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Implementing Design Thinking in STEM Education: A Systematic Review of Trends and Challenges

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This study presents a systematic review of the literature on the implementation of the Design Thinking (DT) methodology in STEM education. Using the Scopus and Web of Science databases, 54 articles were analyzed after applying inclusion and exclusion criteria, from a total of 358 initial studies. The research focuses on characterizing the scientific production related to DT and STEM, evaluating its results, challenges, and limitations. The bibliometric results highlight a significant increase in publications on DT in STEM since 2018, with the United States, Thailand, and Australia as the main contributors in the field. In addition, a predominant focus is observed on qualitative studies, focused on exploring participants' experiences and perceptions in the application of DT. Despite the significant growth and contributions, challenges such as small sample sizes, time constraints, and the requirement for more teacher training and resources for an effective implementation of DT in STEM education were identified.

Keywords: systematic review, prisma method, design thinking, STEM, education

INTRODUCTION

STEM education has established itself as a fundamental pillar in modern education, valued for its ability to develop essential skills such as computational thinking, problem-solving, collaboration, and self-confidence (Bano et al., 2023; Ladachart, Radchanet, et al., 2022). Another of its purposes is to train students to actively participate in the acquisition and understanding of technology, engineering, and mathematics (Chang & Yen, 2023; Gamage et al., 2022), promoting innovation, creativity, and the development of forward-thinking entrepreneurial skills (Juškevičienė et al., 2021; Sudarsono et al., 2022).

Recent educational policies highlight the importance of engineering in increasing student participation in STEM fields, underscoring how it can expand scientific

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knowledge by engaging students in solving locally relevant problems (McGowan & Bell, 2020; Razali, 2021). To address the shortage of STEM professionals, as observed in the United States, the K-12 Science Education Framework has been developed, which serves as the foundation for next-generation science standards. This framework highlights the integration of engineering design into science education as a core concept (Han & Kelley, 2022), and so STEM education must shift toward more design- and problem-solving-focused approaches (Schad et al., 2025; Shang et al., 2023).

Design Thinking emerges as a valuable complement to STEM education, as it is an approach that seeks to have students address problems by creatively redefining and reimagining solutions, similar to the professional skills of designers (Aldalalah, 2022). This approach integrates creativity, empathy, and rationality to arrive at specific solutions. Unlike other educational approaches, Design Thinking is based on authentic inquiry and perfects creative problem-solving skills, focusing on developing solutions to improve the world (B. Bush et al., 2022).

Despite the growing interest in Design Thinking (DT) within STEM education, gaps in the research and literature persist, justifying the need for this systematic review. There is a particular lack of studies that comprehensively analyze the implementation of DT at different educational levels and disciplines within STEM, which hinders the understanding of its scope and effectiveness in diverse contexts (Thomason & Hsu, 2024; Hsiao et al., 2023). Furthermore, there are contradictions regarding the impact of DT on the development of creative skills and self-efficacy in students, as evidenced by previous research (Wingard et al., 2022; Yildiz Durak et al., 2023; Chen et al., 2023; Ladachart et al., 2022). These discrepancies limit the possibility of establishing standardized conclusions about its benefits and applicability in STEM teaching. Another important factor is that methodological differences between studies make it difficult to compare results, highlighting the need for a more in-depth analysis of the approaches used.

Therefore, this research presents a systematic review of the literature on Design Thinking in STEM education, with the main objective of characterizing the scientific production related to the topic. To achieve this objective, the following research questions were raised:

What are the main characteristics of scientific works that address Design Thinking and STEM education?

What are the most frequent or outstanding results obtained through the application of Design Thinking in the context of STEM areas and education?

What are the main challenges and limitations identified in the literature regarding the successful implementation of Design Thinking in STEM education?

METHOD

Considering the steps and general outline for preparing a scientific article, the PRISMA 2020 Declaration is presented as a very useful tool when planning and carrying out systematic reviews to ensure that as much information as possible is captured on a given topic to be investigated (Page et al., 2021). In the educational field, the PRISMA 2020 protocol can be used to carry out Systematic Reviews. As a result of this trend, there has been significant growth in the number of scientific publications that are governed by this protocol (Sánchez-Serrano et al., 2022).

For this systematic review, a structured search strategy was designed using Boolean operators to maximize the retrieval of relevant studies. The search was conducted in the SCOPUS and Web of Science databases, using the following Boolean search string:

("Design Thinking" OR "Design Thinking") AND (education OR education) AND ((STEM) OR (STEAM))

This combination of terms withdrew studies focused on the integration of Design Thinking in STEM and STEAM education at different educational levels and disciplinary contexts.

The article selection and evaluation process was carried out by a single reviewer, who independently reviewed the titles and abstracts of the identified studies. Inclusion and exclusion criteria were established based on thematic relevance, JCR/SC classification, journal impact factor, and the methodological rigor of the study.

The data extracted from each study included: article title, database (SCOPUS, Web of Science), year of publication, JCR/SC classification, impact factor, journal, ISSN, authors, country, language, keywords, objectives, approach, research question, educational level, study location, study duration, gender distribution, age of participants, materials used, and references cited.

Specialized tools were used to analyze the collected information. Voyant Tools was used for content analysis, allowing the identification of key terms and patterns in the selected studies. Additionally, Microsoft Excel was used for graphical data visualization, facilitating the structuring and synthesis of findings.

Data analysis

Table 1
Search equations, articles found and selected

Data base	Search equations	Found articles	Selected articles
Scopus	("Design Thinking" OR "Design Thinking") AND (education OR education) AND ((STEM)OR (STEAM))	23	8
Web of Science		75	25
Scopus y web of science		43	21
TOTAL		141	54

This systematic review was conducted from May to October 2024. The Scopus and Web of Science databases were used to search for information, as they are considered the most relevant in the field of research at the level of international scientific production. The key terms Design Thinking, education, and STEM were used to construct the search. The search parameters and the established equation are shown in Table 1.

According to the PRISMA statement, the search strategy is developed in 4 stages: identification, screening, selection and final articles included as shown in figure 1.

Table 2
Inclusion and exclusion criteria established for the selection of documents

Inclusion criteria	Exclusion criteria
Articles published in Scopus and Web of Science databases.	Articles whose objective is a systematic review or meta-analysis.
Articles published from 2016 to 2023	Articles that do not deal exclusively with education
Works or research dedicated to Design Thinking and the study of STEM areas.	Articles that refer to industry and management of organizations
Publications in English and Spanish	

The identification stage focused on searching the Scopus and Web of Science databases; the data was filtered to select only research articles. A total of 358 studies related to the topic were found, eliminating 217 duplicate works during this phase.

In the selection and inclusion stage, which consisted of an initial sample of 141 papers, a preliminary evaluation of the content was carried out and the inclusion and exclusion criteria were applied as shown in Table 2. As a result, those papers that did not deal exclusively with Design Thinking and were not related to STEM education and Design Thinking were discarded. After applying the relevant criteria during the stages, a final sample consisting of 54 articles was finally obtained.

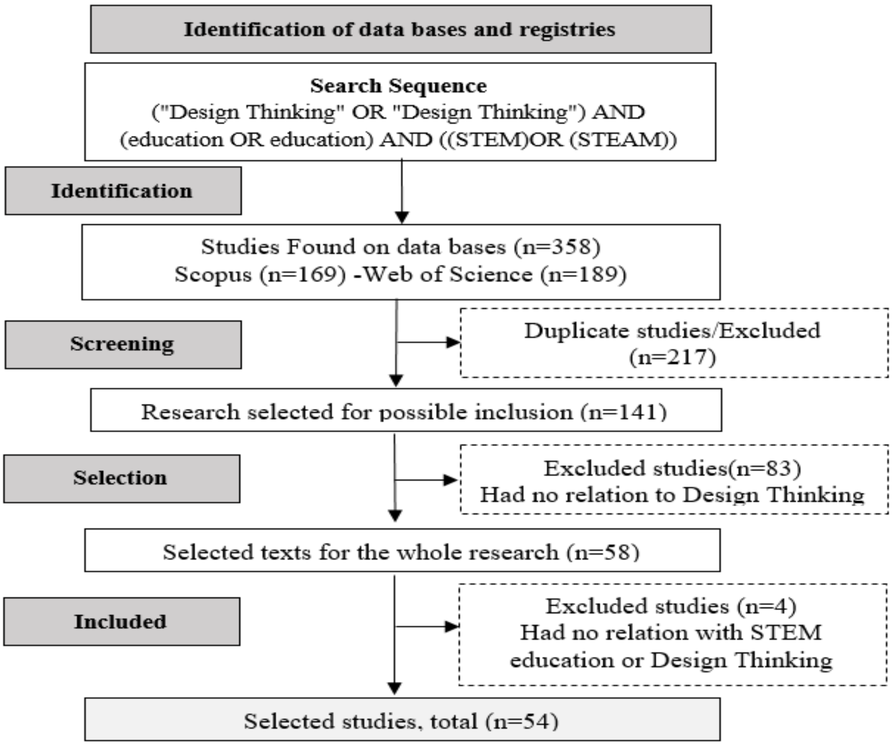

Figure 1
Flowchart of the search carried out considering the PRISMA statement
Source: Own elaboration considering the PRISMA declaration (Page et al., 2020)

With the information obtained, a content analysis is carried out in response to the research questions. Table 3 presents the analysis categories used and their respective descriptions.

Table 3
Definition of the analysis units

Analysis unit	Definition
Bibliometric indicators	Database, year of publication, country, authors, keywords, educational level, research participants and most cited references.
Methodological design	Research approaches used with the application of Design Thinking in STEM contexts.
Design Thinking	Scientific works that address the Design Thinking methodology to promote the study of STEM areas.
Challenges and limitations	Data on the main challenges and limitations identified in the literature regarding the successful implementation of the Design Thinking methodology in the study of STEM areas.
Educational contexts	Recommendations in the literature to improve the application of the Design Thinking methodology in the context of STEM areas.

In a first phase, the information was analyzed qualitatively in each study, coding the information according to the previously defined analysis units. To do this, an extraction matrix was constructed that was designed considering the research questions posed. The presentation of the results is structured based on the criteria used for data extraction. The credibility of the entire methodological process, from the systematic search to the data analysis and interpretation of the results.

FINDINGS

Bibliometric indicators of the selected articles

In relation to the years of publication, figure 2 shows that, starting in 2016, the publication of papers began to be recorded, which is why this year features in the inclusion criteria. In 2021, the number of publications began to increase significantly, reaching a total of 13 publications in 2023. Since 2024 has not yet ended, it is not known whether the number of publications will increase, but to date 5 articles have already been published.

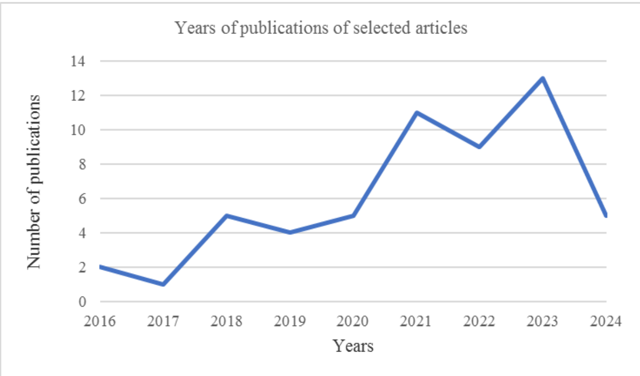

Figure 2
Publications by year of the selected articles

Figure 3 shows the methodological approaches used in the articles analyzed in the systematic review. Three types of approaches stand out: quantitative, qualitative, and mixed, the latter being the most common, with a total of 23 documents. The qualitative approach is next, present in 20 articles, while the quantitative approach is represented the least, with 11 studies.

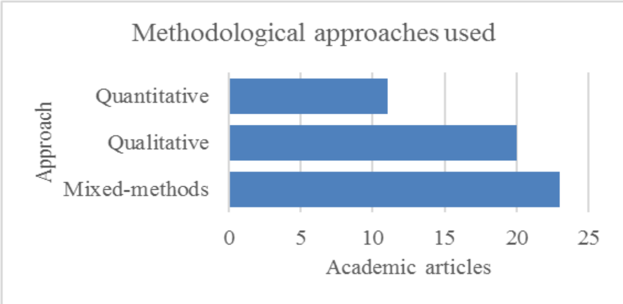

Figure 3
Methodological approaches used

Figure 4 shows the countries where the research was carried out. We observe that the United States has the highest number, with 15 publications, followed by China, with 6, and Taiwan, with 5 publications, these being the three countries where the most research related to the topic has been developed. These results indicate the relative contribution of each country to the field of Design Thinking and STEM education. It is important to highlight that the number of publications provides an overview of the research activity in each country in relation to the topic of study and the publications that are made are increasing every year.

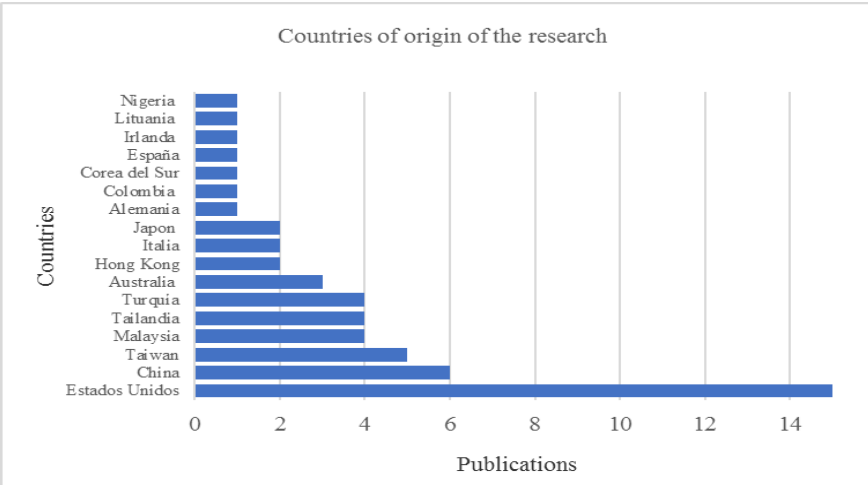

Figure 4
Country of publication of the selected articles

As for publications by author, all authors of the included publications were taken into account, totaling 148 authors. Figure 5 provides a detailed view of the authors with the most publications related to the topic. We observe that the first author stands out with 4 publications, Luecha Ladachart, and other authors with 3 publications, Rie Kijima and Wilawan Phothong, being the three authors with the most publications. Luecha

Ladachart and Wilawan Phothong belong to the School of Education, Phayao University, Thailand (citation) and Rie Kijima is an assistant professor at the Munk School of Global Affairs and Public Policy at the University of Toronto, Canada.

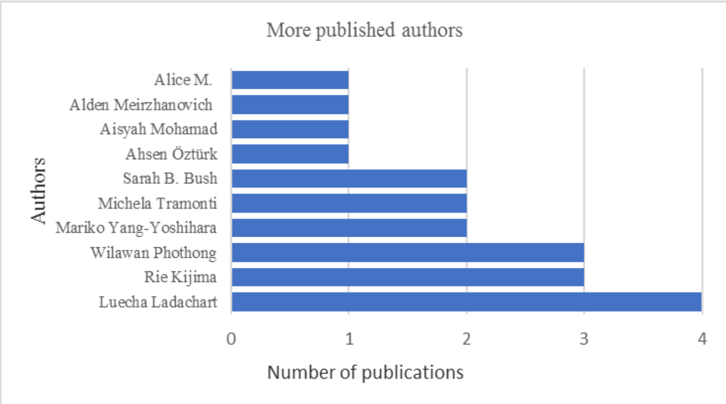

Figure 5
Publications by author

The most recurrent keywords in the analyzed research are presented in figure 6, which shows the 11 most mentioned words out of a total of 161. The most frequent word is "Design Thinking", with a total of 52 mentions in 54 documents analyzed. The remaining documents mention this word with variations such as “Design Thinking Disposition”, “Design Thinking for Educators” and “Design Thinking Model”. The second most recurrent word, aligned with the search for information, is "STEM Education", with a total of 14 mentions. Likewise, this word has several variations “STEM”, “STEAM”,” STEM teachers” and “STEAM instruction”.

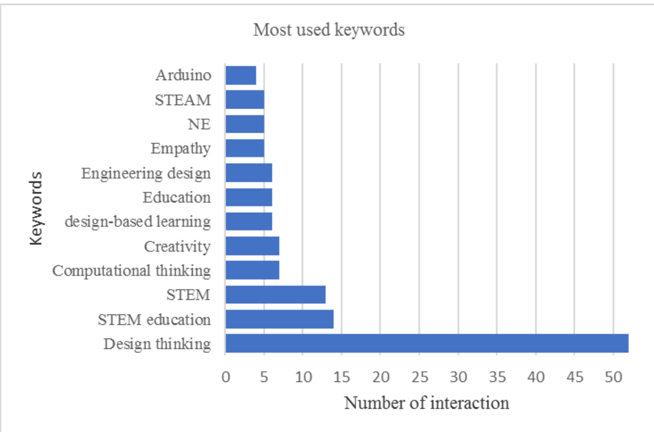

Figure 6
Most used keywords in the selected research

The educational level in which the research was carried out is presented in figure 7. It can be observed that the majority of the studies were developed with secondary school students, with a total of 25 publications. This level is followed by the primary level, with 8 investigations, the university level, also with 8 investigations, and the teacher level, with a total of 6 investigations. In last place is the high school level, with 2 investigations. It should be noted that 4 of the studies covered two educational levels simultaneously.

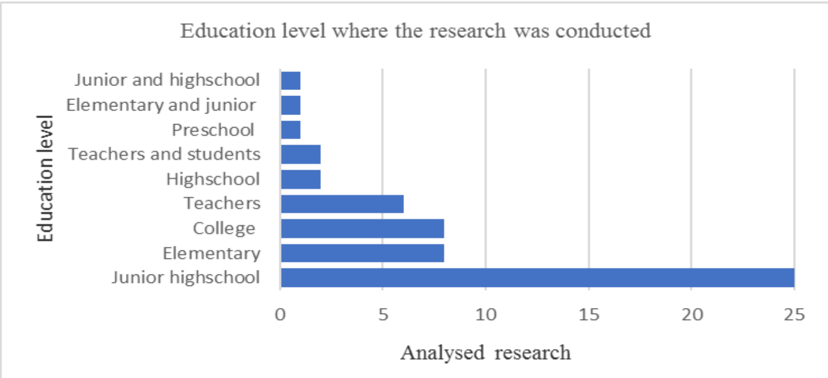

Figure 7
Educational level where the research was carried out

The number of participants in each of the studies is presented in Figure 8. Of the studies analyzed, 11 had more than 100 participants, while 36 involved less than 100 participants. It should be noted that 7 articles did not mention the number of participants involved**.**

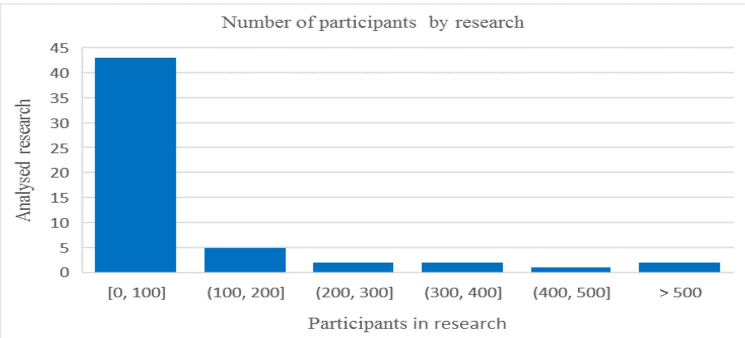

Figure 8
Number of participants per study

The proportion of women and men participants is mentioned only in 29 studies, as shown in figure 9. Adding the participants reported in these studies, a total of 1008 women and 951 men are recorded.

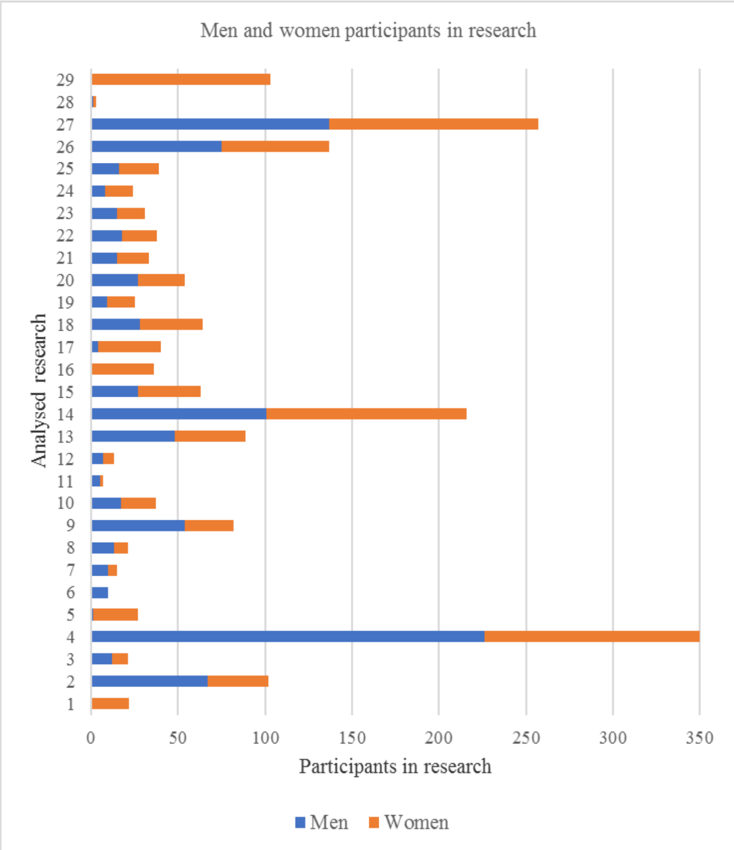

Figure 9
Men and women participating in the research

The analysis of the references mentioned in the research is presented in figure 10, where the first 26 most referenced authors are highlighted. These references were extracted from the specific content of the research that mentions the concept of Design Thinking, obtaining a total of 1234 cited authors. The most cited author is Brown, T., with 28 articles, followed by Carroll, M.; Cook, K.; d.School; Li, X.; and Razzouk, R., who were cited in 17 articles each.

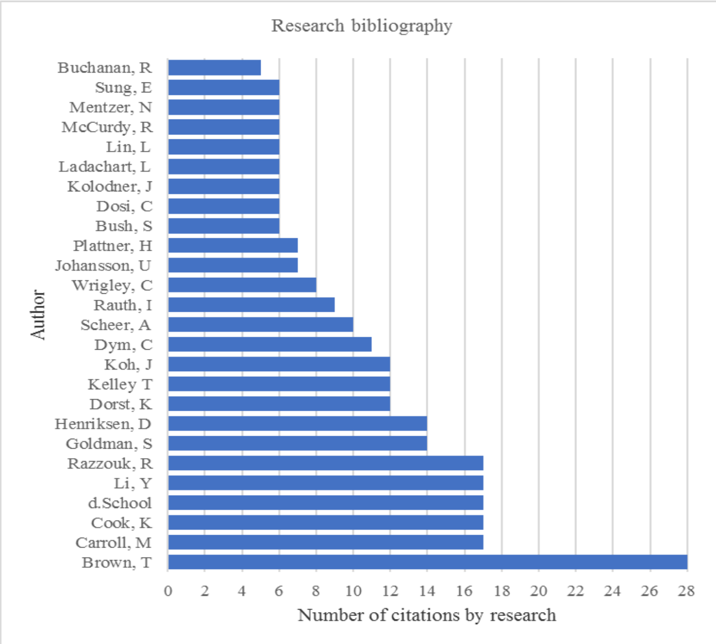

Figure 10
Research references

Tim Brown, "CEO and President of IDEO, an innovation and design firm based in Palo Alto, California, has been widely recognized for his contributions to the field of Design Thinking. His designs have received numerous awards and have been exhibited at renowned institutions such as the Museum of Modern Art in New York, the Axis Gallery in Tokyo, and the Design Museum in London" (Brown, 2008).

Maureen Carroll, Ph.D., research director of REDlab; a partnership between Stanford University's School of Education and the Hasso Plattner Institute of Design (d.school), is also an influential figure in this field. Carroll, who holds a PhD in Education from the University of California at Berkeley, a master's degree in Special Education, and a bachelor's degree in Biology, is co-founder of Lime Design, a consultancy that seeks to catalyze innovation in the educational and corporate sectors (*REDlab- Research in Education & Design*, 2009).

The analysis of the objectives of research on Design Thinking (DT) in STEM education reveals several important similarities. The studies share the purpose of exploring how DT can foster essential 21st-century skills such as creativity, collaboration, critical thinking, and problem-solving. For example, several studies highlight the importance of developing these skills through tools such as educational robotics (Tramonti et al., 2023), digital storytelling, and the use of empathy maps (Stork, 2020; Yeung & Ng, 2023). Another important group of research focuses on the impact of DT on students' creativity and self-efficacy, analyzing how this methodology can increase students' confidence in tackling complex problems. For example, Wingard et al. (2022) examine how adolescent girls develop creative self-efficacy in STEM workshops focused on DT, while He et al. (2023) explore how DT influences fifth grade students' creative self-efficacy.

From a theoretical perspective, Design Thinking is related to Piaget's constructivism, as it encourages learning through experimentation and the active construction of knowledge by iterating prototypes and exploring alternative solutions. This approach promotes experiential learning in which students acquire knowledge through direct interaction with real-life problems, which reinforces the internalization of concepts and deductive reasoning (Hsiao et al., 2023; Arifin & Siew, 2023). Likewise, Design Thinking allows students to accept ambiguity and explore unbiased and imperfect responses, moving away from the search for absolute answers, which aligns with Piaget's constructivist perspective on the progressive construction of knowledge (Kijima et al., 2021).

Design thinking also connects with Vygotsky's social learning theory, as it emphasizes collaboration and teamwork as key elements of the design process, where students not only construct their own knowledge but also do so in a social context that allows them to develop cognitive skills through interaction with their peers and facilitators (Kijima et al., 2021). This process facilitates the co-construction of knowledge, as students work together to define problems, devise solutions, and evaluate their prototypes in a collaborative environment. Participation in Design Thinking activities fosters empathy and perspective-taking, which strengthens meaningful learning within a social-constructivist framework (Arifin & Siew, 2023).

Other research uses Design Thinking for the development of educational innovations, proposing pedagogical frameworks such as the use of makerspaces or co-design projects in curriculum planning. For example, Stevenson et al. (2019) explore how DT-based professional development can improve teachers' pedagogical capabilities in makerspaces, and (Li et al., 2024) investigate the development and transformation of maker mindsets in primary school students. Also, Kelly et al. (2019) propose an iterative model that integrates DT into curriculum planning in collaboration with secondary school teachers.

Regarding interdisciplinary integration and collaboration in STEM environments, several investigations address how DT facilitates the combination of disciplines and promotes collaborative work. An example is the study by Mikic et al. (2016), which evaluates how DT can integrate liberal arts and STEM in an educational context, fostering innovation and interdisciplinary collaboration. Likewise, Chen et al. (2023) study how DT can be integrated into translational research in biomedicine, achieving an effective fusion between science and education. In her research Norliyana Md. Aris, (2024) seeks to develop a chemistry module using the Design Thinking approach to improve students' innovation skills.

Some research evaluates the impact of DT on academic performance and skill development. For example, work by Simeon et al. (2022) examines how DT affects performance on physics concepts, and Taleyarkhan et al. (2018) study how the use of

CAD simulations improves DT in engineering students. Other research also focuses on teacher professional development, with studies such as Arrington & Willox (2021) examining how DT-based professional development can improve teachers' pedagogical skills.

Scientific works that address the Design Thinking methodology to encourage the study of STEM areas include the study carried out by (Ladachart, Cholsin, et al., 2022), where this methodology was used to improve learning in STEM areas among socioeconomically disadvantaged students. The educational intervention, which included collaborative design activities, showed that students feel more confident in tackling engineering problems after participating in the activity. Another approach, presented by Dotson et al. (2020), proposes the IGNITE model, based on peer-led collective learning. This model focuses on ideation and rapid prototyping, providing practical skills relevant to real life in low-resource communities, suggesting its scalability and sustainability in Design Thinking-based activities.

B. Bush et al. (2022) and Francis et al. (2017) highlight the use of Design Thinking to foster STEM areas, emphasizing empathy, problem-solving, and collaboration. In addition, they highlight the importance of a more humanistic approach in education to benefit students and society at large. These studies, along with others cited, underline the versatility and effectiveness of Design Thinking in STEM educational contexts, addressing diverse issues and promoting inclusion and creativity.

In the work of (Ladachart, Cholsin, et al., 2022), the use of Design Thinking to improve learning in STEM areas among socioeconomically disadvantaged students is highlighted. The educational intervention, based on Design Thinking, shows that students feel more comfortable solving engineering problems after participating in collaborative design activities. Likewise, English (2023) focuses on the development of critical thinking and problem-solving skills in students through Design Thinking, highlighting its contribution to innovation and non-predetermined outcomes in technology and engineering.

The main challenges and limitations identified in the literature on the implementation of the Design Thinking methodology in the study of STEM areas are evidenced in the studies by Galoyan et al. (2022) and Ladachart, Khamlarsai, et al. (2022). These investigations present limitations such as a small sample size, gender imbalance, and limited time for the implementation of the curriculum. The need for further research is highlighted to verify and elaborate the results, underlining the limitation of generalization due to the small sample and suggesting future studies with larger populations and qualitative data.

B. Bush et al. (2022) and English (2023) mention challenges and limitations in the successful implementation of Design Thinking in STEM education, such as the need to maintain the integrity of individual disciplines, additional training for educators, investment in resources and technology, and an interdisciplinary and collaborative approach. Meanwhile, Zhou et al. (2021) mention the need to build conceptual cohesion and the importance of examining the use of the verbal modality in engineering design processes.

CONCLUSION

The predominance of mixed-method and qualitative studies in this systematic review has allowed for a detailed analysis of experiences and perceptions surrounding the implementation of Design Thinking (DT) in STEM education. This trend also poses limitations in terms of the ability of the findings to be standardized. The lack of robust quantitative studies, such as meta-analyses or longitudinal studies, prevents a more precise assessment of the impact of DT on long-term learning outcomes (Wu et al., 2019). Previous research has pointed to the need to develop standardized tools that allow for a more objective measurement of the effectiveness of DT in improving students' creativity, self-efficacy, and academic performance (Chiu et al., 2021). Similarly, the reliance on qualitative studies limits the ability to establish causal relationships between the implementation of DT and its effects in STEM education, underscoring the importance of developing mixed-methodology approaches with more balanced approaches (He et al., 2023).

Another relevant finding is that the geographic concentration of scientific production in the United States, China, Thailand, Malaysia, Turkey, and Australia could indicate differences in national priorities for STEM education reform (Ladachart et al., 2022). This highlights the need to conduct studies in underrepresented regions to evaluate the adaptability of DT in diverse educational contexts, especially in countries with limited resources or in marginalized communities (Norliyana Md. Aris, 2024). Some studies have begun to explore the implementation of DT in educational settings with less access to advanced technology, demonstrating its potential to foster more meaningful and contextualized learning (Tramonti et al., 2023). However, gaps persist in the literature regarding the evaluation of its impact on different demographic groups, such as students from rural communities or vulnerable populations (Thomason & Hsu, 2024).

In terms of STEM disciplines, the results indicate that the effectiveness of Design Thinking varies depending on the area of knowledge in which it is implemented. While its integration into engineering and technology teaching has been widely documented due to its iterative and problem-oriented nature (Öztürk & Korkut, 2023), its application in science and mathematics requires specific strategies to ensure its alignment with curricular objectives (Zhu et al., 2024). The combination of DT with problem-based methodologies or project-based learning has been shown to be an effective strategy for improving student motivation and engagement (Chang et al., 2023), although further studies analyzing its impact on academic performance in these areas are still needed.

Studies show that TD fosters interdisciplinary collaboration and the integration of 21st-century skills such as creativity, critical thinking, and communication (Juškevičienė et al., 2021). However, the lack of teacher training in this methodology remains an obstacle to its effective implementation (Ho & Pang, 2024). Previous research has highlighted the importance of designing professional development programs that provide teachers with tools to incorporate TD into their teaching practices (Chiu et al., 2021). Furthermore, TD training should consider strategies to address equity challenges in STEM education, ensuring that its implementation does not deepen existing gaps between students with different levels of access to educational resources (He et al., 2023).

Regarding recommendations for future research, it is crucial to conduct longitudinal studies to assess the impact of DT on the development of STEM skills over time, as well as its influence on career choices in these disciplines (Wingard et al., 2022). Likewise, it is suggested to develop standardized measurement tools to evaluate the effectiveness of DT in terms of learning, self-efficacy, and student motivation (Zhou et al., 2021). Finally, it is essential to delve deeper into the relationship between DT and specific STEM disciplines, analyzing how this methodology can be differentially effective in science, technology, engineering, or mathematics, in order to optimize its integration into formal education (Zhu et al., 2024).

The findings of this systematic review confirm that Design Thinking represents a methodology for transforming teaching and learning in STEM education. Its ability to foster creativity, problem-solving, and collaboration places it as a valuable pedagogical approach in the current educational context. However, methodological and structural challenges persist that must be addressed to maximize its impact. The scarcity of quantitative studies, the lack of research in diverse educational contexts, and the need for further teacher training are factors that limit its effective implementation. Overcoming these challenges will require a joint effort between researchers, educators, and educational policymakers to ensure that Design Thinking becomes an accessible and adaptable tool for diverse educational realities, thus promoting more equitable and inclusive STEM education.

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