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STEM education in primary schools of Southeast Asian countries: An analysis of scientific publications in the Scopus database from 2000 to 2022

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Abstract

STEM education, which stands for science, technology, engineering, and mathematics, is an important educational model in primary and secondary schools, including elementary schools. STEM education is being emphasized in many countries around the world. In Southeast Asia, the current state of STEM education is quite diverse and there is a discrepancy between countries. This study focuses on analyzing quantitative scientific indicators based on 490 publications on STEM education in elementary schools from 2000 to December 2022 in the Scopus database. The data is analyzed by bibliometrics software Biblioshiny and VOSviewer on the collaboration network between scientists in the field of STEM education in elementary schools, countries with the most publications, emerging keywords and related keywords, as well as research trends on STEM education in elementary schools for Southeast Asian countries. The results of the study show that publications on STEM education in elementary schools in Southeast Asian countries started to be studied from 2008 and have been increasing rapidly; scientific papers published in some high-impact factor journals; the countries with the most publications are not necessarily Southeast Asian countries, mainly in the Americas, Europe, Asia, with Indonesia being the only Southeast Asian country in the top-5 countries with the most publications on this research trend. Based on the analysis, the article proposes some directions for STEM education research in elementary schools in Southeast Asian countries to achieve high effectiveness in training at elementary schools.

Keywords: STEM education, elementary schools, Southeast Asia, bibliometrics

INTRODUCTION

STEM education plays a crucial role in developing the capabilities of high school students. STEM stands for science, technology, engineering, and mathematics–four fundamental education fields considered as the foundation for students' capacity development in the learning process. Teaching in the direction of STEM education helps equip students with the knowledge and skills necessary to solve complex problems in life, improve their critical thinking and analysis skills, explore and create (Mpofu, 2012).

STEM-focused education also helps students develop soft skills such as communication, teamwork, problem-solving, and practical skills during the learning process. These skills are essential in daily life and particularly important in business and technical fields. Moreover, STEM education is one of the models that help equip students with better opportunities in the future to seek high-paying jobs, meet the demand for high-skilled labor to adapt to the Industry 4.0 revolution, thereby contributing to the development of society (Corlu et al., 2014).

Education in Southeast Asian countries is in the process of development and there are differences between countries (Parker & Fraillon, 2016). Some countries have education systems considered among the best in the world, such as Singapore, some have developing education systems like Thailand, Vietnam, while some countries still have limitations such as Laos,

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Contribution to the literature

- This study will contribute to the field of educational science by supplementing theories on STEM education in primary schools, providing insights into the context and current situation of STEM education research in Southeast Asian countries over a period of more than 20 years (from 2000 to 2022).
- This will assist scientists and policy makers in Southeast Asian countries in proposing measures for the development of STEM education in primary schools and advancing this research direction to enhance the quality of primary education in Southeast Asia.

Cambodia (Kristhopher Donna Sweinstani, 2016). Especially, the infrastructure, and the capacity of the teaching staff in secondary education in Southeast Asian countries are widely different, therefore, applying STEM education model in primary schools in Southeast Asian countries still has many differences and needs to be carefully studied (Bernardo et al., 2022).

This study focuses on the quantitative analysis of scientific publications on STEM education research in primary schools in Southeast Asian countries from 2000 to December 2022, published in the Scopus database. Specifically, the study focuses on

(1) the authors, journals, publishers, countries, and educational institutions with the most publications,

(2) current research trends, emerging research trends, important keywords, and newly emerging keywords in this research area, and

(3) the collaboration networks of scientists worldwide and the development of this research area in the future.

Based on the research findings, new conclusions and proposals will be made regarding STEM education in primary schools in the Southeast Asian region, aiming to enhance the quality of education in this region.

OVERVIEW

STEM Education

Research STEM stands for science, technology, engineering, and mathematics, corresponding to the subjects of science, technology, engineering, and mathematics. STEM education is considered a comprehensive and diverse educational approach that helps students develop skills in logical thinking, problem-solving, collaboration, and creativity. It is a topic of great interest and investment worldwide, including countries with strong STEM education systems such as the USA, Japan, South Korea, China, Europe, and others (Burrows & Slater, 2015).

In the USA, STEM education program has been integrated into the curriculum of schools from kindergarten to university. The USA government has invested a significant budget to support STEM education, particularly for schools with limited resources. In addition, non-profit organizations also contribute to promoting STEM education by organizing extracurricular activities, summer camps, and STEM competitions that are used in education discussions with original initiatives to address the shortage of qualified candidates for high-tech jobs in the USA (Daugherty, 2013). STEM emphasizes integrated teaching programs rather than separate subjects. Mastery of STEM fields is seen as a hallmark of success in the USA educational system (Breiner et al., 2012). Additionally, the term is widely used in policy debates about the USA's approach to visa access for highly skilled immigrant workers in these fields. It has also become prevalent in education discussions as a reference to the shortage of skilled workers and inadequate education in these fields (Sanders, 2012).

There have been numerous efforts to establish approaches to STEM education across Australia (Carter, 2017). In 2009, the iSTEM (invigorating STEM) program was established, which is an enrichment program for high school students in Sydney, Australia. The program focuses on providing activities for students and families interested in STEM (Penprase, 2020). Many universities and science organizations have supported the program's success. The expansion of the iSTEM vocational teaching program in 2015 received an award from the Australian government at the time (Murphy et al., 2019).

Canada started later than other developed countries, with STEM programs beginning in 2015 (DeCoito, 2016). However, Canada has a graduation rate of 21.20% for students studying STEM programs, ranking 12th out of 16 countries, higher than the USA. In addition, the Schulich Leader scholarship aims to attract talented youth to STEM fields (Lee & Lee, 2022).

Turkey does not focus on increasing the number of STEM students but instead concentrates on those who are dedicated to improving the quality of STEM education through the collaboration of scientists and educators (Yilmaz et al., 2018). The AL-Bairaq competition in Qatar has engaged high school students in a STEM-focused program that utilizes project-based learning, encourages students to tackle real-world problems, and requires them to work together as a group to build real solutions (Ali et al., 2021).

In France, STEM education is covered at all levels of schooling, and is implemented in the primary school stage, where students learn about mathematics, natural sciences, and technology (Berglund et al., 2021). Students have participated in experiential learning activities aimed at promoting their interest in science and technology, while also developing their critical thinking skills. The goal is to enhance students' understanding of the world from both natural and artificial perspectives. Students are focused on problem-solving and research-oriented learning, encouraging them to have knowledge and serious thinking about their world, understanding mathematical principles, and solving mathematical problems (Sutaphan & Yuenyong, 2019). Moreover, currently, France is implementing an integrated science and technology learning program that provides a curriculum including physics, chemistry, life and earth science, and technology. However, these contents are taught in an integrated manner rather than being taught as separate subjects (Boyd & Tian, 2018).

In the UK, teaching STEM has been developed into a national program with the goal of producing a high-quality scientific research workforce (Hoyle, 2016). The UK's action plan to promote STEM education includes four main content areas: First, recruiting STEM teachers. Integrated teaching is not a teacher teaching multiple subjects at once, but teachers from different subjects collaborating to build lessons so that students can apply knowledge and skills from multiple subjects to solve a problem. Second, enhancing the level of teacher training. Third, improving and enriching the curriculum both in and outside of the classroom. Fourth, developing supportive infrastructure for teaching and learning. This requires not only investment from the state budget but also from the private sector. The experience of teaching STEM in the UK is not to separate STEM teaching from the mainstream curriculum, but to integrate STEM experiences into the teaching program and textbooks (Villanueva Baselga et al., 2022). The concept of teaching STEM in the UK is an approach and a direction, not a subject. Some ways to incorporate STEM teaching into the UK curriculum are, as follows:

(1) STEM projects are taught in a single subject, where teachers help students establish problems, design problem-solving methods, gather information and evidence, and finally draw conclusions.

(2) STEM projects are taught in multiple subjects. In this way, different teachers will teach the same STEM topic but from their own disciplinary perspective.

(3) STEM projects integrate multiple subjects, with each subject approaching the topic from their own specialized knowledge. The content resolved in the previous subject will be a prerequisite for teaching in the next subject.

(4) STEM projects are carried out in parallel with the curriculum. Students will study their regular subjects, but at the same time, they will participate in a STEM project, where they will apply the knowledge they have learned to solve the problems posed by the project (Bell, 2017).

In Asia, Japan is also focusing on the development of STEM education to meet the demands of modern economy and promote sustainable development. The Japanese government invests a significant amount of budget to create better learning and working environments for future scientists and engineers. Additionally, Japanese companies also contribute greatly to STEM education by sponsoring science competitions, funding research, and providing quality learning programs (Sulaeman et al., 2020). South Korea is also one of the leading countries in STEM education. The South Korean government has invested heavily in developing STEM education in schools and universities (Kang, 2019). They have also created a better learning and working environment for future scientists and engineers (Hong, 2017). Malaysia's education plan for the 2013-2015 period includes 11 key areas, including "providing equal access to internationally benchmarked quality education", turning teaching into a career choice, and using information technology to expand the scale and quality of education throughout Malaysia (Bahrum et al., 2017). With this trend, STEM education in Malaysia is becoming more popular and important. STEM is everywhere and shapes daily life. Students exposed to STEM have the opportunity to get better-paying jobs. Therefore, high-quality schools in Malaysia are increasingly offering STEM-related subjects. Currently, Malaysia has developed an inquiry-based teaching program based on contexts, questions, and issues. In addition, Malaysia has also built comprehensive STEM teaching and learning resources (Edy Hafizan et al., 2017).

One of the important issues that education aims at is to prepare high-quality human resources for the future, especially in the context of the fourth industrial revolution that is booming globally. STEM education is one of the important keys to effectively address the issue that many countries around the world have applied (Sy Nam, 2018).

STEM Education in Southeast Asian Countries

The Association of Southeast Asian Nations currently consists of ten member states, specifically Indonesia, Malaysia, the Philippines, Thailand, and Singapore (all in 1967), Brunei (1984), Vietnam (1995), Laos and Myanmar (1997), and Cambodia (1999) (Kirkpatrick, 2017). Most of the countries in Southeast Asia are coastal and up to one-third of the area is covered by water. Indonesia and the Philippines are countries that include large archipelagos and have the highest population densities in the region (Booth, 1999). Some mountainous countries have active volcanoes, making education accessibility difficult (Singh & Espinoza-Herold, 2014). The geography of Southeast Asia includes cities, inland rural areas, mountainous regions, and islands, so the geographical location, economic and social conditions of these countries are quite different. The economies of these countries also vary significantly, with some highly developed countries having high incomes (Singapore and Malaysia), developing countries (Myanmar, Vietnam, Indonesia, Philippines, and Thailand), and slow-developing countries such as Laos and Cambodia (Graham & Jordan, 2011). Furthermore, the diversity of ethnic groups in Southeast Asian countries is quite significant (Chong, 2018). Moreover, the diversity of ethnic groups has shown that language diversity is a prominent feature of all Southeast Asian countries. Minority language speakers face many difficulties in the education process compared to the majority language speakers. Countries with a large number of ethnic groups tend to use the language of the majority ethnic group as the national language and the common language of education for the country. In all Southeast Asian countries, the national language or official language is usually the language of the ethnic group with the highest population. In some countries, experiments have begun to use some minority languages in education. Therefore, education in Southeast Asian countries is quite diverse and there is a significant distinction between countries and ethnic groups (World Bank, 2009).

With the exception of some educationally developed countries that can compete with schools worldwide such as Singapore and Malaysia, students from other countries have lower self-reliance and adaptability, especially students from some countries such as Vietnam, Thailand, Laos, and Cambodia who are still considered passive and memorization-oriented. Students in Southeast Asian classrooms are rarely involved in experiential learning activities, and most of their time is spent listening to their teachers' lectures (Cao, 2011).

The economy remains a significant issue that determines the quality of education in Southeast Asia, as the slow development of the economy in countries such as Vietnam, Malaysia, and the Philippines has led many parents to migrate for work, leaving little time for their children's education. As a result, they primarily send money back home to support their families, which has a significant impact on education in Southeast Asia, particularly at the primary level, where children do not receive the attention they need from their parents during the learning process (Graham & Jordan, 2013).

Policy-makers in Southeast Asian countries have recognized the importance of education for societal development and have initiated significant policies to expand and improve their national education systems in recent years (Cheng, 1999). Singapore, Malaysia, and Thailand are striving to achieve economic and social development, and most of these countries have a clear national vision for the new century and believe that education can play a vital role in achieving this vision. As a result, many education policies have been enacted, and educational reforms are taking place in these fields in Southeast Asian countries (Goujon & Samir, 2008).

As a result, after several decades, policy-makers in Southeast Asian countries are paying more attention to the quality and equality of education, and many policies on curriculum reform, teacher training, improving schools and teaching conditions, as well as decentralization in educational management, have been initiated and implemented to improve the quality of education in most of these fields (Kristhopher Donna Sweinstani, 2016).

Furthermore, Southeast Asian countries value peace and aim to build a peaceful nation. In these countries, global education and peace education are highly regarded and implemented from primary school education. Schools in Southeast Asian countries emphasize the curriculum and teaching methods that aim for peace education. The acceptance of new learning models and methods in general schools and primary schools in particular are highly regarded by these countries (Parker & Fraillon, 2016).

One can provide a general overview of the education in Southeast Asian countries, as shown in **Table 1**.

Due to the quality of education, infrastructure, education policies, and language used in education by ethnic groups, STEM education model has been implemented in Southeast Asian countries in which some pioneer countries have placed a strong emphasis on STEM education for primary schools, such as Singapore and Malaysia. These countries have comprehensive STEM teaching programs and invest heavily in high-quality facilities, equipment, and teachers to ensure the quality of teaching.

However, in some other countries in the region, such as Vietnam, Thailand, the Philippines, and Indonesia, STEM education is still in the process of development and needs improvement. Schools still lack equipment, teachers with sufficient expertise, and curriculum updates to international standards. Although some governments have included STEM in their secondary education curriculum, these countries still face challenges with a lack of equipment, teachers with insufficient expertise, and curriculum that needs to be updated to meet international standards.

In 2018, Vietnam became a country that introduced STEM and STEAM education into the national curriculum with the goal of effectively implementing STEM education in primary and secondary education to develop students' comprehensive abilities (Trang, 2021). Vietnam has identified that in order to apply STEM to the national curriculum in a systematic way, a long-term plan with a roadmap for implementation at various levels and suitable forms is needed, rather than just a passing trend. Above all, there needs to be unified guidance and awareness among the team of educators

Table 1. General overview of education in Southeast Asian countries

Country	Education & education policies
Brunei	Education in Brunei has a relatively good quality & offers diverse learning programs.
Cambodia	Education in Cambodia is undergoing development & requires investment to improve its quality.
Indonesia	Education in Indonesia is undergoing development & many efforts have been made to improve its quality.
Laos	Education in Laos lacks sufficient infrastructure, equipment, & highly qualified teachers.
Malaysia	Education in Malaysia is currently undergoing development & many reforms have been implemented to enhance quality of education.
Myanmar	Education in Myanmar still has many limitations, including a lack of equipment, insufficiently qualified teachers, & outdated learning programs.
Philippines	The education system in the Philippines still has many limitations, including a lack of equipment & insufficiently qualified teachers.
Singapore	Singapore's education system is considered one of the best in the world, with high-quality education & highly qualified teachers.
Thailand	Education in Thailand has a relatively good quality, but still faces many challenges that need to be addressed.
Vietnam	Education in Vietnam is undergoing development, and many reforms have been implemented to enhance quality of education, however, there are still many challenges that need to be addressed.

and teachers. Organizing experiential learning activities in STEM-oriented education helps develop scientific skills, ignite passion for exploring real-world problems, and create products that solve students' problems. Professional development needs to be emphasized in STEM thinking and awareness of STEM careers. This provides favorable conditions for "realizing STEM education for sustainable development goals" in Vietnam (Khuyen, 2020).

However, many efforts have been made to improve the quality of STEM teaching in Southeast Asia. Governments and non-governmental organizations have invested in projects and teacher training programs to improve the quality of STEM teaching. In addition, schools, organizations, and businesses are working together to incorporate STEM education to create a smarter and more creative generation of students for the future.

BIBLIOMETRICS OF SCIENTIFIC PUBLICATIONS IN DATABASES

Bibliometrics is a quantitative method of analyzing information on trends, relationships, and effectiveness of scientific documents. It uses data and statistics to analyze and evaluate publications in databases such as Web of Science, Scopus, Google Scholar, and other databases (Chellappandi & Vijayakumar, 2018). Some key contents of Bibliometrics analysis include (Waltman et al., 2010).

1. **Number of articles:** Number of articles, books, reports, scientific information published in a certain period of time, usually a year.
2. **Author index:** This index measures the influence of an author based on the quantity and quality of their published articles.
3. **Journal index:** This index measures the influence of a journal based on the quantity and quality of articles published in that journal/book.
4. **Citation index:** This index measures the number of times articles are cited in other articles. Citation index is also used to evaluate the impact of an author or a journal/book.
5. **Hirsch index:** Hirsch index (also known as the h-index) measures the influence of an author based on the number of their articles and the number of citations per article/publication.

Bibliometrics provides researchers, managers, and other organizations a way to evaluate and compare scientific documents, authors, and journals within the same field. It also helps researchers and organizations to identify and develop new research topics (Ha et al., 2020). General bibliometric analysis methods include (Waltman et al., 2010):

1. **Counting the number of documents:** This method simply counts the number of documents in a specific directory. This method shows the development of the field during a certain period of time.
2. **Evaluating the quality of documents:** This method evaluates the quality of documents using indices such as impact factor, Eigenfactor score, or SCImago journal rank. These indices help to evaluate the influence of the documents in the research field.
3. **Analyzing authors and research collaboration:** This method analyzes authors and research collaborations in a research field. Indices such as authorship index, collaboration index, and top-author index are used to evaluate the relationships among authors and the research community.
4. **Analyzing keywords:** This method analyzes the keywords in the documents to evaluate popular research topics in the field. Indices such as key phrase index and subject index are used to evaluate the most commonly used keywords in the research field.

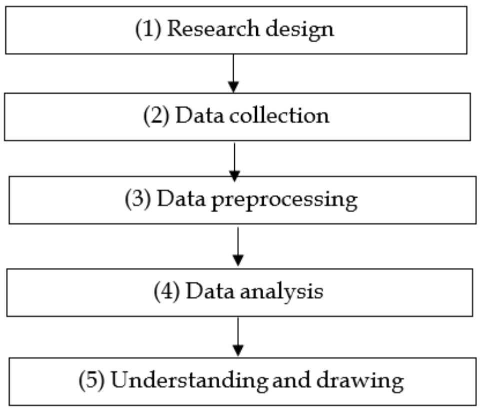

Figure 1. General process of bibliometric analysis (Pham-Duc et al., 2020)

5. **Analyzing citations:** This method analyzes the quantity and types of citations used in the documents. Indices such as average citation count, citation rate index, and citation impact index are used to evaluate the influence of the documents in the research field.

The general process of bibliometric analysis of documents usually includes the steps, as shown in **Figure 1** (Pham-Duc et al., 2020).

1. **Step 1:** Research design, which includes determining the objectives of Bibliometrics analysis, such as evaluating the development of a research field or assessing the effectiveness of a specific research program. In addition, the research scope needs to be determined, including the time frame, research field, and research database.
2. **Step 2:** Data collection, which involves the first process of collecting data for analysis. Data can be collected from databases such as Web of Science, Scopus, or Google Scholar. These data may include information on documents, authors, citations, and keywords.
3. **Step 3:** Data preprocessing, which is necessary to ensure the accuracy and completeness of the data before analysis. This includes removing duplicate records, correcting errors, and converting data formats.
4. **Step 4:** Data analysis, which involves using Bibliometrics methods to analyze the data after preprocessing. These methods may include counting the number of documents, evaluating the quality of documents, analyzing authors and research collaborations, analyzing keywords, and analyzing citations.
5. **Step 5:** Understanding and drawing conclusions, where it is necessary to understand and draw conclusions from the Bibliometrics analysis results. The results of Bibliometrics analysis can help evaluate the effectiveness of research programs, assess the development of a research field, and make proposals for future research directions.

There are various software tools available for bibliometric analysis, some of which are commonly used, including Bibexcel, Biblioshiny, BiblioMaps, CiteSpace, CitNetExplorer, SciMAT, Sci2 Too, VOSviewer, among others (Moral-Muñoz et al., 2020).

1. **VOSviewer** is a free and user-friendly software for document and citation analysis. It allows users to generate keyword maps and networks of documents and authors.
2. **CiteSpace** is a free software for document and citation analysis that provides features such as keyword analysis, network analysis, topic analysis, and dynamic analysis.
3. **Bibliometrix** is a free R software used for document and citation analysis. It provides features such as productivity analysis, author and collaboration analysis, keyword analysis, and citation analysis.
4. **SciMAT** is a free software for document and citation analysis that provides features such as author and collaboration analysis, keyword analysis, and network analysis.
5. **Microsoft Excel** and **SPSS** are popular statistical software used for bibliometric data analysis. They can be used to calculate indices such as document index, citation index, and author index.

Bibliometric analysis is an important quantitative method for evaluating research effectiveness, identifying research trends, detecting links and interactions in research, and evaluating research culture. Bibliometric analysis is a crucial method in scientific research and has many benefits and advantages, including (Bales et al., 2020).

Measuring research effectiveness: Bibliometric analysis provides quantitative indicators for evaluating the effectiveness of research, including the number of articles, citations, author indices, document indices, h-index. These indicators help researchers assess the impact of their research work.

Identifying research trends: Bibliometric analysis allows researchers to identify research trends in their field, including popular topics, famous authors, and reputable journals.

Discovering connections and interactions in research: Bibliometric analysis provides tools to discover connections and interactions between authors, documents, and research fields. This helps researchers understand the structure and relationships between documents and authors in their research field.

Evaluating research culture: Bibliometric analysis provides indicators for evaluating the research culture in one's field, including the number of articles, citations, author indices, document indices, h-index.

RESEARCH METHODOLOGY

Using secondary data extracted from the Scopus database through publications on journals, books, conference proceedings on STEM education in primary schools in Southeast Asian countries. The data mining was conducted in March 2023 to extract and clean published data on STEM education in primary schools over a period of 22 years (from 2000 to 2022). The command for data mining is, as follows: (*stem* AND *"elementary school"*) AND PUBYEAR>*1999* AND PUBYEAR<*2023* AND (LIMIT-TO (LANGUAGE, *"English"*)) AND (LIMIT-TO (EXACTKEYWORD, *"STEM"*) OR LIMIT-TO (EXACTKEYWORD, *"STEM education"*) OR LIMIT-TO (EXACTKEYWORD, *"STEM (Science, Technology, Engineering, and Mathematics)"*) OR LIMIT-TO (EXACTKEYWORD, *"elementary school Students"*) OR LIMIT-TO (EXACTKEYWORD, *"Southeast Asia"*)).

The data collection process was conducted in five stages, as follows:

1. **Stage 1–Raw data collection:** Using the first command, a total of 787 publications related to keywords in the command were collected, including publications in books, book chapters, scientific articles, and conference reports.
2. **Stage 2–Data cleaning:** The study utilized a literature review method to read the abstracts or full text of the 787 publications from the raw data to filter out irrelevant data containing one or more related keywords (e.g., works that did not include at least three types of STEM education, primary schools, or Southeast Asian keywords), as well as duplicate and misspelled directories, and broad-meaning words were removed.
3. **Stage 3–Data extraction:** After filtering the data, the organized data extraction consisted of 490 research papers on STEM education in primary schools in Southeast Asian countries that had been standardized, including all relevant information about the published work, such as author name, publication title, publisher name (or journal name), publishing country, citation index, etc.
4. **Stage 4–Data visualization:** VOSviewer software (www.vosviewer.com) and Bibioshiny (using the packages "bibliometrix" of the Rstudio software to install) were used to analyze and graph the data obtained on the publication network, collaboration network between researchers, participating organizations, key and emerging keywords in STEM education research in Southeast Asian countries.
5. **Stage 5–Interpretation of results:** After data visualization the study analyzed tables and graphs extracted from the VOSviewer and Bibioshiny software to find research results on STEM education publications in Southeast Asian countries.

Table 2. General information on STEM education research publications in countries belonging to Southeast Asia

Description	Results
Main information about data	
Timespan	2008:2022
Sources (journals, books, etc.)	228
Documents	490
Annual growth rate (%)	34.59
Document average age	4.18
Average citations per document	12.78
References	22,069
Document contents	
Keywords plus	1,562
Author's keywords	1,062
Authors	
Authors	1,567
Authors of single-authored documents	46
Authors collaboration	
Single-authored documents	46
Co-authors per document	3.57
International co-authorships (%)	12.24
Document types	
Article	257
Book chapter	8
Conference paper	192
Review	17

Note. Source: Analysis by authors using Biblioshiny tool

RESEARCH FINDINGS & DISCUSSION

General Information on STEM Education Research Publications in Southeast Asia

The general information on the collection of STEM education research publications in countries belonging to Southeast Asia is presented in **Table 2**.

Table 2 shows that a total of 490 publications related to STEM education in primary schools in Southeast Asian countries were published from 228 different sources indexed in the Scopus database. Data analysis shows that although the data was collected from 2000 to 2022, publications on this field in Southeast Asian countries only began from 2008 to 2022, indicating that Southeast Asian countries started their STEM approach 20 years later than the USA (Gonzalez & Kuenzi, 2014) but in line with the context of STEM implementation in Asian countries (Yan et al., 2020). Of 490 publications published in 15-year period (2008-2022), original articles accounted for 52.44% with 352 documents, book chapters accounted for 1.63% with eight chapters, and no books were published on STEM education in primary schools in Southeast Asian countries; there were 192 scientific conference papers on STEM (39.20%) (**Figure 2**).

There were 1,567 authors appearing in 490 published works of which only 46 authors were listed alone on a

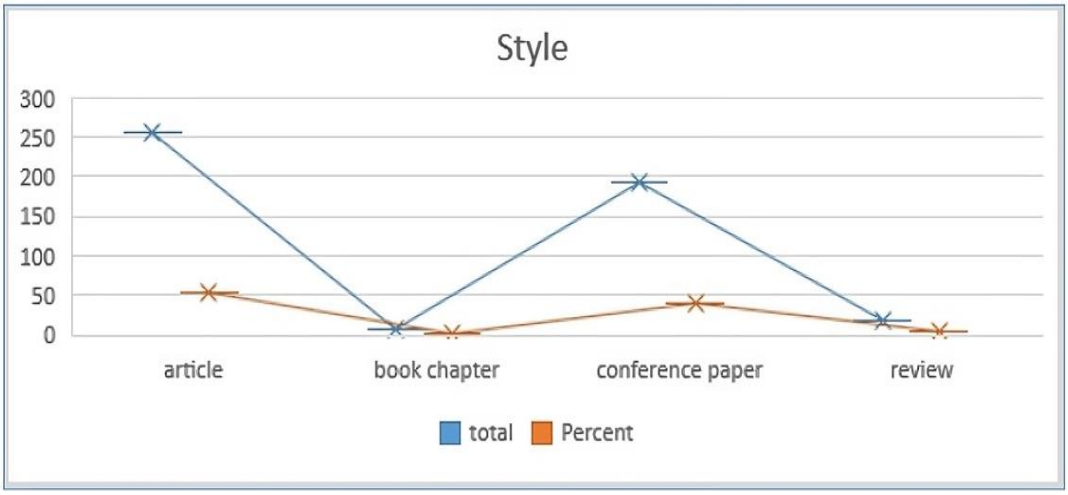

Figure 2. Types of published STEM education materials in primary schools across Southeast Asian countries during period of 2000-2022 (Source: Authors' own elaboration, conducted on Bibioshiny software)

publication (accounting for 9.38%). As of the end of 2022, each publication received an average of 12.78 citations.

On average, each document in the dataset had 3.57% co-authors. These results indicate that the network of STEM education researchers in primary schools in Southeast Asian countries has a lower proportion compared to the world (Gil-Doménech et al., 2020). Specifically, no book on this issue in Southeast Asia has been published in the Scopus database, despite the fact that there have been many conferences discussing STEM education in primary schools in Southeast Asian countries (the proportion of conference papers accounting for more than 1/3 of the publications). This is consistent with the context of unequal education and difficulties in teacher capacity and infrastructure in Southeast Asia, as analyzed in the overview section. This is the reason why STEM education in primary schools in Southeast Asian countries is approaching the issue almost 20 years later than the world, and publications on this issue are still very limited.

Contribution of Countries to STEM Education Research in Primary Schools in Southeast Asian Countries

The data analysis from VOSviewer software revealed that a total of 34 countries (or territories) participated in publishing works related to STEM education in primary schools in Southeast Asian countries (as shown in **Table 3**).

The USA had the highest number of publications with 236 works (accounting for 48.16% of the total publications) and also had the highest total citation count (4,625 citations). This is consistent with the reality of STEM education development worldwide, as the USA was the first country to introduce STEM into primary school education in the early 1990s and has been actively promoting STEM education in countries around the world, particularly in developing countries, including

Table 3. Countries with publications on STEM education in primary schools in Southeast Asian countries

Country	Documents	Citations	TLS
United States	236	4,625	26
Indonesia	59	268	17
Turkey	28	199	4
Australia	18	195	4
Taiwan	18	53	5
Malaysia	17	131	6
Spain	15	140	5
China	12	70	8
Thailand	8	11	3
United Kingdom	8	82	3
Germany	7	60	4
Hong Kong	7	77	5
Japan	7	46	3
South Korea	7	37	4
Canada	6	98	3
Hungary	6	52	8
South Africa	6	25	4
Finland	5	28	5
Greece	5	24	1
Brazil	4	10	2
Croatia	4	35	4
Israel	4	24	0
Singapore	4	85	5
Sweden	4	14	3
Austria	3	21	2
Belgium	3	22	2
Chile	3	12	1
France	3	25	6
Ireland	3	21	2
Italy	3	35	0
Mexico	3	6	0
Netherlands	3	116	2
Norway	3	81	2
Russian Federation	3	1	1

Note. TLS: Total link strength & Source: Analysis by authors using VOSviewer tool

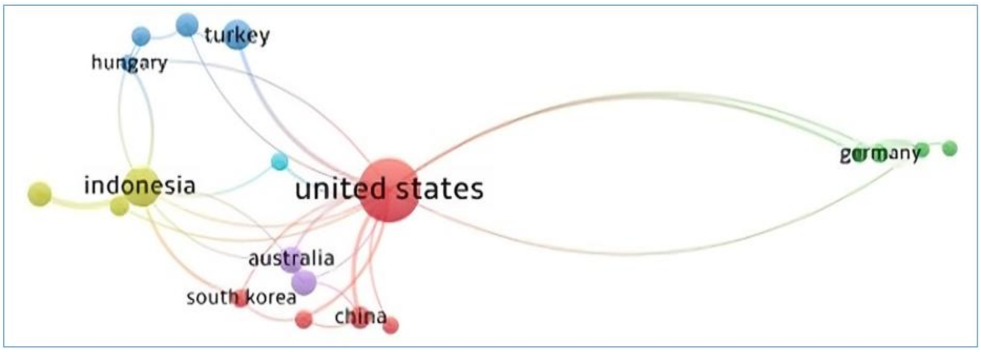

Figure 3. Diagram representing number of publications & collaboration among countries (Source: Authors' own elaboration, using VOSviewer software)

Southeast Asian countries. This finding is also similar to the results of previous analyses by researchers on STEM education in Southeast Asia (Ha et al., 2020). Indonesia ranked second in terms of the country with the most publications in this field, with 59 publications (12.04% of the total) and a total of 268 citations.

This analysis shows that Indonesia is actively promoting STEM education in schools, although it is not the country with the most developed education system or the best infrastructure for STEM education. This result is due to the Indonesian government's recognition of STEM education as one of the directions for innovation in primary education, which is consistent with the publication by Farwati et al. (2021) when studying STEM education in Indonesia. Therefore, the results show that Indonesia is the leading country in Southeast Asia and Asia in terms of STEM education publications in primary schools in Southeast Asian countries. Among the top-5 countries with the most publications in this field, there are three other countries, Turkey (ranked third with 28 publications, accounting for 5.70%), and two countries with the same number of publications, 18 works each (accounting for 3.67%), including Australia and Taiwan. However, the number of citations for publications from Taiwan is relatively modest (a total of 53 citations), only about one-fourth of the citation count of Turkey (199 citations) and Australia (195 citations). This study is consistent with the international context, as these three countries have been interested in implementing STEM education since the early 2000s (Penprase, 2020; Yilmaz et al., 2018; Zhou & Li, 2021). Therefore, promoting STEM education in primary schools in Southeast Asian countries is also consistent with this trend.

In addition to Indonesia, in Southeast Asia, Malaysia ranks 6th (with 17 publications and 131 citations) and Thailand ranks 9th (with eight publications and 11 citations) among the top-10 countries with the most publications in STEM education in primary schools in Southeast Asian countries. This demonstrates that the implementation of STEM education in primary schools in Southeast Asian countries is unevenly distributed, with varying levels of interest and difficulties in implementation and research.

Collaborative Network of Scientists from Countries on STEM Education at Primary Schools in Southeast Asian Countries

VOSviewer software was also used to analyze the collaboration network among scientists from countries on STEM education at primary schools in Southeast Asian countries, as shown in **Figure 3**. Each country is represented by one node and illustrated in different colors, and the collaboration between countries is represented by the connecting lines between two nodes. The larger the node, the more publications are represented. Due to the disparate distribution of publications among the 34 countries, only a few countries with a large number of publications are shown in **Figure 3**. Countries with fewer than 10 publications are difficult to identify on the graph due to their small node size.

On **Figure 3**, it is shown that the nodes and lines are encoded in different colors, the red nodes and lines represent the collaboration between the USA, South Korea, and Hong Kong, China, which are the countries with strong cooperation in this research direction. The scientists in these countries collaborate to research STEM education in elementary schools in Southeast Asian countries. The second blue group is the collaboration between Hungary, Turkey, and Spain. A group of purely Southeast Asian countries collaborating with each other is represented in light yellow, including Indonesia, Malaysia, and Thailand. The fourth strong collaboration group is represented in green and includes Germany, Finland, and Greece. There are also some other groups, but because the number of collaborative publications is too small, they are difficult to display on the figure due to the very small connecting lines.

Through the analysis, it is shown that STEM education in primary schools in Southeast Asian countries is of global concern and is being researched collaboratively. The strongest research collaboration is still between the USA and Asian countries.

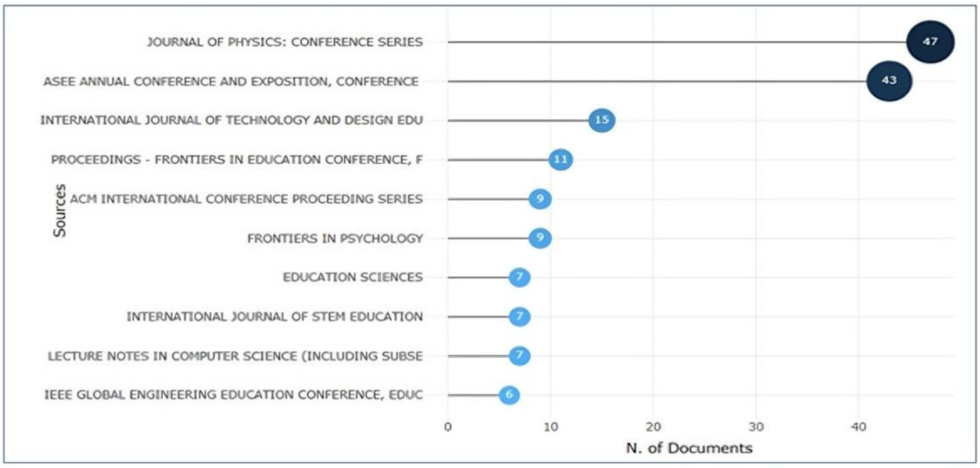

Figure 4. Top-10 organizations with highest contributions to research on STEM education in primary schools in Southeast Asian countries (Source: Authors' own elaboration, conducted on Bibioshiny software)

Contributions of Journals & Publishers in Publications on STEM Education in Primary Schools in Southeast Asian Countries

The results of the analysis using Bibioshiny software with 490 publications extracted showed that they were published by 228 organizations (journals, publishers, conferences, etc.). The participating organizations are reputable organizations to ensure that the publications are indexed in the Scopus database. Among the 228 organizations that contributed to publications in this field, there is a list of the top-10 organizations that have the most effective contributions and publish the most in this research field, as shown in **Figure 4**.

The Journal of Physics: Conference Series is the highest ranked journal with 47 publications in 22 years (2000-2022) (accounting for 9.60%)–this journal typically publishes papers from STEM conferences worldwide, making it an appropriate leader among organizations contributing to this research field. Similarly, the ASEE Annual Conference and Exposition, Conference Proceedings is also one of the journals that often publishes papers from conferences, making it the second-ranked organization with 43 publications. Two organizations had more than 10 publications in 22 years, which are the International Journal of Technology and Design Education (with 15 publications) and Proceedings–Frontiers in Education Conference, FIE (with 11 publications). All remaining 224 organizations published less than 10 publications over 22 years, which is a relatively modest number compared to other fields worldwide. This indicates that research in STEM education in primary schools in Southeast Asian countries has not yet been fully developed and invested in. This is consistent with the current educational context in Southeast Asia, where the economic and social conditions and income levels of some countries are still low, and infrastructure in certain regions, particularly in ethnic areas, has yet to meet the demands of implementing STEM education (Manalastas et al., 2017).

Contribution of Authors in STEM Education Research in Primary Schools in Southeast Asian Countries

Contributions of authors in STEM education research in primary schools in Southeast Asian countries are presented in **Table 4**, with 35 authors having a productivity of three or more publications in this field.

Table 4. List of top-35 contributing authors in STEM education publications in primary schools in Southeast Asian countries

No	Author	Documents	Citations
1	Yildirim, B.	6	10
2	Hamdu, G.	5	2
3	Adnan, M.	4	27
4	Capraro, M. M.	4	249
5	Capraro, R. M.	4	24
6	Chiang, F.-K.	4	17
7	Grandgenett, N.	4	11
8	Guzey, S. S.	4	40
9	Karlimah, K.	4	5
10	Kist, A. A.	4	33
11	Lidinillah, D. A. M.	4	5
12	Quek, F.	4	78
13	Tillinghast, R. C.	4	24
14	Ahmad, C. N. C.	3	9
15	Barroso, L. R.	3	21
16	Boeve-de Pauw, J.	3	22
17	Bottomley, L.	3	8
18	Burušić, J.	3	32
19	Chen, K.	3	73
20	Chu, S. L.	3	77
21	Firdaus, A. R.	3	7
22	Jeon, M.	3	21
23	Kuttolamadom, M.	3	9
24	Maiti, A.	3	19
25	Mansouri, M.	3	16
26	Master, A.	3	189
27	Maxwell, A. D.	3	19
28	Moore, T. J.	3	40
29	Orwin, l.	3	19
30	Rahayu, G. D. S.	3	7

Note. Source: Authors conducted on VOSviewer software

Table 4 (continued). List of top-35 contributing authors in STEM education publications in primary schools in Southeast Asian countries

No	Author	Documents	Citations
31	Ring-Whalen, E. A.	3	60
32	Roehrig, G. H.	3	60
33	Wang, J.	3	19
34	Wang, M.-T.	3	922
35	Wieselmann, J. R.	3	38

Note. Source: Authors conducted on VOSviewer software

Bekir Yildirim (Mus Alparslan University, Mus, Turkey) tops the list with six publications and a total of 10 citations. Ghullam Hamdu (Universitas Pendidikan Indonesia) is the second most contributing author to this research area, with five publications and a modest two citations. Meanwhile, Ming-Te Wang (University of Pittsburgh, Pittsburgh, PA, USA) ranks fourth with three publications, but has a citation count nearly 10 times higher than the first and second-ranking authors combined, with a total of 922 citations. Jessica L. Degol (University of Pittsburgh, Pittsburgh, PA, USA) is a co-author with Ming-Te Wang on some publications and has a total of two publications in this field, but with a total citation count of 490. The remaining authors also published three-four papers with citation counts of no more than 250.

The authors interested in this research direction mainly published their works recently (from 2015 to present), with very few publications in 2015. **Figure 5** illustrates the publication time of the works of the top-10 scientists with the highest number of publications among the 490 extracted works.

The analysis in **Figure 5** reveals that although STEM education in primary schools in Southeast Asian countries began to gain attention in 2008, the majority of publications were concentrated from 2015 onwards. This is consistent with the context of education in Southeast Asia, where there was a need for a new education model, particularly STEM education in primary schools. However, the success of STEM education is dependent on various factors, including teacher capacity, STEM instructional materials, school infrastructure and student conditions, societal context, geographical location, among others. Therefore, it took nearly 10 years for STEM education to penetrate into primary education in Southeast Asian countries.

In addition, among the 1,567 authors of the 490 extracted publications, the network of cooperation between co-authors is displayed in **Figure 6**.

Each node represents an author, and the size of the node indicates the number of publications, where a larger node represents a higher number of publications. The cooperation between authors is indicated by the lines connecting nodes. A node with many connections represents an author who has collaborated with many other authors in the research and publication process of this field.

Figure 6 shows that there are 10 groups of co-authors, with the largest group consisting of six people, and the group with the least number of co-authors having two people. These research groups are relatively independent of each other and there is no connection between them.

In the co-authorship network, there are several authors who act as corresponding authors in the process of collaboration and publication of papers, which is shown in **Figure 7**.

Figure 7 shows that authors from the USA played the role of corresponding authors with the highest proportion, followed by authors from China, Indonesia, and Turkey in the second and third positions of research orientation on STEM education in elementary schools across Southeast Asian countries.

An analysis of keywords used in publications on STEM education in elementary schools across Southeast Asian countries was conducted. Co-occurrence keyword analysis was used to extract the keywords used in publications retrieved from the Scopus database on STEM education in elementary schools across Southeast Asian countries, to determine the main keywords, related keywords, and group of emerging keywords in this research direction. The results obtained the main

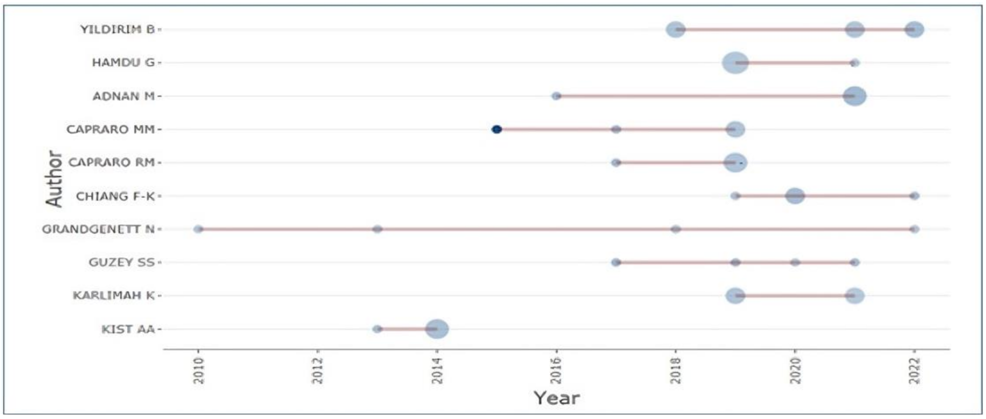

Figure 5. Timeline graph of authors publishing STEM education papers in primary schools across Southeast Asian countries (Source: Authors' own elaboration, conducted with Biblioshiny software)

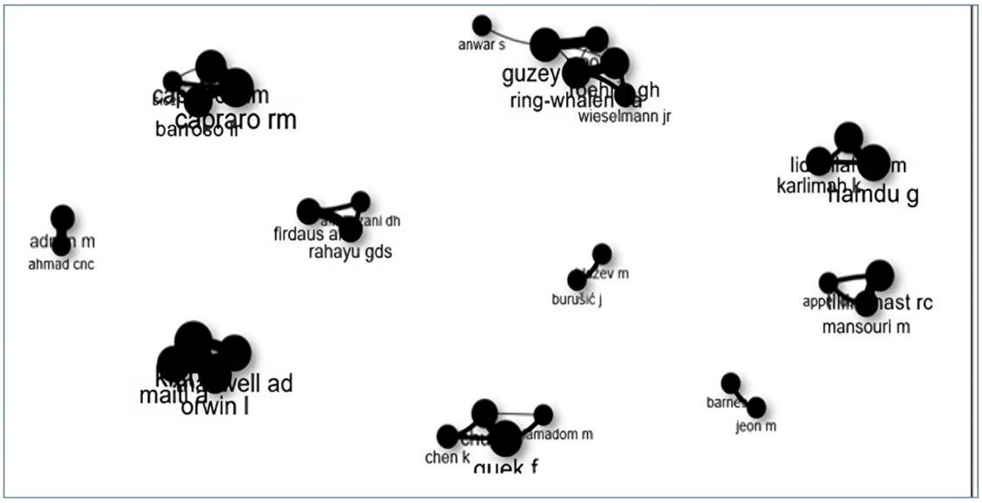

Figure 6. Co-authorship network of researchers collaborating & publishing on STEM education in primary schools across Southeast Asian countries (Source: Authors' own elaboration, conducted with Biblioshiny software)

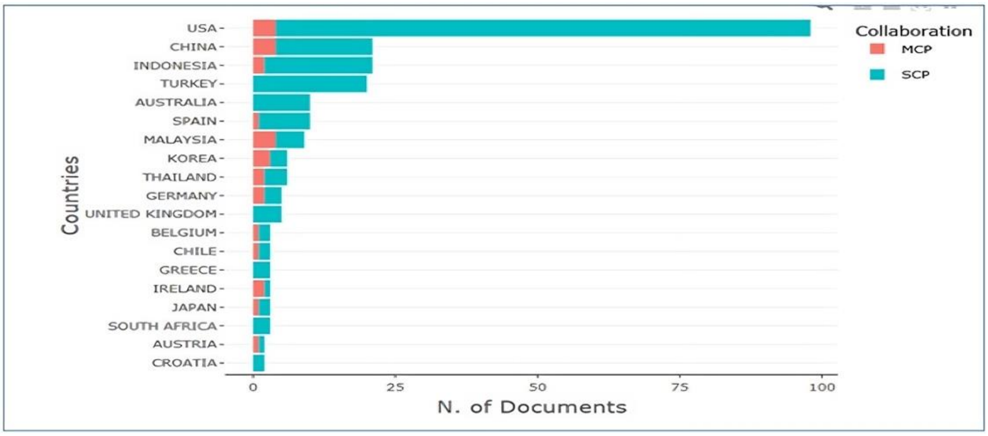

Figure 7. Collaborative authorship network & publication on STEM education in elementary schools across Southeast Asian countries (Source: Authors' own elaboration, conducted with Biblioshiny software)

clusters of keywords in this research direction include STEM, STEM education; stem (science, technology, engineering, and mathematics); elementary schools; students. The top-10 most frequently used keywords in these research directions are presented in **Table 5**.

In addition to the top-10 most used keywords, there are also related keywords in the research direction of STEM education in elementary schools in Southeast Asian countries, as shown in **Figure 8**.

Each node in **Figure 8** represents a keyword, and the thickness of the lines between nodes indicates the strength of the relationship between keywords, determined by their co-occurrence in 490 published papers extracted from the Scopus database.

The word cloud shows the most frequently used keywords in publications related to STEM education at primary schools in Southeast Asian countries analyzed by the Biblioshiny software, and the results are presented in **Figure 9**.

In **Figure 9**, there are also some emerging keywords that are frequently used in these publications, such as engineering education, curricula education, education computing. These are new and emerging keywords that reflect the development of STEM education in the future, meeting the needs of the development of science and technology in the 4th industrial revolution.

Table 5. List of top-10 keywords frequently used in publications

No	Keyword	n	TLS
1	STEM	298	930
2	STEM (science, technology, engineering, and mathematics)	227	1,363
3	Students	177	1,166
4	Engineering education	121	853
5	Elementary schools	80	499
6	Teaching	74	512
7	Curricula	61	434
8	Education	59	412
9	STEM education	52	338
10	Science, technology, engineering, and mathematics	46	331

Note. TLS: Total link strength; n: Number of occurrences; & Source: Authors analyzed on VOSviewer software

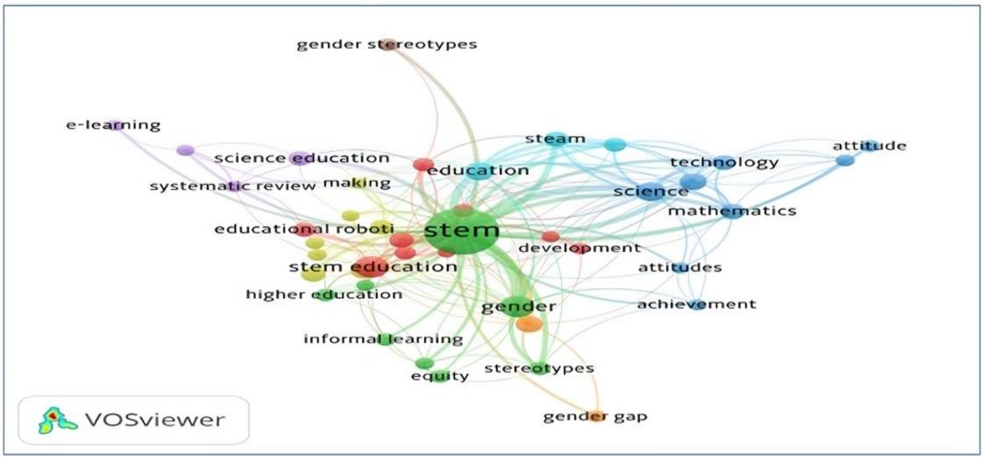

Figure 8. Most popular keywords in STEM education research at primary schools in Southeast Asian countries (Source: Authors' own elaboration, using VOSviewer software)

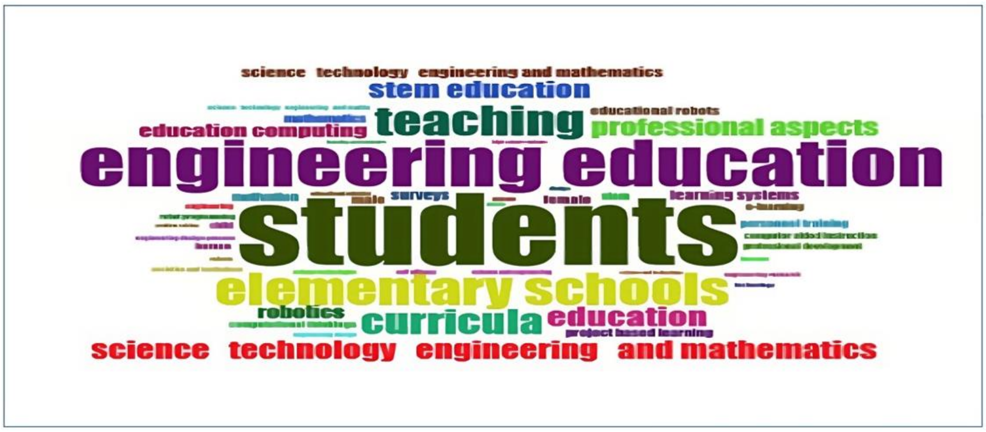

Figure 9. Keyword cloud (Source: Authors' own elaboration, conducted with Biblioshiny software)

DISCUSSION

The analysis of the distribution of STEM education literature in the Scopus database reveals a picture of STEM education at the primary level in Southeast Asian countries. STEM education was introduced in Southeast Asia in 2008, approximately 20 years later than in the rest of the world (Gonzalez & Kuenzi, 2014). The delayed implementation of STEM education in Southeast Asia compared to the USA and European countries is primarily attributed to the slower development of the educational context in the region (Yan et al., 2020).

The analysis results indicate that despite the later initiation and development of STEM education in Southeast Asia, global researchers have shown interest in the subject. Over the span of 15 years (2028-2022), there have been 490 articles, book chapters, and conference reports related to STEM education published in the Scopus database. Notably, 39.20% of these reports are conference proceedings indexed in the Scopus database. The research also reveals that 34 countries have contributed to studies on STEM education at the primary level in Southeast Asia, reflecting global interest in STEM education for the region as a whole and primary education in particular. Among these, the USA is the leading country in researching STEM education at the primary level in Southeast Asia, followed by Indonesia, Turkey, Australia, and Taiwan. This finding aligns with Farwati et al.'s (2021) research on STEM education in Indonesia.

Additionally, the study identifies a collaborative network among global researchers in the field of STEM education research at the primary level in Southeast Asia. The strongest collaborations involve researchers from the USA, South Korea, Hong Kong, China, followed by researchers from Hungary, Turkey, Spain, Indonesia, Malaysia, and Thailand. This information serves as a foundation for researchers worldwide, publishers, and journals to establish contact with these researchers for collaborative research and publications on relevant topics.

The study reveals that there are scientific journals publishing extensively on STEM education at the primary level in Southeast Asia. Journals such as The Journal of Physics, which specializes in publishing reports in STEM education science conference proceedings, the ASEE Annual Conference and Exposition, Conference Proceedings, International Journal of Technology and Design Education, are prominent in publishing research related to STEM education. This discovery aids researchers in finding reference materials on STEM education from journals and in disseminating their own research on STEM education.

Furthermore, the research results indicate the most cited publications in this research field. This information helps scientists identify valuable and scientifically relevant publications for reference and citation in their individual research projects. Additionally, the identification of new keywords, main keywords, and sub-keywords such as engineering education, curricula education, education computing in the published works assists researchers in exploring and innovating new research topics in STEM education to develop their own research directions.

CONCLUSIONS

Southeast Asia is a region of developing countries with diverse geographical locations, topography, population, and natural resources, resulting in significant differences among the countries. The economic conditions of each country are also different and vary greatly, with some countries having top-ranked education systems globally, while others still have many limitations and are not yet internationally integrated in education. STEM education is a comprehensive education model that has been implemented in schools from elementary level and has gained global attention. Southeast Asian countries have also implemented STEM education in elementary schools, but there are still many issues such as teachers' ability to implement STEM education, uniform infrastructure, and socio-economic conditions that make many countries struggle in implementing STEM education in primary schools.

Research on STEM education in elementary schools in Southeast Asian countries has attracted the attention of researchers worldwide, with 490 publications in the form of scientific articles, book chapters, conference reports, and review articles published in the Scopus database. Data analysis shows that the USA has the highest number of publications and the most affiliated authors. In Southeast Asia, Indonesia, Malaysia, and Thailand are among the top-10 countries with the most publications, along with the USA, Turkey, Taiwan, and Australia. The research has identified 10 key keywords and emerging keywords related to the research direction, which will help scientists discover new research results on STEM education in elementary schools in Southeast Asian countries.

Therefore, to effectively implement STEM education at the primary level in Southeast Asian countries, it is essential for the countries in the Southeast Asian region to invest in infrastructure and facilities. They should also provide training to enhance the teaching capabilities of STEM educators. Additionally, these countries need to develop specific policies for STEM education during the primary school teaching process.

Scientists in Southeast Asian countries, as well as worldwide, can use the analysis results from this study to pursue research directions related to STEM education at the primary level in Southeast Asian countries. This can contribute to improving the quality of teaching with a focus on developing students' competencies.

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Ethical statement: The authors stated that ethical permission was not required for the study. The study does not include humans and animal subjects. The highest ethical guidelines were followed throughout the study.

Declaration of interest: No conflict of interest is declared by the authors.

Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author.

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