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The Role of STEM Education in Improving the Quality of Education: A Bibliometric Study

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Abstract:

The United Nations (UN) has launched several initiatives to promote the role of education in Sustainable Development Goals (SDGs) and set Goal 4 for quality education among other SDGs. The integrated Science, Technology, Engineering, and Mathematics (STEM) approach is a promising educational framework for sustainable development that improves education quality. In this study, a bibliometric analysis was conducted to evaluate the scientific results of the role of integrated STEM education specifically in improving the quality of education (SDG 4). A hundred and fifty publications, with an increasing trend in the number of documents each year, out of the total number of 74,879 documents related to “education quality” and 5,430 documents related to “STEM education” were chosen from the SCOPUS database. The study analyzes the growth and development of research activities in the area of “STEM education” and “Quality education” as reflected in the publications output in the time span of 27 years from 1993 to 2020. The publication and citation trends, the most frequently used keywords, the most influential authors and journals, and the research hotspots were investigated using VoSviewer and Bibliometrix software. Accordingly, the United States happened to be the most productive country in this field owning two-thirds of the number of publications. The "Science Education" journal is ranked at the top of the highly cited journals. The findings show that topics such as "early childhood education", "computing education", and "environmental education" are the main hotspots in the research area of STEM and quality of education. The results of this study will help enhance the understanding of integrated STEM education in improving the quality of education and will support future works in this area.

Keywords:

Sustainable development, Quality of education, STEM education, Computing education, Early childhood education

Availability of data and material

The datasets generated and/or analyzed during the current study are available in the ZENODO repository, http://doi.org/10.5281/zenodo.4722562.

Introduction:

The United Nations (UN) General Assembly proposed a set of global Sustainable Development Goals (SDGs) which comprises 17 goals and 169 targets in 2015 (Hák et al., 2016). The UN has launched several initiatives to promote the role of education in sustainable development (Nguyen et al., 2020). Education is crucial for the achievement of SDGs. Educational policies play a key role in the effective implementation of education for sustainable development and influence the development of curricula, teacher training, learning materials, and learning environments (Nguyen et al., 2020). The Sustainable Development Goal 4 (SDG 4) is about quality education among the 17 SDGs. The SDG 4 has deep roots in many international declarations, “Universal Declaration of Human Rights”, “Millennium on Rights of the Child”, “World Declaration on Education for All”, “Dakar Framework for Action” and “Millennium Development Goals”; thus considering education is very crucial for the wellbeing of individuals, nations and the world (Mohanty, 2018). Education is a fundamental way to achieve sustainable development. Classrooms are spaces where teachers can promote and inculcate values and attitudinal changes that allow the SDGs to achieve their goals. Therefore, it is easy to understand that SDG 4, “Quality Education” is a fundamental aspect of achieving, expanding, and effectively implementing the rest of the SDGs (Del Cerro Velazquez & Lozano Rivas, 2020). On the one hand, SDG 4, “Quality Education” as one of the 17 SDGs has an important role in sustainable development. On the other hand, implementation of the Science, Technology, Engineering, and Mathematics (STEM) approach in education will improve the “Quality Education”. An integrated STEM approach is a promising framework for sustainable development education (Nguyen et al., 2020). Therefore, there is a linkage between “Quality Education” and STEM education.

The importance of STEM education

STEM education is an approach to learning where rigorous academic concepts are coupled with real-world lessons (Samsudin et al., 2020). STEM education delivers learning benefits to students since students can explore their creativity to solve a problem through some disciplines (Suratno et al., 2020). When students apply STEM in context, it makes connections between school, community, work, and the global enterprise with the ability to compete in the new economy (Bruce-Davis et al., 2014; Hacioglu & Gulhan, 2021). STEM education aims to equip students with a broad mix of skills and interdisciplinary knowledge (Nguyen et al., 2020). According to Roehrig et al. (2021), integrated STEM education is based on the idea that real-world issues require multiple perspectives, skills, and knowledge to be productively addressed (Reynante et al., 2020). Integrated STEM education is an effort to combine science, technology, engineering, and mathematics into one class that is based on connections between the subjects' real-world problems. Fully integrated STEM with project-based learning can increase the effectiveness of teaching (Jamali et al., 2017). Integrated STEM approaches can transform education into innovative and inclusive education for social equality and sustainable development (Nguyen et al., 2020). According to Wahab et al. (2021), the integrated STEM approach has the potential to develop STEM education content.

STEM education and quality education

Suratno et al. (2020) stated that factors affecting the quality of education could be observed in students' problem-solving abilities and academic learning achievements. STEM education leads students to be better problem solvers and reach higher levels of achievement (Jamali et al., 2017; Samsudin et al.). Aslam et al. (2018) connected STEM education and quality education and argued that one alternative way to improve the quality of education is to apply STEM education (Suratno et al., 2020). In addition, Sumirat (2019) argued, "the awareness toward the importance of STEM could be one of the solutions to enhance educational quality". The STEM education approach also affects students' creative thinking skills which affects the quality of education as well (Monsang & Srikoon, 2021). Over the past decade, STEM education for students has received increased attention, with calls for both a greater emphasis on these fields and improvements in the quality of curricula and instruction (Wahono & Chang, 2019). However, the relevant publications on STEM education in improving the quality of education have not received any attention from bibliometric researchers. Therefore, this study has a bibliometric approach to exploring the role of STEM education in improving the quality of education.

The application of Bibliometric study

Bibliometric is a statistical technique for assessing and quantifying the number of publications in a particular research field (Fellnhofer, 2019; Khodabandelou et al., 2019). The bibliometric technique has recently gained favor since it can reduce the effect of objectivity and potential bias (Jiang et al., 2019). Bibliometric allows researchers to understand the structure characteristics, and the pattern of research activities by analyses of scholarly outputs, top-cited publications, countries, most frequent keywords, and the trend of publications to quantitatively explore a specific research area (Ale Ebrahim et al., 2020). The bibliometric educational research to date has focused on publication trends in physics education (Jamali et al., 2015), comparison of educational growth within developing countries (Shakiba et al., 2016), major trends in distance education research (Amoozegar et al., 2018), analysis of the papers on urban education (Liang & Wang, 2018), research trends in robot education (Yang et al., 2020), and the most recent research trends of artificial intelligence in mathematics (Hwang & Tu, 2021).

Previous bibliometric studies

Previous bibliometric studies concentrate on co-words analysis of the titles, keywords, and abstracts of the relevant literature in STEM education (Assefa & Rorissa, 2013), the scientific production on STEM education between 2010 and 2018 with analyzing of 65 documents published in SCOPUS database (Ferrada et al., 2019), trends of STEM education 175 publications by the Association of Southeast Nations (ASEAN) region for the period 2000-2019 (Ha et al., 2020), used Web of Science (WoS) database for analyzing of the evolution and development of STEM education over the last years (Gil-Doménech et al., 2018), mapping the landscape and structure of research on education for sustainable development for SCOPUS indexed documents published between 1990 and 2018 (Hallinger & Nguyen, 2020), analyzing of the production about the quality education which exists in SCOPUS database (Sola-Martínez et al., 2020), and analysis of performance and co-words in Web of Science about STEAM in education (Marín-Marín et al., 2021). None of them integrated the global sustainable development goal four (SDG 4) “quality education” and STEM education in their bibliometric studies. As a result, this research tries to fill this gap by conducting a bibliometric study.

Objectives of the study

This bibliometric study aims to assess the role of integrated STEM education in improving the quality of education and answer research questions by collecting data from well-known scientific databases. The results of the study are expected to be the basis for further research on STEM and quality of education.

The study seeks to answer the following four research questions (RQs):

RQ1. What are the publication trends?
RQ2. What are the average citations per year?
RQ3. What are the most used index keywords?
RQ4. What are the most used author's keywords?
RQ5. What are the authors' keywords growth maps?
RQ6. What are the most influential authors?
RQ7. What are the most influential journals?
RQ8. What are research hotspots?

Method

There is a new predefined search query for "UN Sustainable Development Goals" (SDGs) in the SCOPUS database that consists of 16 different Pre-generated search queries. Therefore, the data were collected from the SCOPUS database. SCOPUS has broad coverage in social science in comparison to WoS (Aghaei Chadegani et al., 2013). The data were collected on March 28, 2021. The timespan covered the range from the 1st of January 1993 to December, 2020. The current year 2021 data was not complete and excluded from the data set. Table 1 displays the search sets, which are used during each step of the search. The SDG 4 is "Quality education" and its relevant search term is listed as set #1 in Table 1. All relevant documents to the "STEM education" were collected through search within document title, abstract, and keywords, which is called set #2. The search strategy flow diagram which prepares according to the PRISMA "Preferred Reporting Items for Systematic Reviews and Meta-Analyses" flow diagram (Page et al., 2021) illustrated in Figure 1. The data sets for this study consists of "Quality education", "STEM education" and a combination of both search term #1 and #2, with 74,879, 5,430, and 160 documents respectively. The data were collected on March 28, 2021. Therefore, the last year's (2021) data were not completed and excluded from the study.

Table 1 Search strategy

Set	Search Terms
#1*	TITLE-ABS-KEY ((school OR education OR educational) AND ("school attendance" OR "school enrollment" OR "school enrolment" OR "inclusive education" OR "educational inequality" OR "education quality" OR "educational enrolment" OR "educational enrollment" OR "adult literacy" OR "numeracy rate" OR "educational environment" OR "educational access" OR ("development aid" AND "teacher training") OR "early childhood education" OR "basic education" OR "affordable education" OR "educational financial aid" OR "school safety" OR "safety in school" OR ("learning opportunities" AND ("gender disparities" OR empowerment)) OR ("learning opportunity" AND ("gender disparities" OR empowerment)) OR "youth empowerment" OR "women empowerment" OR "equal opportunities" OR "child labour" OR "child labor" OR "discriminatory" OR "educational inequality" OR "educational gap" OR ("poverty trap" AND "schooling") OR "special education needs" OR "inclusive education system" OR ("schooling" AND ("gender disparities" OR "ethnic disparities" OR "racial disparities")) OR "education exclusion" OR "education dropouts" OR "global citizenship" OR "sustainable development education" OR "environmental education" OR "education policy" OR "educational policies" OR "international education" OR "education reform" OR ("educational reform" AND "developing countries") OR "educational governance" OR ("developing countries" AND "school effects") OR "education expenditure" OR "foreign aid" OR ("teacher training" AND "developing countries") OR "teacher attrition") AND NOT "health literacy")
#2	TITLE-ABS-KEY ("STEM education*" OR "STEAM Education*" OR "Science, technology, engineering, and mathematics" OR "Science, Technology, Engineering, the Arts and Mathematics" OR "integrated STEM" OR "integrated STEAM" OR "STEM element*" OR "STEM approach" OR "STEM content" OR "STEM field*" OR "STEM program*" OR "STEM professional*" OR "STEM methodology" OR "STEM initiative*" OR "STEM teacher*" OR "STEM industries" OR "STEM subject*" OR "STEM literature" OR "STEM classes" OR "STEM process" OR "STEM practice*" OR "STEM career*" OR "STEM integration" OR "STEM contexts" OR "STEM disciplines" OR "STEM learning" OR "STEM teaching")
#3	#1 AND #2
#4	#3 AND EXCLUDE (PUBYEAR, 2021)

* There are sixteen pre-generated queries on the UN Sustainable Development Goals 2020, on SCOPUS advanced search database that one of them is relevant to "Quality education" with these predefined search terms.

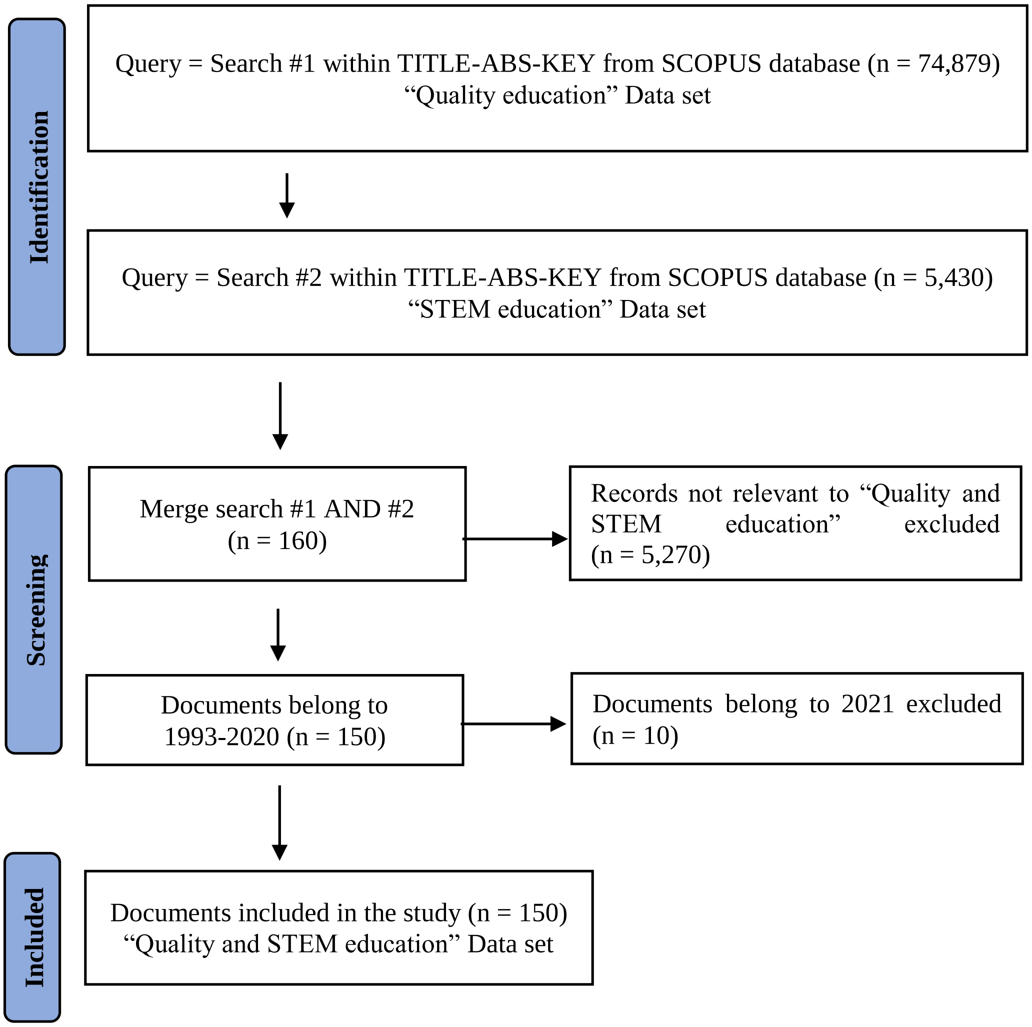

Figure 1 Search strategy flow diagram

According to (Chaparro & Rojas-Galeano, 2021), there are two stages of bibliometric assessment which are dynamics and structure analysis. The dynamics analysis considers the publications growth and distribution, the author's timelines, as well as the trends of the terms, keywords frequency, citation counts and distribution, and other bibliometric impact indicators, such as the h-index. The structure analysis consists of word dendrograms, co-occurrence networks, thematic maps, and collaboration and co-citation networks. The dynamics and structure analysis for bibliometric data were analyzed by using the "visualization of similarities" (VOS) Viewer software (Van Eck & Waltman, 2010) and the R-Tool of the Bibliometrix-package that was specifically designed for quantitative Bibliometrics research (Aria & Cuccurullo, 2017).

Results

Table 2 summarizes some descriptive statistics of the "Quality and STEM education" final data set during the timespan (1st of January 1993 to the end of December, 2020.). Regarding the dynamics of production, 150 documents from 106 sources were published during this time span. The average citation per document was 7.37 which is considered very high in comparison to social sciences (2.1) (Mumu et al., 2021) and engineering (6.92) (Ale Ebrahim et al., 2020). The average number of author's keywords per document was 2.76 (414/150 documents) which is less than the typical five author keywords per document.

Table 2 also represents the structure of the research products such as the author's specifications and references. There were 421 authors that appeared in 437 of the 150 documents, with an average of 2.81 (421/150) authors per document. There were 28 documents written by a single author. In addition, the average number of unique authors per document was 2.81, which is close to the number of co-authors per document (2.91) which indicates a few common documents. Moreover, the collaboration index that indicated the average number of authors in documents by multiple authors (Chaparro & Rojas-Galeano, 2021; Elango & Rajendran, 2012), was 3.25. The last parameter in Table 2 is the number of references. The average number of references per document was 43.58 (6,537/150). Therefore, future researchers in the area of "STEM education" and "Quality education" should consider the average of 44 references per document. Table 3 illustrated the 150 document types for the "Quality and STEM education" final data set.

Table 2 Bibliometrics statistics for the "Quality and STEM education" data set

Dynamics		**Structure**	
Timespan	1993:2020	Authors	421
Sources (Journals, Books, etc)	106	Author Appearances	437
Documents	150	Single-authored documents	28
Average citations per document	7.37	Authors per Document	2.81
Average citations per year per doc	1.12	Co-Authors per Documents	2.91
Keywords Index	480	Collaboration Index	3.25
Author's Keywords	390	References	6,537

Table 3 Document types for the "Quality and STEM education" data set

Document types	No.	Percentage
Article	85	53.13%
Conference paper	34	21.25%
Book chapter	19	11.88%
Book	6	3.75%
Review	3	1.88%
Editorial	2	1.25%
Short survey	1	0.63%

Publication trends

The annual distribution and corresponding cumulative results of the "Quality and STEM education" data set of 150 documents are illustrated in Figure 2. The current year 2021 data was not complete and excluded from the data set. The first document which was a conference paper recorded in the SCOPUS database was published in 1993, entitled "Federal policy options to achieve renewal in undergraduate education" written by Fortenberry (1993). The development of publications could be generally divided into two periods. The first period extended from 1993 to 2007, during which publications related to "Quality and STEM education" were rare and grew slowly, reflecting the fact that "Quality and STEM education" was in its infancy stage. The second period began in 2008. The "Quality and STEM education" publications have exponentially grown since 2008, which indicates the number of researchers increasing constantly, and the progression of knowledge opens new fields of interest (Dabi et al., 2016; Liu et al., 2020). The publication trends show that the "Quality and STEM education" research area will remain thriving in the next few years.

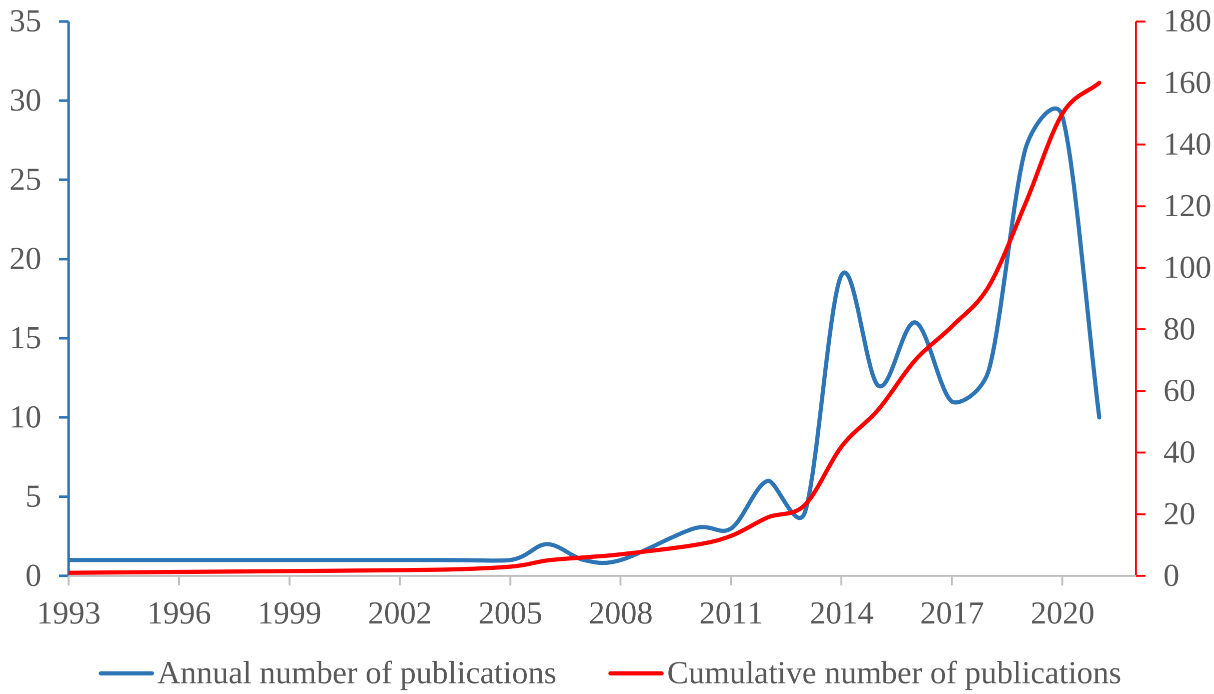

Figure 2 Temporal distribution of “Quality and STEM education” data set publications from 1993 to 2020

Figure 3 illustrates the average citations per year of the “Quality and STEM education” research area. The citation dynamics of documents published in 2016 accumulated the highest number of citations per year (3.72); the overall curve shows a saw-tooth pattern, but no citations have been accrued by documents from 1993 to 2004. Probably because it is too early in their mature cycle of “Quality and STEM education” research area. Therefore, the years 1993-2004 were omitted from the x-axis. The top three documents published were in the year 2016 and had the most contribution to increasing the number of citations per year. These documents are Master et al. (2016), Aladé et al. (2016), and Jang (2016) with total citations of 126, 65, and 63.

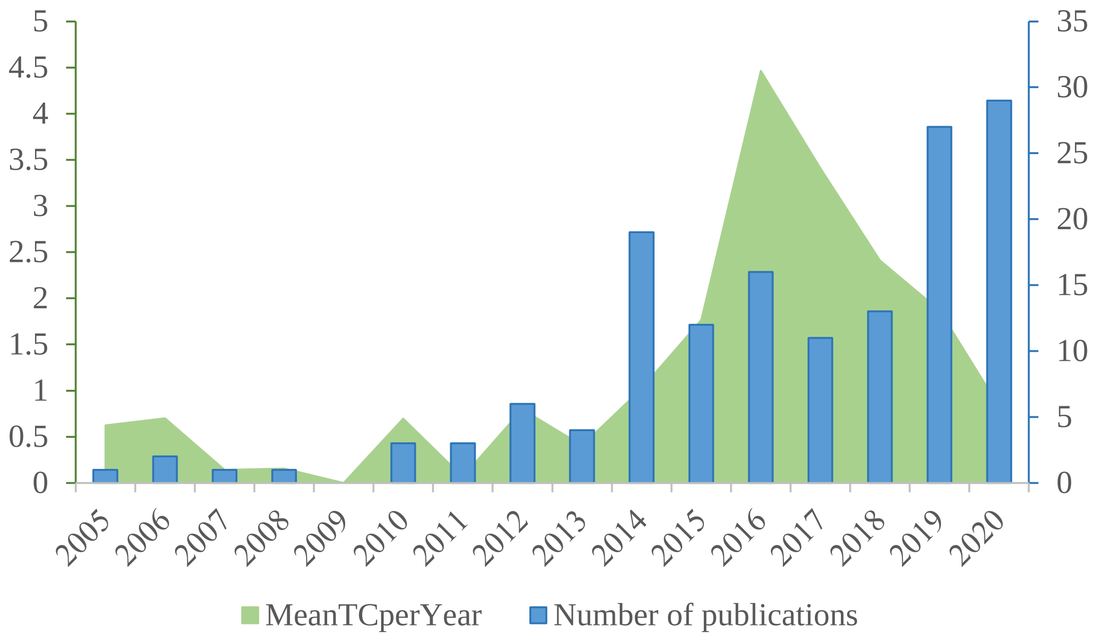

Figure 3 Average citations per year (MeanTCperYear) of "Quality and STEM education"

Keywords co-occurrence analysis

Keywords co-occurrence analysis is employed to identify and explore leading and emerging topics in the "Quality and STEM education" research area. Analyzing the co-occurrence frequencies of the keywords in publications can provide insights into main topics and research trends (Liu et al., 2020). Co-occurrence analysis is based on the assumption that two items appear in the same context when they are related to some degree. VoSviewer software (Van Eck & Waltman, 2010) is used to visualize the outcomes of co-occurrence frequencies of the keywords. The 150 documents provide 480 SCOPUS "Keywords Index" and 390 "Author's Keywords". The general terms like "human" and "student" were not excluded. Figure 4 illustrates SCOPUS "Keywords Index" co-occurrence network in the "Quality and STEM education" research area. The yellow color shows leading and emerging topics in the research area. Keywords' different colors indicate the initial date of their related publications, and the lines show the co-occurrence links between different keywords (Ale Ebrahim et al., 2020). "Computing education" is one of the most emerging topics in the "Quality and STEM education" research area. There were not enough SCOPUS "Keywords Index" within 2017-2020 to meet the frequency threshold of five. The "Author's

Keywords" diversity is very high in comparison with SCOPUS "Keywords Index". As illustrated in Figure 5, "primary education", "self-efficacy", and "human capital" were the most emerging keywords in the "Author's Keywords".

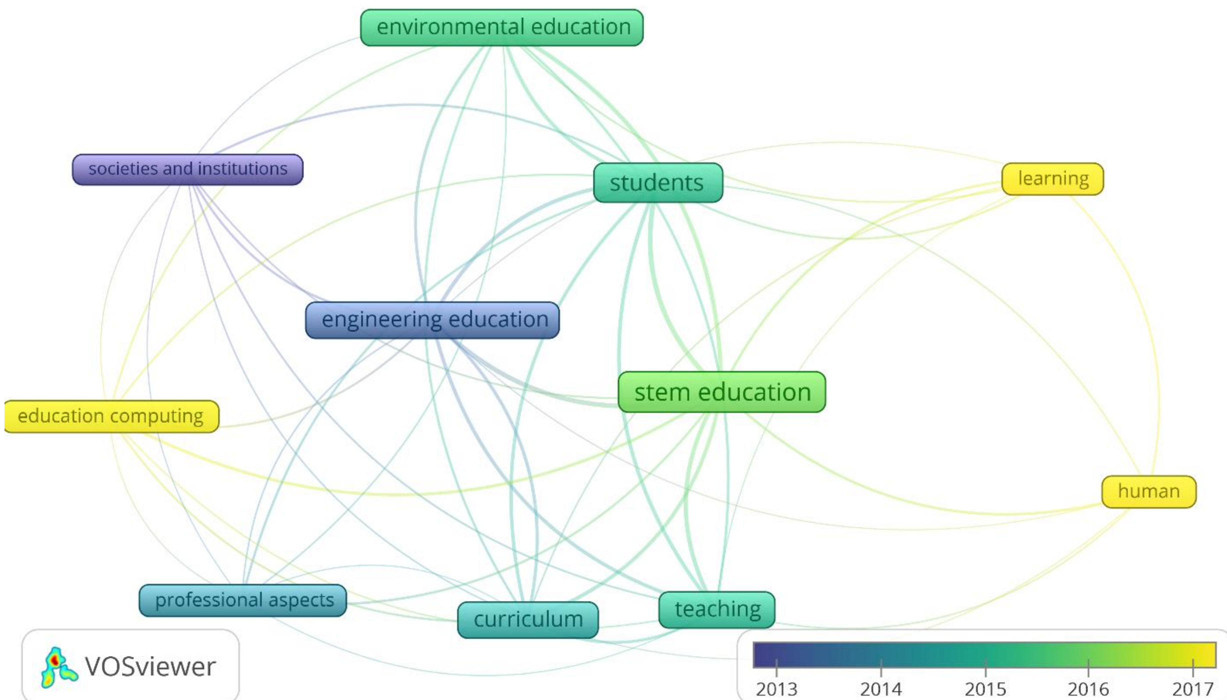

Figure 4 SCOPUS "Keywords Index" co-occurrence network - More detail is available in the online version of the map.

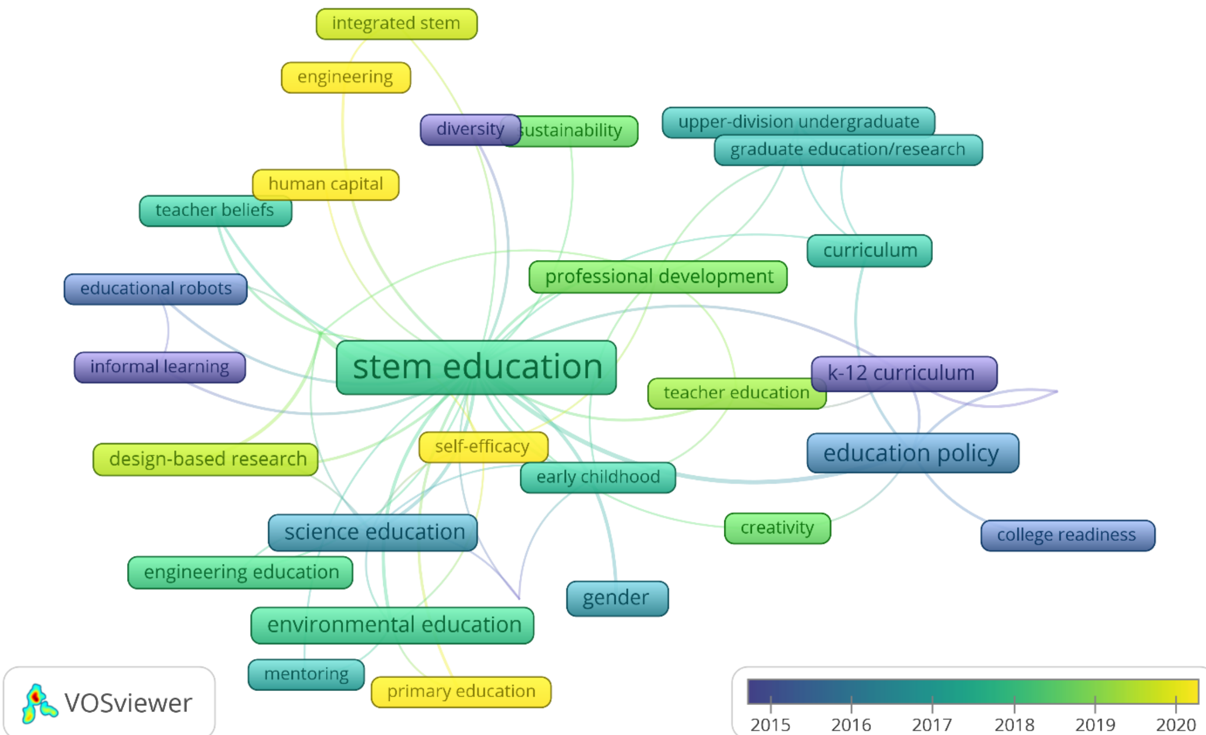

Figure 5 "Author's Keywords" co-occurrence network - More detail is available in the online version of the map.

The most frequent keywords can be divided into two clusters by using VoSviewer software. Figure 6 illustrates a cluster map of SCOPUS "Keywords Index" in the "Quality and STEM education" research area. Clustering is one of the techniques for bibliometric analysis. In the figure, the size of each node indicates the occurrence of the keywords while the links between the nodes represent the co-occurrence between the keywords. There are two clusters, the Red cluster, and the Green cluster; they had 12, and 7 items respectively. The words "Students" and "Environmental education" were at the heart of the Red cluster beside "STEM education". Whereas "Learning" was in the heart of the Green cluster.

The trend topics of the Bibliometrix-package (Aria & Cuccurullo, 2017) shows that "computing education" is a more recent (2019) topic in the SCOPUS "Author Keywords", in comparison to "environmental education" (2015) with the lower word frequencies. The distribution of "Author's Keywords" can indicate the popular research topics among publications that are illustrated in

Figure 7. Besides the "STEM education", "early childhood education" is growing very dramatically in the "Author's Keywords" of "Quality and STEM education" research area. The trend shows that "early childhood education" and "design-based research" are more recent topics in the "Author's Keywords".

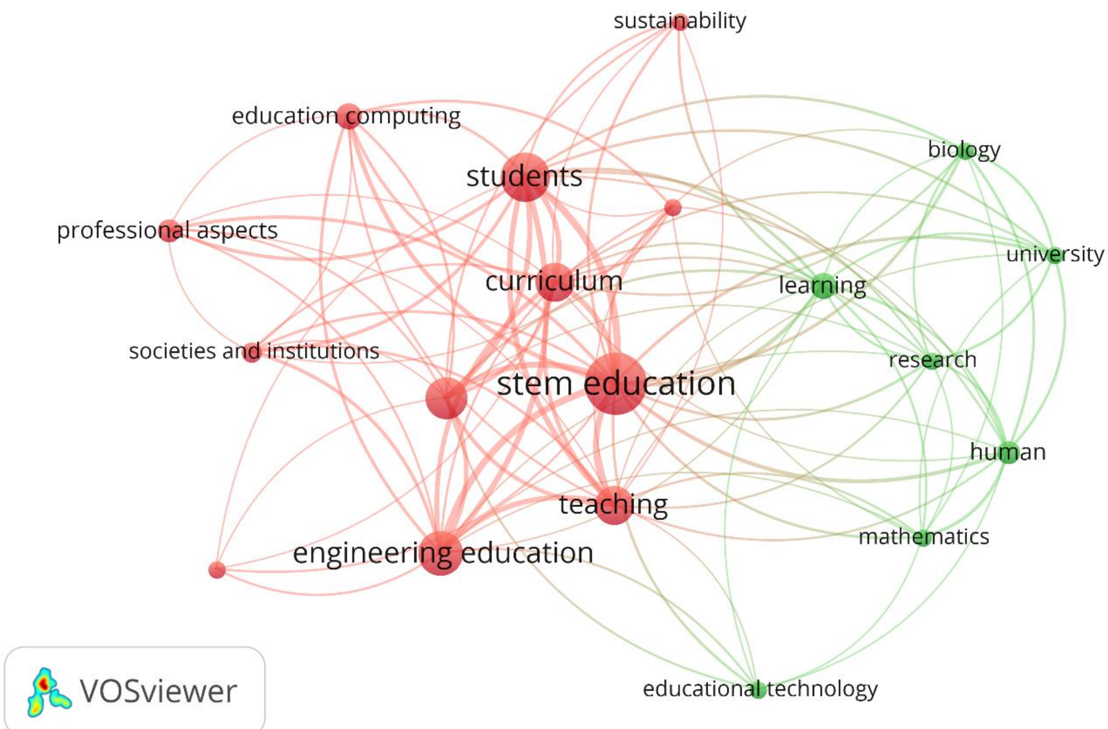

Figure 6 Cluster map of SCOPUS "Keywords Index" in the research area- More detail is available in the online version of the map.

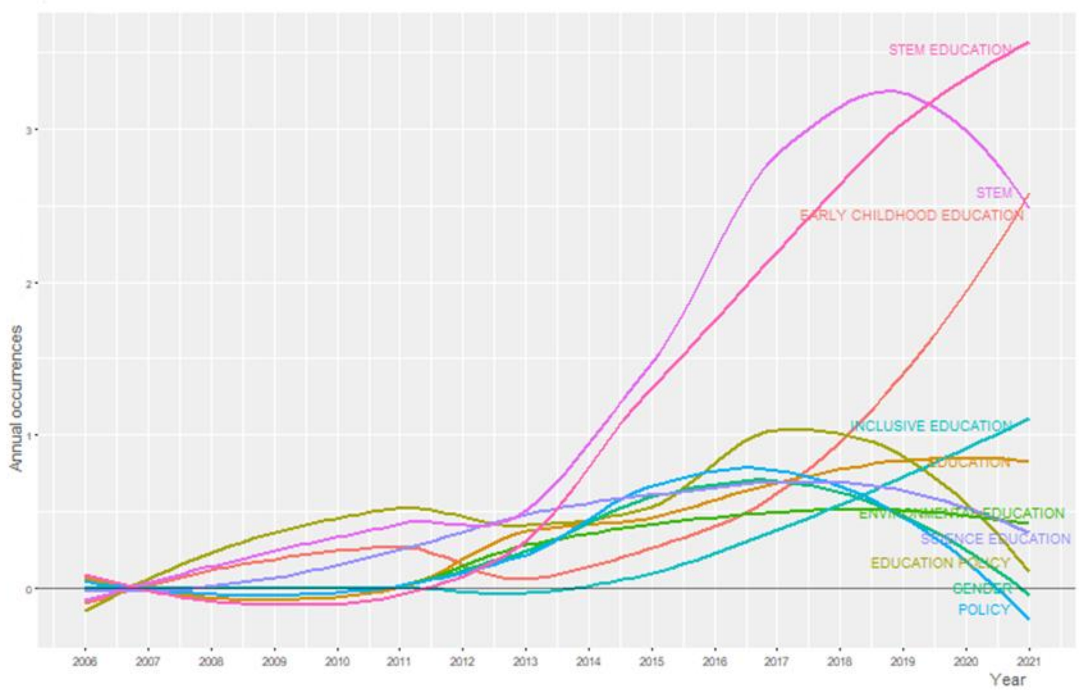

Figure 7 “Author's Keywords” growth map

The most prolific authors and sources

Analysis of data indicates that 421 authors contributed 150 published documents (Table 2). 407 authors published only one document, and 11 authors published two documents. While two authors published three documents and one author has published four documents. Table 4 shows the authors' production over time. There were two criteria for including the author’s name in Table 4. Firstly, the author should have at least two publications in the data set (150 documents). Secondly, the author should have received at least two citations for their publications in the previous years. In summary, authors with a minimum of two publications and two citations were listed in Table 4. The authors' list ranked according to the number of times cited per year (TCpY) which was a normalized indicator to compare early-career researchers with mid-career researchers’ publications.

The most impactful author which their publication (Aladé et al., 2016) received 9.29 citations per year (TCpY = 9.29), was Fashina Aladé from the School of Communication, Northwestern University, United States. The second (Kylie Peppler) and third (Karen Wohlwend) row authors

(Buchholz et al., 2014) publication received TCpY = 6.44. Kylie Peppler is an assistant professor in the Learning Sciences Program and Karen Wohlwend is a professor at the Center for Research on Learning and Technology; the Curriculum and Instruction department of Indiana University. Mubarak K. Al-Salami is a researcher at the School of Education, Colorado State University. Marilyne Stains and their research group including Marytza Abebe at the University of Virginia focus on closing the gap between research and practice in chemical and science education at the postsecondary level.

Purdue University with 14 publications, Arizona State University with 7, Indiana University, Louisiana State University, University of California Los Angeles (UCLA), and the University of Washington with 5, Carnegie Mellon University, and Universitas Pendidikan Indonesia with 4 publications were the most productive institutions. The United States with 101, Australia, Taiwan, and Turkey, with 5, Canada, China, Indonesia, Malaysia, and the United Kingdom with 4, and Sweden with 3 publications were the top 10 most productive countries in the “Quality and STEM education” research area. Table 5 shows the top authors’ documents. The documents should receive at least one citation per year for inclusion in Table 5. Future research may investigate why these documents received the highest number of citations per year. However, in the discussions section, some features of high-ranked papers were investigated.

Table 4 Authors' production over time

Author	**Year**	**TC**	**TC Rank**	**TCpY**	**NPpY**
ALAD F	2016	65	1	9.29	1
PEPPLER K	2014	58	2	6.44	1
WOHLWEND K	2014	58	2	6.44	1
AL SALAMI MK	2017	31	3	5.17	1
STAINS M	2016	29	4	4.14	1
ABEBE M	2016	29	4	4.14	1
EVANGELOU D	2010	23	5	1.77	1
ALC H	2016	16	6	2.29	1
BRAGG DD	2017	14	7	2.33	1

PEPPLER K	2018	11	8	2.20	1
WOHLWEND K	2018	11	8	2.20	1
DEMIRCAN H	2017	8	9	1.33	1
ADNAN M	2016	8	9	1.14	1
ABRAHAMSE A	2015	7	10	0.88	1
BRAGG DD	2014	6	11	0.67	1
WUHIB FW	2014	5	12	0.56	2
STAINS M	2019	4	13	1.00	1
GONZALEZ HB	2014	2	14	0.22	3
KUENZI JJ	2014	2	14	0.22	1
KUENZI JJ	2011	2	14	0.17	2

(TC=Time Cited, TCpY=Time Cited per Year, and NPpY=Number of Publications per Year)

Table 5 Top authors' documents

No.	Reference	TC	TCpY
1.	(Aladé et al., 2016)	65	9.29
2.	(Buchholz et al., 2014)	58	6.44
3.	(Al Salami et al., 2017)	31	5.17
4.	(Velasco et al., 2016)	29	4.14
5.	(Malin et al., 2017)	14	2.33
6.	(Sümen & Çalışıcı, 2016)	16	2.29
7.	(Peppler & Wohlwend, 2018)	11	2.20
8.	(Evangelou et al., 2010)	23	1.77
9.	(Ata Aktürk et al., 2017)	8	1.33
10.	(Lane et al., 2019)	4	1.00

(TC=Time Cited, and TCpY=Time Cited per Year)

The retrieved results (Table 2) show 150 documents published in 106 sources (Journals, Books, etc). Source analysis helps to identify the distribution of core journals in the research area. Table 6 ranked the top 10 sources by time cited and a number of publications. The original h-index was formulated for measuring researchers' impact. The definition of the h-index can be generalized beyond the papers-citations framework of a researcher (Egghe, 2013). Nowadays it is used for journal evaluations as well. "Science Education" journal, which has the h-index 5, means there were at least five papers published in the "Quality and STEM education" research area in this particular journal and each of them has been cited at least five times. The "CBE Life Sciences Education" ranked 3 with 4 and 8 citations publications (3, 4, 10), "International Journal of STEM Education" (4, 4, 8), "Proceedings-Frontiers in Education Conference, FIE" (5, 4, 2), "Building STEM Skills through Environmental Education" (6, 4, 0), and "Science and Education" (10, 3, 10) were not listed in Table 6, due to their low citations.

Table 6 Top 10 sources ranked by times cited

Source	**H-index**	**TC**	**TC Rank**	**NP**	**NP Rank**	**PY_start**
Science Education	5	128	1	5	2	2015
Journal of Educational Psychology	1	126	2	1	6	2016
Journal of Science Education and Technology	3	100	3	3	4	2005
Computers in Human Behavior	1	65	4	1	6	2016
Mind, Culture, and Activity	1	58	5	1	6	2014
International Journal of Technology and Design Education	3	48	6	3	4	2016
Journal of Research In Science Teaching	2	37	7	2	5	2017
ASEE Annual Conference and Exposition, Conference Proceedings	2	33	8	7	1	2006
Journal of Chemical Education	2	31	9	2	5	2016
Arts Education Policy Review	3	30	10	3	4	2018

(TC=Time Cited, NP=Number of Publications, and PY=Publications Year)

Discussions

The bibliometric method is the way that gains insight into the state and nature of fields or disciplines (Assefa & Rorissa, 2013). The bibliometric approach arises from an academic interest in obtaining a general vision of the scientific production developed around this subject, enabling us to know the characteristics of the publications made and opening a horizon of new proposals and lines of research. In this sense, the study of quality education as one of the sustainable development goals stipulated in the 2030 agenda is a new scientific field now in full attention. Education in the SDGs is not only an objective itself but also its development is necessary for the achievement of the rest of the objectives (Alonso-Garcia et al., 2019; García et al., 2020; Osei Kwadwo & Konadu, 2020). This bibliometric study aims to assess the role of integrated STEM education in improving the quality of education over 27 years (1993-2020) in nine aspects: 1) Number of publications per year; 2) Average citations per year; 3) “Keywords Index” co-occurrence network; 4) “Author's Keywords” co-occurrence network; 5) Conceptual structure map of “Keywords Index”; 6) “Author's Keywords” growth map, 7&8) the most prolific authors and sources, and 9) research hotspots that are highlighted in this section by using data extracted from SCOPUS.

Firstly, regarding the number of publications per year, this research revealed that the timeline of the outputs of the “Quality and STEM education” research area as shown in

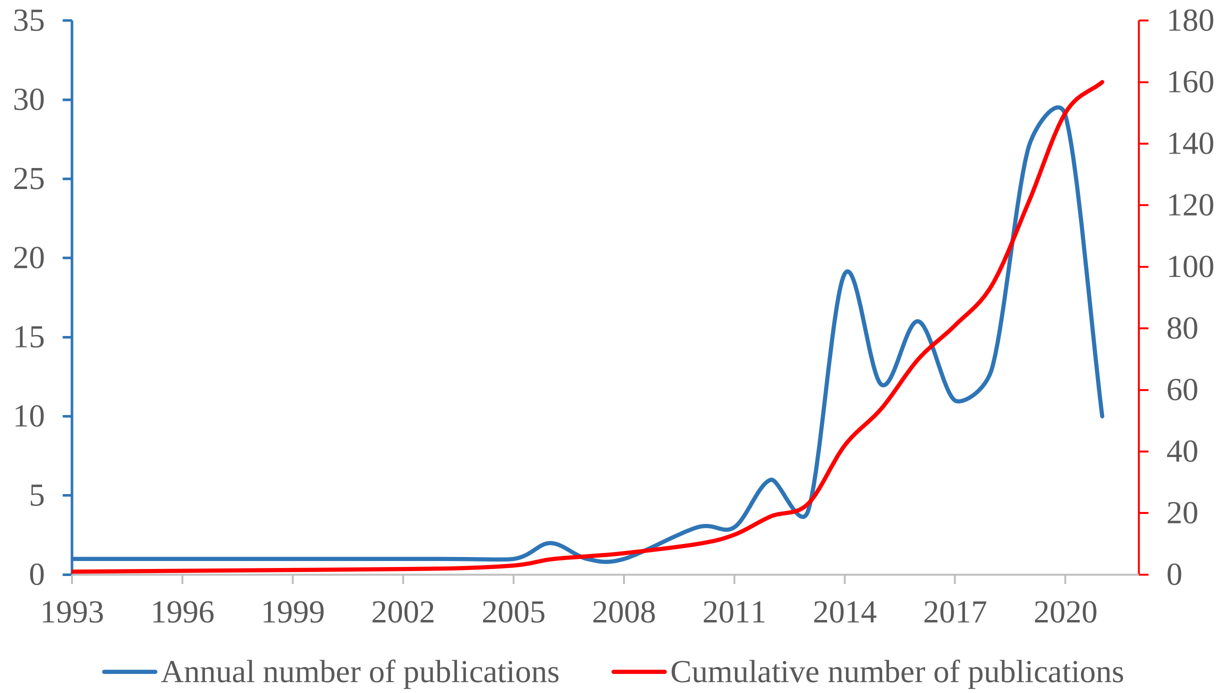

Figure 2 could be divided into three periods: first, the hibernating phase (1993-2008): only seven publications were published, and there were many years with no record of publications at all like

1994-2002, and 2004. Second, the warming-up phase (2009-2013): this period featured a stable but small (one-digit) number of publications annually with 16 publications. Third, the leapfrogging phase (2014 onward): the annual record of publication was always a two-digit number and the growth rate has fluctuated and is positive. A review of the literature revealed that STEM evolved out of government policy, especially from within the National Science Foundation (NSF) (Marrero et al., 2014). NSF first used the acronym SMET for science, mathematics, engineering, and technology in the early 1990s, but determined that this acronym sounded too much like “smut”, and then STEM was born in 2001 (Hacioglu & Gulhan, 2021; Marrero et al., 2014; Sanders, 2009). The policy has played a pivotal role in the history of STEM, during his tenure as president, Barack Obama, and his administration has passed two specific initiatives to improve STEM teaching and learning. They first launched “Educate to Innovate” in 2009, followed by “Change the Equation” in 2010 (Hwang, 2021). “Change the Equation” was a specific call to action for the business community to become more involved in STEM education, which was also one of the goals of Educate to Innovate (Hwang, 2021; Sahin, 2015). Therefore, the number of publications raised after policymakers’ attention. Secondly, regarding the distribution of the publications according to the periods, it can be said that the number of publications has increased in each period. It can be seen that the highest number of publications was spotted from 2014 onward (84.67 %). The results of the present study support the findings of several studies (Ling et al., 2019; Nguyen et al., 2020; Tikly et al., 2018).

To answer the last research question “What are research hotspots” the top authors' document abstracts were reviewed. The first author listed in Table 6 was Aladé et al. (2016). The paper entitled “Measuring with Murray: Touchscreen technology and preschoolers' STEM learning” which was about the effect of using tablet computers in early childhood education for teaching STEM skills. The findings suggested that while preschools can learn early STEM skills from educational technology, interactivity may only further support learning in certain contexts. The second article with the name “Hands-On, Hands Off: Gendered Access in Crafting and Electronics Practices” was written by Buchholz et al. (2014). Buchholz’s article focused on gender disparities in STEM fields. Access to STEM education contributes to girls’ opportunities to develop transferable, technical, and vocational skills, for employment and decent jobs and has the potential to accelerate the elimination of gender disparities in access to crafting and electronics practices and positions girls and women as capable players in the promotion of sustainable development and gender equality in all spheres of life (Buchholz et al., 2014; UNICEF, 2020). Al Salami et al. (2017) paper titled “Assessing changes in teachers’ attitudes toward interdisciplinary STEM teaching” was published in 2017, and rated as the third most cited article in the research area. Al Salami suggested that professional development is considered a key component for preparing teachers to shift to interdisciplinary teaching. Researchers found that there was no overall significant change from the pretest to the posttest administrations in teachers’ attitudes to interdisciplinary teaching, attitudes to teamwork, teaching satisfaction, or resistance to change (Al Salami et al., 2017).

Velasco et al. (2016) developed the Laboratory Observation Protocol for Undergraduate STEM (LOPUS), to characterize teaching assistants’ verbal interactions. Malin et al. (2017) provide several cautions and recommendations for policymakers to improve students’ college and career readiness. Sümen and Çalışıcı (2016) implement the STEM education approach in an environmental education course taught in the second year of a primary school teaching undergraduate program. Peppler and Wohlwend (2018), by reviewing 50 papers and books, argued that policymakers should think about tools needed in classrooms today in which education could play a critical role in STEM disciplines and offer solutions to address STEM pipeline challenges. Evangelou et al. (2010) discussed preschool and early childhood education, which is one of the growing trends of “Quality and STEM education” research area importance in child development. Ata Aktürk et al. (2017) examined the Turkish early childhood education curriculum relative to science, technology, engineering, and mathematics (STEM) education. Lane et al. (2019) investigated how faculty social networks and peer influence rated knowledge and use of evidence-based instructional practices (EBIPs) in undergraduate STEM classes. Ong et al. (2016) like (Ata Aktürk et al., 2017; Evangelou et al., 2010) emphasized the effectiveness of early childhood teachers’ training on STEM integration.

Table 7 illustrates research hotspots highlighted in the top authors’ documents. The majority of high-ranked publications prove the analysis of “Author's Keywords” which was the importance of the "early childhood education" in the "Quality and STEM education" research area. Early childhood education was raised by four more documents in the current data set (Gold & Elicker, 2020; Littell & Hartman, 2017; Simoncini & Lasen, 2018; Tippett & Milford, 2017). There were other documents discussing research hotspots such as educational technology (Chedid, 2005), computing education (Schnabel et al., 2010), gender disparities/educational equity (Nelson et al., 2020; Simon et al., 2017; Subía et al., 2020; Tam et al., 2020), project-based learning (Chen & Lin, 2019; Mustafa et al., 2016), educational environment (Dolgopolovas et al., 2020; ElZomor & Youssef, 2019; Ikarashi et al., 2019; Oreshkina & Gurov, 2020; Shapovalov et al., 2019), college and career readiness (Bragg & Taylor, 2014), evidence-based teaching (Hanauer & Bauerle, 2015), curriculum (Fan & Yu, 2016; Gale et al., 2020; Hsu et al., 2019; MacDonald & Huser, 2020; Sujarwanto et al., 2021; Suwarma & Kumano, 2019), and artifacts (Ryu et al., 2019; Teo & Osborne, 2014).

Table 7 Research hotspots highlighted in the top authors' documents

No.	**Reference**	**TCpY**	**Early childhood education**	**Educational technology**	**Computing education**	**Educational equity**	**Project-based learning**	**Educational environment**	**College and career readiness**	**Evidence-based teaching**	**Curriculum**	**Artifacts.**
1.	(Aladé et al., 2016)	9.29	X	X	X							
2.	(Buchholz et al., 2014)	6.44		X	X	X						
3.	(Al Salami et al., 2017)	5.17					X					
4.	(Velasco et al., 2016)	4.14	X					X				

5.	(Malin et al., 2017)	2.33				X			X			
6.	(Sümen & Çalışıcı, 2016)	2.29						X		X		
7.	(Peppler & Wohlwend, 2018)	2.20		X								X
8.	(Evangelou et al., 2010)	1.77	X									X
9.	(Ata Aktürk et al., 2017)	1.33	X								X	
10.	(Lane et al., 2019)	1.00								X		

(TC=Time Cited, and TCpY=Time Cited per Year)

Limitations

There might be some other relevant documents on the WoS database, which were not included in the research data set. Therefore, one of the study limitations is selecting one debase for retrieving the data. The second limitation is following selected keywords from pre-generated queries on UN Sustainable Development Goals 2020, on SCOPUS advanced search database.

Conclusions

The results of this bibliometric study have several implications. This study has given an overview of the past, present, and somewhat future trends in the research area of STEM and quality of education. Future researchers of the field may directly choose from the hottest topics for their research area. Using this study, they would get familiar with the top authors, top institutions, and top journals within the field, who they can start collaborating with, or where they can download the most relevant papers from. Moreover, the findings of this study support the role of STEM education in improving the quality of education. The lack of bibliometric studies on the field of integrated global SDG 4, quality of education, and STEM education were covered by this study to some extent, showing how the integrated STEM education could contribute to the achievement of SDG 4 and the reason why SDG 4 should have received more attention within sustainable development agendas at national and international levels. Analysis of the top 10 papers, revealed the importance of an “early childhood education” in the “quality and STEM education” research area. Following the considerable attention that, “computing education” and “environmental education" have attracted in recent publications. Therefore, it is necessary for future research to investigate the "early childhood education", "computing education", and "environmental education" roles in education quality. Besides, attention to the role of policymakers was another emphasis of high-ranked publications. Based on the current results of this study, the next step for this research would be to conduct a qualitative analysis to bring a more in-depth discussion on improving the quality of education through integrated STEM.

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