A Bibliometric Review of Technology Application in STEM: Insights for Future Research and Practice

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Keyword
STEM education, technology application, bibliometric analysis

Abstract

Today, STEM development leads to efforts to implement educational openness, emphasizing transparency and unlimited free access to information and knowledge. Rapid information and communication technology development supports efforts to implement open STEM learning. Through this article, the author has mapped study trends regarding the use of technology in STEM education so that it can become an illustration for future studies. The mapping process in this article is carried out using bibliometric analysis, which focuses on scientific publications, collaborations, and citations. Studies on the use of technology in STEM education from 2017 to 2023 show numbers that fluctuate and tend to decrease. The bibliometric analysis in this article also shows the ASEE Annual Conference and Exposition as the most productive proceedings publishing articles on the use of technology in STEM education, Castro M as the most productive author, San Francisco University as the most productive affiliate, United States as the most productive country, and articles compiled by Ibanez with the title Augmented Reality for STEM Learning: A Systematic Review became the most cited articles. This information can be used as a reference for future researchers who wish to study more about the use of information technology in STEM education. Another critical aspect that researchers need to pay attention to if they want to carry out further studies are topics or issues currently popularly associated with using technology in STEM education. Limitations in this article can be completed through further research on the same theme. Future research can include book chapters as a source of metadata. The publication time span can also be added to enrich the analyzed articles.

INTRODUCTION

International attention to the development of STEM education continues to increase yearly and shows no decline. Educators, policymakers, industry players, and other related parties focus on developing STEM capabilities to equip students to contribute to an increasingly advanced society in the era of technology and science [1]–[3]. The National Research Council (1996) describes STEM education as a teaching and learning method that integrates material and skills in the fields of science, technology, engineering, and mathematics [4]–[6]. In addition, STEM education also provides opportunities for students to have good technological literacy, develop problem-solving and scientific thinking skills, increase self-confidence, and encourage them to become innovators and inventors [7], [8].

A literature review over the last ten years shows that the concept of STEM education originated from the policies of the United States government initiated by the National Science Foundation (NSF). Before the term STEM became popular in the 1990s, the NSF used the acronym SMET to abbreviate Science, Mathematics, Engineering, and Technology. However, because it was

ISSN (Online): 2961-9602

felt that the acronym would raise a sensitive issue, the SMET acronym was changed to STEM [6]. The term STEM was first introduced in 2001 by Judith A. Ramaley, former NSF director of education and HR development. Along the way, the NSF expanded the definition of STEM. Not only limited to mathematics, natural sciences, engineering, and computer science but also related to social sciences, psychology, economics, and politics. STEM education was then adapted into various programs at all levels of government in the United States, and various communities engaged in science as part of educational reforms to compete in the global sphere [9].

Today, STEM development leads to efforts to implement educational openness, emphasizing transparency and unlimited free access to information and knowledge [10]. Rapid information and communication technology development supports efforts to implement open STEM learning. This indirectly indicates that the implementation of STEM education needs to accommodate using the latest information technology to create independent, creative, collaborative, and fun learning [11]. Technology is not only part of STEM content but is also used to improve the quality of the process. Issues related to information and communication technology use in STEM education encourage academics, scientists, and researchers to conduct in-depth studies and research. These efforts resulted in several studies on STEM education, especially in aspects of technology and information utilization, including mobile-first learning platforms [12], human interactive robotic programs [13], virtual design studios [14], Augmented reality information system [15], Artificial Intelligence method (AIM) [16], and various other innovations.

From now on, studies on the use of technology in STEM education will continue to develop over time. This is due to the development of scientific information, which is increasing daily [17], [17]. In the era of globalization, no boundaries can hinder the rapid dissemination of information and the rapid development of technology and science. The presence of the latest technological innovations, such as big data analysis [18], augmented reality [19] and virtual reality [20] need to be explored further to support the realization of an independent STEM education, creative, collaborative, and fun [11]. Through this article, the author has mapped study trends regarding the use of technology in STEM education so that it can become an illustration for future studies. The mapping process in this article is carried out using bibliometric analysis, which focuses on scientific publications, collaborations, and citations [21]. In carrying out the process of mapping studies on the use of technology in STEM education, the authors refer to the research questions below:

RQ 1: How is the development of studies on the use of technology in STEM education?

RQ 2: What are the main journals, authors, affiliations, countries, and documents in the field of technology application in STEM education?

RQ 3: What are the trend topics related to technology application in STEM education?

RQ 4: What are the theme classifications about technology application in STEM education?

RQ 5: What are future technology applications in STEM education topics that provide opportunities for further research?

RQ 6: What is the potential for research collaboration on technology application in STEM education?

METHOD

The study on mapping research trends in technology application in STEM education in this article uses the bibliometric analysis method. Bibliometric analysis is a branch of quantitative research methods that focuses on analyzing trends in the literature on particular themes, and the results can be used as a reference for future research work [22], [23]. Bibliometric analysis is used to understand better the trend of discussing themes related to technology application in STEM education in international publications. This article focuses on mapping studies published in scientific papers from 2017 to 2023.

This research was conducted through five stages: determination of keywords, article search, article selection, data validation, and data analysis. Based on the research questions to be answered, the keywords used to conduct this research are "technology application on STEM education". These keywords are then used to search articles on the Scopus database (scopus.com). In the article search process, several inclusion criteria were determined as follows:

TITLE-ABS-KEY (technology AND application AND on AND stem AND education) AND (LIMIT-TO (SRCTYPE , "p") OR LIMIT-TO (SRCTYPE , "j")) AND (LIMIT-TO (PUBSTAGE , "final")) AND (LIMIT-TO (DOCTYPE , "ar") OR LIMIT-TO (DOCTYPE , "cp")) AND (LIMIT-TO (PUBYEAR , 2017) OR LIMIT-TO (PUBYEAR , 2018) OR LIMIT-TO (PUBYEAR , 2019) OR LIMIT-TO (PUBYEAR , 2020) OR LIMIT-TO (PUBYEAR , 2021) OR LIMIT-TO (PUBYEAR , 2022) OR LIMIT-TO (PUBYEAR , 2023)) AND (LIMIT-TO (LANGUAGE , "English")).

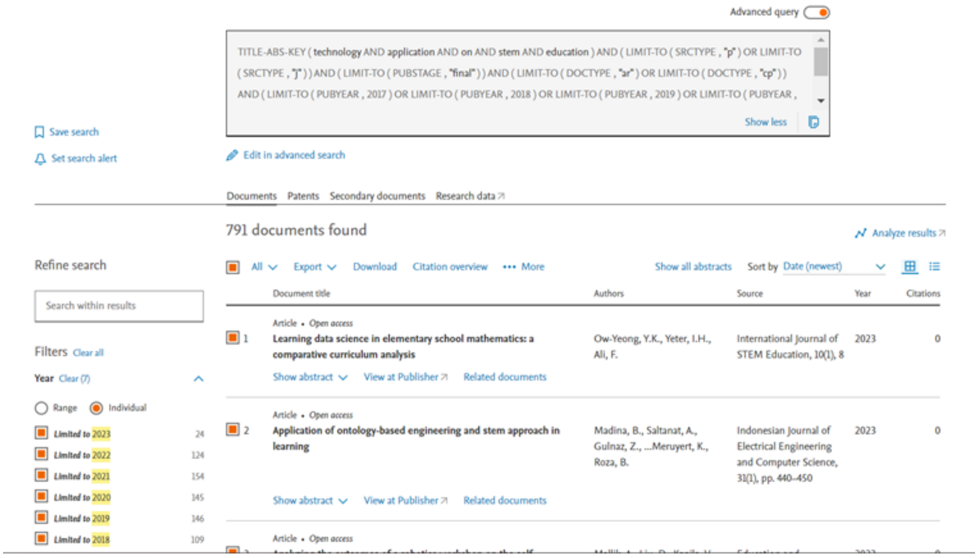

Figure 1. screenshot of article browsing on Scopus

The search results for the data obtained from the Scopus database were then processed using the bibliometric package available in R software. The data processing stages consisted of the selection process and article validation. Both selection and validation are carried out in diagrams and data tables, which are categorized into several types. The data processing process in R software will produce two main pieces of information: research performance and science mapping. Research performance is an explanation related to Main Information, most relevant Source, most relevant Author, most relevant Affiliation, Country Scientific Production, and Document. Science mapping is the result of processed data relating to the Trend Topic, Co-Accurance Network, Thematic Map, Thematic Evaluation, Co-citation Network, Histograph, Collaboration Network, and Collaboration WorldMap.

RESULTS

From 2017 to 2023, the number of studies on the use of technology in STEM education is identified as fluctuating and tends to decrease. Bibliometric analysis in this article has succeeded in analyzing the contributions of individuals, institutions, and countries regarding research trends in the use of technology in STEM education. Some of the things that are considered in the contribution analysis process in this article are the journals that publish the most articles about the use of technology in STEM education, the countries that are the most active in producing articles, the most productive authors, and the authors with the highest number of citations. In addition, this article also tries to map the interrelationships between issues or topics regarding the use of technology in STEM education. The mapping carried out is related to intellectual interactions and structural connections between research constituencies. Some of the things that are considered in the science mapping process in this article are popular topics used as research themes about the use of information technology in STEM education, the relationship of one issue to another, the density and centrality of a topic, and mapping related to research collaboration between agencies and countries.

Development of Technology Applications Literature on STEM Education

Based on data collected from the Scopus database, the amount of literature discussing the use of technology in STEM education tends to fluctuate. From 2017 to 2019, there was an increase. In 2020 it will decrease and then increase again in 2021. After that, in 2022 and 2023, the number will decrease.

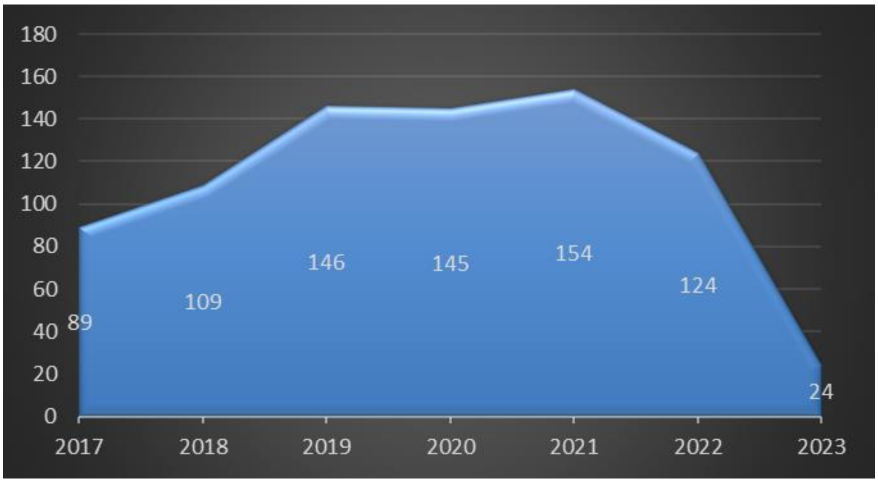

Figure 2. Annual Scientific Production about Technology Application Literature on STEM Education

In 2017, there were 89 articles related to the use of technology in STEM education. In 2018, this number increased to 109 articles. An increase also occurred in 2019, with the number of published articles totaling 149. After experiencing growth for three years, the production of articles on the use of technology in STEM education decreased in 2020. However, the decrease was insignificant because only one article was fewer than the previous year. In 2021, article production again increased, with 154 articles published. However, in 2022 article production declined again, with 124 published articles. The number of articles published in 2023 has decreased significantly. Only 24 articles had been published until the mapping of this article was carried out. The article data collection from the Scopus database was carried out in June 2023. In the remainder of the year, this number may increase.

The Main Journals, authors, affiliations, countries, and documents in the field of technology application in STEM education

The Main Journals in the field of technology application in STEM education

This section describes the most productive journals and proceedings for publishing articles related to technology application in STEM education.

ISSN (Online): 2961-9602

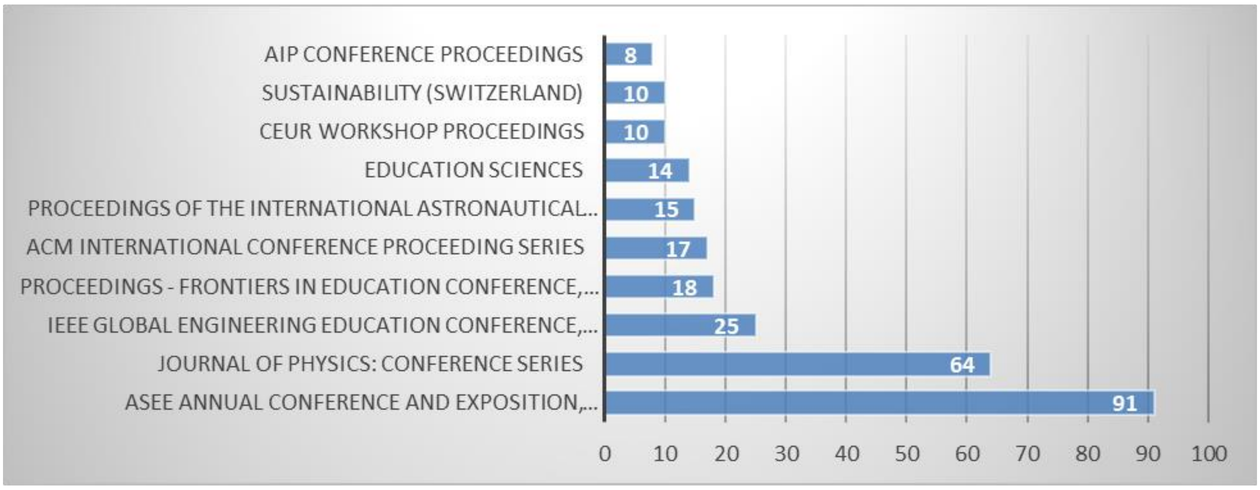

Figure 3. the most productive journals and proceedings publishing articles related to the application of technology in STEM education

Based on figure 3, it is known that the ten productive sources publishing articles on the application of technology in STEM education from 2017 to 2023 are dominated by proceedings with details of eight proceedings and two journals. The ASEE Annual Conference and Exposition is the most productive proceeding in publishing articles on the use of technology in STEM education, with 91 articles. The Journal of Physic: Conference Series has published 64 articles in second place. The IEEE Global Engineering Education Conference is the third most productive resource that has published 25 articles. In fourth place is the Proceedings – Frontiers in Education conference which published 18 articles in the form of proceedings. ACM International Conference Proceeding Series is in fifth position with 17 published articles. As for the sixth position, the Proceedings of the International Astronautical Conference has 15 published articles. Unlike the top six sources, which are proceedings, the seventh position is the Education Sciences Journal, which published 14 articles. Eighth and ninth positions went to CEUR Workshop Proceedings and Sustainability (Switzerland) Journal, both of which published ten articles. Finally, in the top ten most productive sources for publishing articles about the use of technology in STEM education is the AIP Conference Proceeding, with eight articles published in the last six years.

The Main Authors in The Filed of Technology Application in STEM Education

The section below describes ten of the most prolific authors writing articles on the use of technology in STEM education. The image below shows the results of the analysis.

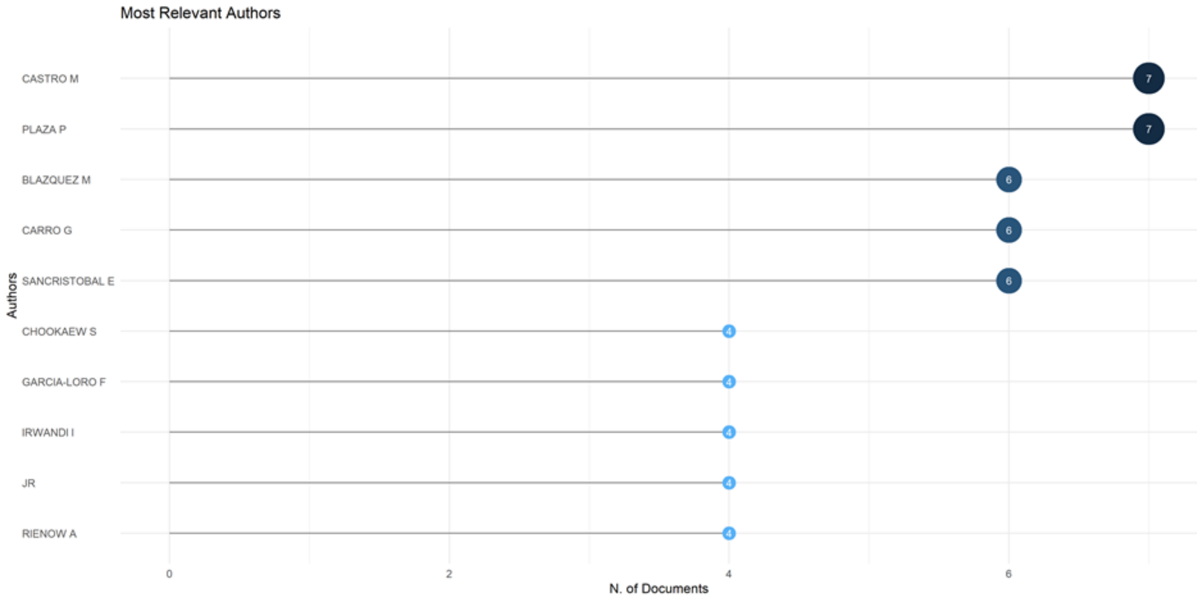

Figure 4. Most relevant authors in the field of technology application in STEM education

In the figure 4, it can be seen that Castro M and Plaza P are the most productive authors in writing articles about the use of information technology in STEM education. They have published seven articles in the field. Blazquez M, Carro G, and Sancristobal E filled the third, fourth, and fifth ranks with the same number of publications, namely six articles. Furthermore, in the sixth, seventh, eighth, ninth, and tenth rankings, there are Chookaew F, Garcia-Loro F, Irwandi I, JR, and Renow A, with four published articles each. The chart provides an overview of the productivity of authors in writing articles about the use of information technology in STEM education. Castro M and Plaza P stand out as the main contributors with seven articles, followed by Blazquez M, Carro G, and Sancristobal E with six articles, and the other five authors with four articles each.

The Main Affiliation in The Field of Technology Application in STEM Education

This section describes the institutions that are most productive in producing articles about the use of technology in STEM education. The results are shown in the image below

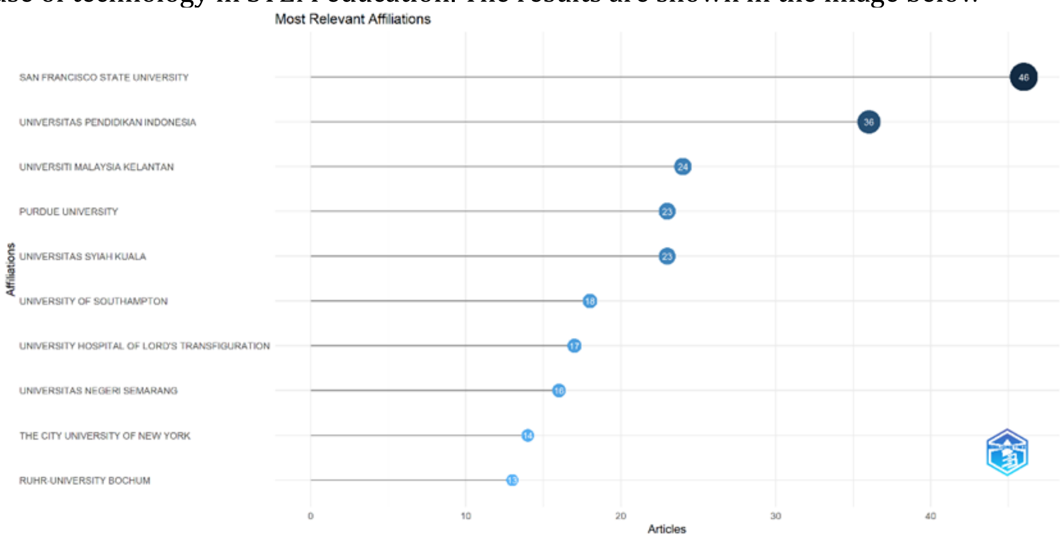

Figure 5. Most relevant affiliations in the field of technology applications in STEM education

ISSN (Online): 2961-9602

In the chart above, we can see which agencies are the most productive in producing articles on the use of technology in STEM education. San Francisco State University is the most productive institution, with 46 published articles. Then, in second place is Universitas Pendidikan Indonesia which has produced 36 articles. Universiti Malaysia Kelantan is in third place with 24 published articles. Purdue University and Universitas Syiah Kuala occupy the fourth and fifth ranks. Each published 23 articles. The University of Southampton is in sixth place with 18 published articles. The seventh position is filled by the University Hospital of Lord's Transfiguration with 17 articles. Universitas Negeri Semarang occupies the eighth position with 16 published articles. The City University of New York and Ruhr University Bochum are in the ninth and tenth positions with 14 and 13 articles, respectively. This information provides an overview of the productivity of these agencies in producing articles on the use of technology in STEM education.

The Main Countries in The Field of Technology Application in STEM Education

This section describes the countries that are the most productive in producing articles related to e-learning in Indonesia. The distribution of e-learning articles in various countries can be seen in the image below.

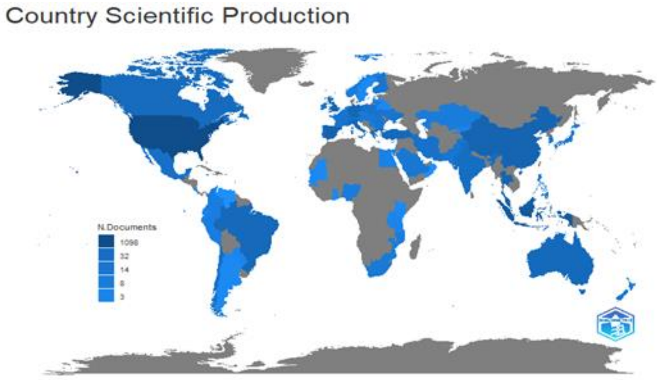

Figure 5. Country scientific production map

The figure above shows the distribution of article production related to information technology in STEM education in various countries. The darker the blue on the map, the more articles will be generated. Details of countries with the most article production can be seen in the diagram below.

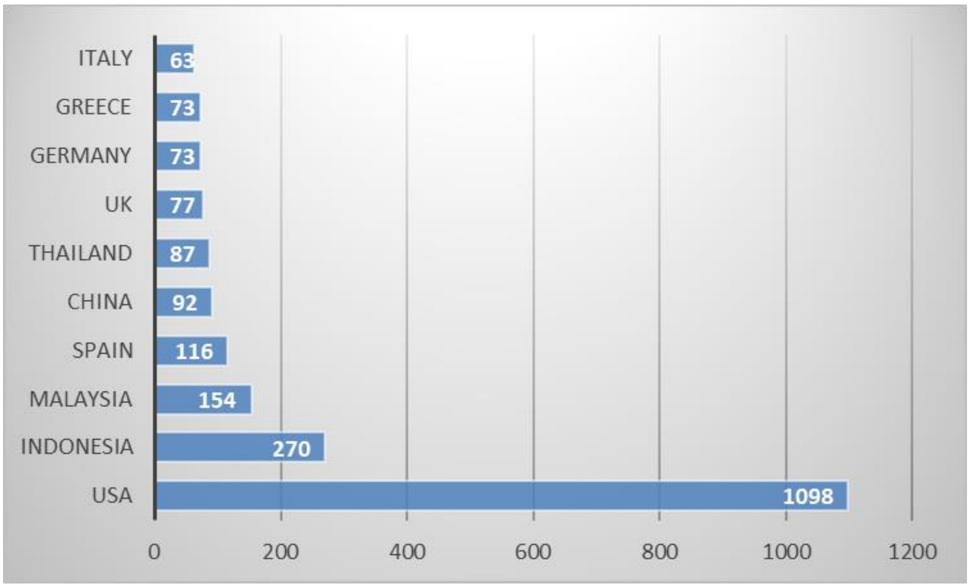

Figure 6. Country scientific production chart

Based on data analysis from the Scopus database, the United States has produced the most articles discussing the use of technology in STEM education, with a total of 1098 articles. In second place is Indonesia, which has produced 270 articles on this topic. Furthermore, Malaysia is in third place with a total of 154 articles. Spain is in fourth place with a production of 116 articles. China is in the fifth position with 92 published articles. Thailand is in the sixth position with 87 published articles. Furthermore, the United Kingdom (UK) occupies the seventh position with 77 articles. Germany and Greece occupy the eighth and ninth positions, each with 73 articles. In tenth place is Italy, which has published a total of 63 articles. This information shows the contribution of these countries in producing articles about the use of technology in STEM education.

The Main Document in The Field of Technology Application in STEM Education

This section provides information related to the most cited articles. The table below presents the results sequentially of the ten most cited articles on the use of technology in STEM education.

Table 1. Most cited articles in the field of technology application in STEM education

Paper	DOI	Total Citations
IBÁÑEZ M-B, 2018, COMPUT EDUC	10.1016/j.compedu.2018.05.002	404
JOHNSON-GLENBERG M, 2018, FRONT ROBOT AI	10.3389/frobt.2018.00081	143
FAN S-C, 2017, INT J TECHNOL DES EDUC	10.1007/s10798-015-9328-x	88
DOROUKA P, 2020, INT J MOBILE LEARN ORGAN	10.1504/IJMLO.2020.106179	85
SIMPSON TW, 2017, ADDIT MANUF	10.1016/j.addma.2016.08.002	79
COOPER G, 2019, EDUC MEDIA INT	10.1080/09523987.2019.1583461	65
CHALMERS C, 2017, INT J SCI MATH EDUC	10.1007/s10763-017-9799-1	59
GARCÍA-HOLGADO A, 2019, ACM INT CONF PROC SER	10.1145/3362789.3362902	56
GENG J, 2019, ASIA PAC EDUC RES	10.1007/s40299-018-0414-1	56
OWENS MT, 2017, PROC NATL ACAD SCI U S A	10.1073/pnas.1618693114	55

Based on the data in the table above, articles written by Ibanez are the most cited, with 404 citations. In the second place, an article written by Johnson Glenberg has been cited 143 times. The third position is occupied by an article written by Fan-SC with 88 citations. The article written by Dorouka is in fourth place with 85 citations. In fifth place, an article written by Simpson TW has been cited 79 times. The article written by Cooper G occupies the sixth position with a total of 65 citations. The article written by Chalmers is ranked seventh with a total of 59 citations. In the eighth and ninth positions are articles written by Garcia Holgado A and Geng J, with 56 citations. Finally, in the tenth position, there are articles written by Owens MT with 55 citations. This data gives an idea of these articles' popularity and influence in the academic world, measured by the number of citations received.

Trend Topic

This section explains the trend of themes most often associated with the use of technology in STEM education each year from 2017 to 2023. The data is sourced from keywords the authors include in articles published on Scopus.

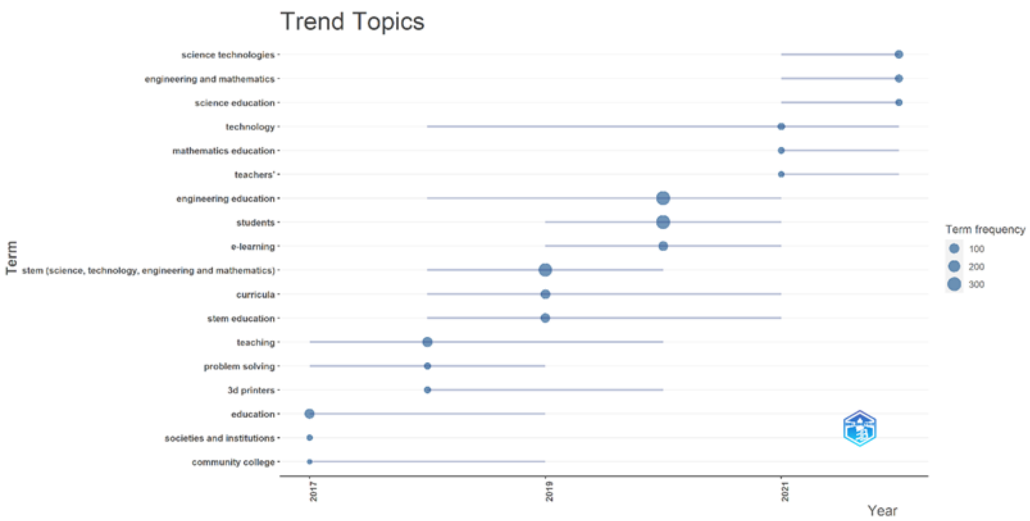

Figure 7. the trend of themes most often associated with the use of technology in STEM education each year from 2017 to 2023

Based on the picture above, in 2017, three keywords were associated with the study of the use of technology in STEM education, namely *community College*, *Societies and institutions*, and *Education*. Of the three keywords, the *Education* keyword has the highest density related to articles discussing technology use in STEM education. In 2018 there was a shift in trend where the keywords most often used were *teaching*, *problem solving*, and *3d printers*. In 2019, the keywords that most often appeared in connection with the study of technology use were *STEM* (*Science, Technology, Engineering, Mathematics*), *Curricula*, and *STEM Education*. In 2020, the most popular topics associated with using technology in STEM education were *engineering education*, *students*, and *e-learning*. In 2021, the topics most often associated with *Mathematics Education*, *Technology*, and *Teachers*. In 2022, the themes were *science technology*, *engineering and mathematics*, and *Technology Education.*

Theme Classification About Technology Application in STEM Education

This section describes the grouping of topics that are most often associated with one another in studies of the use of technology in STEM education. The image below shows the interrelationships between these topics.

ISSN (Online): 2961-9602

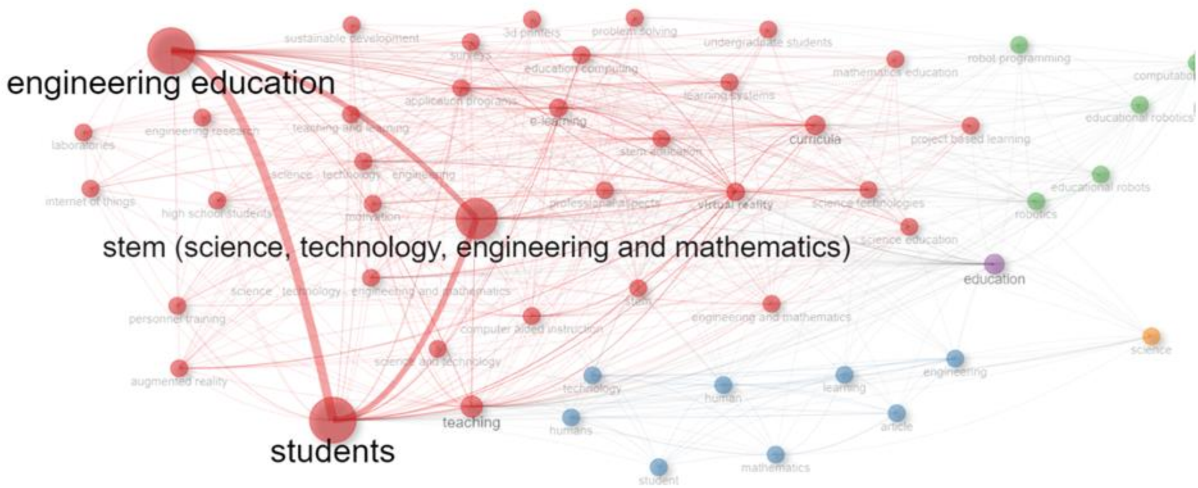

Figure 8. The grouping of topics that are most often associated with one

Based on the results of a bibliometric analysis with the keywords Technology Application on STEM Education, 10 clusters were formed, namely:

Cluster 1: consists of 30 topics, namely STEM (Science, Technology, Engineering, and Mathematics), Engineering Education, students, undergraduates student, internet of things, laboratories, sustainable development, surveys, motivation, virtual reality, engineering research, problem solving, education computing, computer aided instruction, augmented reality, engineering and mathematics, 3d printers, teaching and learning, learning systems, science technologies, personal training, project based learning, curricula, application programs, science education, science and technology, Professional aspects, e-learning, dan mathematics education.

Cluster 2: consists of seven topics, namely technology, article, human, learning, students, mathematic, and engineering.

Cluster 3: consists of five topics, namely educational robots, robot programming, robotics, educational robotics, and computational thinking.

Cluster 4: consists of one topic, education.

Cluster 5: consists of one topic, science.

Future Technology Application in STEM education Topics That Provide Opportunities for Further Research

This section describes the grouping of research themes based on their density and centrality. Regarding density, the higher the position indicates that the research theme has been carried out frequently. Meanwhile, centrality relates to the relevance of a theme to the development of e-learning in Indonesia. The further to the right means, the more relevant and more influential the theme is on the major topic being studied. Analysis of the density and centrality of research themes related to technology application in STEM educatin is presented in the quadrants below.

ISSN (Online): 2961-9602

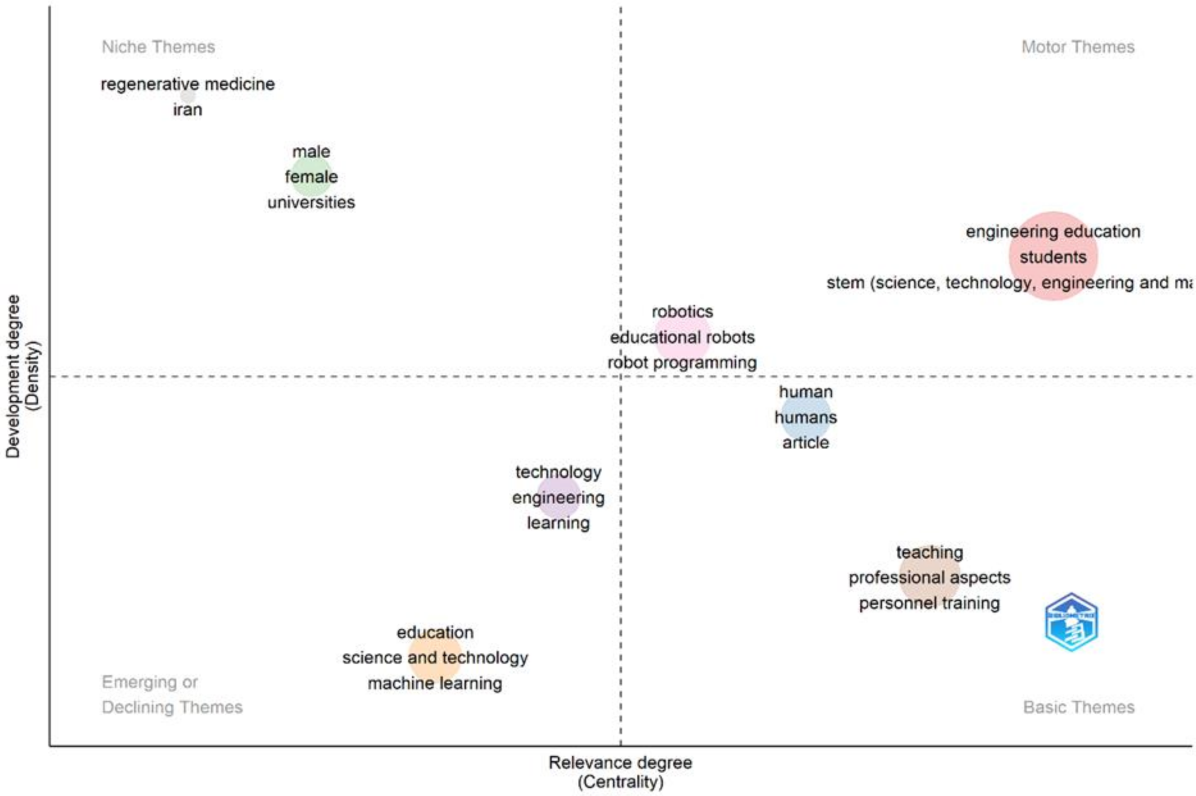

Figure 9. The quadrant of the density and centrality of research themes related to technology application in STEM educatin

The quadrants above provide information related to research themes based on their position. There are four quadrants for analyzing thematic maps, namely:

- Top Right Quadrant: Motor themes; Motor themes; This quadrant represents the themes that are most often researched and most relevant to the study of developments in the use of technology in STEM education. It is located on the right (centrality) and above (density). Among the themes in this quadrant are engineering education, student, STEM, curricula, e-learning, education computing, STEM education, Science, Technology, engineering, application programs, and learning systems, robotics, educational robots, robot programming, computational thinking, open-source software, mathematical programming, computational theory, open systems, and cost.
- Bottom Right Quadrant: Basic Themes; The themes in this quadrant are included in the central theme category because they have relevance to the study of technology use in STEM education. Even though they are relevant, the themes included in this quadrant are rarely studied, so they are still relatively low in density. The themes in this quadrant include teaching, professional aspects, personal training, motivation, decision making, mobile applications, professional development, problem-based learning, educational environment, deep learning, human, article, mathematics, student, human experiment, curriculum, standards, and thematic.
- Bottom Left Quadrant: Emerging or declining themes; This quadrant has two possible themes. Existing themes are starting to be abandoned or otherwise becoming popular to be appointed as research. If it is declining, these themes shouldn't need to be the focus of the study. However, if these themes become popular, it becomes a good opportunity to be used as a research topic. Further studies are needed by reading in more detail the articles whose themes fall into this quadrant to find out which themes are starting to be abandoned or, on the contrary, are gaining popularity for study. Technology, engineering, learning, science, automation, perception,

chemistry, education, science and technology, machine learning, community collage, qualitative research, high school, statistics, and agriculture.

- Top Left Quadrant: Niche Themes (a very niche theme); This quadrant shows the grouping of research themes which could be more central and related to the use of technology in STEM education but have a high density because they are often studied. The themes in this quadrant include male, female, universities, adult, united states, procedures, clinical articles, educational development, Iran, and regenerative medicine.
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Potential Research Collaboration About Technology Application in STEM Education

Collaboration Network

Based on network collaboration analysis, three affiliated clusters are interrelated and often collaborate in research on the use of technology in STEM education. The three clusters are presented in the image below.

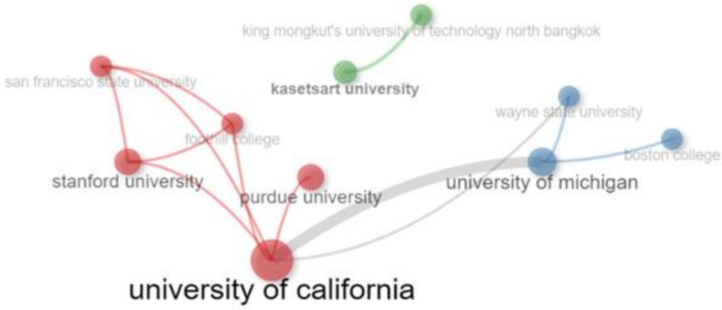

Figure 10. Three collaboration network clusters

The details of the three collaboration network clusters are as follows:

- Cluster 1 consists of the University of California, Purdue University, Stanford University, San Francisco State University, and Fodhill College
- Cluster 2 consists of the University of Michigan, Boston College, and Wayne State University.
- Cluster 3 consists of Kasetsart University, King Mongkut's University of Technology North Bangkok

Collaboration World Map

The results of the Collaboration World Map show a network of cooperation between countries related to research on the use of technology in STEM education. This pattern of cooperation is reflected in the thickness of the lines formed, indicating the high frequency of conducting research together. The thicker the lines, the more often research is done collectively. In addition, the increasing number of "line to country" shows the level of cooperation that is increasingly being carried out by related countries. The Collaboration World Map describes significant cross-country collaboration in research on the development of e-learning in Indonesia.

ISSN (Online): 2961-9602

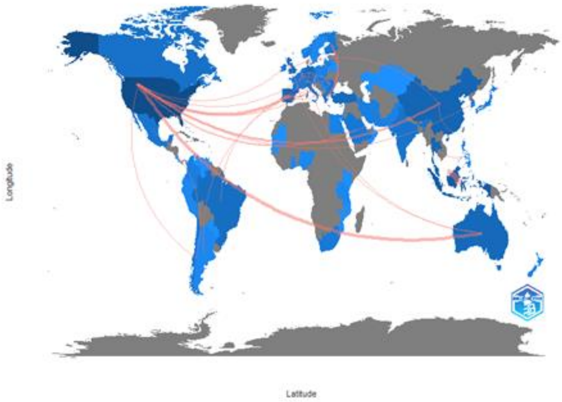

Figure 11. Collaboration world map

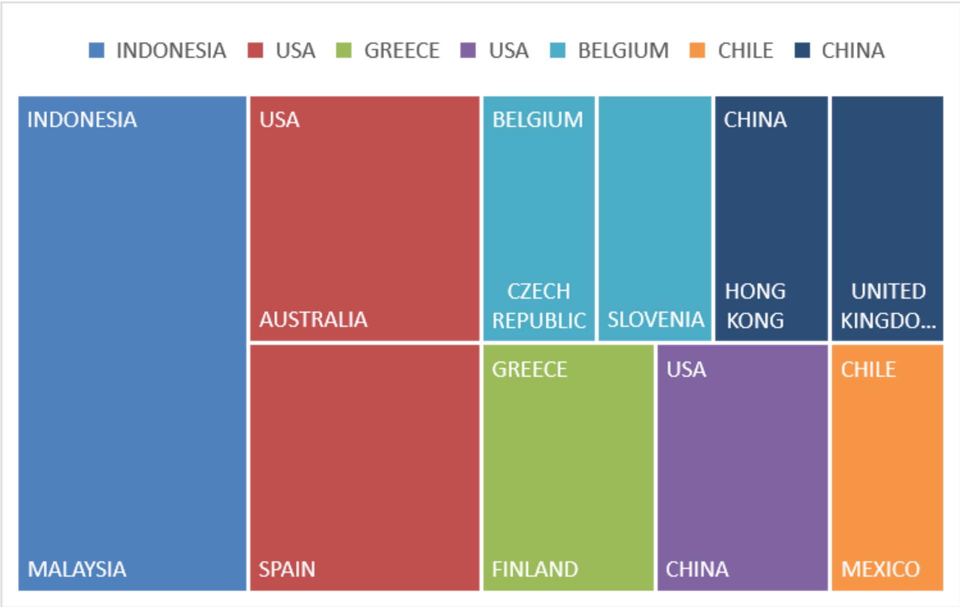

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Figure 12. Chart of world collaboration

Figure 11 and 12 explain the ten most intense collaboration processes between the two countries. The most intense collaboration related to research on the use of technology in STEM education was carried out between Indonesia and Malaysia, with eight collaborations. In the second and third positions, there were four collaborations between the United States and two countries, namely Australia and Spain. In fifth place, Greece and Finland collaborated three times. Likewise, in the sixth position, the United States and China have collaborated three times. Six to ten countries have collaborated twice, namely Belgium-Czech Republic, Belgium-Slovenia, Chile-Mexico, China-Hong Kong, and China-United Kingdom.

CONCLUSION

Studies on the use of technology in STEM education from 2017 to 2023 show numbers that fluctuate and tend to decrease. The bibliometric analysis in this article also shows the ASEE Annual Conference and Exposition as the most productive proceedings publishing articles on the use of technology in STEM education, Castro M as the most productive author, San Francisco University as the most productive affiliate, United States as the most productive country, and articles compiled by Ibanez with the title Augmented Reality for STEM Learning: A Systematic

Review became the most cited articles. This information can be used as a reference for future researchers who wish to study more about the use of information technology in STEM education.

Another critical aspect that researchers need to pay attention to if they want to carry out further studies are topics or issues currently popularly associated with using technology in STEM education. Based on the analysis results in this article, further researchers are advised to pay attention to the themes in cluster one in the theme classification sub-chapter. Then to find out the density and centrality of a theme, future researchers are advised to pay attention to the themes in the Top right Quadrant in the sub-chapter on topics that provide opportunities for further research. This article also provides information regarding the potential for collaboration between agencies and countries which can be used as a reference for researchers who wish to build relationships regarding further studies on the use of technology in STEM education.

The results of this bibliometric analysis are not fully maximized. The researcher sets some limitations. Metadata retrieved from the Scopus database is only devoted to journals and proceedings. This article also focuses on analyzing publications published between 2017 and 2023. Research on the use of technology in STEM education outside of these years is not included in the analysis process. In addition, the data source for the analysis carried out in this article only comes from the Scopus database. Limitations in this article can be completed through further research on the same theme. Future research can include book chapters as a source of metadata. The publication time span can also be added to enrich the analyzed articles.

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