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Innovation in Action: How Design Thinking is Shaping the Future of STEM Education

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Abstract. Design thinking has emerged as a significant pedagogical approach in STEM (Science, Technology, Engineering, and Mathematics) education, promoting creativity, problem-solving, and innovation among learners. Despite its increasing relevance, the knowledge base surrounding design thinking in STEM education remains fragmented across disciplines. This study conducted a comprehensive science mapping analysis to examine the intellectual, conceptual, and thematic structure of the field. A total of 897 Scopus-indexed publications from 2010 to 2025 were analyzed using citation, co-citation, and co-word techniques through VOSviewer. Results showed a consistent growth in scholarly output, with the United States (US), China, and Australia identified as the top contributing countries. Citation analysis highlighted influential foundational works that anchor the field and shape ongoing research directions. Co-citation mapping revealed interconnected intellectual traditions related to engineering education, reflective practice, and pedagogical innovation. Co-word analysis further identified three dominant thematic clusters: design-oriented pedagogies, teacher professional development, and interdisciplinary applications of design thinking within STEM learning environments. Overlay visualization of keywords demonstrated an emerging shift toward contemporary priorities, including sustainability, artificial intelligence (AI), and inclusive education, indicating a broadening of the field's pedagogical and societal relevance. These findings provide a structured understanding of how design thinking has evolved within STEM education, offering insights that can guide future scholarly inquiry. The

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study highlights the importance of transdisciplinary collaboration and context-responsive pedagogical models in strengthening the integration and long-term sustainability of design thinking in STEM education.

Keywords: Bibliometric analysis; design thinking; science mapping; STEM education; VOSviewer

1. Introduction

A growing need for instructional methods that cultivate creativity, critical thought, and innovation has become evident as individuals continue to deal with the impact on society of technological advances, social issues, and the changing nature of work in the 21st century (Antonio & Sison, 2026; Bellanca & Brandt, 2010). Design thinking has become an increasingly popular approach to combining cognitive, social, and technical skills within a single paradigm, enabling students to solve problems through empathy, creativity, and iterative processes (Liedtka, 2015; Razzouk & Shute, 2012). The roots of design thinking can be traced back to engineering and architecture; however, they are now being used in many other educational settings, especially in STEM education, where students need to combine knowledge across disciplines and engage in hands-on problem-solving using user-centered design principles (Henriksen et al., 2017; Li et al., 2019).

Recently there has been considerable movement in STEM education as it is viewed as critical to preparing learners for future job opportunities and the 4th Industrial Revolution (Bybee, 2013). Traditional STEM education often fails to teach students how to resolve complex issues creatively and humanistically using their minds and skills (English, 2016). The design thinking method addresses this conceptual and pedagogical gap by focusing attention on developing a mindset that supports experimentation, empathy, relationship-building, and resilience, which are traits necessary for students to engage effectively in inquiry, innovation, and addressing social needs through problem-solving (Bequette & Bequette, 2012; Noweski et al., 2012). For this reason, the use of design thinking as a pedagogical approach and as a cognitive skill set has become increasingly widespread in STEM classrooms (Li & Zhan, 2022).

There is an increasing amount of research on the topic of design thinking in STEM education at all levels. However, there is still a lack of cohesion in terms of how design thinking is being defined, how it is being used, what its effect on scholar-students is, and what it is being utilized for (Elwood, 2018; Mintrop, 2020). Many studies have examined the use of design thinking within K–12 and higher education settings; however, there has yet to be thorough mapping into the field. This mapping would help identify where the core concepts of design thinking fall in relation to other fields; this would be beneficial for educators and researchers trying to advance design thinking as an integral part of STEM education.

This study used a bibliometric and science mapping method that enables the systematic description of the evolution of design thinking, its current state, and some of the prevalent topics being studied around design thinking within the context of STEM education. This study aimed to develop an understanding of the field through the analysis of publishing activity, the identification of potential influence through citation patterns, the establishment of networks by means of co-citation analysis, and an examination of the frequency with which various key terms co-occur in the literature. This work is important to the development of the science of design thinking, design education, and design policy within STEM classroom environments for planning the future progression of research into design thinking and informing the design of influential curriculum.

2. Literature Review

2.1 Design Thinking as an Educational Paradigm

Since the early 2000s, design thinking has been recognized as a human-centered, iterative process, combining analytical reasoning and empathy with generative idea creation, prototype design, and reflection (Brown, 2009; Razzouk & Shute, 2012). Initially developed in the industrial design and engineering sectors (Cross, 2023), design thinking has expanded to include elements of transdisciplinary learning in educational environments, emphasizing meeting user needs through collaboration and experimentation to promote the development of 21st-century critical skills such as creativity, adaptability, and systems thinking (Henriksen et al., 2017; Liedtka, 2015).

The approach of design theory serves as an effective alternative to rote learning that isolates students and their knowledge. This approach focuses on providing students with real-life inquiry-based learning opportunities, including the ability to identify and investigate potential solutions to their own identified problems, generate creative ideas to solve those problems, create and implement prototypes or solutions to address the identified problems, and finally, analyze the effectiveness of their solutions (Noweski et al., 2012). In addition, this pedagogical framework encourages continual exploration through iterations rather than a single, fixed procedure; hence, this method provides students with an opportunity to develop a more flexible and empathetic response when attempting to solve complex ambiguous problems (Mintrop, 2020). Additionally, these characteristics make this model particularly appealing for educators to adopt, especially as the nature of STEM education increasingly demands real-world problem-solving and interdisciplinary integration within its curriculum.

2.2 Integration of Design Thinking in STEM Education

Combining design thinking with a focus on STEM will change the way we think about and approach education. While STEM has been focused on developing students' ability to use critical thinking skills and logic through experimentation with substances and processes, many have observed that the use of a strictly procedural approach to STEM has left out critical elements such as creativity, societal responsibilities, and the ability to understand problems within the context of real-world situations (Bybee, 2013; English, 2016). When students apply design thinking in conjunction with STEM education, their ability to think critically expands as they learn to consider multiple perspectives, develop innovative solutions, identify ethical considerations, and evaluate the effectiveness of their solutions within the larger context of a problematic situation (Li et al., 2019).

Several studies have demonstrated that incorporating design thinking into STEAM (Science, Technology, Engineering, Arts and Mathematics) education has increased student interest in STEM subjects. For example, design thinking has been shown to have a positive impact on the motivation, understanding, and collaborative work of elementary school-aged students who participate in STEAM projects utilizing design thinking techniques (Cook & Bush, 2018). The use of a framework to integrate design thinking with problem-based learning was presented by Nordin et al. (2024) as a method to empower students and encourage them to become reflective practitioners. Additionally, Becker and Mentzer (2015) studied the impact of design thinking on the problem-solving skills and understanding of engineering concepts of secondary school students.

Developing teachers have emerged as leaders in leveraging design thinking within teacher preparation. According to Chai (2019), design thinking can improve a teacher's professional development; it provides educators with a process of reflective thought and how educators develop thoughtful educational decisions. Despite this, educators often lack sufficient preparation or training to utilize design thinking effectively, primarily owing to a lack of clarity regarding the framework and the absence of a comprehensive conceptual model (Henriksen et al., 2017).

2.3 Knowledge Gaps and Fragmentation in the Literature

Although there is an increasing interest in design thinking in STEM education, the available literature remains divided on how it should be applied and defined, making it difficult to compare. Different terminology exists for "design thinking", "design-based learning", and "human-centered design" that are often used synonymously but may come from separate theoretical frameworks (Buchanan, 1992; Cross, 2011). Because of this lack of conceptual clarity, comparison studies cannot be easily performed, nor can coherently learning pedagogies be developed across STEM education. Additionally, although many individual case studies or small-scale projects have been conducted, very little has been accomplished in terms of synthesizing and mapping out the intellectual structure of the field or tracking the development of its themes over time (Zupic & Čater, 2015).

Many empirical investigations suffer from regionality; consequently, owing to the many operationalization methods of design thinking, it is difficult to draw comprehensive comparisons between the many contexts of investigation (Li et al, 2019; Mintrop, 2020). In addition, there are very few longitudinal or large-scale studies that gauge the development of the discipline, identify clusters of concepts that have formed over time, and identify areas requiring further study (Aria & Cuccurullo, 2017; Donthu et al., 2021). Therefore, there is a need for bibliometric studies to be conducted that not only provide overviews of the literature to date but also indicate how to quantify the level of scholarship, citation patterns, notable works, and emerging trends within the discipline.

2.4 Rationale for a Science Mapping Approach

Using bibliometric analysis to conduct science mapping provides a methodologically rigorous approach based on data to analyze the development and structure of research fields, as well as the changing patterns of knowledge within them (Donthu et al., 2021). With bibliometric mapping, one can identify prolific authors, the most influential articles, collaboration networks, and thematic clusters by using indicators such as co-citations, co-authorship, and keyword co-occurrence (Aria & Cuccurullo, 2017; Zupic & Čater, 2015). Areas such as design thinking within STEM education are rapidly evolving and have become increasingly popular; therefore, bibliometric mapping enables researchers to identify the theoretical foundations, connections between concepts, and areas where further research is needed.

Although numerous bibliometric studies have been conducted on the broader topic of STEM education (Cobo et al., 2011) and creativity within education (Ammar et al., 2024), very few have specifically examined the intersection of design thinking and STEM. As such, given the potential instructional implications and policy relevance of this area, it is the right time for an all-encompassing bibliometric study of this subject area so that educators, researchers, and education policymakers can gain a better understanding of how best to promote design thinking in STEM education from an integrated perspective at all levels (Ghufrooni, 2024)

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2.5 Research Objectives

In response to the identified gaps, this study aimed to:

2.5.1 analyze the publication trends, citation impact, and authorship patterns of research on design thinking in STEM education;

2.5.2 identify the most influential publications and intellectual foundations through citation and co-citation analyses;

2.5.3 map the conceptual structure and emerging research themes using co-word analysis, and;

2.5.4 explore the thematic evolution and recent trends in the field from 2010 to 2025.

3. Methodology

3.1 Bibliometric Approach

This bibliometric research design analyzed the intellectual and thematic structure of the scholarly literature on design thinking integrated into STEM education in a systematic manner. In contrast to the qualitative and interpretive based forms of narrative and systematic reviews, the quantitative methods of bibliometric analysis allow the researcher to evaluate such items and illuminate respective areas as defined within the scope of a defined area study by means of published works and citations. This includes how and by whom those citations relate to defined item structures and other such methodological approaches (Merigó & Yang, 2017; Moral-Muñoz et al., 2020). Only bibliometric analysis can effectively assess large bodies of scientific and technological literature in a systematic manner and with significant objectivity. This ensures that data presented by an author, institution or research organization is more trustworthy than would be possible with either narrative or systematic reviews (Mukherjee, 2021).

Owing to the rapidly evolving nature of the global economy and society, particularly in STEM education where concepts continuously advance alongside research and technological developments, bibliometric methods provide valuable opportunities for researchers. These methods enable the identification of prolific authors and institutions, the recognition of key intellectual milestones, the analysis and mapping of research trends over time, and the detection of underexplored areas that require further investigation (Ghaffari, 2015).

Aria and Cuccurullo's (2017) method has provided guidance to research with respect to four basic components: (a) obtaining data from the Scopus database, (b) refining and cleansing the file, (c) analyzing the data for descriptive and network attributes, and (d) building visual representations of the results. Co-citation, co-word analysis, and temporal overlay were created using the VOSviewer software program, which has become a standard for developing and displaying bibliometric networks in research. Co-citation maps help shape the foundation of the discipline, keyword co-occurrence maps help clarify the way thematic areas are structured, and overlay maps show where research outputs are trending over time.

3.2 Search Strategy and String

To gather pertinent literature for the bibliometric review, an extensive search of the Scopus database—a highly regarded, peer-reviewed literature source that provides a multidisciplinary overview of the academic literature—was carried out. The Scopus database offers high-quality access to the academic literature in many of the advanced bibliometrics software products, including VOSviewer and bibliometrics (Baas et al., 2020). A search strategy based on Boolean logic was developed to identify literature that expressly discusses design thinking as applied to various areas of STEM education.

The TITLE-ABS-KEY search string applied was: ("design thinking" OR "design thinking skills" OR "design thinking competence" OR "design thinking approach") AND ("STEM education" OR "science education" OR "technology education" OR "engineering education" OR "mathematics education" OR "biology education" OR "chemistry education" OR "physics education" OR "environmental education" OR "STEM learning" OR "STEM teaching" OR "STEM integration").

This search formulation attempted to cover both broad and discipline-specific aspects of STEM disciplines by allowing the identification of a range of contexts where design thinking has been used, examined, or theorized. The strategies for combining related terms were based on the systematic application of Boolean operators to improve the recall and precision of the identified literature. Table 1 outlines the rationale behind the components of the search string:

Table 1: Search string in Scopus database

	Keywords/Operators	Justification
1	"design thinking", "design thinking skills", "design thinking competence", "design thinking approach"	Captures various conceptualizations and terminologies used in the literature to describe the construct of interest.
2	"STEM education", "science education", "technology education", "engineering education", "mathematics education" "biology education", "chemistry education", "physics education", "environmental education", "STEM learning", "STEM teaching", "STEM integration"	Encompasses general and specific disciplinary contexts in which design thinking is being implemented or explored in education.
3	AND / OR	Enables the effective combination of concept domains and ensures retrieval of literature that lies at the intersection of design thinking and STEM.
4	TITLE-ABS-KEY	Searches the title, abstract, and keywords fields to balance topic specificity and relevance while avoiding retrieval of unrelated full-text content.

3.3 Inclusion and Exclusion Criteria

To maintain the academic integrity of the bibliometric analysis, strict parameters were applied to create an appropriate and relevant dataset before analyzing the articles. The parameters included language requirements. All documents analyzed must have been published in English, and only those articles that included relevant keywords within their title/abstract/or keywords would be included in the analysis. Conversely, if any publication was published in a language other than English, it was removed from the dataset. In addition, any duplicate entries and incomplete bibliographic records were eliminated from the dataset to ensure data integrity. The established criteria for the final dataset appropriately reflect the body of literature surrounding design thinking in STEM education.

3.4 Data Cleaning and Preparation

The metadata generated from the initial search in Scopus was downloaded as two separate exports (in .csv) containing all fields of bibliographic data that would allow comprehensive analysis (e.g., title of the article, names of authors, institutions of affiliation, keywords, abstract, year of publication, and number of times cited). A rigorous cleaning process was undertaken to ensure that any analytics based upon the data were accurate. The duplicates were deleted, the names of authors and institutions were standardized, and the terms used to describe keywords were normalized by clustering semantically similar terms to enhance the coherence of the co-word mapping. The cleansed dataset was loaded into VOSviewer to perform descriptive and relational bibliometric analyses, including co-authorship networks, keyword co-occurrence maps, source impact assessment, and thematic evolution mapping.

3.5 Analytical Techniques

This study provided a systematic examination of the intellectual landscape and thematic progression of design thinking within STEM education through the application of multiple bibliometric indicators and science mapping techniques using a quantitative bibliometric methodology. Utilizing both structural and semantic facets of design thinking, the bibliometric indicators enabled the researchers to obtain a multidimensional understanding of design thinking's evolution, its scholarly impact, and how design thinking will develop moving forward.

Citation analysis served as the foundation for assessing the scholarly impact and scholarly productivity of researchers in design thinking in STEM education. Through citation analysis, citation counts could be quantified to identify the most significant articles, authors, and journals in design thinking in STEM education. This makes the writings visible that have had the most significant impact on shaping the discourse around design thinking in STEM education (Ardanuy, 2012). Citation analysis also indicated the key intellectual milestones that form the basis of this scholarly area.

To further define the intellectual structure of the research in design thinking in STEM education, co-citation analysis was conducted. Co-citation analysis measures the number of times that a pair of documents is cited together and reveals the conceptual connections between these documents and thus identifies groups of studies with similar themes (Kleminski et al., 2020). The use of co-citation analysis enabled researchers to identify the cognitive architecture and theoretical foundations of a research area.

To provide an additional view of the literature, co-word analysis was used to describe the semantics of the literature. Co-word analysis was based on an analysis of the co-occurrence and frequency of keywords published by authors to determine the primary research themes, connections between concepts, and trends that have emerged in the area (Su & Lee, 2020). Co-word networks were also used to visually represent and therefore interpret clusters of themes as well as determining hot spots of research in STEM education.

Thematic evolution analysis was a third method for examining the evolution of key topics over time. By segmenting the full dataset into time-based periods of publication and identifying keyword clusters within each period, the analysis reveals the longitudinal evolution of the research area. The analysis demonstrates how specific research areas in design thinking within STEM education have emerged, grown, declined, or sustained attention over time, revealing whether these areas have maintained consistent focus (Cobo et al., 2011). Thus, through the combined application of these analyses, the contours and trajectories of design thinking literature as it relates to STEM education have been mapped based on empirical data.

4. Results and Findings

4.1 Descriptive Characteristics

Descriptive analyses revealed that scholarly publications relating to design thinking in STEM education have been produced by many countries globally. The geographic location of the publications shown in Figure 1 indicates that while research has been produced across multiple regions, most of the research has come from several leading countries. The US has been the largest contributor to research output, indicating that the US maintained the dominant global position about design thinking.

China, the United Kingdom (UK), Australia, Canada and Germany were also leaders in the number of publications produced and indicate that both Western and Asian scholars are actively engaged in design thinking. Additionally, the representation of other countries such as India, South Korea and the Netherlands reinforced the growing global interest in how to incorporate design thinking methods into STEM education. Therefore, design thinking could be viewed as an educational methodology that is universally applicable across cultures (Figure 1):

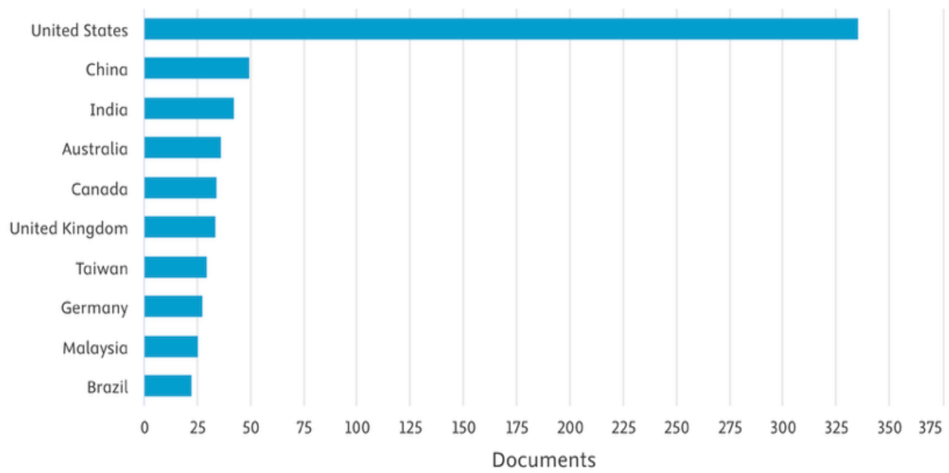

Figure 1: Documents by country

Figure 2 illustrates the various disciplines to which the different publications relate; many researchers have produced work which encompasses many different disciplines. It appeared that there is considerable overlap between these disciplines in the body of literature related to design thinking. The dominant types of journals identified in the analysis were Engineering (with the greatest number of articles), Education, Computer Science and Social Sciences; therefore, it can be concluded that design thinking is relevant in technical as well as pedagogical domains.

The analysis also showed that several academic disciplines are represented in the literature on this topic, such as Psychology, Arts and Humanities and Business and Management, demonstrating that design thinking is multi-faceted in its origin, combining the characteristics of both human-centered and creative disciplines. The intersection of Engineering (technical) and Education (pedagogical) represented the central axis of this research area, evident by the high frequency of co-occurring keyword combinations relating to "engineering education", "curricula" and "students".

Taken altogether, these insights into the description of design thinking in STEM education showed that it has developed in scope and depth because of increasing global participation and collaboration across disciplines. This may enable more in-depth analysis of its intellectual structure and thematic pathways for future research possibilities in this area.

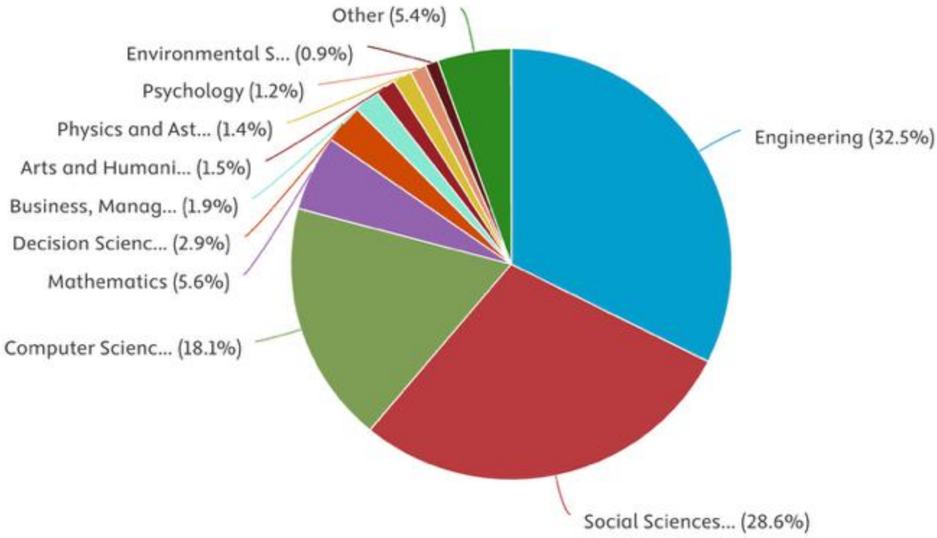

Figure 2: Documents by subject area

4.2 Citation Analysis

The Scopus database yielded a bibliometric analysis of 906 documents that included the use of "design thinking" and "STEM education" together with all relevant disciplines, such as biology and chemistry as well as physics and math. To provide an eligible dataset, the study filtered for language (English), document type (articles or conference papers) and then screened for relevance. The final eligible dataset consisted of 897 published documents from 2010 to 2025 (mid).

As a group, these documents have received 9,235 citations, indicating a significant increase in academic interest regarding design thinking as a transformative approach to pedagogy and problem solving within STEM environments. The h-index of 36 indicated that there were 36 published documents within the dataset that have received at least 36 citations each, indicating that most of this work has a moderate or strong scholarly impact in this area of study. The average number of citations per document was approximately 10.3, indicative of an overall consistent level of citation performance across the body of literature (Figure 3):

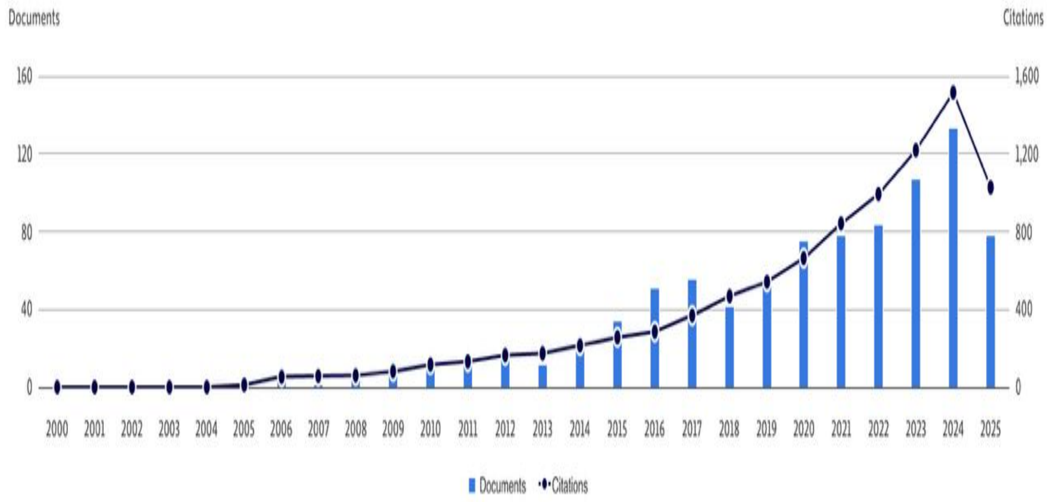

Figure 3: Number of publications and citations (Source: Scopus)

The growth rate of both publications and citations over the two years was exponential as evidenced by Figure 3. The initial growth of publication output was modest during the early 2000s but has seen a dramatic increase from 2012 onwards. In 2023, the highest number of published works (over 130) occurred, and the number of citations was also at the highest level (more than 1,400). There appears to be a decline in citation counts for 2024 and 2025; however, the overall figures still indicate sustained academic interest in the subject. The upward trend reflected an increase in awareness of the potential for design thinking to enhance creativity, promote teamwork and encourage innovation in STEM education, as well as its alignment to 21st-century skills and interdisciplinary education.

Citation analysis was a significant factor in evaluating bibliometric studies, as it revealed not only the scholarly influence and contribution of each publication but also provided insights into the intellectual foundations of a particular field of study (Zupic & Cater, 2015). Table 2 includes the most frequently cited ten publications from the dataset. Citation counts ranged from 90 to 2,747. The insights provided by the highest number of cited publications may shed light on the various theoretical foundations, pedagogical innovations, and technological developments that have shaped the discipline.

Table 2: Top 10 most cited documents

Rank	Author(s)	Year	Title	Source	Citations
1	Dym, C. L., Agogino, A. M., Eris, O., Frey, D. D., & Leifer, L. J.	2005	Engineering design thinking, teaching, and learning	*Journal of Engineering Education*, 94(1), 103–120	2,747
2	Dove, G., Halskov, K., Forlizzi, J., & Zimmerman, J.	2017	UX design innovation: Challenges for working with machine learning as a design material	*Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems*, 278–288	330
3	Li, Y., Schoenfeld, A. H., diSessa, A. A., Graesser, A. C., Benson, L. C., English, L. D., & Duschl, R. A.	2019	Design and design thinking in STEM education	*Journal for STEM Education Research*, 2(2), 93–104	167
4	English, L. D., & King, D. T.	2015	STEM learning through engineering design: Fourth-grade students' investigations in aerospace	*International Journal of STEM Education*, 2(1), 14	158
5	Hey, J., Linsey, J., Agogino, A. M., & Wood, K. L.	2008	Analogies and metaphors in creative design	*International Journal of Engineering Education*, 24(2), 283	150
6	Kuo, H. C., Tseng, Y. C., & Yang, Y. T. C.	2019	Promoting college students' learning motivation and creativity through a STEM interdisciplinary PBL human-computer interaction system	*Thinking Skills and Creativity*, 31, 1–10	149
7	Chai, C. S.	2019	Teacher professional development for STEM education: A review from the TPACK perspective	*The Asia-Pacific Education Researcher*, 28(1), 5–13	118
8	Cook, K. L., & Bush, S. B.	2018	Design thinking in integrated STEAM learning: Exploring exemplars in elementary grades	*School Science and Mathematics*, 118(3–4), 93–103	101
9	Becker, K., & Mentzer, N.	2015	Engineering design thinking: High school students'	*2015 Int'l Conf. on Interactive Collaborative*	92

			performance and knowledge	*Learning (ICL)*, 5–12. IEEE	
10	Geng, J., Jong, M. S. Y., & Chai, C. S.	2019	Hong Kong teachers' self-efficacy and concerns about STEM education	*The Asia-Pacific Education Researcher*, 28(1), 35–45	90

As shown in Table 2, the cornerstone article written by Dym et al. (2005) has been cited over 2,747 times and laid the theoretical foundations for understanding how design thinking relates to engineering education. Additionally, it has been influential in asserting the importance of designing epistemology and reflective practice as integral parts of the STEM learning process. The top-cited articles reflected several thematic trends.

First, Dym et al. (2005), Hey et al. (2008), and Li et al. (2019) share a common theme: the development of creativity, analogical reasoning, and epistemic growth through design. Collectively, the three articles helped define design thinking as both a cognitive and an educational construct. Secondly, there was a strong focus on combining curricular areas into a single unit and developing innovative teaching methods through design thinking in elementary and secondary schools. Publications by English and King (2015), Cook and Bush (2018), and Becker and Mentzer (2015) discussed the use of inquiry-based and hands-on projects, including aerospace investigations and engineering design challenges, in the primary and secondary classroom environments.

Together, these three publications demonstrated the value of adopting a design-oriented approach to enhance student engagement and improve academic achievement. A third emerging theme was the use of technology and interdisciplinary learning environments within these studies. For example, Dove et al. (2017) and Kuo et al. (2019) showed that by using digital tools such as machine learning and human-computer interactions, students have access to increased opportunities for collaboration, personalized instruction, and innovative creation while participating in STEM education through design thinking processes. In addition to being representative of innovative practices across global educational systems, they also illustrated those digital tools and technology support new methods of collaboration, individualization of the learning process, and innovative creation.

Fourth, teacher competency and their ongoing professional development represented a major theme in two studies by Chai (2019) and Geng et al. (2019). These articles examined the significance of a teacher's TPACK, self-efficacy, and concerns regarding the effective implementation of design thinking in STEM education. Their inclusion among the most frequently cited studies reflects a call for more systemic support and teacher readiness within the field. Lastly, several articles emphasized the potential for interdisciplinary application of design thinking; specifically, it can serve as a bridge between the STEM fields and the arts. The integration of creativity, science, and engineering can be found in studies on STEAM learning experiences and problem-based, interdisciplinary models. This indicates a movement toward holistic, cross-disciplinary approaches to education. According to the citation analysis, there was a multidimensional growth of research on design thinking in STEM education. The field continued to mature with a strong theoretical foundation while new classroom practices, technology-based learning, and teacher training were rapidly evolving. These three dimensions of research demonstrated the increasing need for future-ready or design-based pedagogies and approaches to learning in STEM education.

4.3 Co-Citation Analysis

Co-citation analysis allowed researchers to identify patterns in citation between publications (Boyack & Klavans, 2010). Co-citation analysis identified 68 important references (minimum threshold of 11 citations) from 24678 total citations that establish the foundation of creativity research in STEM education. The 10 most frequently referenced publications are listed in Table 3:

Table 3: Top 10 most co-cited documents and their total link strength

Rank	Author(s)	Year	Title	Source	Citations	Total Link Strength
1	Dym, C. L., Agogino, A. M., Eris, O., Frey, D. D., & Leifer, L. J.	2005	Engineering design thinking, teaching, and learning	*Journal of Engineering Education*, 94(1), 103–120	47	152
2	Razzouk, R., & Shute, V.	2012	What is design thinking and why is it important?	*Review of Educational Research*, 82(3), 330–348	40	116
3	National Research Council	2013	*Next Generation Science Standards: For States, By States*	The National Academies Press	24	80
4	Schön, D. A.	1983	*The Reflective Practitioner: How Professionals Think in Action*	Basic Books	11	77
5	Buchanan, R.	1992	Wicked problems in design thinking	*Design Issues*, 8(2), 5–21	21	64
6	Lawson, B., & Dorst, K.	2009	*Design Expertise*	Taylor & Francis	9	63
7	Crismond, D. P., & Adams, R. S.	2012	The informed design teaching and learning matrix	*Journal of Engineering Education*, 101(4), 738–797	15	59
8	Cross, N.	2013	*Design Thinking: Understanding How Designers Think and Work*	Berg Publishers	8	58

9	Goel, V.	1995	*Sketches of Thought*	MIT Press	7	55
10	National Research Council	2012	*A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*	The National Academies Press	13	49

The most important paper on this topic was "Engineering Design Thinking, Teaching, and Learning" by Dym et al. (2005). This publication received 47 citations and had a combined linkage strength of 152, indicating it formed the basis of a very strong co-citation network between other articles. Dym et al. (2005) were known to have been the first to define engineering design thinking for education, which remains a significant source in STEM-based research of design thinking. This was supported by Razzouk and Shute (2012), who discussed both the characteristics and significance of design thinking to education. Razzouk and Shute received 40 citations; their linkage strength was 116. Razzouk and Shute have been co-cited often with both theoretical and practical articles, as their article played an important role in aiding other researchers to conceptualize design thinking across many different fields.

The two official reports published by the National Research Council (2012, 2013)—A Framework for K–12 Science Education and the Next Generation Science Standards (NGSS)—were two of the most heavily co-cited documents, with 24 and 13 citations, respectively. Their inclusion exemplified both curricular and policy-level endorsement for the integration of design practices within STEM education.

Additionally, seminal contributions from authors including Schön's (1983) The Reflective Practitioner, Buchanan's (1992) "Wicked Problems in Design," Lawson and Dorst's (2009) "Design Expertise" showed that these pieces of work are similar in terms of scholarly impact, as reflected by their high degree of co-citation and link strength. These three documents were frequently cited together in literature examining cognitive, reflective, and expert aspects of design thinking. The list also included works such as "Informed Design Pedagogy" (Crismond and Adams, 2012), "Design Cognition" (Cross, 2011), and "Design as Thought Process" (Goel, 1995). Although the citation counts of some of these works are lower, their strong link strength (49–77) suggests a prominent role within the co-cited literature network.

The high number of citations and strong connections among these articles indicated that they are key articles by many authors when they conduct research about how to use design thinking in the context of STEM education. The articles have helped develop theory and methods in the field and are the oldest and most contemporary reference points for the many articles published on design thinking in STEM education.

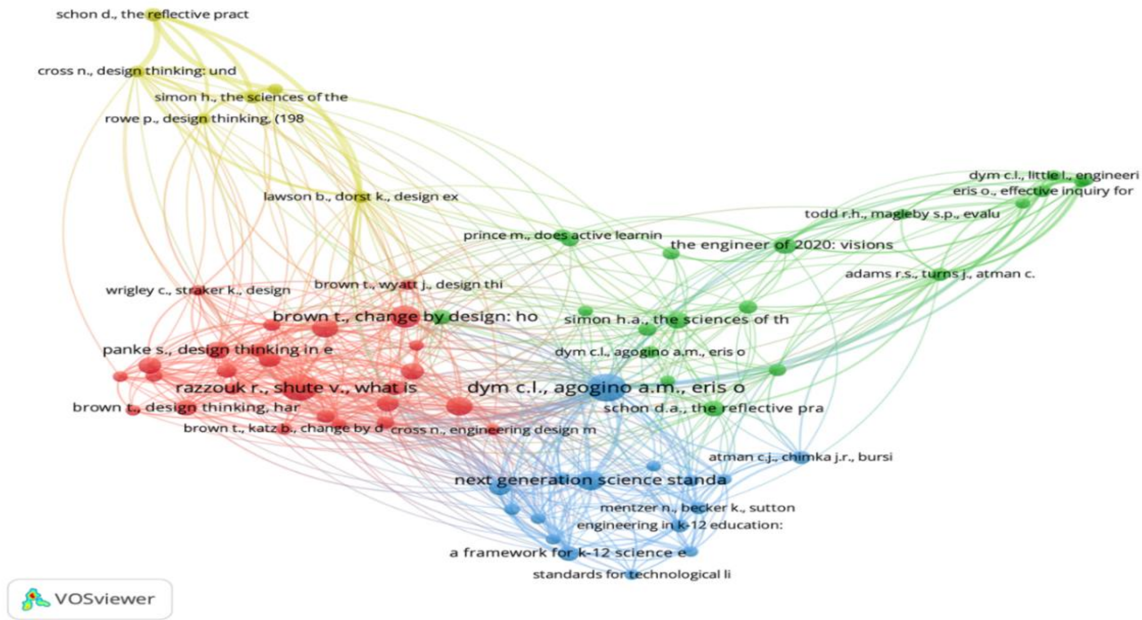

Figure 4: Co-citation analysis of design thinking research in STEM education

4.3.1 Conceptual foundations of design thinking (Red cluster)

The largest, most interlinked, group in the co-citation map was the red cluster. This cluster represented the most extensive collection of literature focusing on the theoretical and conceptual foundations of design thinking. Within this cluster are the seminal papers written by Brown (2009), Buchanan (1992), Cross (2023), and Razzouk and Shute (2012) that characterize design thinking as a creative and cognitive process that enables ideas, empathy, and problem solving for innovation. These papers focused on what differentiates design thinking from traditional forms of scientific inquiry; and how it supports divergent thinking, iteration, and user-centered approaches. Collectively these papers have laid the groundwork for establishing design thinking as one of the major competencies needed for success in STEM education in the 21st century.

4.3.2. Engineering design pedagogy and informed practice (Green cluster)

The green cluster, led by Dym et al. (2005) and backed by Crismond and Adams (2012) and others, consisted of academic literature focused on design-based pedagogy within engineering and technology education. This body of work also included practical pieces that describe the actual application of design-based pedagogy and related processes, while incorporating structured models such as the Informed Design Teaching and Learning Matrix (Crismond & Adams, 2012), and common instructional strategies, including scaffolding, iteration, team-based learning, and systems thinking. The foundation provided by the green cluster forms an employment framework for design thinking procedures in both classroom and project-based learning and work environments.

4.3.3. Curriculum and policy frameworks supporting design thinking (Blue cluster)
The blue cluster contained important resources for academic and policy frameworks. For example, the NGSS (NRC, 2013) and the K–12 Framework for Science Education (NRC, 2012) both provided a systematic set of tools for supporting the incorporation of design thinking into the science curriculum by including components called "science and engineering practices", "crosscutting concepts", and "disciplinary core ideas". Additionally, these two references have been co-cited frequently in other literature as a testament to the legitimacy and institutionalization of design thinking as a legitimate process in formal education systems (specifically, in science education) by way of national educational policy.

4.3.4. Reflective practice and design expertise (Yellow cluster)
The yellow cluster reflected scholarship that is founded on reflective practice and cognitive strategies associated with design. This cluster included books such as Schön's (1983) *The Reflective Practitioner*, Lawson and Dorst's (2009) *Design Expertise*, and Goel's (1995) *Sketches of Thought*. These books describe expert designers as individuals who use reflection on action, make their tacit knowledge public, and continuously develop their work through iterative cycles of improvement. This cluster reflected an understanding of how designing involves not only the steps of doing design but is also a process of reflective thinking about what has been done, and how practitioners develop their design thinking through self-awareness and intuition, as well as learning through experience.

Together, these four clusters represent an expansive, multidimensional area of intellectual inquiry, bringing together theory, practice, pedagogy (teaching methodologies), and educational policy. The co-citation network showed that research on the use of design thinking in STEM education has been supported by a large, heterogeneous yet cohesive body of research that has been rapidly advancing during the past few years and becoming more synthesized. This convergence indicated that design thinking is emerging both as an instructional approach and a transformative paradigm of student learning that prepares students to succeed in STEM education of the future.

4.4-Co-word analysis
Through co-word analysis (Khasseh et al., 2020), data can be analyzed to find connections through the frequency of use and relationships between words. In this paper, 4,775 unique author keywords were gathered from the database, with a cutoff of a minimum of 12 occurrences per keyword, with 62 keywords included in this analysis. A co-occurrence network created by VOSviewer detailed three primary significant clusters of words. Figure 3 provides information about the co-word pattern, while Table 4 lists the 15 most frequently used keywords, the number of times they have been used, and the total link strength for each keyword.

Table 4: Top 15 keywords identified in the co-occurrence network analysis

Rank	Keyword	Occurrences	Total Link Strength
1	engineering education	636	3,072
2	students	444	2,422
3	design thinking	509	2,206
4	curricula	299	1,724
5	teaching	205	1,258
6	design	196	1,080
7	product design	142	796
8	education	123	710
9	engineering design	96	549
10	education computing	88	523
11	e-learning	55	338
12	project-based learning	53	324
13	engineering research	50	282
14	professional aspects	50	280
15	design education	50	267

The most frequent keyword across all search results was "engineering education", which occurred 636 times and had a cohesive link strength (CLS) of 3072, the highest CLS or significant presence in relation to the topic area in question. Engineering education most typically represented the environment in which design thinking was investigated, thereby reinforcing the importance of engineering pedagogy within literature. Second in frequency was the keyword "students", which occurred 444 times, with a CLS of 2422, thus, reflecting an ongoing interest in educating students about design thinking, learning outcomes and competencies within the realm of STEM education.

The keyword "design thinking" was the third highest in frequency with 509 occurrences and a total CLS of 2206, thus, supporting the role of design thinking as a conceptual and methodical center within the area of study. Terms such as "curricula" (299), "teaching" (205), "design" (196), and "product design" (142) also represented areas of pedagogical and instructional frameworks of applying design thinking. The keyword "education", while being a general term, also demonstrated significant relevance to the overall area of research with 123 occurrences.

Keywords such as "project-based learning", "e-learning" and "learning systems", indicated that the link between design thinking and constructivist learning approaches is a growing area of interest within digital learning environments. The use of the keywords "professional aspects" and "engineering research" also showed that design thinking is being used outside the classroom to prepare students for future employment and to support research in the engineering profession.

Overall, co-word analysis of the keywords associated with design thinking in STEM education revealed an increasing focus on engineering education, learner-centered pedagogy, curriculum development, and the integration of technology and pedagogical practice. The keyword associations also demonstrated that as the research continues to develop, the priorities and techniques will change based on the context in which the research is occurring.

The visualization of co-word network analysis was represented by each point on the graph. The graph also showed how research related to design thinking in STEM education is organized into four (4) clusters, showing their semantic relationship to each other. The Authors Keywords overlap has been analyzed to identify these clusters. Additionally, the clusters have been assembled based on their author's keyword and the number of papers published using those keywords. These clusters can also be characterized as their conceptual density and proximity to one another.

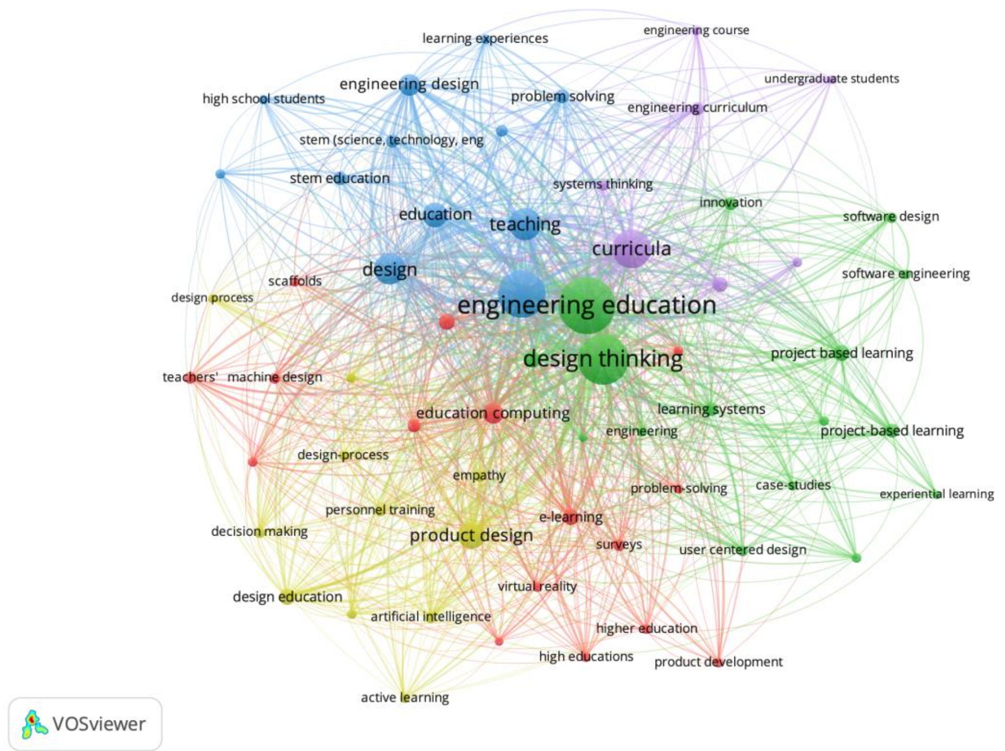

Figure 5: Co-word analysis of creative thinking research in STEM education

*4.4.1 Engineering-centered pedagogy and core education practices (Green cluster***)**

The top priority within the keywords' network was the green cluster which includes the four high-impact keywords: "engineering education", "design thinking", "teaching", and "curricula". The cluster indicated that many researchers have placed emphasis on understanding how design thinking will be integrated into engineering programs and STEM teaching practices. Architects of this work, such as Dym et al. (2005) and Crismond and Adams (2012), have created theoretical foundations for using design processes as an integral part of instructional environments. In addition, the links between teaching and students indicated that many researchers want to understand the impact that the integration of design has on students' performance. Therefore, it is important to note that the nature of the curriculum and student outcomes will be important factors in future design-integrated curricula (English & King 2015) within the engineering education professional development community.

4.4.2 Digital learning environments and educational technology (Red cluster)
Keywords such as "e-learning," "education computing," "machine learning," and "virtual learning environments (VLEs)" are clustered in the red cluster. These keywords provide evidence for a new theme emerging at the intersection of design thinking and digital pedagogy. The presence of the keywords "artificial intelligence" and "active learning" indicated an increased interest in the use of adaptive technologies and intelligent systems in the support of inquiry-based learning. This is consistent with research conducted by Dove et al. (2017) which identified both the challenges and opportunities provided by machine learning for UX and design innovation. Furthermore, the keyword "education computing" (88, 523) demonstrated that as digital infrastructures become more entrenched in how STEM education and design thinking were researched and taught, design thinking is becoming even more imbued with digital technologies.

4.4.3 Product and industrial design integration (Yellow cluster)
The yellow cluster presented keywords including "product design" (142, 796), "design education" (50, 267), and "product development." This cluster contained research that identifies design thinking as being designed and developed in alignment with vocational and industry practices. The importance of prototyping, aesthetics, and user-centered development were significant components of this research. Buchanan (1992) and Lawson and Dorst (2009) were both widely referenced in this area of research, supporting the prevalence of design expertise from a creative and professional perspective. Professional aspects of the yellow cluster included "professional aspects" (50, 280), highlighting how valuable design thinking can be in supporting students as they prepare to meet real-world challenges across different disciplines.

4.4.4 Project-based and collaborative learning approaches (Purple cluster)
Keywords representing collaborative learning, problem-solving and teamwork were found in association with constructivist and experiential theories of education that emphasize project-based learning as well. Keywords associated with these theories showed the extent to which design thinking as an inquiry-driven and social process has been documented in studies such as those conducted by Kuo et al. (2019) and Cook and Bush (2018) who found that design-based methods enhance motivation, creativity, and retention of learning. They further emphasized the importance of authentic, real-world group-based projects as effective instructional tools for creating design-oriented instruction within STEM education.

4.4.5 Learner identity and demographics in STEM contexts (Blue cluster)
The blue cluster illustrates sustained interest in how various "students" (high school students, university students, and learning experiences) engage with design thinking as part of a larger body of literature surrounding this area of study. These topics focus on student identity and learning profiles. Examples of research on design thinking at the secondary and tertiary levels include studies

by Becker and Mentzer (2015), Geng et al. (2019), and others who have studied the same topic across both educational levels.

The inclusion of terms such as "learning systems" indicated an interest in developing an instructional approach based upon the needs of learners within a variety of contexts. The co-word map formed from analyzing clusters created a clear map of the many dimensioned landscape of design thinking research in STEM education: Engineering pedagogy was the foundation for this field. However, owing to recent developments, the field is now rapidly extended into digital learning, industrial practice, student-centered instruction, and demographic-oriented practices for educators. Insights revealed by the combined analyses of co-occurring patterns and citation frequencies illustrate how design thinking has become a cross-curricular, theoretically driven area of educational research that is practically applicable.

4.6. Overlay Visualization of Keyword Co-Occurrence

The temporal evolution of design thinking research within STEM education was assessed through the creation of an overlay of author keywords generated using VOSviewer (Figure 4). An overlay provides a visual representation of the co-occurrence relationships between keywords and their corresponding average publication years, facilitating an understanding of how the design thinking research area has evolved over time.

In Figure 6, the nodes represent author keywords, and the graph displays both the frequency of use for each keyword (node size) and the average year of publication for the keywords (node color). The colors of the nodes represent a range from dark blue (or older, 2018-2019) to yellow (or more recent, 2023-2025), reflecting the changes in the themes of design thinking research throughout STEM education.

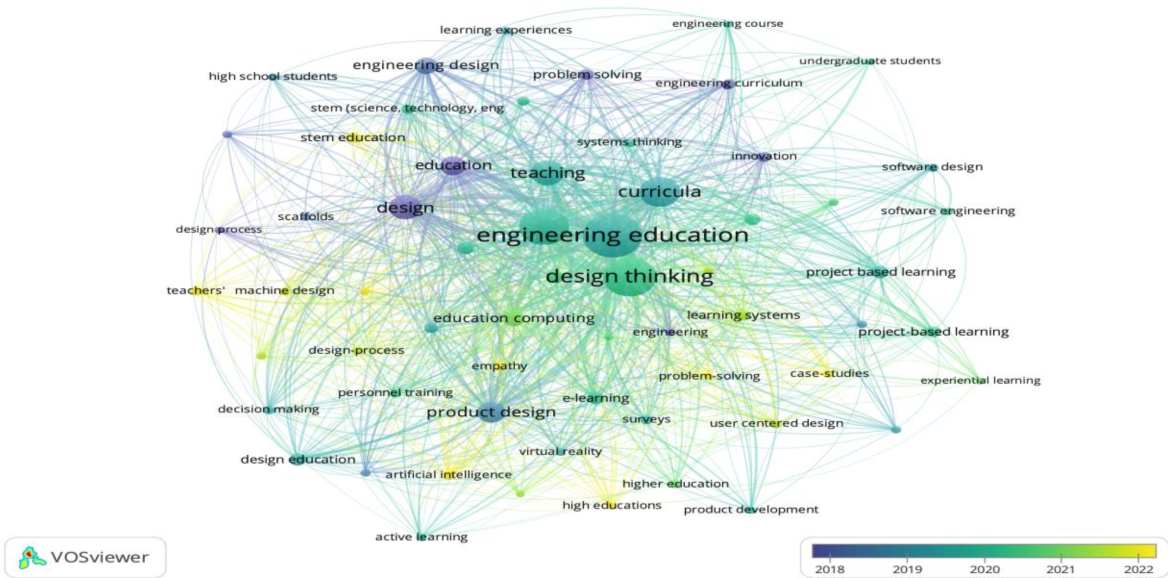

Figure 6: Overlay visualization of keyword co-occurrence in Scopus-indexed articles on design thinking in STEM education (2018–2025)

The largest nodes in dark green to blue hues indicate that many of the terms used to describe the keywords, such as "engineering education," "design thinking," "students," and "curriculum," were widely represented by the keywords in this early research literature base; therefore, these keywords are likely to be foundational (i.e., the main focus was on applying design thinking to engineering in formal learning environments). This is consistent with previous high citation levels associated with authors, including Dym et al. (2005) and Li et al. (2019).

The yellow to light green nodes highlight new ideas that are gaining attention from academia. Some of the most prominent examples are user-centered design, project-based learning (PBL), authentic learning, software design, electronic (e-) learning, VLEs and AI. The fact that these key terms have become increasingly common in the most recent academic publications indicates that there has been a major shift toward integrating design thinking with technology-enhanced learning (TEL), technology-mediated collaboration (TMC), and student-centered methodologies. This shift is consistent with the documented current trends in STEM education and is supported by recent research studies (Dove et al., 2017), which demonstrate an increased interest in the flexible, tech-driven, and adaptive use of design thinking in STEM education.

The yellow hues of product development, professional aspects, and higher education are also emerging in workforce readiness and competencies at the tertiary level. They represent not only the use of design thinking as a classroom strategy but also the development of innovation, creativity, and real-world problem-solving skills in preparation for entering the workforce. In the yellow-green spectrum, there were also keywords that represent "AI," "learning systems," "decolonizing," and "design ethics," although they are fewer in number. These keywords represent new research areas that connect design thinking with ethical, cultural, and systemic aspects of education. The inclusion of these keywords suggested that the field is expanding its scope to encompass issues related to inclusivity, digital equity, and social impact.

In summary, the overlay visualization illustrates a rapidly changing temporal trajectory. Whereas the focus has historically been on engineering pedagogy and curricular reform in STEM education, the focus of new studies has shifted toward integrating technology, collaborative learning models, and context-sensitive, future-oriented practices. This shift exemplifies how the field is adapting to the changing educational landscape by becoming more flexible and transdisciplinary, as well as more innovation-oriented in applying design thinking within STEM education.

5. Discussion

This bibliometric analysis presents a wide-ranging examination of the development of design thinking used in education. It combines data from various sources to investigate patterns of publication activity, the extent to which articles have been cited, how articles are related through co-citation relationships, and how they fit into thematic clusters. The research findings provide valuable insights into how to conceptualize design thinking, the potential for using design thinking to transform teaching and learning within the context of STEM education, and how design thinking fits within the broader context of education for the 21st century.

5.1 Global Participation and Knowledge Production: Innovation Rooted in Policy and Practice

The descriptive analysis found that research on design thinking in STEM education is globally dispersed. However, it is disproportionately concentrated in a few countries, including the USA, China, UK, Australia and Canada. As a result of both structural advantages (e.g., research funding, STEM infrastructure, policy innovation) and national priorities that regard design thinking as a vehicle for educational transformation, most of the literature is from these countries. In particular, the USA has led early initiatives for integrating engineering design into K-12 (Kindergarten through 12th Grade) curricula based on the Next Generation Science Standards (NGSS), which emphasize engineering practices and cross-disciplinary learning (National Research Council, 2013). Similarly, China has undertaken massive reforms in STEM areas, while Australia has invested in developing design- and inquiry-based curricula, which may explain their high levels of scholarly productivity.

This geographic imbalance also raises important questions about global equity of knowledge production. Although the literature was dominated by high-income countries, emerging contributions from developing regions, such as India and Brazil, indicated a growing recognition of the role of design thinking in addressing the unique educational challenges faced by many of these countries. Further studies should explore how cultural, socioeconomic, and linguistic factors will influence the adoption and adaptation of design thinking pedagogies across diverse contexts (Geng et al., 2019).

5.2 Theoretical Anchoring and Citation Impact: A Mature yet Expanding Field

Design thinking in STEM education seems to have a solid theoretical basis and pedagogical richness, as shown by a thorough citation analysis. Examples of frequently cited articles (Dym et al., 2005; Razzouk & Shute, 2012) that examined both cognitive and epistemological and creative dimensions of design thinking included an understanding of the concept of design in terms of a systematic approach (iterative ideation, reframing problems, and innovative products). Examples from applied research (English & King, 2015; Li et al., 2019) demonstrate the effectiveness of design thinking in fostering student engagement, interdisciplinary perspectives, and systems-based approaches to education.

Notably, the inclusion of studies on professional development (Chai, 2019) and teacher self-efficacy (Geng et al., 2019) in the context of classroom innovation signals a paradigmatic shift. Design thinking is no longer viewed solely as a student-centered approach; it is increasingly conceptualized as a systematic process that informs teaching practice. This shift aligns with the TPACK framework and supports the development of inquiry-oriented professional learning communities. Koehler and Mishra (2009) noted that teacher agency, reflective practice, and the ability to design quality instruction are critical elements for effectively integrating design thinking into STEM education.

5.3 Intellectual Structure: A Multi-Theoretical and Cross-Sectoral Knowledge Network

Co-citation analysis showed four overlapping yet distinct intellectual clusters that define the core area of this field. The red cluster brings together theoretical underpinnings such as Schön's (1983) reflective practice, Buchanan's (1992) "wicked problems", and Cross's (2011) design cognition as philosophical supports or lenses to situate design thinking as a metacognitive process that gives importance to the ideas of iteration, ambiguity, and meaning-making — qualities that help solve complex STEM problems.

The green cluster is concerned with how engineering design pedagogy operationalizes design thinking in the classroom through structured models, such as the Informed Design Matrix (Crismond & Adams, 2012). The blue cluster comprises curricular policy documents, such as the NGSS and the A Framework for K–12 Science Education, which establish the importance of design thinking in the institutionalization of design thinking through educational standards. The yellow cluster focuses on the development of reflective expertise and the development of designers and educators, highlighting the development of design competence through experience, intuition, and context (Goel, 1995; Lawson & Dorst, 2009).

The diverse nature of the disciplines that comprise this field (education, engineering, psychology, philosophy) has created a pluralistic framework. This diversity has contributed significantly to the richness of this body of work; however, it requires further development of a common language and an integrated epistemological framework to achieve coherence across the disciplines.

5.4 Conceptual Landscape: Pedagogical Anchors and Expanding Horizons

Through co-word analysis, a more granular overview of the conceptual terrain of the field was generated. The five most frequently used terms were a) "engineering education", b) "students", c) "design thinking", d) "curriculum", and e) "teaching". The higher concentration of occurrences of these five keywords indicated that the engineering education field is primarily pedagogical in nature as its focus is on incorporating design thinking into formal STEM educational settings. The convergence of these five keywords highlights the consistent positioning of design thinking within the field of engineering education, particularly in relation to student-centered and standards-aligned instructional design.

The inclusion of keywords such as "project-based learning", "e-learning", "education computing" and "professional aspects" provided evidence that the field of education engineering is evolving. The keywords indicated that engineering education is growing with regard to blended learning environments, digital literacy and career readiness. The keywords were also evidence that design thinking is not limited to traditional classroom environments anymore, but has extended into virtual, collaborative, and real-world learning environments. As such, the evolution of engineering education aligns with present day educational imperatives which require that students are prepared to face VUCA (volatile, uncertain, complex and ambiguous) futures using authentic, design driven tasks in the learning process (Kuo et al., 2019)

5.5 Temporal Dynamics: From Foundational Pedagogy to Emerging Frontiers
Through the overlay visualization, the temporal progression of this field becomes clear. In the first set of years (2018-2020), foundational term associations with terms such as "engineering education" and "curricula" revealed an early focus on integrating design with formalized educational systems. However, in the most recent group of years (2022-2025), one observes the rise of new keywords such as "AI", "user-centered design", "VLEs", "decolonization", and "design ethics" that show the trend of incorporating technology, as well as inclusivity and ethical responsibility into a forward-looking agenda.

The differences in time periods indicate a transformational phase for this field. The shift from descriptive studies of implementation towards a greater focus on equitable practices, social justice, and systemic change is evident from the growth in the use of keywords associated with these areas ("decolonization" and "design ethics"). It demonstrates an important shift in examining how design thinking can be utilized to disrupt traditional ways of thinking about epistemology and create more inclusive, culturally responsive, and contextually relevant STEM education systems (Becker & Mentzer, 2015; Duke et al., 2017).

5.6 Theoretical and Practical Implications for the Future of STEM Education
This bibliometric analysis shows that design thinking has a theoretical basis for understanding pedagogy and the framework used to implement STEM education in the classroom. The theory has come together from various schools of thought, including constructivist learning theory, reflective practice, systems thinking, and cognitive engineering design. This positions design thinking well beyond simply being a teaching strategy; it is an epistemological view on how individuals learn. As its focus is on iterative thinking, idea reframing for problem solving, ambiguity tolerance, and integrative meaning making, it resonates with the current state of STEM issues being complex and interdisciplinary.

The co-citation trends show that there is a pluralistic knowledge base that is interconnected across multiple fields of study (education/engineering/psychology/philosophy), demonstrating the ability of design thinking to develop metacognitive awareness, adaptive expertise, and collaborative problem solving. The inclusion of design engineering practices in curricular standards is another indication to leadership that design thinking is fundamental to reforming STEM instruction. The emergence of themes relating to AI, VLEs, decolonization, and design ethics show the evolution of design thinking to a broader definition that places design thinking in a context that includes more social equity issues, technological advancements, and innovation through social responsibility.

The study results demonstrate clearly that systemic alignment (between policy, curriculum, teacher preparation, and institutional culture) is necessary for effective implementation. The research output concentration (in higher-income countries) shows the critical role of funding, infrastructure, and reform-oriented policies on the ability to sustain innovation. To influence and shape STEM education globally into the future, design thinking needs to be embedded in national standards and assessment systems and not be treated as an isolated initiative. Teacher capacity building is essential; teachers need ongoing professional development to build pedagogical content knowledge, gain technological fluency, and develop confidence to facilitate inquiry, iterative learning environments. Professional learning communities support reflective practice and instructional coherence. In addition to this, digital and blended environments can facilitate the expansion of authentic design challenges using both AI and collaborative technologies, as long as ethical considerations and equal access to these tools are at the forefront. When supported by coherent policy, ongoing professional learning, and inclusive adaptation, design thinking provides a pathway to transform STEM learners into innovative and socially responsible STEM learners.

6. Conclusion

A global bibliometric study on design thinking in STEM educational settings has been presented, covering 897 documents indexed in the Scopus database. Using co-citation, co-word, and overlay analyses, the study has established the intellectual structure of the discipline, identified the conceptually significant directions for the development of design thinking research, and examined the trends related to the evolution of design thinking research over time. Based on the findings, design thinking research has developed as a major area for growth in an extensive, cross-disciplinary body of literature, with significant foundation in the fields of education, engineering, cognitive science, and curriculum studies.

The results of the citation analysis highlight the significance of works that define design thinking, specifically those that teach design and develop creativity, foster problem-solving skills, and encourage reflection on one's work. The results of the co-citation analysis identify four distinct domains of knowledge related to design, covering a wide range of topics, including the theoretical framework for design thinking, methods for teaching design, instructional approaches for design, and educational policies. The results of the co-word network also illustrate that the pedagogical focus of design thinking includes such themes as engineering education, student-centered learning, and curricular development, and provides an overview of some of the emerging trends in education today, including the increasing importance of digital learning, ethics, and inclusivity.

Lastly, the findings of the temporal mapping of the citation analysis revealed firstly, that there has been an evolution in the development of design-thinking pedagogy from an early focus on large-scale reform to the current emphasis on developing innovative design practices to address the challenges posed by the modern educational context (STEM). Secondly, this is moving from being just another approach to teaching and learning to an enabler of systematic change in the educational system.

The knowledge map created from reviewing the existing literature will be beneficial to researchers, educators, and policymakers interested in applying design thinking as a pedagogical method within STEM contexts. Future research should focus on longitudinal and impact-oriented studies, the development of culturally responsive iterations for applying design thinking in STEM, and the consideration of ethics related to design-based learning in diverse educational systems.

7. Recommendation

Findings from this bibliometric study offered suggestions for further advancements related to design thinking within STEM learning and education in the future. The recommendations reflected various areas of design thinking that can be developed from the creation of partnerships between different fields (e.g., engineering, educational technology, psychology, and human-computer interaction) through the processes of co-citation analysis and keyword comparison.

In addition to strengthening an interdisciplinary partnership among all these areas, future research should encourage collaboration within each area to build a broader range of conceptual frameworks and develop more comprehensive pedagogies. A focus on learner-centered or local context of design, or both, over time may become increasingly important as we continue to evolve the application of design thinking in STEM education. Designers, educators, and researchers need to develop and adapt design thinking practices further to the specific context of their local communities, the needs of their learners, and their equity-oriented goals, especially in situations where students are from underrepresented populations or in vulnerable environments.

The available literature has robust examples of studies both conceptually and experimentally; however, there are few examples of continued empirical evaluations of design thinking. Therefore, longitudinal studies should be conducted on the long-term benefits of design thinking interventions on students' creativity, problem-solving capabilities, and career trajectories in STEM. In addition, the increase in keywords such as “e-learning”, “educational computing”, and “digital education” provided evidence of the growing importance of technology-enhanced learning environments. Therefore, future research should continue to identify how design thinking integrates with digital technologies and ethical implications i.e., AI, data privacy, and responsible innovation.

Fifth, the creation of global and comparative research agendas for STEM education is recommended. As design thinking in STEM education develops globally, research and literature on design thinking continue to grow in some parts of the world, while declining in others. Conducting a comparative analysis of sociocultural impacts on the adoption and success of design thinking across multiple countries will yield considerable benefits. Lastly, there is an ongoing need to support the ongoing professional development of teachers. While teachers are important to the delivery of design-based learning, many still lack the necessary preparation. Teacher professional development programs should include design thinking, collaborative curriculum planning, and reflective teacher practice, as well as aligning with existing models of education, such as TPACK and inquiry-based learning. Collectively, these suggestions represent a framework through which the discipline may progress toward more equitable, evidence-based, and globally informed practices within STEM education.

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