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Review Article

Trends of Design Thinking Research in STEM Education: Bibliometric Analysis

Rifqi Ghufrooni

Department of Chemistry Education, Universitas Negeri Jakarta, Indonesia

Abstract
Research on design thinking in education is increasing from year to year. design thinking offers creative freedom to teach, serving as a guide to enhancing the STEM experience for students. The purpose of this study is to provide an up-to-date map that explains and systematizes a collection of information from the Scopus database relating to design thinking research in STEM education. The keywords used are "design thinking" AND "STEM Education". A total of 812 documents were identified from various types of documents and years. All data were used in bibliometric analysis. The findings show that design thinking research in STEM education has increased every year with the use of English as the most widely used language. The most published type of document is the Conference Paper. The United States of America is the most productive country with the highest number of publications and citations. The most published author is Lee. CS while Ramani K got the most citations. The most influential journal is Design Studies while the most productive source is ASEE Annual Conference and Exposition. While articles written Stempfle (2002) recorded as the most cited articles. The most used author keyword in articles is design thinking.

Keywords: Bibliometric Analysis, Design Thinking, Education, STEM, Trends, VosViewer

Rifqi Ghufrooni
rifqi.gufrooni212@gmail.com

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1. INTRODUCTION

In recent years, design thinking has attracted the attention of many researchers to apply it in various fields of research. (Aris et al., 2021). Starting from architecture and art schools, design thinking has been widely used both in the fields of business and education (Rao et al., 2022). The experts' discussion on design thinking was first conducted regarding the exploration of research related to design and design methodology, seen from the perspective of design thinkin. Various models of design thinking have emerged since then based on the viewpoint of understanding design situations and situations and using theories and models from design methodology, psychology, education, etc. Although many argue that design thinking was popularized by IDEO or Stanford Design School, it can be explained that its beginnings were based on the pragmatic tradition of American philosophy. In short, the pragmatic tradition says that ideas and theories from individuals or groups need to be evaluated in terms of their impact on implementation (Buchanan, 1992). This basic idea makes Design an interventionist discipline. Currently, design thinking is known as a new method of dealing with problems in various fields, especially in the

field of technology and information(Lesselroth et al., 2021; Mentzer, 2014) and business (Hacker et al., 1998; Kortzfleisch et al., 2013).

The Teaching Approach through design thinking has shown increasing interest among researchers in the last 10 years (Henriksen et al., 2017; Souza et al., 2020; Thienen et al., 2011). One of the factors is that design thinking encourages students to associate learning contexts with problems in everyday life. Students act like a designer in creatively generating solutions based on user experience. This is in accordance with the results of researchers who found that design thinking is creativity in understanding real problems that are ambiguous and complex to be solved using the integration method of students as designers (Thienen et al., 2017; von Thienen et al., 2014). design thinking triggers students to produce creative ideas through a direct approach. Several studies report that design thinking helps develop 21st- century skills such as problem-solving, creativity, and communication (Brenner et al., 2016; Darbellay et al., 2017; Noweski et al., 2012; Olsen, 2015). This is good for students to prepare for the future.

The design thinking process prioritizes student experiences in creating innovative and creative solutions. This is important in the learning process to improve the quality of learning more optimally. Learning in the classroom does not only focus on the cognitive domain but needs to be related to the social and emotional characteristics of everyday life (Bialik et al., 2015. Johnson & Acabchuk, 2018; Meyer & Norman, 2020; Urbani et al., 2017). Several research reports confirm that design thinking is important as a theoretical lens in the field of education related to teaching and learning (Kirschner, 2015; Razzouk, 2012). Most of Design Thinking's research focuses on the corporate industry and educational context. (Carlgren et al., 2016).Its application in effective learning is to elaborate scientific findings into innovations and stimulate students for cross-disciplinary collaboration between academia and industry (Gonera & Pabst, 2019). The linkage of learning with the industrial sector is also something that needs to be considered considering that more and more graduates must be equipped with 21st century skills so they are ready to fill job needs.(Allen & van der Velden, 2012; Bialik et al., 2015b; Koh et al., 2015; Lamb, 2017; Valenciano et al., 2019)

Several applications of design thinking in education have been applied to both students (Cutumisu et al., 2020; Guaman-Quintanilla et al., 2022; Rao et al., 2022)and teachers (Cortés Loyola et al., 2020; Gleason & Jaramillo Cherrez, 2021; Henriksen et al., 2020). Design thinking has been applied in various fields of education such as business (Buhl et al., 2019; Shan et al., 2021), engineering (Lin et al., 2020), computer science (O'Callaghan et al., 2020; Ocares-Cunyarachi & Andrade-Arenas, 2022; Rodriguez et al., 2019; Snow et al., 2019), food (Veflen & Gonera, 2023), design (Evans, 2012)involving individuals, institutions and stakeholders. (Redante et al., 2019)Starting from the Stanford Design School institution, design thinking has become popular and is growing quite rapidly in the world of education (Auernhammer & Roth, 2021; Camacho, 2016). In its implementation, design thinking relies on cognitive skills and a designer's approach to solving a problem (LaPensee et al., 2021). As experts argue that not all problems can be solved rationally and systematically (Earle & Leyva-de la Hiz, 2021). Many real-life problems require other creative approaches to solving complex and even ambiguous user-centric problems (Brown, 2008; Georgiev, 2012; Rodgers & Winton, 2010; Stanford et al., 2017).

One application of design thinking in education is STEM integration. Integrating design thinking with STEM (Science, Engineering, Technique, Math) is increasingly in demand by many researchers. Several Design thinking studies on

STEM education have been conducted (Carroll, 2015; Chiu et al., 2021; Yalçın & Erden, 2021; Alashwal, 2020; Dotson et al., 2020; Henriksen, 2017; Kijima et al., 2021; Malele & Ramaboka, 2020; Simeon, 2022) . design thinking offers teachers a new way of teaching by giving teachers the freedom to develop more creative and interdisciplinary practices as work guides that can enhance students' STEM learning experiences. Design thinking and STEM have the same working principle, namely to foster students' problem-solving skills so that students can think and explore life's problems and then design appropriate solutions.

Previous Bibliometric analysis on design thinking has been carried out by several researchers such as Bhandari (2022)on entrepreneurship, Aris et al., (2021a)on academic evaluation, and Johann et al. (2020)a combination of Literature Review Studies, Content Analysis and Bibliometric Analysis. The previous author discussed extensively the themes and sub-themes of design thinking. Therefore, the previous author suggested conducting further research in accordance with specific objectives in order to dig further regarding design thinking. The author in this article emphasizes the discussion of design thinking in the field of education focused on the STEM field. Several previous literature reviews on design thinking in STEM education have been conducted (Alashwal, 2020; Carroll et al., 2010; Henriksen, 2017). Data analysis was carried out based on a comprehensive and updated Scopus data set from 1975-2022. The discussion is supported by enriching findings and providing the latest visual overview of world development trends regarding design thinking.

2. RESEARCH METHOD

2.1 Research Design

Bibliometric data analysis has been widely used by researchers in understanding trends in statistical information about Design thinking (Aris et al., 2021b). Gu (2004) explained that bibliometrics can be used to understand the amount of research flows on a topic or in a particular research field. Bibliometric data analysis can also be used to label the number, features, and increase in literature publications through data exploration (Elaish et al., 2019) and evaluating the results (Kasemodel et al., 2016). The ease of accessing data that can be downloaded from academic data centers (such as Scopus, Web of STEM, and Dimensi) and the availability of media (such as VOS viewer, CitNetExplorer, and CiteSpace) have a significant influence on increasing the number of studies conducted using bibliometric analysis (Zakaria et al., 2021).

2.2 Procedures

In this study, the bibliometric data analysis method was used to create a network map from the research literature on the topic of design thinking. The bibliometric analysis uses data sources from Scopus which were accessed on September 17, 2022. The search keywords for Title, Abs, and Key are "design thinking" AND "STEM Education". The keywords used focus on searching design thinking data related to STEM education. This will provide an overview of the trends and directions of design thinking research on STEM education. This study uses the PRISMA Flow guidelines, the details of which can be seen in Figure 1. All documents are subject to bibliometric analysis. This is done so that the discussion can be carried out in a comprehensive and thorough manner. This study uses Microsoft Excel 2016 to calculate the frequency and percentage of publication results and create charts and graphs. Making a network map and visualizing it using the Vos Viewer Application (version 1.6.18) is then analyzed and explained keywords in the abstract, author, country, and publication.

The author determines 6 research questions for this study, namely:
1. How is the growth and trend of design thinking publications in STEM education?
2. What are the authors and countries on design thinking research on STEM education that are most productive and collaborative?
3. What journals are most cited regarding design thinking in STEM education?
4. What are the most cited articles on design thinking research in STEM education
5. What are the keywords most frequently used in design thinking research in STEM education?

3. RESULTS AND DISCUSSION

3.1 Description of the Literature Found

A total of 812 documents were collected from the Scopus database based on the type of document and type of source according to the keywords used. Ten documents related to design thinking consist of conference paper, article, book chapter, conference review, review, book, note, editorial, erratum, and short. A summary of the types of published documents is presented in Table 1.

Table 1. Types of Documents Collected

Document type	Total Publications	Percentage (%)
Conference Papers	369	45.4
Articles	314	38.7
Book Chapter	54	6.7
Conference Reviews	26	3.2
Reviews	26	3.2
Book	10	1.2
Note	8	1.0
Editorial	3	0.4
Erratum	1	0.1
Short	1	0.1
Total	812	100

Most of the papers were in English (97.4%) when published, followed by Chinese (0.9%), Spanish (0.6%) German (0.4%), Portuguese (0.4%), Croatian (0.1%), Korean (0.1%), and Russian (0.1%). There are 2 documents in 2 languages (german and english) so that the total number of documents is 814. A summary of the use of document languages can be seen in Table 2.

Table 2. The Type of Language Used

Document Language	Amount	Percentage (%)
English	793	97.4
Chinese	7	0.9
Spanish	5	0.6
German	3	0.4
Portuguese	3	0.4
Croatian	1	0.1
Korean	1	0.1
Russian	1	0.1
Total	814	100

3.2 Growth of Publications and Trends in the Term design thinking Related to STEM Education

The search for articles used in this study experienced varied growth from 1975 to 2022. There were 812 publications of the total document types each year. The data

source used is from the Scopus database using the keyword " design thinking ". Figure 2 shows the trend of publication of design thinking documents each year. At the beginning of publication in 1975 there was only 1 article published until 2022 there were a total of 812 publications recorded. 2020 was recorded as the year with the most publications, namely 122 documents, while the highest number of citations occurred in <2000, where the initial document source for the development of design thinking is the main reference for further research development. Publication trends and citations are important factors in describing the development of a particular field of knowledge, field or topic.

From 1975 to 2006 there were 22 published documents and this publication was cited 1191 times. Trends have increased from 2007 to 2014 with 139 publications and cited 2060 times. It is nine that a significant increase in publications and citations related to design thinking. Publications have increased from 2015 to 2022 with 651 articles with 2,785 citations. The highest productivity was observed in 2020 with 122 documents. However, there was a decline afterwards from 2021 to 2022. It should be noted that the R2 value of 0.83 reveals that the trend of the exponential line is reliable. The endpoint of the data collected in this review is September 2022 (month 9) which explains why there are 72 documents (60 citations) appearing in 2022 which are expected to continue to increase until the end of 2022.

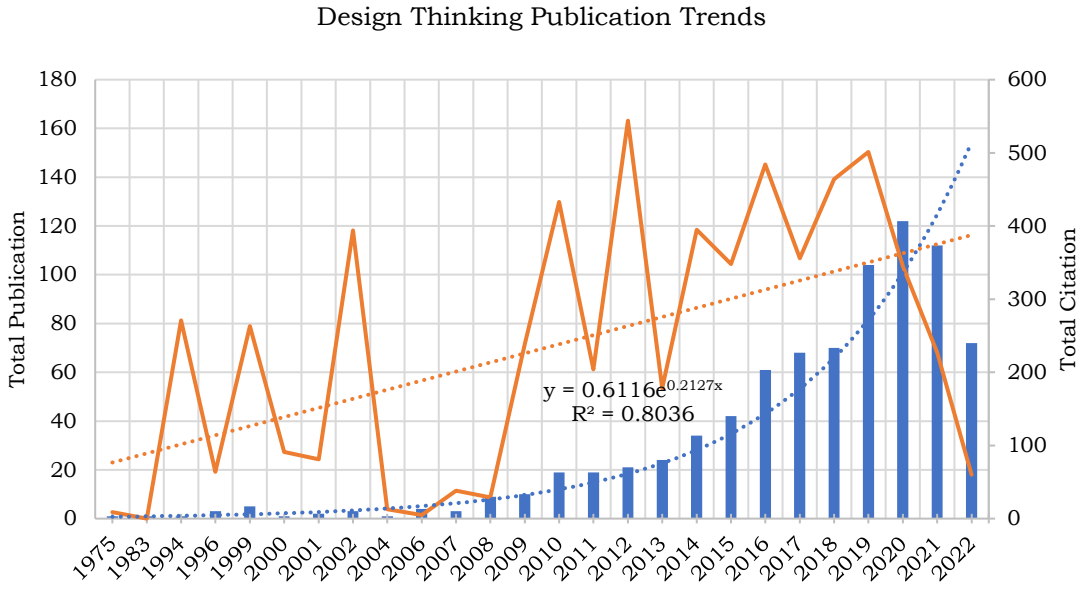

Figure 2. Design Thinking Publication Trends

Table 3. Number of Annual Publications and Citation Matrix

Year	TP	NCP	TC	C/P	C/CP
<2000	11	10	607	55.2	60.7
2000	1	1	91	91.0	91.0
2001	2	1	81	40.5	81.0
2002	3	3	394	131.3	131.3
2004	1	1	13	13.0	13.0
2006	4	2	5	1.3	2.5
2007	3	3	38	12.7	12.7
2008	9	8	29	3.2	3.6
2009	10	9	239	23.9	26.6
2010	19	13	433	22.8	33.3
2011	19	16	204	10.7	12.8

Year	TP	NCP	TC	C/P	C/CP
2012	21	14	544	25.9	38.9
2013	24	19	178	7.4	9.4
2014	34	24	395	11.6	16.5
2015	42	35	348	8.3	9.9
2016	61	45	484	7.9	10.8
2017	68	52	356	5.2	6.8
2018	70	52	464	6.6	8.9
2019	104	70	501	4.8	7.2
2020	122	66	345	2.8	5.2
2021	112	54	227	2.0	4.2
2022	72	22	60	0.8	2.7

Note: TP=total number of publications; NCP=number of cited publications; TC = total citations; C/P=average citations per publication; C/CP=average citations per cited publication

3.3 The Most Productive and Collaborative Authors and Countries in design thinking Research

Spread all publications resulting from design thinking research during 1975 to 2022 come from 87 countries from all over the world. Selection of the threshold for the minimum number of documents filled out is 1 with no minimum limit for the number of citations. The highest order both in publication and citation was obtained by the USA. There are 246 documents that have been published by the USA with 2148 citations. Followed by the second country United Kingdom with 52 documents with 634 times cited. A summary list of the top 10 based on the number of publications and citations from each country is summarized in table 4. A network map visualization of the 10 countries with the most publications on design thinking is shown in Figure 3.

Table 4. Top 10 Countries with the Most Design Thinking Papers Published

No	Country	Documents	Citations	Total Link Strength
1	United States	246	2148	73
2	United Kingdom	52	634	19
3	Germany	51	580	13
4	China	51	127	8
5	Australia	30	674	34
6	Canada	31	389	20
7	Taiwan	30	204	9
8	Netherlands	26	247	12
9	Brazil	20	77	2
10	Finland	19	84	10

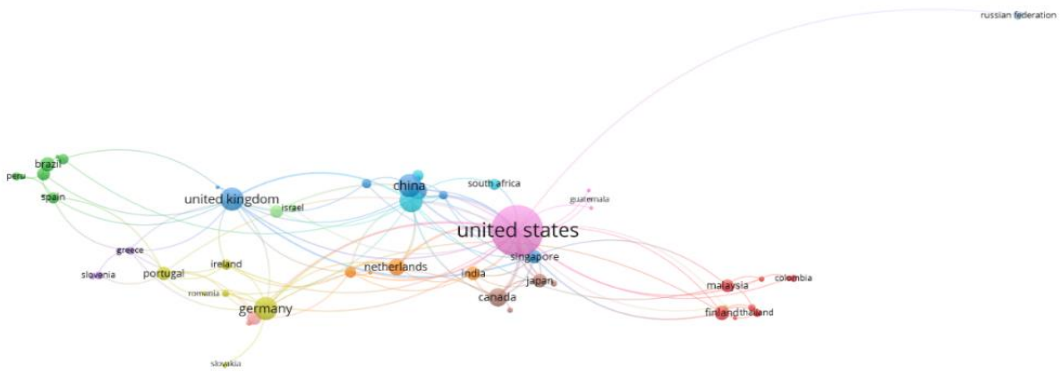

Figure 3 . Network Map of Countries Publishing Design Thinking

The results of the data above illustrate that the USA is the most influential country in design thinking research which has developed many studies as evidenced by the most publications and total link strength. In addition, countries that are developing in technology and business have also implemented design thinking a lot. This can be seen from data such as Germany, China, Taiwan(UNCTAD, 2021). Finland as a leading country in education ranks 10th (Delisle & Cooper, 2019).

Authors in the field of design thinking have increased since their inception until they continued until the time this article was written in 2022. Based on Scopus data with a minimum publication author threshold of 1 and no minimum publication limit, 2013 authors were obtained with 2103 findings. The summary of the top 10 authors based on the highest number of documents is in table 5. Lee.CS was named the author with the most 6 documents who conducted research with design thinking . Meanwhile, the author with the highest number of citations was obtained by Ramani K. with 342 citations. The author network map displays 193 clusters that are not related to each other. Vos Viewer limits results to 1000 items out of a total of 2103 items. The author network map is in Figure 4.

Table 5. The Most Influential Author on Design Thinking Research

Author	Affiliation	N	Citations	Total Link Strength
Lee. cs	Sunway University	6	22	5
Leifer l.	Stanford University	5	31	8
Gero J.	University of Sydney	4	51	15
Ejsing-duun s.	Aalborg University	4	4	10
Hanghoj t	University College Copenhagen	4	4	10
Chai CS	Chinese University of Hong Kong,	4	92	3
Ramani K.	Purdue University	3	342	17
Lattermann C.	Jacobs University	3	29	12
Simon D.	Braunschweig University of Technology	3	29	12
Taajamaa V.	University of Turku	3	19	11

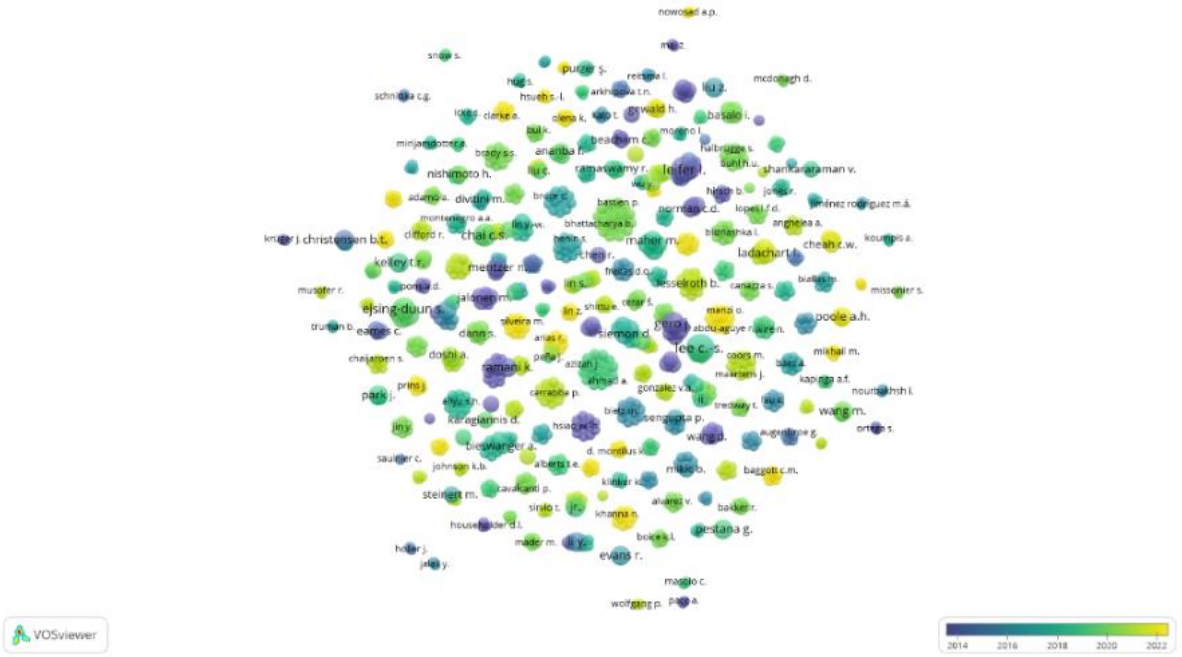

Figure 4. Co-Authorship Network based on Author Analysis

3.4 The Most Cited Journal (Co-Citation and Citation) on Design Thinking Research

The number of citations is important in describing how much influence the research has in that field. Based on the analysis of data obtained from Vos Viewer, the 10 most cited journals were obtained between 1975 and 2022. Filling in the minimum threshold of 2 documents and 2 times cited resulted in 483 journals with 81 findings. Journal of Design Studies with 10 documents, is the most cited journal with 1052 times. The second place is occupied by the International Journal of Technology and Design Education with 152 citations and 11 documents. The summary of the top 10 journals with the most citations is in table 6. While the sources with the most number of documents (n=31) are in the ASEE Annual Conference where Conference Papers are the most productive type of document published. An overview of the map citation network is given in Figure 5 while an image of the co-citation map network is given in Figure 6. There are 4 clusters of 14 items. Visualizations are created only in journals that have a link. The thickness of the link indicates the number of linkages in the research field in other studies. The size of the nodes is proportional to the number of citations. The distance of one node to another indicates the closeness of the journal in the research topic.

Table 6. Network Map Citation Analysis of Publication Sources on Design Thinking Research

Source	Cited	N	Total Links
Design Studies	1052	10	2
International Journal of Technology and Design Education	152	11	5
International Journal of Engineering Education	121	11	0
International Journal of STEM Education	114	3	4
ASEE Annual Conference and Exposition, Conference Proceedings	99	31	1
Conference on Human Factors in Computing Systems-Proceedings	94	2	1
Journal of cleaner production	80	2	1
Asia-Pacific Education Researcher	77	2	0
Translational Behavioral Medicine	71	2	0
Thinking Skills and Creativity	66	2	0

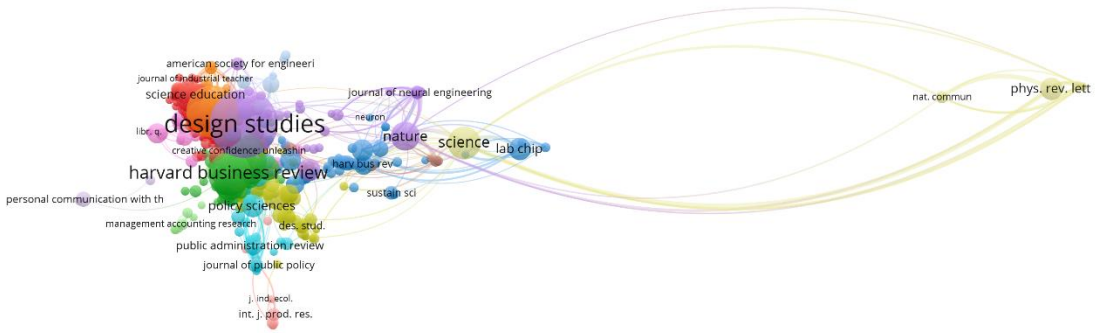

Figure 5. Network Map of Citation Analysis In Design Thinking Research

Figure 6. Map Network Co-Citation Analysis on Design Thinking Research

Table 7. The 10 Most Cited Articles

Document	Citations	Links
Stempfle, J., & Badke-Schaub, P. (2002). Thinking in design teams - an analysis of team communication. Design Studies, 23(5), 473–496. doi:10.1016/s0142-694x(02)00004-2	372	2
Ramani, K., Ramanujan, D., Bernstein, WZ, Zhao, F., Sutherland, J., Handwerker, C., Thurston, D. (2010). Integrated Sustainable Life Cycle Design: A Review. Journal of Mechanical Design, 132(9), 091004. doi:10.1115/1.4002308	340	0
Goldschmidt, G. (1994). On visual design thinking: the vis kids of architecture. Design Studies, 15(2), 158–174. doi:10.1016/0142-694x(94)90022-1 10.1016/0142-694	271	0
Maier, JRA, Fadel, GM Affordance based design: a relational theory for design. Res Eng Design 20, 13–27 (2009). https://doi.org/10.1007/s00163-008-0060-3	186	0
Howlett, M. (2014). From the “old” to the “new” policy design: design thinking beyond markets and collaborative governance. Policy Sciences, 47(3), 187–207. doi:10.1007/s11077-014-9199-0	185	2
Altman, M., Huang, TTK, & Breland, JY (2018). design thinking in Health Care. Preventing Chronic Disease, 15. doi:10.5888/pcd15.180128	147	4
Kimbell, L. (2012). Rethinking design thinking: Part II. Design and Culture, 4(2), 129–148. doi:10.2752/175470812x13281948975	137	3
Bowers, J. (2012). The logic of annotated portfolios. Proceedings of the Designing Interactive Systems Conference on - DIS ‘12. doi:10.1145/2317956.2317968	134	0
Bannon, LJ & Ehn. P. 2012. Routledge International Handbook of Participatory Design. Taylor and Francis. ISBN: 978-113626626-3;978-041569440-7. DOI: 10.4324/9780203108543	125	0
Louridas, P. (1999). Design as bricolage: anthropology meets design thinking. Design Studies, 20(6), 517–535. doi:10.1016/s0142-694x(98)00044-1	110	0

3.5 The Most-Cited Articles in Design Thinking Research in The STEM and Education Fields

519 documents obtained according to the Vos Viewer threshold for the type of analysis is Citation and the unit of analysis is Document with a minimum of 1 quote. Stempfle & Badke-Schaub (2002)is the article with the highest number of citations, namely 372 times. Followed by the next sequence Ramani et al. (2010)) 340 times,

Goldschmidt (1994)271 times and Maier & Fadel (2009)186 times. The summary of the top 10 articles with the most citations is in Table 7. Meanwhile, a network map image is shown in Figure 7.

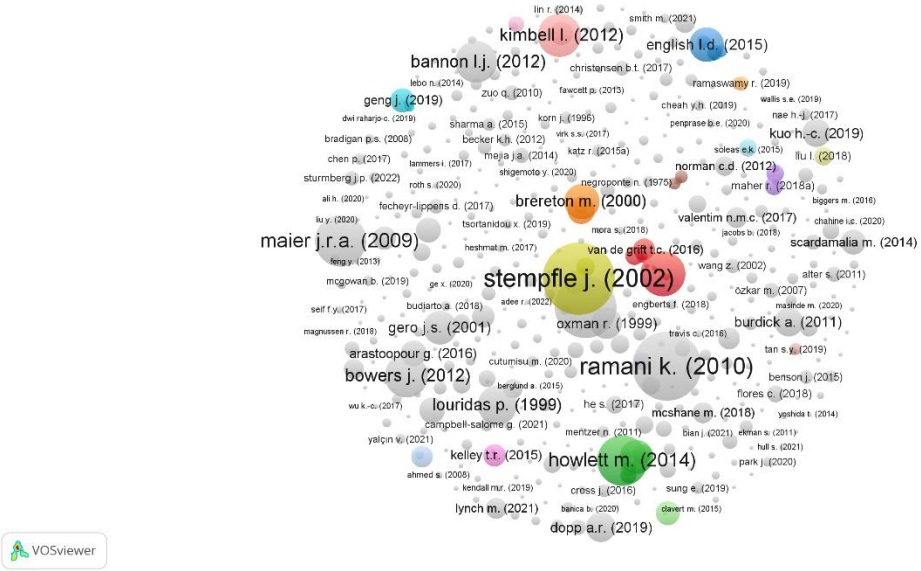

Figure 7. Distribution Most Cited Documents in Design Thinking Research

3.6 The Most Used Keywords in Articles on the Use Design Thinking in Science and Education

Making maps from Scopus data that has been collected based on the most used keywords using co-occurrence analysis by selecting author keywords. The minimum number of occurrences of keywords set is 2 resulting in the number of keywords generated being 2227 with 360 findings that match the limit. The map that has been created is represented in Figure 6. The results show that there are 23 clusters and 356 items. The most keywords are design thinking with the word appearing 332 times and a total link strength of 687. The next sequence is innovation (n= 45, total link strength = 132)), design (n=36, total link strength = 86), creativity (n=27, total link strength= 70), education (n=12, total link strength= 45), design science (n=18, total link strength=42), interdisciplinary (n=14, total link strength = 37) etc. The order of the top 10 most keywords related to design thinking in STEM and education is summarized in table 7.

These results show that the most focus is on design thinking which relates to innovation, design, creativity, and education that requires interdisciplinary implementation. These results prove that the application of design thinking in STEM field research and education still applies the principles of a Designer such as innovation, creativity, and interdisciplinary (Henriksen, 2017; Li et al., 2019)These results also provide an overview of design thinking education in STEM developing students' skills as a designer in solving problems. The emergence of STEM education (n = 15, total link strength = 29) ranks 7th. Meanwhile, the keywords STEM (n = 9, total link strength = 25) and STEAM (n = 11, total link strength = 31) are still small. outside 10 as big. The addition of Art in STEM as an expansion of scope resulted in the new term "STEAM". The term STEAM education related to design thinking is still relatively small (n=4 with total links=9). These results illustrate that Design thinking research related to STEAM is still new so it has opportunities to be further developed.

The network map visualization is in figure 8 and the annual distribution is in Figure 9.

Table 8. Top 10 Most Researched Keywords in Design Thinking

Keyword	Occurrences	Total link strength
Design thinking	332	687
Innovations	45	132
Design	36	86
Creativity	27	70
DesignScience	18	45
Engineering education	17	42
STEM Education	15	37
Interdisciplinary	14	37
ServiceDesign	14	36
Design Science Research	13	33

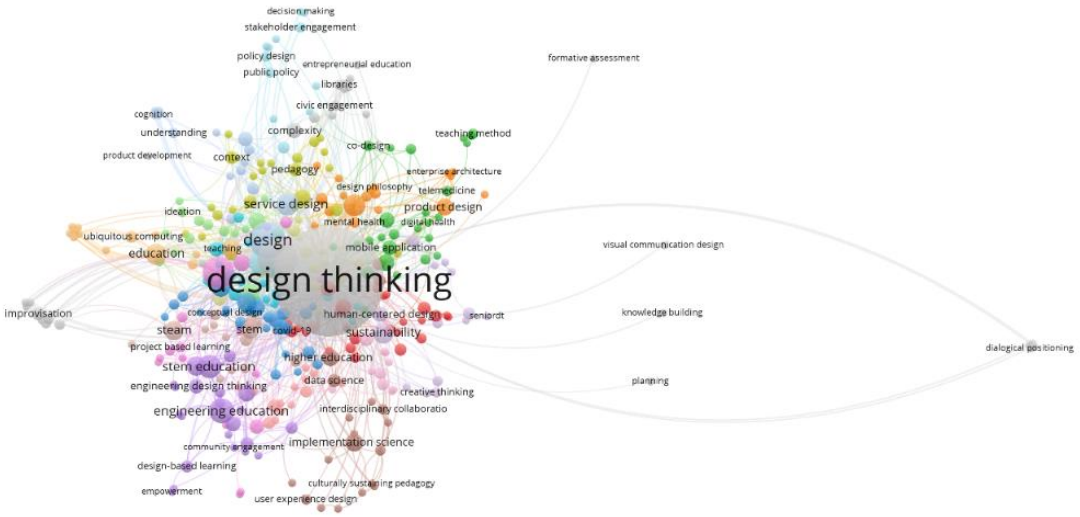

Figure 8. The Keyword Network Used in the STEM and Education Fields

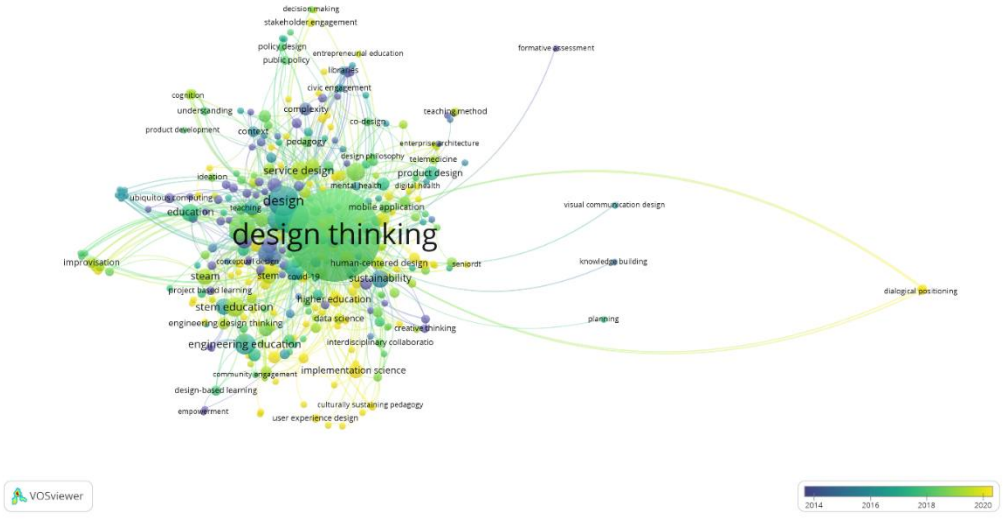

Figure 9. Total Distribution of Articles based on Keywords Each Year

4. CONCLUSION

This research reviews scientific publications on design thinking in STEM education between 1985 and 2022 (17 September) from the Scopus database. Based on the Bibliometric analysis of design thinking in STEM education, it can be concluded that there has been an increase in the number of publications in recent years which has had a positive effect on the number of citations. Conference papers and articles are the most common types of documents published. The United States of America is the most productive country with the highest number of publications and citations. The most published author is Lee. CS from Sunway University while Ramani K from Purdue University got the most citations. The most influential journal is Design Studies while the most productive source is ASEE Annual Conference and Exposition. While articles written by Stempfle & Badke-Schaub (2002)recorded as the most cited articles. The most used author keyword in articles is design thinking.

It is hoped that the findings from this analysis can help researchers, academics, and students to identify scientific results regarding design thinking research in STEM education, to improvise previous findings and to identify important topics and issues that will help design future research.

Conflict of Interest

The authors reported no potential conflict of interest.

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