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A systematic review on design thinking in science education research (DTiSER) on 21st century skills

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Abstract

Background: Design thinking is essential for developing 21st century competencies, and there is a growing need and interest in introducing design thinking to science education students.
Aim. The purpose of this study was to review high-quality empirical research on design thinking in science education research (DTiSER) and explore future research perspectives.
Method: A systematic review based on a five-stage methodology comprising of (1) research article collection from the databases, (2) research article inclusion/exclusion norms, (3) reviewing the processed research articles, (4) analyzing the research articles to extract the information, and (5) inferring the extracted information to derive at the future research direction. The paper contributes to reviewing 31 research articles, specifically on design thinking in science education research (DTiSER).
Results: The results indicate that: (1) Research trends on design thinking in science education research (DTiSER) between 2015 and 2023 increased. (2) The United States is a country that mainly conducts research on design thinking in science education research (DTiSER) between 2015 and 2023 (3) Research trends of highly cited papers published in academic journals between 2015 and 2023, i.e., articles written by Smith et al. (4) The science materials that have been applied to design thinking from 2015 to 2023 are electricity, magnetism, mechanics, climate, planets, earth science, conservation biology, environment, thermodynamics, disaster mitigation, soil classification, microba and organisms.
Conclusion. As seen from the results, emerging research directions in DTiSER include DTiSER trends, top countries and authors contributing to DTiSER, and the application of science materials in Design Thinking. The findings provide valuable insights for future researchers and also have practical implications for science educators and policymakers. As such, this research aids effective development in fostering 21st-century skills.

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INTRODUCTION

A systematic review performs many important functions. They can synthesize the state of knowledge in the field from which future research priorities can be derived. It can answer questions that individual studies could not answer. They can identify primary research questions to address in future studies. You can also develop or evaluate theories about how or why phenomena occur. Therefore, systematic reviews produce different kinds of knowledge. (e.g. Page et al., 2021; Torrijos-Muelas et al., 2023) To ensure that systematic reviews are of value to users, authors should explain why the review was conducted, what was done (e.g., how studies were identified and selected), and What you discovered (e.g., characteristics of contributing studies and results of meta-analyses). In

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addition to the benefits of systematic reviews, there is growing interest in improving science education through innovative approaches such as design thinking.

Emerging from the field of design, design thinking has attracted significant interest from both practitioners and academics because it offers a novel approach to innovation and problem-solving (Micheli et al., 2019; Li & Zhan, 2022). In the artificial world, design plays an essential role in the development of human society by realizing "transformation from the current situation to a desirable state" (e.g. Chen, 2020; Sachdeva & Ali, 2022). In design, design thinking is tied to understanding design expertise. For example, what constitutes design expertise and how to help beginners acquire that expertise to become experts and good designers (e.g. Zhang et al., 2022; Sarkar et al., 2023). According to Jonathen's typology, Design problems tend to be among the most complex and unstructured problems encountered in practice (e.g. Burre et al., 2023; Lu et al., 2023). Therefore, experienced designers with creative problem-solving methods are considered a group of innovative problem-solvers, and they and their thinking have something important to offer to other fields.

As an innovative problem-solving method, design thinking gradually expands from a technical concept to a more general one (Li & Zhan, 2022). Today, "design thinking" is recognized as an exciting new paradigm for addressing problems in many fields, such as IT, business, education, and healthcare (e.g. Mesa et al., 2022; Chidambaran et al., 2022; Li & Zhan, 2022). Practitioners and researchers have published their views on design thinking. Design thinking, for example, is a term used in the rapidly changing world of business to "use the sensibilities and methods of the designer to align what is. It is defined as "that which can be converted into a market opportunity" (e.g. Adams & Nash, 2016; Matthews & Wrigley, 2017; Rylander Eklund et al., 2022). A similar definition was put forward by the Kelly brothers, who sees design thinking as "a method of finding human needs and using the tools and mindsets of design practitioners to create new solutions" (Gross & Gross, 2016; Mansoori & Lackeus, 2020). According to (Jaggi & Bhushan, 2020; Li & Zhan, 2022), design thinking is rooted in abductive thinking and is the next competitive advantage. Some researchers in this cluster argue that non-designers can (and should) learn and adopt design thinking (e.g. Knight et al., 2019; Bertão et al., 2023).

Design thinking models help students better understand the design thinking process and the basic principles of design thinking. Typical models such as the Stanford d.school five iteration stages (empathy, define, idea, prototype, test) (Su & Xu, 2020) and the IDEO process model (discover, interpret, idea, experiment, evolve) (Foster, 2021) Such as the double diamond model (discover, define, develop, deliver (Kim & Park, 2021) has been introduced into education. As an innovative method, design thinking has been used in many fields, including education. Design thinking is applied to prepare students for their future lives and careers by developing abilities such as creativity, collaboration, communication, critical thinking, or 21st-century skills (Li & Zhan, 2022). For this reason, there is a growing interest in design thinking in science education.

However, there are also lingering issues, such as the "gap between design and science", where projects focus more on creating successful design products than on people. Science and related scientific principles (Chase et al., 2019) and the question of whether training in design thinking can actually foster creativity or simply create unfounded confidence are not accompanied by real creative achievements (e.g., Liedtka, 2018; (Li & Zhan, 2022) . More evidence is needed using empirical research to show whether design thinking is an effective approach to science education and how it applies in a science education context. Therefore, it is necessary to systematically review the literature to present the current research on design thinking in science education research(DTiSER).

With these limitations in mind, our study aimed to review DTiSER studies systematically and in more detail than previous reviews. A particular focus is on empirical studies applying Design Thinking In Science Education Research (DTiSER). This survey aims to (1) systematically review high-quality empirical research on DTiSER at all educational levels and (2) consider future research perspectives in Design Thinking In Science Education Research (DTiSER) based on the articles reviewed. The following research questions (RQs) form the basis of this review.

a. What has the trend of Design Thinking In Science Education Research (DTiSER) publication been over the years?
b. Which country mainly researches design thinking in science education from 2015 to 2023?
c. What are the research trends of highly cited papers published in academic journals between 2015 and 2023?
d. What science materials have been implemented with design thinking between 2015 and 2023?

METHOD

Research Design

Methods is a research strategy outlining how a study approaches a research question. This study addresses literature review methods that are most appropriate when research aims to determine current research trends and identify conceptual works for future research (e.g. Paz & Pow-Sang, 2014; Valverde-Berrocoso et al., 2020; Nyirahabimana et al., 2022).

This research utilized the Systematic Literature Review (SLR) technique. An extensive literature search was conducted for this article. A total of 543 first publications were collected from reliable sources such as Scopus, with publication dates from 2015 to 2023. This systematic literature review focuses on design thinking in science education research

Procedures and if relevant, the time frame :

The research utilized a "method consisting of five stages" by Nyirahabimana et al. (2022) to search, locate, select, review, and analyze the selected articles on design thinking in science education. Some procedures in this research method can be seen in Figure 1.

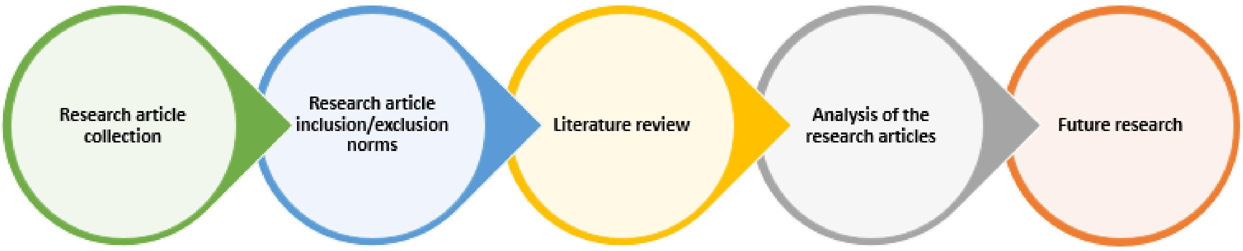


Figure 1. Literature Review Procedures

a. Step I: Research article collection

The first step was to select and collect the data sources that best fit the scope of the research area. We identified several bibliographic databases (e.g., PubMed, Springer Link, EBSCO). However, due to certain limitations, they do not provide all the necessary information needed for effective bibliographic analysis. Therefore, Scopus, one of the leading scientific databases, was utilized to identify journal articles for this study. A search was conducted in the Scopus database on February 28, 2023, using the search keywords "Design Thinking" AND "Education" AND "Science" OR "Physics" OR "Biology" OR "Chemistry." A total of 543 papers were obtained.

b. Step II: Research article inclusion/exclusion norms

This study examined and evaluated papers on design thinking in science education research from various Scopus-indexed journal publications. Title, abstract, and keyword selection methods were employed to identify the most relevant papers on design thinking in this field. The established criteria included the year of publication (2015-2023), document type (article), language (English), and source type (journal). A total of 112 articles met these criteria.

Additionally, from March to June 2023, the lead researcher presented and discussed the articles with other researchers based on their reviews of abstracts, keywords, and article content to identify relevant articles. Out of the 112 relevant articles, 31 were selected and analyzed for this study. Figure 2 illustrates the process of how the research papers were searched in the Scopus database and the search criteria used to locate them.

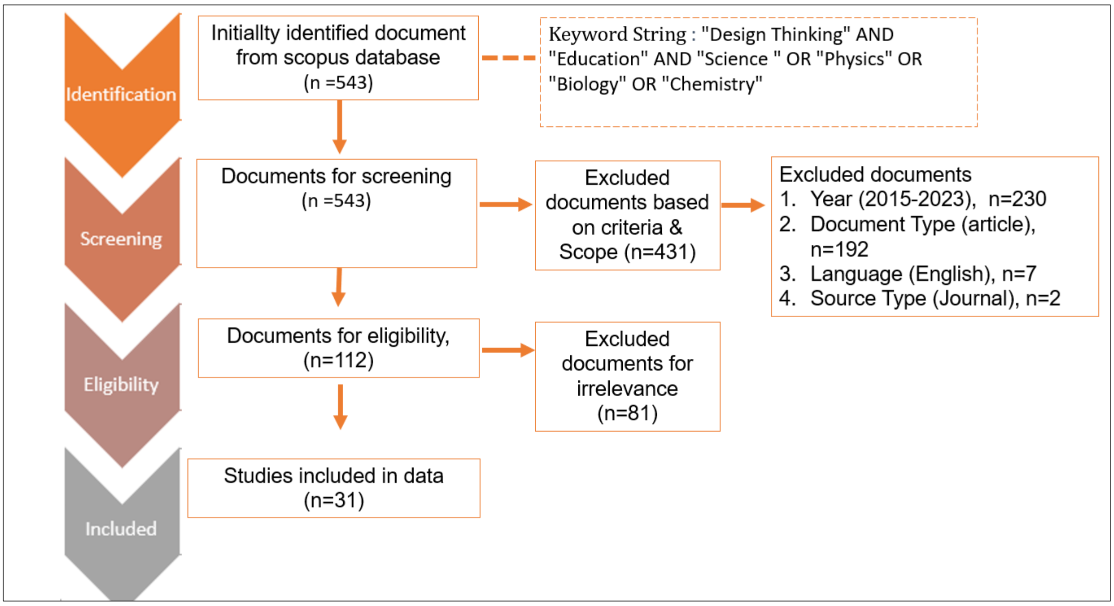


Figure 2. PRISMA Process

c. **Step III: Literature review**

The chosen articles were scanned and reviewed to gather bibliographic data and article content for researching the application of design thinking in science education.

d. Step IV: Analysis of the research articles

The 31 selected articles were subjected to bibliographic and content analysis. The bibliographic analysis consisted of publication trends for each year and country, as well as visualization of topic trends, keywords, and co-citation networks using the biblioshiny program coded from the R Studio application. Content analysis was conducted to identify science materials applied in design thinking in science education research. Furthermore, the results of both analyses are discussed in detail in section 5 to identify research gaps.

e. Step V: Future research

Research gaps identified in the work analysis are noted in the discussion section. Further work to be performed is also determined based on the gap. The research implications of this study, both in theory and practice, are also presented in the discussion section.

RESULTS AND DISCUSSION

a. Trend of publication of Design Thinking In Science Education Research (DTiSER) between of 2015 and 2023

The bibliographic analysis framework used in this study was adapted from Nyirahabimana et al. (2022). Thirty one articles have been shortlisted using the search setting explained in Figure 2. 31 The articles were analyzed to produce Figure 3 showing Research Trends on Design Thinking in Science Education Research (DTiSER).

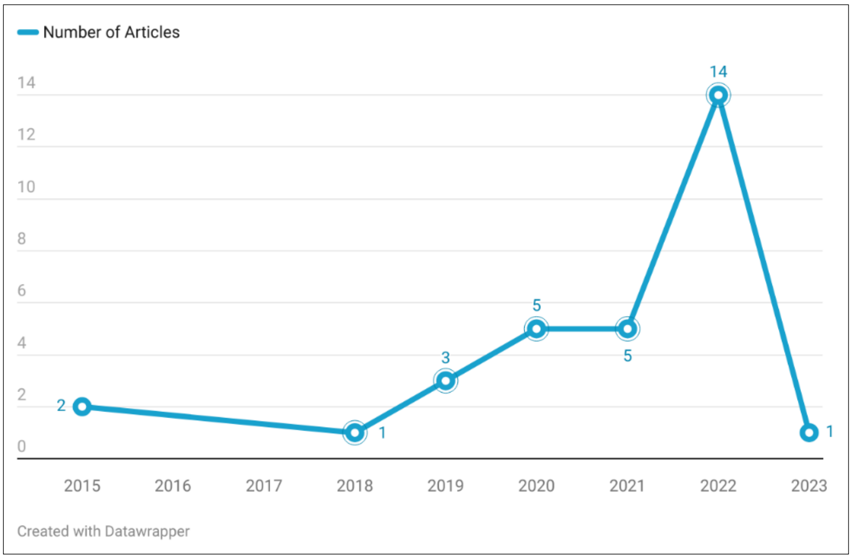


Figure 3. Trends in Design Thinking in Science Education Research (DTiSER)

The analysis revealed increased trends in Design Thinking in Science Education Research (DTiSER) publications. In 2022, he had 14 research papers published, but in 2023, he had only 1 papers. Since the year is just beginning, the number of items will likely increase further by the end of 2023. In 2022, the topic "Design Thinking in Science Education Research" (DTiSER) was covered by 12 countries, including Indonesia.

Afterward, Table 1 depicts the distribution of processed articles indexed in both Scopus and Web of Science. The data presented in Table 1 also determined that journals with a background in technology, Design Education, and STEM education published numerous articles on Design Thinking in Science Education Research (DTiSER).

Table 1. The Journals That Have Been Selected for Review

Journals	F	Indexing	
		Scopus (SJR)	Web of Science (JIF)
International Journal of Technology and Design Education	6	Q1 (0.75)	SSCI, SCIE (0.88)
International Journal of STEM Education	3	Q1 (1.82)	SSCI, SCIE (2.46)
Thinking Skills and Creativity	2	Q1 (1.16)	SSCI (1.93)
Applied Sciences (Switzerland)	1	Q2 (0.51)	SCIE (0.59)
Australasian Journal of Engineering Education	1	Q2 (0.48)	N/A (-)
Biomimetics	1	Q2 (0.69)	SCIE (0.7)
British Journal of Educational Technology	1	Q1 (1.87)	SSCI (2.77)
Design Journal	1	Q2 (0.33)	AHCI (1.5)
Educational Technology Research and Development	1	Q1 (1.72)	SSCI (2.83)
Eurasia Journal of Mathematics, Science and Technology Education	1	Q2 (0.57)	N/A (-)
Frontiers in Education	1	Q2 (0.58)	ESCI (0.89)
GAIA - Ecological Perspectives for Science and Society	1	Q2 (0,34)	SCIE (0,26)
IAFOR Journal of Education	1	Q3 (0,36)	ESCI (-)
International Journal of Art and Design Education	1	Q1 (0.41)	SSCI,AHCI (1.12)
International Journal of Child-Computer Interaction	1	Q1 (1.03)	N/A (-)
International Journal of Environmental Research and Public Health	1	Q1 (0.81)	N/A (-)
International Journal of Innovation in Science and Mathematics Education	1	Q3 (0,29)	ESCI (0,83)
International Journal of Instruction	1	Q2 (0.5)	ESCI (0.69)
Issues in Educational Research	1	Q2 (0.44)	ESCI (0.61)
Journal of Turkish Science Education	1	Q2 (0.5)	N/A (-)
Open Education Studies	1	Q2 (0,34)	- (-)
Sustainability (Switzerland)	1	Q1 (0.66)	SSCI, SCIE (0.65)
Sustainability Science	1	Q1 (1.78)	SCIE (1.09)

Trend Topics DTiSER is shown in Figure 4. The size of the sphere shows the frequency of terms that appear. The greater the frequency of terms that appear, the larger the sphere. The top 10 terms in DTiSER trend topics include design, thinking, students, stem, learning, study, education, knowledge, processes, and curriculum. These top 10 terms have a frequency of occurrence in the abstracts of the analyzed articles greater than 13.

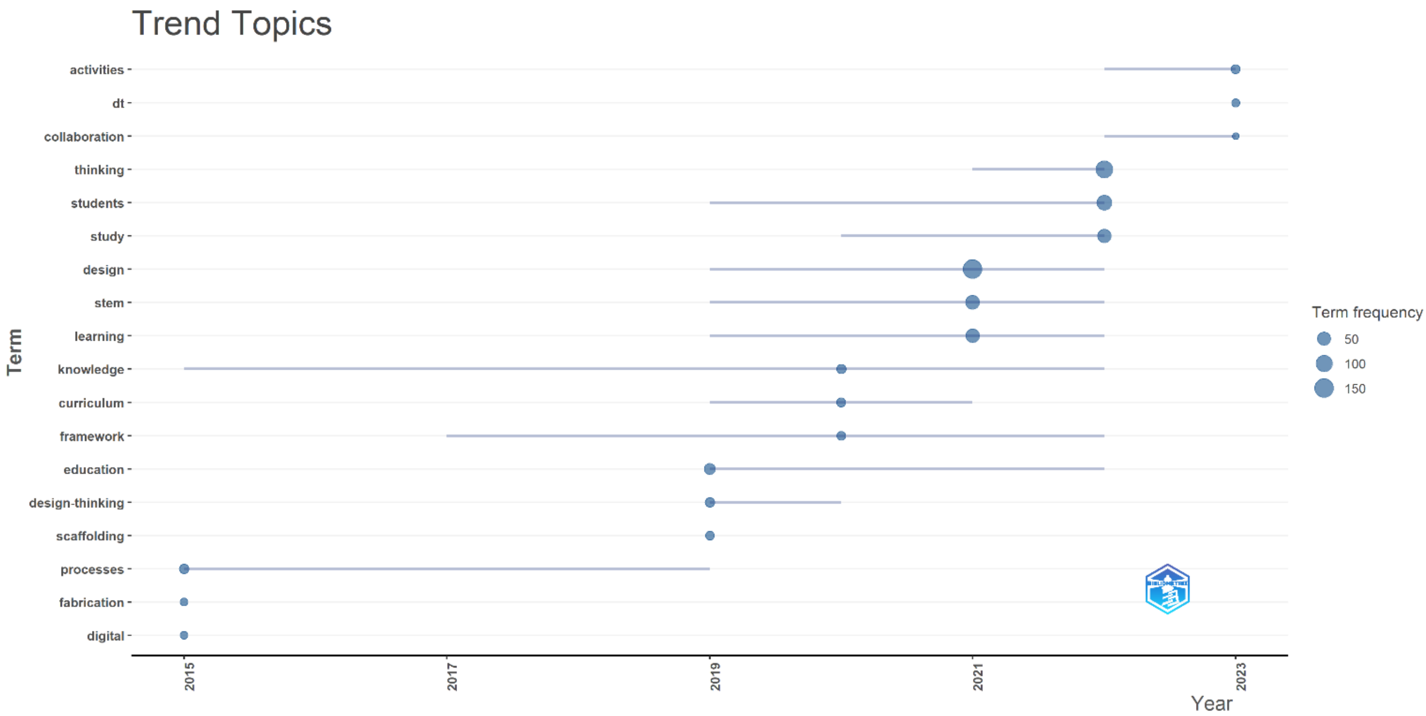


Figure 4. DTiSER Topic Trends

Figure 5 shows the most frequently used keywords in Design Thinking in Science Education Research (DTiSER) publications. The font size indicates that words are frequently used in this topic. The most frequently used words are design thinking, students, engineering education, health status, product design, united states, design, female, personnel training, and risk factor.

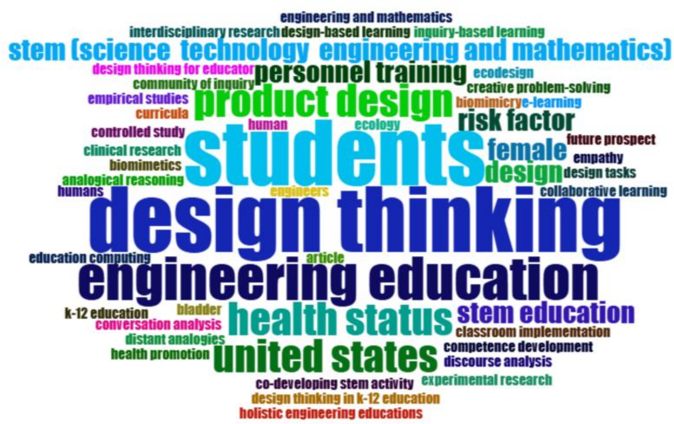
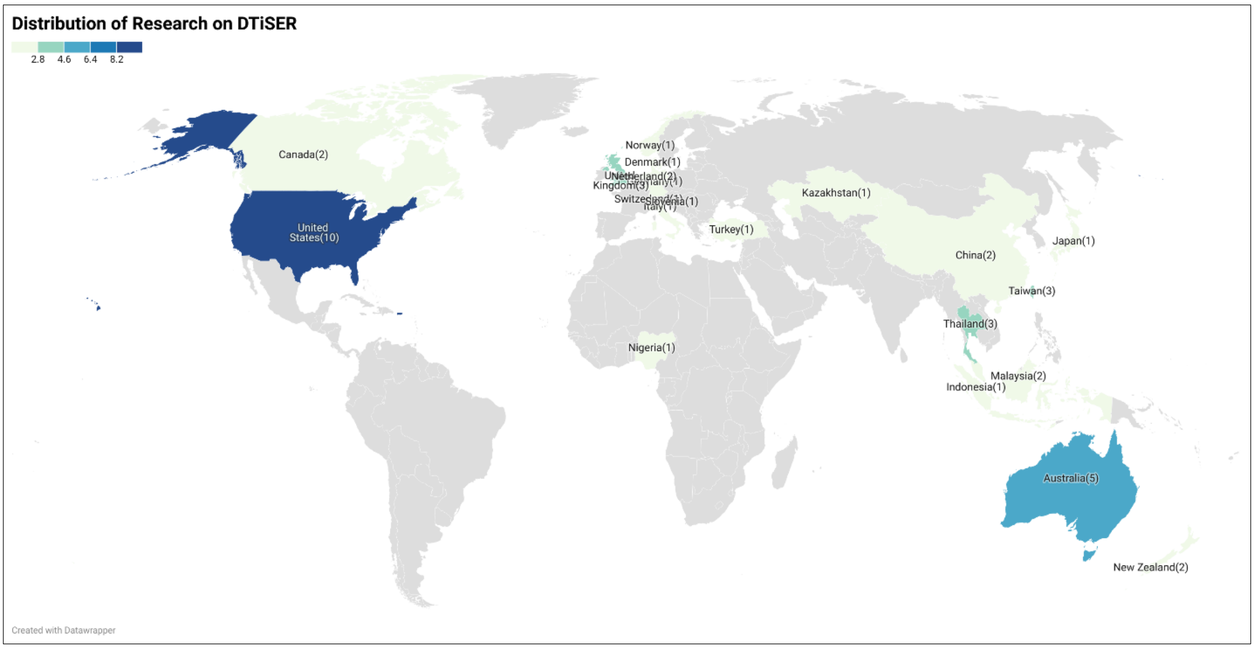


Figure 5. Most Relevant Keywords

b. The Country mostly conducts research on Design Thinking In Science Education Research (DTiSER) the between 2015 and 2023

In addition, a bibliometric analysis is conducted to assess each country's contribution. Figure 6 displays the Distribution of Research on DTiSER Based on Countries.



(a)

(b)

Figure 6. The Distribution of Research on DTiSER Based on Countries.

United States dominates the list of publications on Design Thinking in Science Education Research (DTiSER) topics with 10 authors. Australia in the 2nd with five authors; the UK, Thailand,

and Taiwan in the 3rd with three authors; followed by New Zealand, Netherland, Malaysia, China, Canada, two authors; Turkey, Switzerland, Slovenia, Norway, Nigeria, Kazakhstan, Japan, Italy, Indonesia, Germany and Denmark are each represented by one author.

c. The research trends of highly-cited papers published in academic journals between 2015 and 2023

The top 10 papers in Design Thinking in Science Education Research (DTiSER) research from 2015 to 2023 are shown in Table 2. The publications are then ranked by the number of citations in the Design Thinking in Science Education Research (DTiSER) domain to answer a fourth research question.

Table 2. Top 10 Cited Articles on Design Thinking in Science Education Research (DTiSER)

Authors	Cited by
Smith et al.,(2015)	124
English et al., (2015)	105
Maher et al., (2018)	32
Lin et al., (2021)	30
Wu et al., (2019)	28
Kijima et al., (2021)	23
Pohl et al., (2020)	18
Kewalramani et al., (2020)	12
Simeon et al., (2022)	11
Severino et al., (2021)	10

Figure 7 shows the DTiSER co-citation network. This network illustrates research trends, relationships between topics, and publications that have had a major impact on DTiSER. In this visualization, Razzouk R. 2012 appears to be the most dominant publication, characterized by its large size and many connections, indicating that it is an important reference in DTiSER and is frequently co-cited with works such as Schweitzer J. 2016 and Wrigley C. 2015

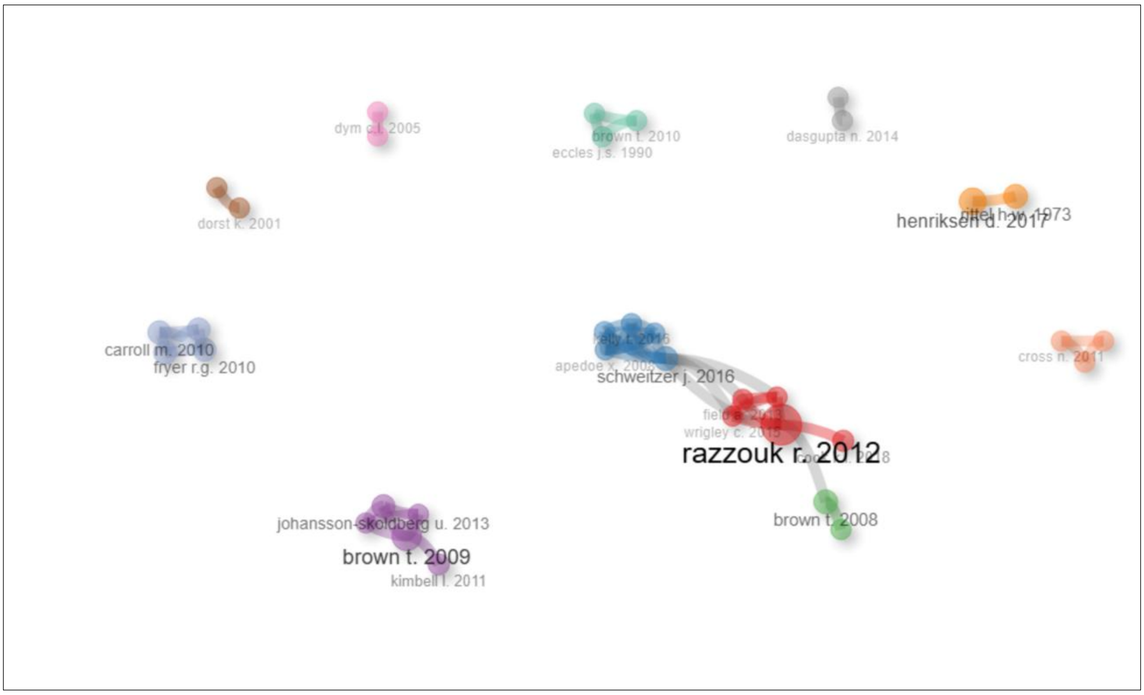


Figure 7. DTiSER co-citation network

d. The science materials have been implemented with design thinking between 2015 and 2023

The science materials that have been applied to design thinking from 2015 to 2023 are shown in Table 3.

Table 3. Science materials applied in Design Thinking

Science Materials	Authors
Mechanics	Hsiao H.-S.; Chang Y.-C.; Lin K.-Y.; Chen J.-C.; Lin C.-Y.; Chung G.-H.; Chen J.-H. (2022)
Motion	Simeon M.I.; Samsudin M.A.; Yakob N. (2022)
Force	Simeon M.I.; Samsudin M.A.; Yakob N. (2022) English L.D.; King D.T. (2015)
Energy	Simeon M.I.; Samsudin M.A.; Yakob N. (2022)
Speed	Simeon M.I.; Samsudin M.A.; Yakob N. (2022)
Acceleration	Simeon M.I.; Samsudin M.A.; Yakob N. (2022)
Friction	Lin K.-Y.; Wu Y.-T.; Hsu Y.-T.; Williams P.J. (2021)
Newton's First Law of Motion	Lin K.-Y.; Wu Y.-T.; Hsu Y.-T.; Williams P.J. (2021)
Organisms	Stevens L.; Kopnina H.; Mulder K.; De Vries M. (2021) Stevens L.L.; Fehler M.; Bidwell D.; Singhal A.; Baumeister D. (2022)
Planet & Space	Öztürk A.; Korkut F. (2022)
Thermal Expansion	Ladachart L.; Cholsin J.; Kwanpet S.; Teerapanpong R.; Dessi A.; Phuangsuwan L.; Phothong W. (2022)
Renewable/Alternative Energy Sources	Nichols K.; Musofer R.; Fynes-Clinton L.; Blundell R. (2022)
Non-renewable Energy Sources	Nichols K.; Musofer R.; Fynes-Clinton L.; Blundell R. (2022)
Energy Transformation	Nichols K.; Musofer R.; Fynes-Clinton L.; Blundell R. (2022)
Solar Cells	Elwood K.; Jordan M.E. (2022)
Soil classification	Elwood K.; Jordan M.E. (2022)
Microbes	Elwood K.; Jordan M.E. (2022)
disaster mitigation	Elwood K.; Jordan M.E. (2022)
Electrical	Smith R.C.; Iversen O.S.; Hjorth M. (2015) Hsiao H.-S.; Chang Y.-C.; Lin K.-Y.; Chen J.-C.; Lin C.-Y.; Chung G.-H.; Chen J.-H. (2022) Nichols K.; Musofer R.; Fynes-Clinton L.; Blundell R. (2022)
measurement	English L.D.; King D.T. (2015)
Earth science	Maher R.; Maher M.; Mann S.; McAlpine C.A. (2018)
Environmental Management	Maher R.; Maher M.; Mann S.; McAlpine C.A. (2018)
Sustainable practices	Maher R.; Maher M.; Mann S.; McAlpine C.A. (2018)
Conservation biology	Maher R.; Maher M.; Mann S.; McAlpine C.A. (2018)
Water Pollution	Dotson M.E.; Alvarez V.; Tackett M.; Asturias G.; Leon I.; Ramanujam N. (2020)
Climate	Pohl C.; Pearce B.; Mader M.; Senn L.; Krütli P. (2020)
Environmental Problems	Pohl C.; Pearce B.; Mader M.; Senn L.; Krütli P. (2020) Dyer M. (2019) Hall A. (2020)
ecology	Pohl C.; Pearce B.; Mader M.; Senn L.; Krütli P. (2020)
Pulleys	Ladachart L.; Radchanet V.; Phothong W. (2022)
Torque	Ladachart L.; Khamlarsai S.; Phothong W. (2022)
Excretory System in Humans	Lewis J.B.; Brady S.S.; Sutcliffe S.; Smith A.L.; Mueller E.R.; Rudser K.; Markland A.D.; Stapleton A.; Gahagan S.; Cunningham S.D. (2020)
Temperature Change	Mardiah A.; Rahmawati Y.; Harun F.K.C.; Hadiana D. (2022)
Thermodynamics	Mardiah A.; Rahmawati Y.; Harun F.K.C.; Hadiana D. (2022)
Electronics (Arduino, LED)	Kewalramani S.; Palaiologou I.; Dardanou M. (2020) Tramonti M.; Dochshanov A.M.; Zhumabayeva A.S. (2023)
Magnets	Kewalramani S.; Palaiologou I.; Dardanou M. (2020)

Based on the content review results in the articles reviewed, most of the science materials applied in design thinking have characteristics that can be applied directly to real life (Hoolohan & Browne, 2020); Lin et al.,(2021). In general, based on the content review of science materials in design thinking, the sub-materials about electricity, magnetism, mechanics, planets, environment, and organisms, if applied to design thinking, are still relevant due to the characteristics that are appropriate / can be applied directly to real life and according to the characteristics of the design approach.

CONCLUSION

This work did an up-to-date systematic review of Design Thinking In Science Education Research (DTiSER) literature. A total of 31 selected articles were analyzed and categorized. The clusters of frequently used keywords were created as subject areas, and the articles were categorized into those clusters using a bibliometric analysis of keywords. The results and discussions concluded : (1) Research trends on design thinking in science education research (DTiSER) between 2015 and 2023 increase. (2) The United States is a country that mainly conducts research on design thinking in science education research (DTiSER) between 2015 and 2023 (3) Research trends of highly cited papers published in academic journals between 2015 and 2023, i.e., articles written by Smith et al.,(2015) (4) The science materials that have been applied to design thinking from 2015 to 2023 are electricity, magnetism, mechanics, climate, planets, earth science, conservation biology, environment, thermodynamics, disaster mitigation, soil classification, microba and organisms.

AUTHOR CONTRIBUTIONS STATEMENT

All authors contributed to the study's conception and design. MAF was responsible for conceptualization, writing the initial draft, methodology, format analysis, and final manuscript preparation. IH contributed to conceptualization, visualization, and manuscript review. AS1 and AS2 participated in the visualization and review processes.

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