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Profile of Top 100 Cited in STEM Education for the Last Twenty Years

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ABSTRACT

The research analyzes the top 100 cited in STEM education in the last twenty years. The research objectives are to analyze the publication type, year, sources publishing, authorship pattern, institution, country, and keywords pattern and review these top-cited publications using bibliometric analysis. The metadata used in this research is the Scopus database. The study result shows that among these top 100 publications, the most common type of publication is journal articles. Most of these publications were conducted at four-year intervals from 2014 to 2017, with an average citation per paper of 70.75. Belland is recognized as the most productive author, whereas National Research Council has become the institution with the most citations. The most contributed institutions included Purdue University and the University of Minnesota. The USA has led over highly cited publications, followed by Australia and the Netherlands. The research areas in these papers mainly emphasize education, STEM, STEM education, engineering education, and every stem aspect. The review result focus on research on the conceptual framework of STEM integration, STEM-based learning media, challenges to STEM, perspectives on STEM education, and the impact of COVID-19 on STEM education. This research implies finding research novelties about STEM education through the results of mapping and visualization patterns based on keywords that often appear.

INTRODUCTION

Science, Technology, Engineering, and Mathematics (STEM) was officially introduced by the US National Science Foundation around 1990 as the theme of the education reform movement (Aktürk et al., 2017). STEM education has been widely applied in the education curriculum of world countries to create superior quality human resources in the STEM field in facing the demands of 21st-century skills (Nugroho et al., 2019; Thu et al., 2021; Widya et al., 2019). STEM can bridge educational institutions and the real world, entering the Industrial Revolution 4.0 era (Kersanszki & Nadai, 2020). In addition, STEM education has also emerged as a global movement to bridge the gap between the need and availability of skills needed for economic development in the 21st Century (Lee et al., 2019).

Research on STEM education has also experienced a rapid increase in the last few decades, published in academic journals and international conferences (Preciado Babb et al., 2016; Ritz & Fan, 2015). For example, in 2014, a new journal appeared, "International Journal of STEM Education," the first journal approved in the Social Science Citation Index in 2019 with an initial number of 13 documents. In 2020 it had 59 documents (Li et al., 2019). STEM research has also undergone many evolutions, resulting in several developments from STEM to STEAM (A = Art/Animation), STREAM (R = Robotics/ Reading/Religion), and STEM-D (D = Disaster) (Badmus & Omosewo, 2020; Connor et al., 2015; Guangfu et al., 2021; Mubarok et al., 2020;

Sampurno et al., 2015; Utami et al., 2017). Another simple thing that can be done to prove that there is a lot of STEM research is to type in the keywords "STEM," "STEM Education," or "STEM Education Research" to find more than 450,000,000 items. Therefore, it needs efforts to find out and understand the status and trends of a research topic to develop and be supported appropriately (Li et al., 2020), and STEM education is no exception.

It is not easy to access the most impactful studies and trending research topics in any field (Suprapto et al., 2021b), especially if the field has many research results. One method that can be used to understand this is bibliometric studies. This study can measure, identify, compare, and analyze the productivity of a study when viewed from an individual, group, institution, or country perspective (Fernandez-Batanero et al., 2020; Kumar et al., 2015). In addition, bibliometric studies can also help identify research trends and impactful studies through information from published bibliographies, such as title, the number of citations, author, affiliation, abstract, and keywords (Li & Xu, 2021; Parmar et al., 2020; Shareefa & Moosa, 2020). Moreover, this method is effortless and does not require high costs (Sengupta et al., 2020).

Another method that can be used to measure the quality of a research publication on the Scimago Journal Rank (SJR), Impact Factor (IR), and h-index is through the number of citations (Devi, 2021). Thus, the papers receiving more citations are expected to have a good quality of research and influence the knowledge domain in a particular field. The number of citations a paper receives is generally considered an indicator of a field's impactful study. Therefore, it is necessary to have a bibliometric analysis on research topics regarding STEM education so that trends can be seen in the highest number of citation publications and impact knowledge development. Research aims to analyze the types of publications, the year-wise distribution, the sources published, the prolific authors, authorship, the institution, the country of origin, and the most keywords occurring in the top 100 cited publications in STEM education. Besides that, this research also reviews some of these articles.

RESEARCH METHOD

General Background

This research has a quantitative type with a bibliometric approach to map research trends regarding STEM education using four stages, as seen in Figure 1 (Jatmiko et al., 2021; Julia et al., 2020; Nawaz & Strobel, 2016; Suprapto et al., 2021a). Mapping research trends can reflect the research hotspots and development trends at a particular stage (Meng et al., 2020). Data collection was carried out on January 16, 2022.

Figure 1. Bibliometric research design (adapted from Julia et al. (2020)).

Searching Procedures

The metadata analyzed was based on the Scopus database (www.scopus.com) because it has the best quality, reputation, and good index with the curated most significant number (Baas et al., 2020). The metadata search was carried out through the subject category "STEM Education" in the last 20 years because STEM was proposed in 2000.

Filtering Bibliography
The search results found 1,841 relevant documents regarding STEM education over the last 20 years. After that, sorting is done based on the highest number of citations, then the 100 articles with the highest citations were extracted in files with *.ris* and *.csv* extensions.

Completing Bibliography
The file *.ris* is used to compile further statistical data using the application *VOSviewer*. This application was chosen because it is open-access, produces easy-to-understand visualizations, and can operate on large databases (Hudha et al., 2020; Shah et al., 2020). The data obtained are the number and trend of publications, the number of articles by author (co-authorship), the most frequently occurring keywords (co-occurrence), and the number of clusters and collaborations. In contrast, the file *.csv* is used to analyze more detailed information about article titles, author names, affiliations, abstracts, keywords, and references to each article. This file can be opened using Microsoft Excel software. Finally, to support the result, the data collection was continued by conducting a literature review on ten articles with the most citations by journal type.

Analyzing Bibliography
Data analysis was carried out descriptively to determine the type of publication, distribution of articles/papers by year, publication source, author, institution, country, and keywords from the top 100 publications in STEM education. Analysis can also be done by looking at the node size and link strength based on the results of mapping or visualization using *VOSviewer* and *WordCloud Generator*. In addition, the literature review results were analyzed based on the findings, limitations, and recommendations in related articles.

RESULTS AND DISCUSSION

Publication Type

The document types of the top 100 publications published in STEM education from the last twenty years are shown in Table 1. It can be seen that article publications have the highest frequency and total citations, namely 75 and 4,278. However, there are other types of publications, such as conference papers, book chapters, editorials, reviews, books, and notes, with less frequency of publication. Meanwhile, notes have the highest average citation, 214.33, followed by books, with an average of 143.50.

The top 100 publications in STEM education have a vast number of citations compared to other topics, such as "physics education," which is 3422 (Suprapto et al., 2021b), even though STEM education was only proposed in 2000. This shows that research trends in STEM education have increased rapidly because their application can revolutionize the current education system in producing STEM-capable human resources (National Research Council, 2011).

Table 1. Document types of top 100 cited publications.

Document Type	Frequency	Total Citation	Average
Article	75	4278	57.04

Document Type	Frequency	Total Citation	Average
Conference Paper	6	351	58.50
Book Chapter	5	536	107.20
Editorial	2	166	83.00
Review	5	527	105.40
Book	4	574	143.50
Note	3	643	214.33
Total	**100**	**7075**	**70.75**

Publication Type

The top 100 cited publications of STEM Education have been published during the last twenty years (from 2001 to 2021). Table 2 shows the distribution of papers by year. The number of articles started in 2001 was 1 article. STEM education was only proposed in 2000, so even in the last 30 years, articles have remained close to the 2000s. The highest number of articles was in 2016, with 17 articles, followed by 2014, with 16 articles, and in 2015 with 12 articles.

Table 2. Year-wise distribution of papers.

Year	Articles	Citations	ACPP	ACCPY	Citable Years
2001	1	32	32.00	1.52	21
2007	1	91	91.00	6.07	15
2008	1	30	30.00	2.14	14
2009	3	324	108.00*	8.28	13
2010	2	162	81.00	6.75	12
2011	4	242	60.50	5.48	11
2012	6	499	83.17	8.32	10
2013	6	312	52.00	5.78	9
2014	16	1562*	97.63	11.64	8
2015	12	677	56.42	8.01	7
2016	17*	1387	81.59	14.09	6
2017	11	627	57.00	11.38	5
2018	10	541	54.10	13.38	4
2019	7	392	56.00	18.43	3
2020	3	197	65.67	32.33*	2
Total	**100**	**7075**	**70.75**	**-**	**-**

*Note: ACPP (Average Citations per Paper); ACCPY (Average Citations per Paper per Year); * (the highest number); * (Highest)*

The highest number of citations was in 2014, with 1562 citations, followed by 2016, with 1387 citations, and other years with fewer citations. The highest average citation per paper was in 2009, which was 108. Meanwhile, the highest average citation per paper per year was in 2020, 32.33.

Sources of Publication

Table 3 lists the sources that have published the top 100 cited publications in STEM education. These top 100 publications have been published in 75 journals, conference proceedings, books, and chapters. The journal "International Journal of STEM Education" led the source publishing of seven articles. Then followed by the "International Journal of Science Education" with five articles. Also, three articles were continued with "Science Education; Cultural Studies of Science Education; Eurasia

Journal of Mathematics, Science and Technology Education." From the number of citations, the "International Journal of STEM Education" has the highest number of citations, 957. As for the average citation per paper, "Science" has the highest number of citations, 182.00.

Table 3. Sources of top 100 cited publications.

Sources	Publisher	Type	Q	OA or not	Articles	Citations	ACPP
International Journal of STEM Education	Springer	Journal Article	Q1	Yes	7	957*	136,70
International Journal of Science Education	Routledge		Q1	No	5	239	47,80
Science Education	Wiley-Liss Inc.		Q1	No	3	150	50,00
Cultural Studies of Science Education	Springer Netherlands		Q1	No	3	177	59,00
Eurasia Journal of Mathematics, Science and Technology Education	Modesto LTD		Q2	Yes	3	180	60,00
American Educational Research Journal	SAGE Publications Inc.		Q1	No	2	69	34,50
CBE Life Sciences Education	American Society for Cell Biology		Q1	Yes	2	115	57,50
Educational Psychology Review	Springer New York LLC		Q1	No	2	78	39,00
International Journal of Technology and Design Education	Springer Netherlands		Q1	No	2	106	53,00
Journal of Chemical Education	American Chemical Society		Q2	No	2	103	51,50
Journal of Engineering Education	Wiley-Blackwell		Q1	No	2	236	118,00
Science	American		Q1	No	2	364	182,00*
Science Advances	Association for the Advancement of Science		Q1	Yes	2	94	47,00
STEM Road Map: A Framework for Integrated STEM Education	Taylor and Francis Inc.	Book Chapter	-	No	2	89	44,50
Other sources (with one paper each)					61	4,118	67.50
Total					**100**	**7,075**	**70**

The article on STEM education has the total citations compared to other documents. In line with research by Özkaya (2019), which analyzes bibliometrics on the Web of Science database, the type of article publication has the highest frequency. Based on the year distribution, articles published in 2014-2017 became the most citations. This shows

that research on STEM education has rapidly increased because publications have increased. However, in 2017-2020 the number of articles decreased due to the relatively new publications. However, the highest average citation per paper per year was 32.33 in 2020. In line with Ha et al. (2020) research result, the research trend on STEM has increased dramatically in the last three years. In addition, when viewed from the source of publication, almost all sources with the top 100 cited publications are published in journal publication sources with quartiles Q1 to Q2. This shows that the quality of publication sources affects the number of citations in the paper/article, and most articles are also not open access.

Authors of Top 100 Publication

The metric results show that 296 authors were associated with these 100 top-cited papers in STEM education. Table 4 shows a list of the top 15 authors sorted by the total number of articles and the most citations. Beeland BR is the most productive author with a top total of 4 articles. Followed by Roehrig GH, Moore TJ, Walker AE, Fernandez F., Ramon EJ, and Ro HK with three articles each. At the same time, other authors have fewer than three items. If sorted by total citations, the National Research Council, Honey MA, Pearson G, and Schweingruber H. obtained a total citation of 475. This finding aligns with Özkaya (2019) that the National Research Council was ranked first in the total citations.

Table 4. Author profile sorted by total articles and total citations.

Sorted by Total Articles				Sorted by Total Citations			
Authors	**Total Articles**	**Total Citations**	**Total link strength**	**Authors**	**Total Articles**	**Total Citations**	**Total link strength**
Belland B. R.	4	195	8	National Research Council	1	475	15
Roehrig G. H.	3	263	11	Honey M. A.	1	475	5
Moore T. J.	3	250	10	Pearson G.	1	475	5
Walker A. E.	3	162	8	Schweingruber H.	1	475	5
Bevans M.	2	70	15	Kelley T. R.	1	368	1
Castro K.	2	70	14	Knowles J. G.	1	368	1
Prince P.	2	70	14	English L. D.	2	343	0
Shelburne N.	2	70	14	Roehrig G. H.	3	263	11
Soeken K.	2	70	14	Cohen C. A.	1	253	1
Zabora J.	2	70	14	Uttal D. H.	1	253	1
Dori J. Y.	2	70	6	Moore T. J.	3	250	10
Labov J. B.	2	73	14	Mayo M. J.	1	234	0
de Jong T.	2	197	5	de Jong T.	2	197	5
Giller D.	2	197	5	Gillet D.	2	197	5
Johnson C. C.	2	89	5	Xie Y.	2	197	5

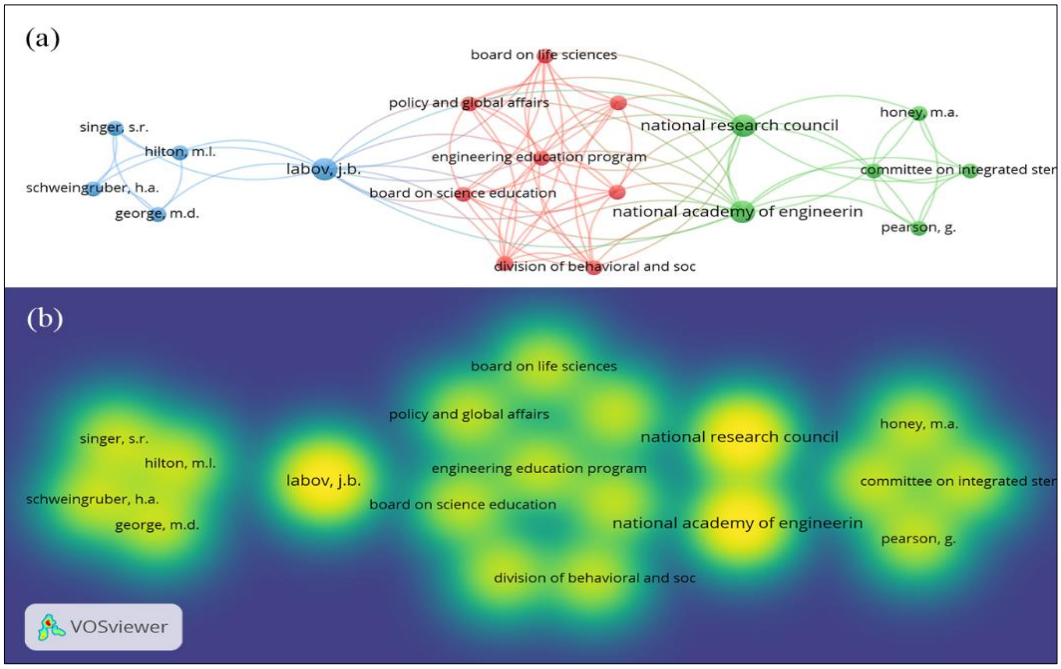

Figure 2. (a) Top authors' cluster; (b) Author production over time

Institutions such as the National Research Council, Committee on Integrated STEM, and National Academy of Engineering have relatively more robust patterns than other authors. This is because the institution is the main point and initiator of the formation of STEM education. Purdue University has the most relevant affiliation because it has published the top 100 cited publications. Figure 2(a) shows the clustering mapping based on co-authorship. There are three clusters indicated with different color nodes. The first cluster has red nodes with eight items. The second cluster has green nodes with six items. Finally, the third cluster has blue nodes with five items. Figure 2(b) shows the density visualization for co-authorship based. It can be seen that the National Research Council, National Academy of Engineering, and Labov BJ have a massive density because they have the highest total link strength compared to other authors.

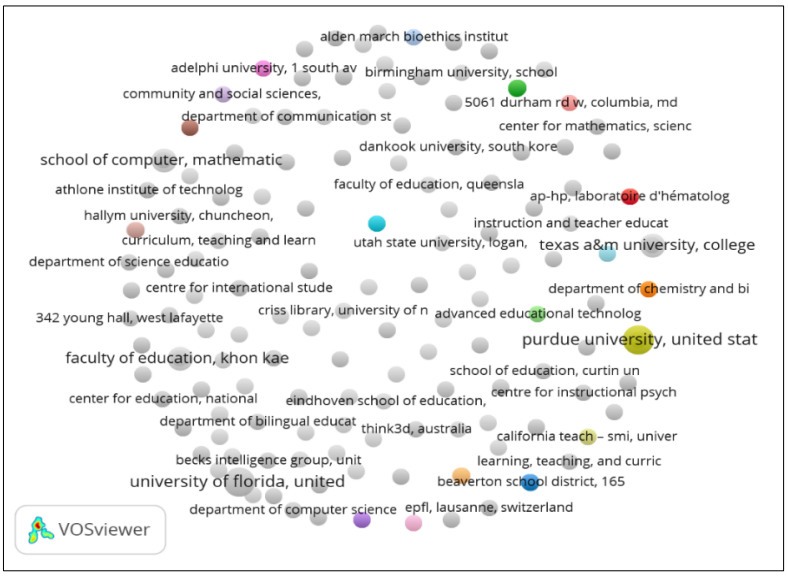

Figure 3. Most relevant affiliations.

Most Relevant Affiliations and Countries

The top 100 cited STEM education publications are affiliated with 305 affiliations from 33 countries. Figure 3 shows the most relevant affiliates. Purdue University and the University of Minnesota have the highest number of top-cited publications, namely three items. Morgan State University has top-cited publications of two items. In comparison, other affiliates have one article each. In calculating the most relevant countries, consider the first author and the co-authors so that the total number of articles counted will be more than 100. The metric results show that 22 countries contributed to the top 100 cited publications in STEM education.

Table 5. Country of publication.

Country	Articles	Total Citations	ACP	Total Link Strength
USA	68	4916*	72,29	9*
Australia	7	536	76,57	1
Netherlands	5	309	61,80	4
Greece	4	277	69,25	4
Canada	4	165	41,25	3
Israel	3	121	40,33	3
Spain	3	263	87,67	1
UK	3	173	57,67	0
Switzerland	2	197	98,50*	4
South Korea	2	80	40,00	1
Malaysia	2	62	31,00	0

Table 5 shows the eight countries that produced the top 100 publications, with 14 other countries having less than 3 top papers. It can be seen that the USA is the country that produces the most top papers, with 90 articles and a total link strength of 10. Australia follows this with 10 top papers and Spain with 6 top papers. Meanwhile, the Netherlands has the highest average citation per paper, 61.80. The average number of citations each county receives is around 0.67 to 61.80 per document.

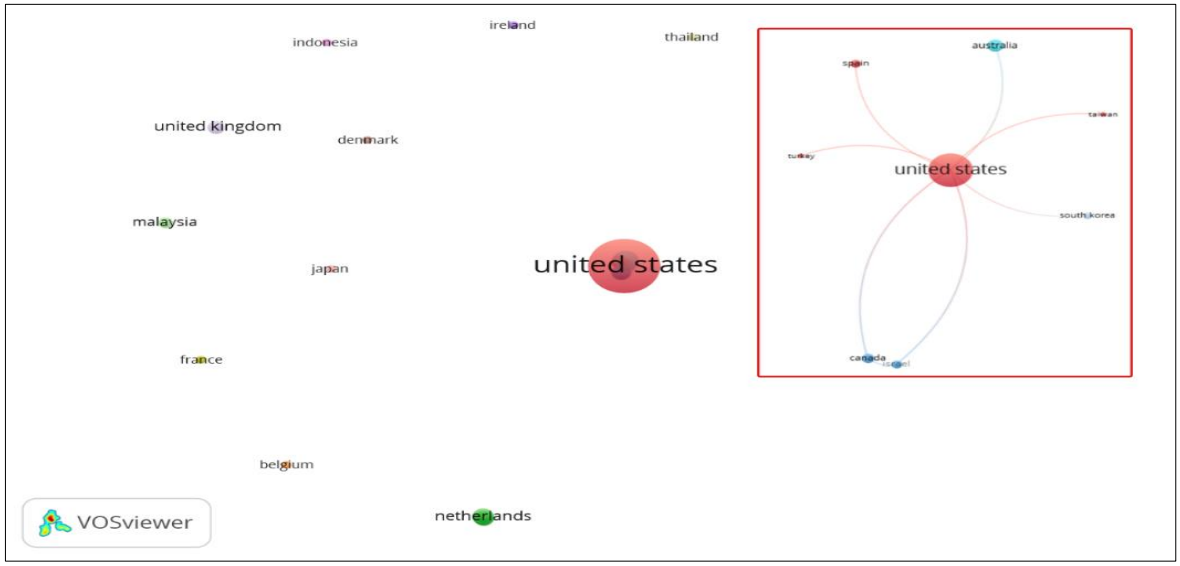

Figure 4. Cluster mapping by country.

The most contributing country to the top 100 cited publications in STEM education is the USA because it is the country that proposes STEM education, so this country has the most significant contribution to the development of STEM education research. This

finding is consistent with Li et al. (2020) research that the USA contributes the most to STEM education research. The mapping of countries based on their clusters can be seen in Figure 4. Figure 4 shows 14 clusters, with the central cluster being the United States connected with Spain, Taiwan, and Turkey, colored red. In addition, this cluster also has a relationship line with several other clusters such as Australia (indigo color, cluster 6), Chile, Germany (blue color, cluster 3), and Canada, Israel (blue color, cluster 3). Apart from these clusters, several other clusters only stand as independent, and there is no relationship between other clusters.

Research Keywords

The most frequently used keywords are indicated graphically in Figure 5. The font size of the text in the figure represents the frequency of the words used in these papers. For example, STEM, education, science, learning, teaching, engineering, mathematics, and technology are more frequent.

Figure 5. Words cloud in top 100 cited publications in STEM education.

Meanwhile, the keyword co-occurrence network in Figure 6 is based on the most frequently occurred keyword-plus words. In this case, 542 such keywords are identified. This keyword co-occurrence network provides a brief insight into the areas/topics on which the research has been conducted (Suprapto et al., 2021b). The map identified 22 such clusters with some common words among these clusters: STEM education (21 times), education (20 times), STEM (19 times), engineering education (14 times), etc. The size of the text represents the more frequently used words. The central cluster among all these clusters has five keywords; the clusters suggest that many researchers have conducted on "STEM education," "STEM," "education," and "engineering education." Some other clusters mainly focus on STEM components, response variables (e.g., creativity, problem-solving skills, conceptualization), learning process, challenges, gender gap, etc.).

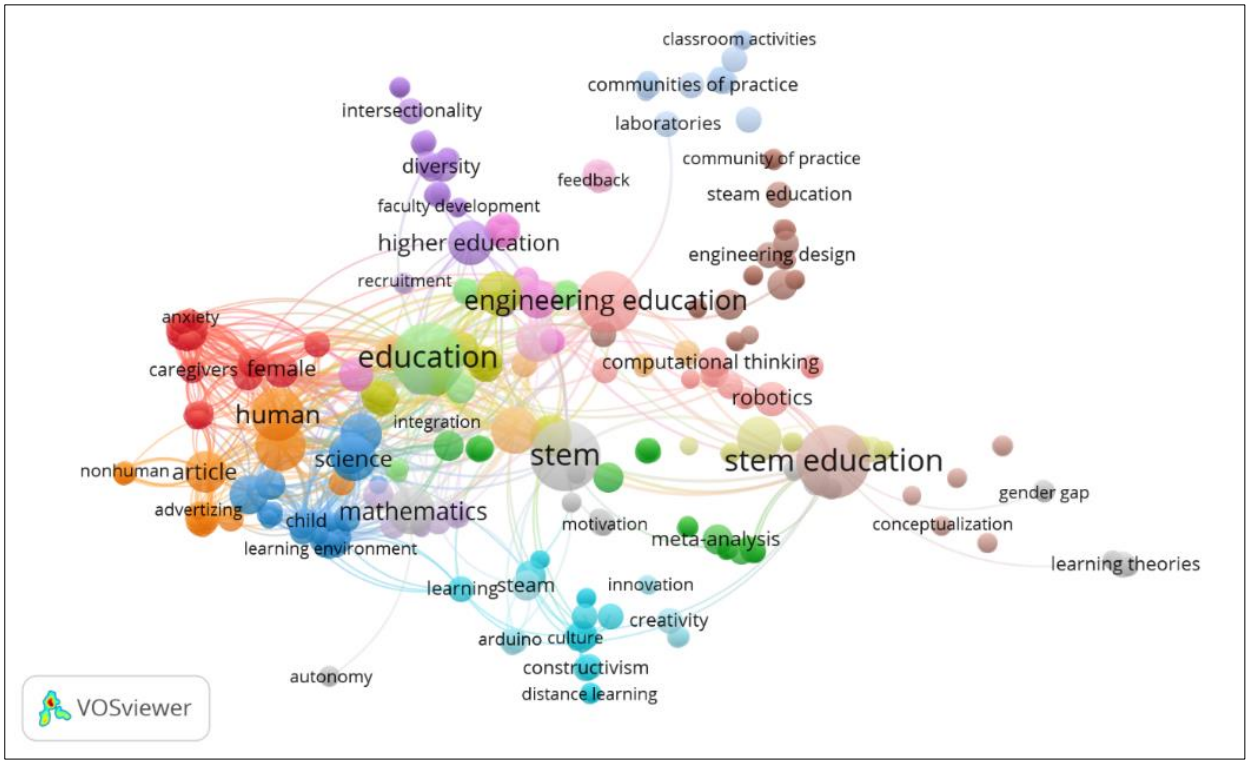

Figure 6. Keyword occurrence cluster mapping network.

The most frequently cited keywords in the top 100 publications are STEM, education, science, learning, teacher, engineering, mathematics, and technology. This is because these keywords are the most basic words for research on STEM education. In line with Ha et al. (2020), the main keywords in STEM education research are engineering education, learning, etc. However, there are differences in a word cloud where the focus is on only one word in this study, while Ha et al.'s research involve more than one word. The results of mapping on keywords also show that the top 100 cited publications mostly use the questionnaire or survey method. In addition, researchers are more focused on integrating STEM into the teaching process by teachers than the student learning process.

Review of the Top Five Cited Articles

The review was conducted on the top five cited publications in the types of journal articles, as shown in Table 6. Each article is analyzed and reviewed the findings, limitations, and recommendations of the article are. These five articles have more than 100 citations, so they can be called classic papers (Fornari & Carboni, 2018).

Table 6. Review of the top five cited journal articles.

Author(s)	Citation	Results/ Finding	Limitation	Recommendation
(Kelley & Knowles, 2016)	368	It could be beneficial if integrated STEM educators could learn various STEM practices and "STEM languages." However, the reality is that in US secondary	This commentary has limitations in presenting quantitative data to support the author's argument. In addition, the author	Can be added quantitative data to support the commentary argument and also conduct a review of funded

Author(s)	Citation	Results/ Finding	Limitation	Recommendation
		education, STEM silo topics have a rigid structure with departmental agendas, requirements, content standards, and year-end exams.	only gives just one example of funded research that seeks to identify the best conditions to teach STEM subjects in an integrated approach to teaching.	research's several examples so that it can better know the best conditions for teaching STEM subjects.
(English, 2016)	241	Mathematics learning advantages are fewer than the other disciplines in programs that focus on STEM integration. More scrutiny is needed on the factors that contributed to these findings. Similarly, learning results for engineering inside K-12 integrated STEM programs need more research.	This commentary has limitations in the absence of empirical research results that complement the author's argument.	Some empirical research results can be added to strengthen the author's argument regarding integration in STEM education.
(Borrego & Henderson, 2014)	176	A single change strategy guides change agents, often implicitly. If they are helped in considering the change from a greater diversity of perspectives, these eight strategies will expand the repertoire of change agents. Change agents can use these descriptions to design more substantial change efforts.	In each change strategy, only the technique of summarizing and summarizing the results of the primary reference review is carried out.	In the analysis, it is essential to add direct observation or interview techniques to strengthen the research results.
(Jong et al., 2014)	150	Go-Lab's purpose of attracting students' interest in a career in science because this platform enables inquiry-based learning. This can encourage acquiring knowledge in deep conceptual domains and inquiry skills. In addition, for students, Go-Lab can	This article only describes the innovations from Go-Lab. It has yet to present the results of experimental research on Go-Lab, so the effectiveness of this platform on students' abilities is unknown.	The results of platform trials can be reported on students' abilities (e.g., creativity, critical thinking). The Go-Lab platform innovation can become a promising online lab to disseminate

Author(s)	Citation	Results/ Finding	Limitation	Recommendation
		provide opportunities for scientific experimentation through online labs in pedagogically structured study rooms.		and apply in STEM education.

Based on a review of five journal articles with the most citations, it can be seen that the majority have the type of article in the form of a review. This is because they summarize the experimental results from many papers to have a lot of information/facts. In line with Ebrahim et al. (2013); Miranda & Garcia-Carpintero (2018), review articles tend to be cited more frequently than original research articles. Ten journal articles on STEM education focus on research on the conceptual framework of STEM integration, STEM-based learning media, challenges to STEM, perspectives on STEM education, and the impact of Covid-19 on STEM education. These articles become fundamental for future research, so they have outstanding citations and impact the development of STEM education topics.

The implication of this research is to find research novelties about STEM education through the results of mapping and visualization patterns based on keywords that often appear. For example, gender differences that affect STEM abilities, learning theories in STEM education, and integration concepts in STEM. In addition, according to the pattern in Figure 5, the main fields with the presence of STEM education research are engineering education, every STEM aspect, and education. So that the focus for further research can consider these main fields. Similar research by Ha et al. (2020) reveals the same thing about these main fields, but most of the research focuses on students. Based on the analysis based on affiliation and country, there is a need to collaborate authorship between countries because, in STEM education, only the USA has the top 100 cited publications. Therefore, it is crucial to research STEM education in a country to determine the application model and the extent to which STEM education contributes to its quality.

CONCLUSION

There are eight conclusions in this study as follows: (1) among these top 100 publications, the most common type of publication is journal articles, as much as 75; (2) The majority of these publications were conducted at four-year intervals from 2014 to 2017, with an average citation per paper is 70; (3) International Journal of STEM Education are the top-rank publication source with the number of articles and citations, respectively 7 and 957. Meanwhile, Springer and the American Association for the Advancement of Science become a publisher that dominates the top 100 publications cited in STEM education; (4) Belland is recognized as the most productive author with 4 total articles, whereas National Research Council received the most significant number of citations with 475 total citations; (5) The most contributed institutions included Purdue University and the University of Minnesota; (6) The USA has predominance over highly cited publications with 68 articles, followed by Australia 7 articles and the Netherlands 5 articles; (7) Based on keyword occurrence, the research areas in these papers mainly emphasize education, STEM, STEM education, engineering education,

and every stem aspect; (8) The results of a review of the top 10 cited journal articles focus on research on the conceptual framework of STEM integration, STEM-based learning media, challenges to STEM, perspectives on STEM education, and the impact of Covid-19 on STEM education. In addition, it recommends for future research using two or more databases (such as Google Scholar and Web of Science) and selecting publications manually on STEM education to obtain more quality and reduce shortcomings in the analysis. In addition, it can also use other applications for bibliometric analysis (such as BibExcel, and HistCite). This study has two limitations. First, only use the Scopus database to make the bibliometric results less widespread. Second, even though the search process used the whole string "STEM Education," several other publications outside the topic of STEM education (i.e., STEM cell) can influence bibliometric analysis.

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