am. Coll. Radiol.*, vol. 17, no. 5, pp. 662–667, 2020, doi: 10.1016/j.jacr.2019.11.019.

[106] A. Abeysiriwardhane, M. Lützhöft, E. S. Petersen, and H. Enshaei, "Future ship designers and context of use; Setting the stage for human centred design," presented at the RINA, Royal Institution of Naval Architects - Marine Design 2015, Papers, 2015, pp. 37–52. [Online]. Available: https://www.scopus.com/inward/record.uri?eid=2-s2.0-84945557836&partnerID=40&md5=39fa6cf936ba1c6e9f0643ed830768fd

[107] C. Soehnchen, A. Rietz, V. Weirauch, S. Meister, and M. Henningsen, "Creating an Intercultural User-Centric Design for a Digital Sexual Health Education App for Young Women in Resource-Poor Regions of Kenya: Qualitative Self-Extended Double Diamond Model for Requirements Engineering Analysis," *JMIR Form. Res.*, vol. 7, no. 1, 2023, doi: 10.2196/50304.

[108] B. Fatmawati, H. Hunaepi, and M. Asy'ari, "The moderating role of cognitive style on the relationship between critical thinking disposition, metacognitive awareness, and metacognitive strategies," *Soc. Sci. Humanit. Open*, vol. 12, 2025, doi: 10.1016/j.ssaho.2025.102006.

[109] C. K. Schlott, "Design Thinking and teamwork—measuring impact: a systematic literature review," *J. Organ. Des.*, vol. 13, no. 4, pp. 163–196, 2024, doi: 10.1007/s41469-024-00177-x.

[110] K. Berková, A. Kubišová, and K. Krelová, "The Future of Integrated Business and Engineering: Reading Skills of Business and Engineering Students," *Int. J. Eng. Pedagogy*, vol. 15, no. 6, pp. 35–51, 2025, doi: 10.3991/ijep.v15i6.57915.