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International Scientific Collaboration and Research Topics on STEM Education: A Systematic Review

Eka Kurniati [1], Hadi Suwono [1*], Ibrohim Ibrohim [1], Ahmad Suryadi [2], Muhammad Saefi [3]

[1] Department of Biology, Universitas Negeri Malang, Malang, INDONESIA
[2] Department of Physics, Universitas Islam Negeri Syarif Hidayatullah Jakarta, INDONESIA
[3] Department of Biology, Universitas Islam Negeri Maulana Malik Ibrahim Malang, INDONESIA

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Abstract

Science, technology, engineering, and mathematics (STEM) education has recently emerged as a mainstream way for the global education community to address global crisis issues. This systematic review provides an in-depth overview of international STEM researcher collaborations and trends in STEM education's most recent research topics. We examined 49 peer-reviewed articles selected from 244 articles published in three reputable international journals from January 2014 to December 2018. We used inclusion criteria, percent agreement, and Cohen's kappa coefficient to reduce research bias. There is an urgent desire to understand why STEM education research trends increase significantly each year. Goals, policies, curriculum, and assessment continue to dominate research topics. Our findings highlight the essential points in implementing STEM education that can be used as a base for future planning. Researchers and stakeholders can use several aspects of the findings to understand how effective carefully preparing school interventions can be. However, it appears that international collaboration among STEM researchers is still minimal. Cross-country and cross-cultural research collaboration should be promoted to play an essential role in maximizing STEM research and dissemination.

Keywords: STEM education, scientific collaboration, STEM topics

INTRODUCTION

Many global challenges (e.g., resource destruction, food production, health, biodiversity damage, and green energy exploration) require advanced science and technology development. Here, many education institutions and policymakers worldwide are pushing for STEM competency improvement to fulfil the demand for today's and the future's STEM workforces. Thus, STEM has become a particular concern to ministries of education worldwide (Lee et al., 2019).

Some empirical studies have shown that STEM education positively influences the improvement of education quality. Students can gain valuable interdisciplinary skills and knowledge to solve real-life engineering or technology problems through STEM education (Fan et al., 2020). Students can also make scientific justifications about the designs they make (English & King, 2019). STEM education contributes to students' attitudes and learning outcomes (Guzey et al., 2016) and improves STEM literacy (Falloon et al., 2020), student creativity (Ozkan & Umdu, 2021), problem-solving skills (Jamaludin & Hung, 2017), and readiness for future career choices (Moore & Smith, 2014).

The application of STEM education does not appear to be as simple as its acronym (science, technology, engineering, and mathematics); in fact, the critical points of its construction are frequently thought about very differently (Tawbush et al., 2020). Some reports have shown a gap between the number of graduates and the workforce's needs in STEM fields (Vulperhorst et al., 2018). This can certainly be a threat to a country's economic growth and development. Therefore, early anticipation is needed to establish and maintain global economic security and stability. Wong et al. (2016) explain a debate among stakeholders about whether

✉ eka.kurniati.1803418@students.um.ac.id ✉ hadi.suwono.fmipa@um.ac.id (*Correspondence) ✉ ibrohim.fmipa@um.ac.id
✉ ahmads@uinjkt.ac.id ✉ msaefi34@yahoo.com

Contribution to the literature

- This study examines trending topics that are developing in STEM education in all continent and highlights the possibility of collaboration between STEM scientists in the world.
- This systematic review has shown that STEM research increases significantly year by year, triggered by academics' interests and concerns in STEM education.
- This systematic review discovered that cross-country and cross-cultural research collaboration should be promoted to play an essential role in maximizing STEM research and dissemination.

STEM is a science agenda or a multidisciplinary agenda. Its implementation at the school level has become very diverse and poorly organized.

In line with various ongoing programs, STEM publications in several journals continue to increase. Between 2013 and 2017, STEM research trends began to emerge and develop (Lin et al., 2019). Like the bibliometric studies conducted by Ha et al. (2020), the trend of STEM research in Southeast Asia has also increased rapidly over the last three years, with Malaysia contributing the most out of the countries. According to data Li et al. (2020a) also showed that STEM publications have increased in Europe and the Americas over recent years.

The increasing publications about STEM education have attracted the attention of researchers who have conducted reviews on both general and specialized scopes (Kaleci & Korkmaz, 2018). Many studies reveal that maximizing STEM outcomes requires a combination of learning approaches, learning orientation, and duration of teaching (Wahono et al., 2020). New technology has been created to aid STEM learning (Ibáñez & Delgado-Kloos, 2018). Review research on the instructional practice of STEM education has shown that teachers face obstacles such as weak pedagogical skills, curriculum limitations, and difficulties in assessing students (Margot & Kettler, 2019; Thibaut et al., 2018).

The purpose of this systematic review of STEM education is to examine trending research topics and authors' nationality that are developing in STEM education in all continent of the world. Studying STEM research topics and trends worldwide will allow researchers to build more advanced STEM education and follow technological advances and local culture. This systematic review differs from existing STEM reviews in several ways. First, this review emphasized the possibility of international collaboration among STEM scientists, which differentiates it from reviews that focus on other STEM topics (Hasanah, 2020; Jayarajah et al., 2014; Li et al., 2019, 2020b). International collaboration research is essential for boosting the science dynamic (Fu et al., 2022; Matthews et al., 2020). This study can serve as a starting point for various educational institutions and stakeholders around the world to collaborate on developing or implementing STEM in the future. Second, this study is unique in that it compares the STEM implemented in some continental. America and Europe continents are closely focused on advancing STEM (Kayan-Fadlelmula et al., 2022; Li et al., 2020b). In global terms, Asia is far behind the other continent and risks being left behind. With this initial step, we wanted to discover how other continents that conceptualize and prioritize STEM education (Tawbush et al., 2020), such as America and Europe, implement STEM in order to inform research and practice in Asia, especially Southeast Asia. Third, this review covers publications from 2014 to 2018. This particular time span was chosen because, prior to the year 2014, publications on STEM education are limited. Finally, the review includes only research journal articles in three reputable journals indexed in the SSCI database and deemed suitable for the purposes of this research, namely Journal of Research in Science Teaching (JRST), International Journal of STEM Education (IJ-STEM), and International Journal of Science Education (IJSE).

METHODS

This research is a systematic review in which individual research reports are the subject of analysis (Cooper et al., 2009). The systematic review is helpful to summarize the latest knowledge on a particular topic with a systematic and transparent method of answering research questions.

Inclusion Criteria

Inclusion criteria are used in systematic reviews to reduce researcher bias (Zawacki-Richter et al., 2020). The following points are the inclusion criteria we used:

1. For this study, articles related to STEM research that were published in journals indexed in the SSCI database were selected. This SSCI database is chosen because they are known for including high impact factors. A series of systematic review studies (Lin et al., 2019; Tsai & Wen, 2005), have continuously documented researchers' interest in science education research on analyzing research publications in three main journals. The current study, which follows a similar research rationale to previous studies, intends to review in three main STEM education journals: JRST IF 4035 (coverage 1963-1967, 1969-2020) (Cite score: 7.2; SNIP: 3,231); IJ-STEM IF 1850 (coverage 2014-2020) (Cite score: 3.0; SNIP: 2058), and IJSE IF 1611

(coverage 1987-2020) (Cite score: 2.8; SNIP: 1,636) as per August 2020.

2. The articles published period is January 2014 to December 2018. Our reason for choosing this particular period is twofold. Publications on STEM education are limited to the year 2014. In addition, IJ-STEM also started its publication also in that year.
3. The articles are published in English.
4. The articles are research articles (i.e., quantitative, qualitative, and mixed-method).
5. The research articles on STEM integrate at least two disciplines.
6. The research setting in the articles is both formal and informal primary to secondary school.

Search Article, Selection, and Assessing Bias

We used keywords with Boolean logic, namely: "STEM EDUCATION" or INTEGRATED STEM" or "STEM INTEGRATION" or "STEM LEARNING" or "STEM INSTRUCTION," to search relevant articles in the three reviewed journals. We collected 244 articles published by the three journals, consisting of 49 articles published in JRST (coded JRST 1 to JRST 49), 51 articles published in IJSE (IJSE 1 to IJSE 51), and 144 articles published in IJ-STEM (IJ-STEM 1 to IJ-STEM 144). The code is given to each article to facilitate researchers to conduct in-depth screening.

We selected articles thoroughly through a screening process using the established inclusion criteria. Two independent raters selected all articles individually. The raters had previously agreed to these inclusion criteria to minimize different perceptions between raters. We measured the reliability of raters by the percent agreement and coefficient of Cohen's kappa. The percent agreement ranges from 0-100, while Cohen's kappa coefficient ranges from -1 to +1. We discussed to concede the judgement's raters or used a third rater to see whether there was a disagreement in deciding which article(s) should be accepted or excluded (Jahan et al., 2016). The percentage agreement between the two raters is 93.4%, and kappa's coefficient is 0.8 with a level in the substantial category, according to (Belur et al., 2018). The evaluation of articles in the screening process resulted in 49 articles that met the criteria and could, thus, be further analyzed. Figure 1 shows the screening process in more detail.

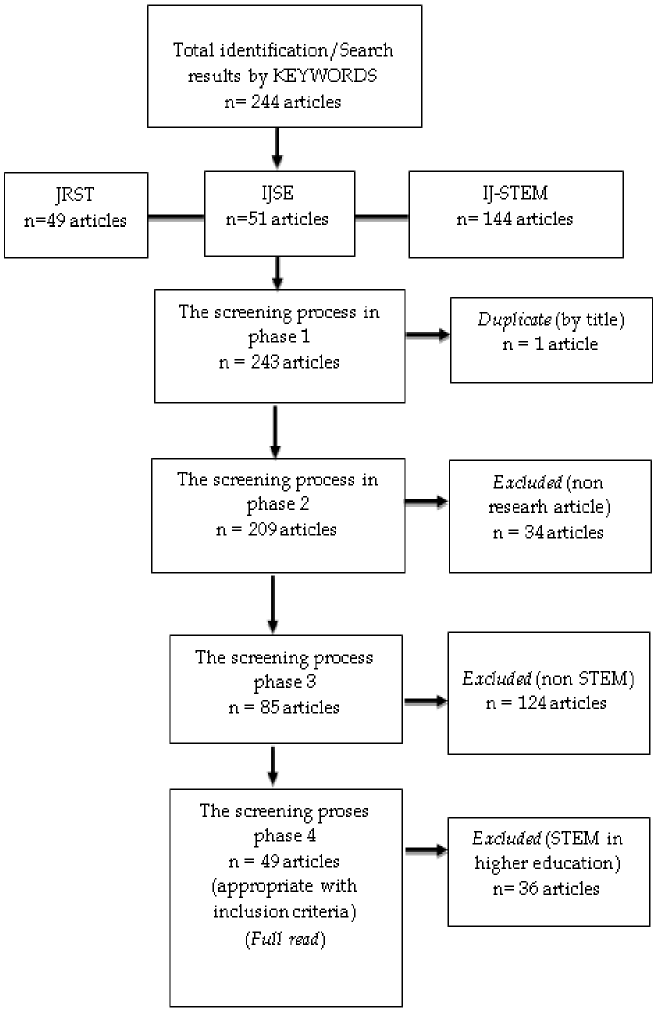

Figure 1. The step of systematic review

Data Analysis

We used the content analysis method in the process of reviewing articles. In this method, articles are classified based on year of publication, research methods, authors' nationality, international collaboration, and research topics. We used a formula developed by Howard et al. (1987) regarding the author's nationality. Author's nationality quantitatively identifies an author's contribution to an article, including articles with multiple authors. The author's nationality score shows the contribution of each author in a publication and can see which countries have most productively contributed to STEM development Howard et al.'s (1987) formula can be calculated:

$$Score = \frac{1.5^{n-i}}{\sum_{i=1}^{n} 1.5^{n-i}}$$

where n is the total number of authors and i is the order of every author. For example, in the paper published by Adamuti-Trache and Sweet (2014), the first author gained a score of 0.6 for USA. The second author from Canada contributed 0.4 to her country. The same method was applied to calculate the country scores for each paper.

We coded using research by Li et al. (2019) and Tsai and Wen (2005) to analyze STEM research topics further. The nine categories are teacher education; teaching; learning conception; learning context; goal, policy, curriculum, evaluation and assessment; cultural, social and gender issue; history, philosophy, epistemology, and nature of science; educational technology; and informal learning.

Table 1. Article distribution by year of publication

Journal	Year of publication					Total
	2014	2015	2016	2017	2018	
JRST	3	0	1	3	4	11
IJSE	1	3	5	2	5	16
IJ-STEM	1	3	2	9	7	22
Total	5	6	8	14	16	49

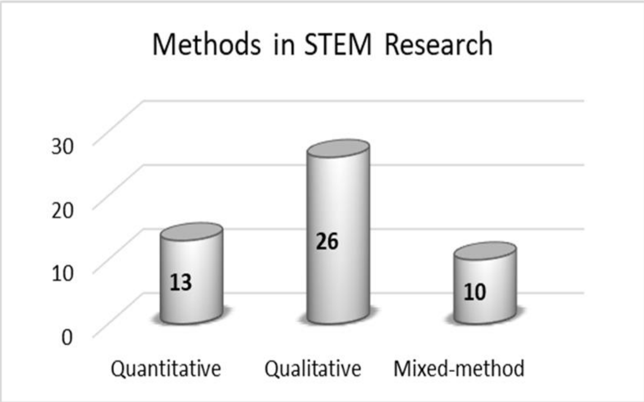

Figure 2. Distribution of articles by research method

RESULTS

Article Distribution by Year of Publication

The number of STEM education articles being published in the three journals increases from 2014 to 2018. Table 1 presents the 49 articles from the JRST, IJSE, and IJ-STEM by year.

From Table 1, we can see that STEM-related topics are increasingly attracting the attention of researchers as there is an increase in the number of publications each year. In 2014, the number of STEM publications was the lowest at 10% in the three journal databases. Also, its increase grew to 12% in 2015 with six articles, and in 2016 to 16% with eight articles. In 2017 it increased to 29% with 14 articles published and reached the highest percentage, 33%, in 2018 with 16 articles.

Research Approach

According to the research method used in the articles, the 49 articles were grouped into quantitative, qualitative, and mixed methods. The frequency distribution chart is presented in Figure 2.

The research methods in STEM education in the journals JRST, IJSE, and IJ-STEM predominantly use qualitative methods. Twenty-six out of 49 articles used qualitative methods with the distribution of five articles in IJSE, six articles in JRST, and 15 articles in IJ-STEM. 13 articles that used quantitative methods were distributed with five IJSE articles, four JRST, and four IJ-STEM. The remaining 10 articles use a mixed-method, with six published in IJSE, one in JRST, and three in IJ-STEM.

Table 2. Ranking of countries contributions from 2014 to 2018 publications in three journals

Rank	2014-2018 (N=49)		Rank	2014-2018 (N=49)	
	Country	Score		Country	Score
1	USA	36.19	8	Slovenia	1.00
2	Canada	2.72	9	Israel	0.68
3	Australia	2.40	10	India	0.60
4	Netherlands	1.79	11	Greece	0.16
5	UK	1.21	12	Iceland	0.12
6	Denmark	1.00	13	Lebanon	0.07
7	Croatia	1.00	14	China	0.05

Several different qualitative methods were found including case studies, phenomenology, document studies, narrative inquiry, and grounded theory. Meanwhile, the quantitative method most frequently used in STEM research is the conduction of surveys or questionnaires rather than the implementation of a learning intervention. Interviews, surveys, and study documents were used in the mixed-method studies.

Author's Nationality and International Collaboration

The author's nationality quantitatively identifies an author's contributions in an article, including articles with multiple authors. The author's nationality score shows each author's contribution in a publication and can be used to determine which countries are most productive in terms of STEM development (Medina-Jerez, 2018). Howard's (Howard et al., 1987) formula estimates each author's contributions to an article fairly neutrally based on the number and order of authors. Table 2 shows the rankings of countries that contributed to STEM education research in the three journals from 2014 to 2018.

We identified that only 14 countries intensively contributed to STEM education development in terms of academic publications over five years. The countries ranked in the top five were the USA, Canada, Australia, the Netherlands, and the UK. The USA contributed enormously with a score of 36.19. The Americas have the highest STEM research contribution score when grouped by country of origin, followed by continental Europe, Australia, and Asia. During the 2014–2018 period, no contributions were found on the African continent in JRST, IJSE, and IJ-STEM articles.

Since STEM is a multidiscipline topic, we can see how writers collaborate in STEM publications. We found the number of publications with two, three, or five authors to be common (Figure 3). Authors can also come from the same or different countries. The data shows that most collaboration happened among authors from the same country, 73.5%, while 12.2% were collaborations among authors from different countries. In other words, international researcher collaboration in STEM education remains limited. Figure 4 shows the pattern of scholarly collaborative research in more detail.

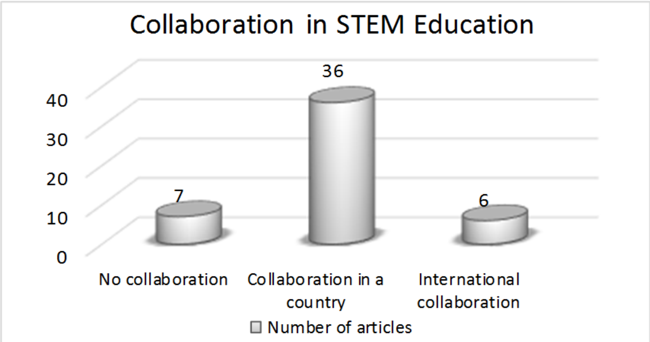

Figure 3. Number of authors in an article

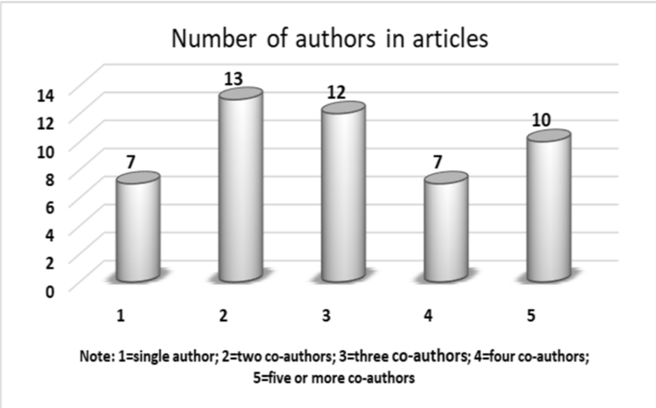

Figure 4. Distribution of scientist collaboration

Research Topics

Research topics in STEM education articles are diverse each year from 2014-2018. We categorize STEM topics according to Tsai and Wen (2005). The results show that STEM research projects are primarily related to goals, policy, curriculum (34.7%), teacher education (22.4), learning context (12.2%), and culture, social aspects, and gender (12.2%) (Table 3).

STEM education's main goal is to increase students' interest in STEM careers and minority participation in STEM fields. To understand the emphasis on students' STEM career preferences, Chachashvili-Bolotin et al. (2016) used social cognitive career theory (SCCT). SCCT was developed to predict what factors influence students' career preferences based on self-efficacy, outcome expectation, interest, environmental support, and barriers (Nugent et al., 2015). Another instrument, expectancy value theory (EVT), developed by Eccles, is used as a framework for predicting STEM career interest (Gottlieb, 2018). EVT emphasizes the relationship between motivation or expectations and task values (Lykkegaard & Ulriksen, 2016). Goals and curriculum are two interrelated things and the STEM curriculum facilitates students to choose their careers in STEM.

Several studies on the STEM education curriculum reform highlighted the opening of inclusive schools and an engineering design process (EDP). Inclusive schools or inclusive STEM high schools (ISHSs) are schools established to broaden the reach of STEM education to underrepresented/underserved/unwelcome people (Lynch et al., 2018). ISHS was created for all low-income students and other minority students to study STEM. ISHSs are schools that do not enforce new student admission criteria–either economic level criteria or academic achievement (LaForce et al., 2016).

Table 3. Tabulation of frequency of research topics in JRST, IJSE, & IJ-STEM

Research topics	2014	2015	2016	2017	2018	2014-2018
Teacher education		1	1	6	3	11(22.4%)
Teaching						0(0.0%)
Learning-conceptions	1	1	2			4(8.2%)
Learning-context	1	2			3	6(12.2%)
Goals, policy, curriculum	2	2	5	3	5	17(34.7%)
Culture, social, gender	1			3	2	6(12.2%)
Philosophy, history, nature of science						0(0.0%)
Educational technology				1		1(2.0%)
Informal learning				1	3	4(8.2%)

EDP is a set of procedures that engineers follow to address problems. The design process is iterative which means the processes are repeated as many times as necessary to arrive at outstanding solutions, making changes along the way as we learn from failure and new design possibilities are revealed. Engineering and technology provide a context where students can test and develop their scientific knowledge through problem-solving activities (Berland & Steingut, 2016). The implementation of EDP builds student's cognitive structures to apply engineering designs in science and technology learning activities.

Teacher education is another fascinating topic to investigate. The scope of research is focused on developing professional teachers and policies supporting STEM education in schools. One of the most significant barriers to STEM integration is the teacher's lack of STEM knowledge (Nadelson & Seifert, 2017). Teachers need professional development to improve effectiveness in STEM teaching (Shernoff et al., 2017). Professional development can facilitate teachers to gain pedagogical knowledge and content if the program is sustainable, collaborative, coherent, and reflective (Estapa & Tank, 2017).

Other issues are related to culture, society, and gender. These topics are never forgotten when we talk about STEM. Adamuti-Trache and Sweet's (2014) findings revealed that revealed that there is still a gender gap in STEM engagement between men and women. People of color still have limited access to STEM education and this education is dominated by the upper-middle class.

Learning conception illustrates how students acquire concepts or apply STEM concepts to make engineering designs to solve problems. Students' conceptual understanding and conceptual change can be assessed when applying engineering design (King & English, 2016). Meanwhile, learning context outlines how a learning environment or learning approach can be created that matches STEM achievements. Research shows that STEM teaching focuses on student-centered learning (Keiler, 2018) and constructivist situations (Wild, 2015) and engages students to develop their interests in science through laboratory enquiry (Burgin et al., 2015).

Informal learning promotes STEM at a higher rate than formal learning (Kim & Keyhani, 2019). The unique settings of an informal program, such as visits to museums, campuses, or science centers, more effectively increase student interest in STEM than the school curriculum teaching (Kisiel, 2014). Informal programs that are often carried out are outreach programs that still have structured activities following certain objectives (Vennix et al., 2018). In the three journals, nothing specifically discusses teaching and philosophy, history, and the nature of science, although these topics can be found implicitly in the discussion of several articles that were reviewed.

DISCUSSION

Article Distribution: Year of Publication and Research Methods

With its varying name (STEAM, STEMM), STEM has been widely presented in various literature. STEM education is believed to be a way to prepare current generations to face many of the world's problems. Scientists, technologists, mathematicians, engineers, and others believe that a country's or world's economy can be restored with STEM (Sheffield et al., 2018). Scientific publications on STEM are published in various journals, books, and conferences by researchers, academics, and educators worldwide to support STEM development (Li et al., 2020a).

From our perspective, the findings of this review show that researchers' focus on STEM topics increases each year. These results simultaneously confirm several previous studies (Lee et al., 2019; Li et al., 2019, 2020a). By implication, the claim that STEM research trends are continuing to rise is a verifiable finding. This systematic review shows that, although the database used is limited, if a credible database is used (i.e., according to scope, reputable database, and referral of the research community), the results obtained are relatively the same as studies that use an extensive database. Nonetheless, this needs to be confirmed in future systematic reviews on other topics.

Concerning research methods, this study shows that qualitative methods are more widely used to study STEM education than other research methods. A qualitative approach is an essential approach in social science research. Researchers can gain a better understanding of the subject of study, investigate the specific individual's context with the activities performed, explain the process in depth between the context of the study and the results discovered, and explicitly combine the researcher's subjectivity (Maxwell & Reybold, 2015). A qualitative study designed and conducted carefully will provide a new source of knowledge about a phenomenon and support the development of a framework (Vishnevsky & Beanlands, 2004). In STEM education, this is very urgent, considering that a consensus on the nature and procedure of implementing STEM has still not been reached (Tawbush et al., 2020).

Author's Nationality

The review analyzed which countries are most productive in terms of academic articles published on STEM development. Interesting here is the contrast in the number of publications between America, Europe, and Asia. Especially in STEM education, there are fundamental differences between the two. This review confirms the findings of previous studies showing that STEM education-related studies are still dominated by America and Europe continent (Gil-Doménech, 2020; Hinojo-Lucena et al., 2020).

These distinctions can be seen in several aspects, such as funding, curriculum, and interest. The USA, Canada, Australia, the Netherlands, and the UK were the top five countries for STEM number publications in the three journals analyzed. When viewed, the 14 countries that contributed to published research on STEM development were countries from the Americas (79%), Europe (13%), Australia and Oceania (5%), and Asia (3%); no publications from sub-Saharan Africa were found in the journals analyzed. If we look at the success of STEM implementation in America and Europe continent, this cannot be separated from government support in terms of both policy and research funding. The more critical STEM is to a country's development, the clearer the support and policies are set out.

America

STEM development and contribution are dominant in the Americas, especially in North America (i.e., the USA and Canada). America has many reasons to improve STEM learning. One of America's main concerns relates to the country's economic condition. Many companies lament job applicants lacking mathematics, computer, and problem-solving skills. Meanwhile, many international students are predominantly Chinese and Indian (47%) who fill job opportunities and choose STEM careers more often compared to American citizens themselves (Burrelli, 2010). In 2017, only 48% of students in America were interested in STEM fields (American College Testing [ACT], 2017). Only 0.17% of high school graduates were interested in taking science, and only 0.43% were interested in mathematics. Compared to other countries, American students also lag in international assessments, where only 10% of grade 8 students compete in TIMSS compared to Singapore's 32% and China's 25%. In line, the study by Kocabas et al. (2019) showed that American students have relatively mediocre scores compared with Asians.

Given the circumstances, the central government plays a critical role in advancing STEM education by collaborating with stakeholders at all levels (Committee on STEM Education, 2018). The framework for K-12 science education issued by the National Research Council implicitly emphasizes guiding students interested in science and continuing their careers in science, engineering, or technology (National Research Council, 2012). Central government policy is also supported by several policies enacted by each state to regulate the implementation of the STEM curriculum (Elaine & Sufian, 2019). In addition, it was recorded from 2003 to 2019 that the US Department of Education has provided funding for 127 development and innovation projects in STEM education (Li et al., 2020b). Meanwhile, since 2007, Canada's Science and Technology Strategy: Mobilizing Science and Technology to Canada's Advantage has supported STEM policy and integration (DeCoito, 2016).

Europe

STEM has been recognized as a significant driver of science education in Europe where many STEM projects are funded to support successful STEM implementation. The Netherlands and the UK are two examples of countries that struggle with STEM. The Netherlands education system has implemented technology education as a separate subject at the lower secondary education level. In 2004, schools could maintain technology education as a separate discipline or integrate it with science. The merge of science and technology can be seen as a movement towards integrated STEM education in some Netherlands schools.

The UK considers STEM critical to its economic success with engineering and manufactured goods being the two most significant contributors to the UK economy. In 2002, a review of science and engineering skills was conducted to prepare for future demands. Here, the main context is that, due to the government's concerns about there being fewer qualified engineers and scientists, the number of young people interested in science, engineering, mathematics, and technology has been decreasing. Furthermore, the government officially established the National STEM Program to address STEM skills issues in schools and colleges in 2006 (Morgan et al., 2016).

Australia and Oceania

Australia has been implementing STEM education as the international community was interested in STEM since the mid-2000s (Blackley & Howell, 2015). The Australian government endorsed the National STEM School Education Strategy 2016-2026 in December 2015 to improve students' STEM skills and aspirations. This was based on a report from the New South Wales Department of Education which stated that STEM should be a national priority because Australia is amidst a STEM crisis (Education Council, 2015).

Australia's STEM education strategy focuses on improving educator capacity while developing students' STEM capabilities through problem-based research and learning. Interestingly, state and commonwealth governments provide financial assistance for implementation or research (Sheffield et al., 2018). Similarly, New Zealand, through the Department of Education in 2007, emphasized the development of an integrated curriculum across disciplines. The curriculum focuses on global and contextual problem-solving. New Zealand recognizes the importance of implementing STEM learning based on the interconnection among science, technology, engineering, and mathematics (Granshaw, 2016).

Asia

This research demonstrates that the contribution of countries in Asia to STEM is still low (3%), although it is known that Asia is the largest continent in the world. This result aligns with previous studies wherein (Lee et al., 2019) claim that contributions to STEM publications in the Asia Pacific were only about 8.5%, while Americans accounted for 65% of studies.

Some research shows that Asia has a high potential for competent human resources and a strong interest in STEM. As per the PISA 2018 score report for science, some countries in Asia occupy levels 4 (very proficient) and 3 (basic proficient), such as China, Singapore, Japan, and Korea. In addition, surveys of secondary school students' STEM career interests in South Korea and Indonesia show that students have a high level of interest in STEM (Shin et al., 2018). On the other hand, it is estimated that the number of undergraduate students majoring in engineering in Asia is much higher than their US and EU counterparts–Singapore (20%) and China (40%) compared to America (about 6%) and Europe (12%) (Johnson et al., 2016). A sophisticated and high-quality STEM curriculum should be better prepared to accommodate and develop students' potential and interest in STEM careers in the future. This will certainly boost economy and national security.

Further support is given by Li et al. (2020b) that more generally asserts that several Asian countries began to engage in and develop STEM education, such as Malaysia, India, Indonesia, Thailand, South Korea, and

China. Malaysia aims to become a developed country by utilizing the literate STEM workforce (Bahrum et al., 2017; Jayarajah et al., 2014). Further, through the New Economic Model, the Malaysian government aims for 31% of the workforce to work within STEM fields by 2020.

India and Indonesia also take advantage of demographic dividends by establishing literate STEM human resources to support sustainable development. India claims that STEM is the future of its country and the future of its children. Meanwhile, Indonesia also has great potential both in terms of its natural and human resources and, thus, should be able to play an essential role in the advancement of science and technology among Asian countries. However, many obstacles remain in implementing integrated STEM, including time, resources, and teacher readiness.

Thailand, South Korea, and China are other Asian countries whose governments fully support STEM implementation. The government and all stakeholders including teachers, experts, and policymakers played a role in Thailand's STEM success (Srikoom et al., 2017). South Korea issued a national policy agenda in 2011 to integrate STEAM (with additional 'A' for arts). Furthermore, China has set the goal of becoming a world-class innovator by 2050. The STEM field higher education research environment significantly impacts whether China successfully transforms from a manufacturing-based economy to an innovation-driven knowledge-based economy (Han & Appelbaum, 2018). The development of STEM in China is also supported by financial investment in Research and Development (R&D) which is the prime determinant for the advancement of science and technology (Gao, 2017).

International Collaboration

Collaboration among countries in STEM implementation is urgently needed (Sharma & Yarlagadda, 2018). International collaboration can expand the scope of research and highlight its impact (Larivière et al., 2015; Sugimoto et al., 2017). Furthermore, there are several advantages to international collaboration: increased visibility, divided project costs, easy access to expensive physical resources, gaining a wider influence by sharing data, and increased creativity by exchanging ideas (Matthews et al., 2020).

Despite the numerous benefits of international research collaboration, this systematic review discovered that international collaboration between authors is rare. Similar findings were also revealed by Gui et al. (2019) and Li et al. (2020a). Some collaborations were found between researchers from the Netherlands and the UK; among Israel, Canada, India, and Australia; the USA and Canada; the USA and Iceland; and the USA, Greece, Lebanon, and China. Even though science is becoming more global and the number of international papers co-authored is rapidly increasing, analysis has revealed that actual participation in international collaboration is much lower. Here, funding, politics, culture, research ethics, and language impede international collaboration (Barrera, 2019; Hwang, 2013; Matthews et al., 2020).

This research also shows that STEM-related research has not been evenly distributed, with researchers in Asia still playing minor roles. Asia has abundant natural resources, a high population, and policies enacted toward developing STEM education. Asian stakeholders must take further steps to improve STEM education. Countries that have implemented STEM in Asia must cultivate publications related to their findings to be studied and adapted by other countries with similar geographic, facility, and cultural characteristics. Collaboration between STEM researchers in Asian countries is essential and needs to be improved.

Other findings in this study revealed no STEM education research in national and international collaborations in Africa in the three journals examined. The world's workforce crisis in STEM fields remains a concern and Africa is no exception. Since the 2014 Ebola pandemic, sub-Saharan Africa has faced a STEM workforce crisis. So far, African countries have engaged in international collaborations for many years. The United States, France, and the United Kingdom serve as the primary collaboration partners, focusing on health and agriculture (Adams et al., 2013). Recently, an Africa-China collaboration to improve the quality of STEM disciplines was announced (Eduan & Yuanqun, 2018). STEM education research collaboration between countries worldwide and countries in Africa is also required for mainstream STEM education.

International collaboration in Africa is an effort that is required to enhance education and research quality. According to Blom et al. (2016), countries in Africa cannot conduct their own scientific research, mainly in STEM education; STEM field research funding frequently relies on international collaboration. Sub-Saharan Africa's research output in STEM lags behind other subject areas. The teachers' lack of teaching experience and confidence in STEM negatively impacts students' achievements and motivations to pursue STEM careers (Hackman et al., 2021; Tarekegn et al., 2020). Other factors affecting this are low acceptance or interest in STEM education in early childhood, high numbers of students dropping out of school, and the perception that STEM fields are abstract and difficult to relate to their daily lives (Demissie, 2019).

Research Topics

The findings of this systematic review study revealed several important points that must be considered or investigated further for the success of STEM implementation at the pre-university level. We divide it into four sections and discuss them in the following paragraph.

First and foremost, standardized curriculum preparation and competent STEM teacher preparation are required. An effective curriculum and teacher mentoring support system will help qualify more teachers to teach STEM subjects. Many teachers are interested in STEM, but they cannot confidently implement it (Shernoff et al., 2017). Professional development can facilitate teachers to gain pedagogical knowledge and content if the program is sustainable, collaborative, coherent, and reflective. Content knowledge is the basis for implementing a STEM approach in the classroom and there is a positive correlation between content knowledge and STEM conceptualization. This suggests that content knowledge should be part of professional development in STEM education (Putra & Kumano, 2018). Content knowledge, pedagogical knowledge, technological knowledge, and pedagogical content knowledge are at the core of STEM education (Chai, 2019). Furthermore, teachers with STEM pedagogical content knowledge and constructivist paradigms become adaptive in STEM teaching (Allen et al., 2016). However, some teachers complain that STEM professional development does not consider each teacher's educational background, resulting in poor program outcomes (Baker & Galanti, 2017). Some things that can be done to develop teacher professional development are classroom action research, designing curriculums, and attending workshops.

Second, engineering design processes should be applied. Here, mathematical and science concepts can be applied quickly in engineering and technology contexts (Berland & Steingut, 2016). Students can design models or prototypes by beginning with brainstorming, progressing until they have redesigned previously created products (Chabalengula & Mumba, 2017). When using engineering design, teachers must package learning with contextual and straightforward concepts. For example, English and King (2015) describe how students are challenged to create the longest-flying paper plane. Students begin by sketching, measuring paper, folding paper with calculations, and then improving the initial design after conducting trials until they can increase the flying time of the aircraft they designed. The students have integrated mathematics, science, and engineering disciplines to measure the length, shape, thickness, and proportions of the fuselage and see how the airflow and the aircraft force affect flight.

Many obstacles exist in applying the EDP, including student conditions, school support, teacher readiness, and facilities (Eastman et al., 2017). Expert intervention is also required to design an appropriate curriculum. Teachers require special assistance when implementing engineering design in the classroom. Furthermore, some teachers have difficulty finding material sources and implementing engineering designs. Many teachers do not explain or have exceptional preparedness to implement engineering design (Bagiati et al., 2015).

Third, informal learning is one of the other features offered that could help with STEM education. Informal learning is significantly aligned with the spearhead of 21st-century learning. These kinds of programs can be conducted either inside or outside the school, most commonly outside the school. There are several characteristics of program outreach to increase student interest or understanding of science. The STEM context relating to a community or company can be transported into schools or schools can visit sites outside and the methods used for teaching are valuable learning and mentoring opportunities (Ashley et al., 2017).

Informal learning is claimed to impact students' STEM attitudes and abilities positively. Through informal learning, students' motivation towards STEM career choices and engagement in STEM increases (Chittum et al., 2017). Another example is who guided students to combine meteorology and engineering in STEM to promote environmental care and awareness of the risks of bad weather (Barrett et al., 2014). Findings of the study by Wiebe et al. (2018) showed the positive correlation between student's academic, life experience and future STEM careers. Following this, teachers should collaborate on formal and informal learning in learning activities.

Fourth, STEM-inclusive schools should be established. Inclusive schools provide opportunities for underrepresented groups to gain access to STEM education. The implementation of inclusive schools positively impacts STEM careers and it is predicted that inclusive school graduates will study more STEM courses in college than non-inclusive school graduates (Means et al., 2016). Inclusive schools are recognized as an effective way for schools to reform and remove racial, gender, and social mobility equality gaps in STEM (Lynch et al., 2018). Directly, inclusive schools support the core goal of STEM education: improving student STEM literacy, closing gaps in minorities, and increasing the STEM field workforce.

CONCLUSION

This systematic review has shown that STEM research increases significantly year by year, triggered by academics' interests and concerns in STEM education. However, integrating STEM into a curriculum or educational program was not identified as an easy job for most teachers or researchers at school. Some of our findings also highlight essential attributes that can help implement STEM education, such as preparing curricula, preparing teachers through continuous professional development, implementing technical curricula, implementing inclusive schools, and enforcing informal learning. STEM policies in various countries must be followed carefully in the future to clarify STEM conceptualization. Researchers and stakeholders in STEM can consider several aspects of the findings to see the effectiveness of implementation in carefully preparing school interventions. This might conclude that several more in-depth studies are needed regarding various aspects of STEM education so that implementation can run effectively and efficiently.

In addition, our study also revealed that cross-country and cross-cultural collaboration among researchers play an essential role in maximizing STEM research and dissemination. This implies that multinational or multicultural collaboration is required to enrich and expand STEM findings to tackle the fact that this collaborative research is slowly progressing around the world.

In general, current research has greatly increased our understanding of trending research topics and authors' nationality that are developing in STEM education. However, the fundamental question of collaboration between STEM scientists in the world remains to be answered. Instead of this systematic review discovered how international collaboration between authors, it is important to identify impact of this type of research. Therefore, further research should be carried out to see how international collaboration expands and identify its impact on government policy and school practices. This is essential for us to develop a better understanding of STEM practices at the school level and their impact on learning outcomes should to convince educators and practitioners to implement STEM in classroom setting.

Besides, though this review was undertaken rigorously, each systematic review is limited by its the parameters. This systematic literature review was not completely comprehensive as the search parameters were restricted to the three journal indexed in the SSCI database within 2014-2018 period, empirical journal articles, and articles written in English. Further research is warranted beyond the three journal in other databases investigated in this study to convince and support claims on collaboration between researchers and countries.

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REFERENCES

Adams, J., Gurney, K., Hook, D., & Leydesdorff, L. (2013). International collaboration clusters in Africa. January. *Scientometrics 98*, 547-556. https://doi.org/10.1007/s11192-013-1060-2

Adamuti-Trache, M., & Sweet, R. (2014). Science, technology, engineering and math readiness: Ethno-linguistic and gender differences in high-school course selection patterns. *International Journal of Science Education*, *36*(4), 610-634. https://doi.org/10.1080/09500693.2013.819453

Allen, M., Webb, A. W., & Matthews, C. E. (2016). Adaptive teaching in STEM: Characteristics for effectiveness. *Theory into Practice*, *55*(3), 217-224. https://doi.org/10.1080/00405841.2016.1173994

American College Testing [ACT]. (2017). *STEM education in the US: Where we are and what we can do*. https://doi.org/10.1007/978-981-10-5448-8

Ashley, M., Cooper, K. M., Cala, J. M., & Brownell, S. E. (2017). Building better bridges into stem: A synthesis of 25 years of literature on stem summer bridge programs. *CBE-Life Sciences Education, 16*(4), es3. https://doi.org/10.1187/cbe.17-05-0085

Bagiati, A., Yoon, S. Y., Evangelou, D., Magana, A., Kaloustian, G., & Zhu, J. (2015). The landscape of preK-12 engineering online resources for teachers: Global trends. *International Journal of STEM Education*, *2*(1), 1-15. https://doi.org/10.1186/s40594-014-0015-3

Bahrum, S., Wahid, N., & Ibrahim, N. (2017). Integration of STEM education in Malaysia and why to STEAM. *International Journal of Academic Research in Business and Social Sciences*, *7*(6), 645-654. https://doi.org/10.6007/ijarbss/v7-i6/3027

Baker, C. K., & Galanti, T. M. (2017). Integrating STEM in elementary classrooms using model-eliciting activities: Responsive professional development for mathematics coaches and teachers. *International Journal of STEM Education*, *4*(1), 1-15. https://doi.org/10.1186/s40594-017-0066-3

Barrera, R. L. (2019). The geography of scientific collaboration. *Social & Cultural Geography, 20*(9), 1333-1334. https://doi.org/10.1080/14649365.2019.1629157

Barrett, B. S., Moran, A. L., & Woods, J. E. (2014). Meteorology meets engineering: An interdisciplinary STEM module for middle and early secondary school students. *International Journal of STEM Education*, *1*(1), 1-7. https://doi.org/10.1186/2196-7822-1-6

Belur, J., Tompson, L., Thornton, A., & Simon, M. (2018). Interrater reliability in systematic review methodology: Exploring variation in coder decision-making. *Sociological Methods and Research, 50*(2), 837-865. https://doi.org/10.1177/0049124118799372

Berland, L. K., & Steingut, R. (2016). Explaining variation in student efforts towards using math and science knowledge in engineering contexts. *International Journal of Science Education*, *38*(18), 2742-2761. https://doi.org/10.1080/09500693.2016.1260179

Blackley, S., & Howell, J. (2015). A STEM narrative: 15 years in the making. *Australian Journal of Teacher Education*, *40*(7), 102-112. https://doi.org/10.14221/ajte.2015v40n7.8

Blom, A., Lan, G., & Adil, M. (2016). *Sub-Saharan African science, technology, engineering, and mathematics research*. The World Bank. https://doi.org/10.1596/978-1-4648-0700-8

Burgin, S. R., McConnell, W. J., & Flowers, A. M. (2015). 'I actually contributed to their research': The influence of an abbreviated summer apprenticeship program in science and engineering for diverse high-school learners. *International Journal of Science Education*, *37*(3), 411-445. https://doi.org/10.1080/09500693.2014.989292

Burrelli, J. (2010). Foreign science and engineering students in the United States. *Info Brief Science Resources Statistics*.

Chabalengula, V. M., & Mumba, F. (2017). Engineering design skills coverage in K-12 engineering program curriculum materials in the USA. *International Journal of Science Education*, *39*(16), 2209-2225. https://doi.org/10.1080/09500693.2017.1367862

Chachashvili-Bolotin, S., Milner-Bolotin, M., & Lissitsa, S. (2016). Examination of factors predicting secondary students' interest in tertiary STEM education. *International Journal of Science Education*, *38*(3), 366-390. https://doi.org/10.1080/09500693.2016.1143137

Chai, C. S. (2019). Teacher professional development for science, technology, engineering and mathematics (STEM) education: A review from the perspectives of technological pedagogical content (TPACK). *Asia-Pacific Education Researcher*, *28*(1), 5-13. https://doi.org/10.1007/s40299-018-0400-7

Chittum, J. R., Jones, B. D., Akalin, S., & Schram, Á. B. (2017). The effects of an afterschool STEM program on students' motivation and engagement. *International Journal of STEM Education*, *4*, 11. https://doi.org/10.1186/s40594-017-0065-4

Committee on STEM Education. (2018). Charting a course for success: America's strategy for STEM education. *National Science and Technology Council*, *December*, 1-35.

Cooper, H., Hedges, L. V., & Valentine, J. C. (Eds.) (2009). The handbook of research synthesis and meta-analysis. SAGE.

DeCoito, I. (2016). STEM education in Canada: A knowledge synthesis. *Canadian Journal of Science, Mathematics and Technology Education*, *16*(2), 114-128. https://doi.org/10.1080/14926156.2016.1166297

Demissie, H. T. (2019). Current state and trajectory of design engineering in Kenya. *African Journal of Science, Technology, Innovation and Development*, *11*(3), 271-277. https://doi.org/10.1080/20421338.2018.1527821

Eastman, M. G., Christman, J., Zion, G. H., & Yerrick, R. (2017). To educate engineers or to engineer educators? Exploring access to engineering careers. *Journal of Research in Science Teaching*, *54*(7), 884-913. https://doi.org/10.1002/tea.21389

Eduan, W., & Yuanqun, J. (2018). *Patterns of the China-Africa research collaborations from 2006 to 2016: A bibliometric analysis*. *The International Journal of Higher Education Research*, *77*(6), 979-994. https://doi.org/10.1007/s10734-018-0314-6

Education Council. (2015). National STEM school education strategy: A comprehensive plan for science, technology, engineering and mathematics education in Australia. *Australian Education Ministers*.

Elaine, J. A. Q., & Sufian, A. F. (2019). Critical analysis of international STEM education policy themes. *Journal of Education and Human Development*, *8*(2), 82-98. https://doi.org/10.15640/jehd.v8n2a10

English, L. D., & King, D. T. (2015). STEM learning through engineering design: Fourth-grade students' investigations in aerospace. *International Journal of STEM Education*, *2*, 14. https://doi.org/10.1186/s40594-015-0027-7

English, L. D., & King, D. T. (2019). STEM integration in sixth grade: Deslgning and constructing paper bridges. *International Journal of Science and Mathematics Education*, *17*, 863-884. https://doi.org/10.1007/s10763-018-9912-0

Estapa, A. T., & Tank, K. M. (2017). Supporting integrated STEM in the elementary classroom: A professional development approach centered on an engineering design challenge. *International Journal of STEM Education*, *4*, 6. https://doi.org/10.1186/s40594-017-0058-3

Falloon, G., Hatzigianni, M., Bower, M., Forbes, A., & Stevenson, M. (2020). Understanding K-12 STEM education: A framework for developing STEM literacy. *Journal of Science Education and Technology*, *29*, 369-385. https://doi.org/10.1007/s10956-020-09823-x

Fan, S. C., Yu, K. C., & Lin, K. Y. (2020). A framework for implementing an engineering-focused STEM curriculum. *International Journal of Science and Mathematics Education*, *25*(1), 24-39. https://doi.org/10.1007/s10763-020-10129-y

Fu, Y. C., Marques, M., Tseng, Y.-H., Powell, J. J. W., & Baker, D. P. (2022). An evolving international research collaboration network: Spatial and thematic developments in co-authored higher education research, 1998-2018. *Scientometrics*. https://doi.org/10.1007/s11192-021-04200-w

Gao, Y. (2017). Integrating STEM education into the global landscape in China. *Asian Research Policy*, *8*(2), 103-121.

Gil-Doménech, D. (2020). STEM education: A bibliometric overview. In J. Kacprzyk (Ed.), *Advances in intelligent systems and computing* (pp. 193-205). https://doi.org/10.1007/978-3-030-15413-4_15

Gottlieb, J. J. (2018). STEM career aspirations in Black, Hispanic, and White ninth-grade students. *Journal of Research in Science Teaching*, *55*(10), 1365-1392. https://doi.org/10.1002/tea.21456

Granshaw, B. (2016). STEM education for the twenty-first century: A New Zealand perspective. *Australasian Journal of Technology Education*, *3*(1). https://doi.org/10.15663/ajte.v3i1.43

Gui, Q., Liu, C., & Du, D. (2019). Globalization of science and international scientific collaboration: A network perspective. *Geoforum*, *105*, 1-12. https://doi.org/10.1016/j.geoforum.2019.06.017

Guzey, S. S., Moore, T. J., Harwell, M., & Moreno, M. (2016). STEM integration in middle school life science: Student learning and attitudes. *Journal of Science Education and Technology*, *25*, 50-560. https://doi.org/10.1007/s10956-016-9612-x

Ha, C. T., Thao, T. T. P., Trung, N. T., Huong, L. T. T., Dinh, N. Van, & Trung, T. (2020). A bibliometric review of research on STEM education in ASEAN: Science mapping the literature in Scopus database, 2000 to 2019. *Eurasia Journal of Mathematics, Science and Technology Education*, *16*(10), 1-11. https://doi.org/10.29333/ejmste/8500

Hackman, S. T., Zhang, D., & He, J. (2021). Secondary school science teachers' attitudes towards STEM education in Liberia. *International Journal of Science Education*, *43*(2), 223-246. https://doi.org/10.1080/09500693.2020.1864837

Han, X., & Appelbaum, R. P. (2018). China's science, technology, engineering, and mathematics (STEM) research environment: A snapshot. *PLoS ONE*, *13*(4), e0195347. https://doi.org/10.1371/journal.pone.0195347

Hasanah, U. (2020). Key definitions of STEM education: Literature review. *Interdisciplinary Journal of Environmental and Science Education*, *16*(3), e2217. https://doi.org/10.29333/ijese/8336

Hinojo-Lucena, F. J., Dúo-Terrón, P., Navas-Parejo, M. R., Rodríguez-Jiménez, C., & Moreno-Guerrero, A. J. (2020). Scientific performance and mapping of the term STEM in education on the web of science. *Sustainability*, *12*(6), 1-20. https://doi.org/10.3390/su12062279

Howard, G. S., Cole, D. A., & Maxwell, S. E. (1987). Research productivity in psychology based on publication in the Journals of the American Psychological Association. *American Psychologist*, *42*(11), 975-986. https://doi.org/10.1037/0003-066X.42.11.975

Hwang, K. (2013). Effects of the language barrier on processes and performance of international scientific collaboration, collaborators' participation, organizational integrity, and interorganizational relationships. *Science Communication*, *35*(1), 3-31. https://doi.org/10.1177/1075547012437442

Ibáñez, M. B., & Delgado-Kloos, C. (2018). Augmented reality for STEM learning: A systematic review. *Computers and Education*, *123*, 109-123. https://doi.org/10.1016/j.compedu.2018.05.002

Jahan, N., Naveed, S., Zeshan, M., & Tahir, M. A. (2016). How to conduct a systematic review: A narrative literature review. *Cureus Journal of Medical Science*, *8*(11), e864. https://doi.org/10.7759/cureus.864

Jamaludin, A., & Hung, D. (2017). Problem-solving for STEM learning: Navigating games as narrativized problem spaces for 21st century competencies. *Research and Practice in Technology Enhanced Learning*, *12*(1), 1-14. https://doi.org/10.1186/s41039-016-0038-0

Jayarajah, K., Saat, R. M., & Rauf, R. A. A. (2014). A review of science, technology, engineering & mathematics (STEM) education research from 1999-2013: A Malaysian perspective. *Eurasia Journal of Mathematics, Science and Technology Education*, *10*(3), 155-163. https://doi.org/10.12973/eurasia.2014.1072a

Johnson, C. C., Burton, E. P., & Moore, T. J. (2016). *STEM road map: A framework for integrated STEM education*. Routledge. https://doi.org/10.4324/9781315753157

Kaleci, D., & Korkmaz, O. (2018). STEM education research: Content analysis. *Universal Journal of Educational Research*, *6*(11), 2404-2412. https://doi.org/10.13189/ujer.2018.061102

Kayan-Fadlelmula, F., Sellami, A., Abdelkader, N., & Umer, S. (2022). A systematic review of STEM education research in the GCC countries: Trends, gaps and barriers. *International Journal of STEM Education*, *9*(1), 2. https://doi.org/10.1186/s40594-021-00319-7

Keiler, L. S. (2018). Teachers' roles and identities in student-centered classrooms. *International Journal of STEM Education*, *5*(1), 34. https://doi.org/10.1186/s40594-018-0131-6

Kim, M. S., & Keyhani, N. (2019). Understanding STEM teacher learning in an informal setting: A case study of a novice STEM teacher. *Research and Practice in Technology Enhanced Learning*, *14*(9), 1-16. https://doi.org/10.1186/s41039-019-0103-6

King, D., & English, L. D. (2016). Engineering design in the primary school: Applying stem concepts to build an optical instrument. *International Journal of*

Science Education, *38*(18), 2762-2794. https://doi.org/10.1080/09500693.2016.1262567

Kisiel, J. F. (2014). Clarifying the complexities of school-museum interactions: Perspectives from two communities. *Journal of Research in Science Teaching*, *51*(3), 342-367. https://doi.org/10.1002/tea.21129

Kocabas, S., Ozfidan, B., & Burlbaw, L. M. (2019). American STEM education in its global, national, and linguistic contexts. *Eurasia Journal of Mathematics, Science and Technology Education*, *16*(1), em1810. https://doi.org/10.29333/ejmste/108618

LaForce, M., Noble, E., King, H., Century, J., Blackwell, C., Holt, S., Ibrahim, A., & Loo, S. (2016). The eight essential elements of inclusive STEM high schools. *International Journal of STEM Education*, *3*(21), 1-11. https://doi.org/10.1186/s40594-016-0054-z

Larivière, V., Gingras, Y., Sugimoto, C. R., & Tsou, A. (2015). Team size matters: Collaboration and scientific impact since 1900. *Journal of the Association for Information Science and Technology*, *66*(7), 1323-1332. https://doi.org/10.1002/asi.23266

Lee, M. H., Chai, C. S., & Hong, H. Y. (2019). STEM education in Asia Pacific: Challenges and development. *Asia-Pacific Education Researcher*, *28*(1), 1-4. https://doi.org/10.1007/s40299-018-0424-z

Li, Y., Froyd, J. E., & Wang, K. (2019). Learning about research and readership development in STEM education: A systematic analysis of the journal's publications from 2014 to 2018. *International Journal of STEM Education*, *6*(1), 4-11. https://doi.org/10.1186/s40594-019-0176-1

Li, Y., Wang, K., Xiao, Y., & Froyd, J. E. (2020a). Research and trends in STEM education: A systematic review of journal publications. *International Journal of STEM Education*, *7*(11), 1-16. https://doi.org/10.1186/s40594-020-00207-6

Li, Y., Wang, K., Xiao, Y., Froyd, J. E., & Nite, S. B. (2020b). Research and trends in STEM education: A systematic analysis of publicly funded projects. *International Journal of STEM Education*, *7*, 17. https://doi.org/10.1186/s40594-020-00213-8

Lin, T. J., Lin, T. C., Potvin, P., & Tsai, C. C. (2019). Research trends in science education from 2013 to 2017: A systematic content analysis of publications in selected journals. *International Journal of Science Education*, *41*(3), 367-387. https://doi.org/10.1080/09500693.2018.1550274

Lykkegaard, E., & Ulriksen, L. (2016). Choices and changes: Eccles' expectancy-value model and upper-secondary school students' longitudinal reflections about their choice of a STEM education. *International Journal of Science Education*, *38*(5), 701-724. https://doi.org/10.1080/09500693.2016.1156782

Lynch, S. J., Burton, E. P., Behrend, T., House, A., Ford, M., Spillane, N., Matray, S., Han, E., & Means, B. (2018). Understanding inclusive STEM high schools as opportunity structures for underrepresented students: Critical components. *Journal of Research in Science Teaching*, *55*(5), 712-748. https://doi.org/10.1002/tea.21437

Margot, K. C., & Kettler, T. (2019). Teachers' perception of STEM integration and education: A systematic literature review. *International Journal of STEM Education*, *6*(2), 1-16. https://doi.org/10.1186/s40594-018-0151-2

Matthews, K. R. W., Yang, E., Lewis, S. W., Vaidyanathan, B. R., & Gorman, M. (2020). International scientific collaborative activities and barriers to them in eight societies. *Accountability in Research*, *27*(8), 477-495. https://doi.org/10.1080/08989621.2020.1774373

Maxwell, J. A., & Reybold, L. E. (2015). Qualitative Research. In J. Wright (Ed.), *International encyclopedia of the social & behavioral sciences*. https://doi.org/10.1016/B978-0-08-097086-8.10558-6

Means, B., Wang, H., Young, V., Peters, V. L., & Lynch, S. J. (2016). STEM-focused high schools as a strategy for enhancing readiness for postsecondary STEM programs. *Journal of Research in Science Teaching*, *53*(5), 709-736. https://doi.org/10.1002/tea.21313

Medina-Jerez, W. (2018). Science education research trends in Latin America. *International Journal of Science and Mathematics Education*, *16*(3), 465-485. https://doi.org/10.1007/s10763-016-9785-z

Moore, T., & Smith, K. (2014). Advancing the state of the art of STEM integration. *Journal of STEM Education: Innovations and Research*, *15*(1), 5-10.

Morgan, R., Kirhy, C., & Stamenkovic, A. (2016). The UK STEM education landscape. Royal Academy of Engineering. https://www.raeng.org.uk/publications/reports/uk-stem-education-landscape

Nadelson, L. S., & Seifert, A. L. (2017). Integrated STEM defined: Contexts, challenges, and the future. *Journal of Educational Research*, *110*(3), 221-223. https://doi.org/10.1080/00220671.2017.1289775

National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. The National Academies Press.

Nugent, G., Barker, B., Welch, G., Grandgenett, N., Wu, C. R., & Nelson, C. (2015). A model of factors contributing to STEM learning and career orientation. *International Journal of Science Education*, *37*(7), 1067-1088. https://doi.org/10.1080/09500693.2015.1017863

Ozkan, G., & Umdu, T. U. (2021). Exploring the effectiveness of STEAM design processes on middle school students' creativity. *International*

Journal of Technology and Design Education, *31*, 95-116. https://doi.org/10.1007/s10798-019-09547-z

Putra, P. D. A., & Kumano, Y. (2018). Energy learning progression and STEM conceptualization among pre-service science teachers in Japan and Indonesia. *New Educational Review*, *53*, 153-162. https://doi.org/10.15804/tner.2018.53.3.13

Sharma, J., & Yarlagadda, P. K. D. V. (2018). Perspectives of 'STEM education and policies' for the development of a skilled workforce in Australia and India. *International Journal of Science Education*, *40*(16), 1999-2022. https://doi.org/10.1080/09500693.2018.1517239

Sheffield, R., Koul, R., Blackley, S., Fitriani, E., Rahmawati, Y., & Resek, D. (2018). Transnational examination of STEM education. *International Journal of Innovation in Science and Mathematics Education*, *26*(8), 67-80.

Shernoff, D. J., Sinha, S., Bressler, D. M., & Ginsburg, L. (2017). Assessing teacher education and professional development needs for the implementation of integrated approaches to STEM education. *International Journal of STEM Education*, *4*(1), 1-16. https://doi.org/10.1186/s40594-017-0068-1

Shin, S., Rachmatullah, A., Roshayanti, F., Ha, M., & Lee, J. K. (2018). Career motivation of secondary students in STEM: A cross-cultural study between Korea and Indonesia. *International Journal for Educational and Vocational Guidance*, *18*(2), 203-231. https://doi.org/10.1007/s10775-017-9355-0

Srikoom, W., Hanuscin, D., & Faikhamta, C. (2017). Perceptions of in-service teachers toward teaching STEM in Thailand. *Asia-Pacific Forum on Science Learning and Teaching*, *18*(2).

Sugimoto, C. R., Robinson-Garcia, N., Murray, D. S., Yegros-Yegros, A., Costas, R., & Larivière, V. (2017). Scientists have most impact when they're free to move. *Nature*, *550*, 29-31. https://doi.org/10.1038/550029a

Tarekegn, G., Terfa, D., Tadesse, M., Atnafu, M., & Alemu, M. (2020). Ethiopian preservice primary science teachers' perceptions of mentoring in science teaching. *Journal of Science Teacher Education*, *31*(8), 894-913. https://doi.org/10.1080/1046560X.2020.1774699

Tawbush, R. L., Stanley, S. D., Campbell, T. G., & Webb, M. A. (2020). International comparison of K-12 STEM teaching practices. *Journal of Research in Innovative Teaching & Learning*, *13*(1), 115-128. https://doi.org/10.1108/jrit-01-2020-0004

Thibaut, L., Deprez, J., Van de Velde, D., De Cock, M., Hellinckx, L., Van Petegem, P., Struyf, A., Boeve-de Pauw, J., Dehaene, W., Struyven, K., Knipprath, H., Goovaerts, L., Depaepe, F., De Meester, J., Langie, G., De Loof, H., & Ceuppens, S. (2018). Integrated STEM education: A systematic review of instructional practices in secondary education. *European Journal of STEM Education*, *3*(1), 1-12. https://doi.org/10.20897/ejsteme/85525

Tsai, C. C., & Wen, M. L. (2005). Research and trends in science education from 1998 to 2002: A content analysis of publication in selected journals. *International Journal of Science Education*, *27*(1), 3-14. https://doi.org/10.1080/0950069042000243727

Vennix, J., den Brok, P., & Taconis, R. (2018). Do outreach activities in secondary STEM education motivate students and improve their attitudes towards STEM? *International Journal of Science Education*, *40*(11), 1263-1283. https://doi.org/10.1080/09500693.2018.1473659

Vishnevsky, T., & Beanlands, H. (2004). Qualitative research. *Nephrology Nursing Journal*, *31*(2), 234-238. https://doi.org/10.1044/1058-0360(2003/062)

Vulperhorst, J. P., Wessels, K. R., Bakker, A., & Akkerman, S. F. (2018). How do STEM-interested students pursue multiple interests in their higher educational choice? *International Journal of Science Education*, *40*(8), 828-846. https://doi.org/10.1080/09500693.2018.1452306

Wahono, B., Lin, P. L., & Chang, C. Y. (2020). Evidence of STEM enactment effectiveness in Asian student learning outcomes. *International Journal of STEM Education*, *7*(36), 1-18. https://doi.org/10.1186/s40594-020-00236-1

Wiebe, E., Unfried, A., & Faber, M. (2018). The relationship of STEM attitudes and career interest. *Eurasia Journal of Mathematics, Science and Technology Education*, *14*(10), em1580. https://doi.org/10.29333/ejmste/92286

Wild, A. (2015). Relationships between high school chemistry students' perceptions of a constructivist learning environment and their STEM career expectations. *International Journal of Science Education*, *37*(14), 2284-2305. https://doi.org/10.1080/09500693.2015.1076951

Wong, V., Dillon, J., & King, H. (2016). STEM in England: Meanings and motivations in the policy arena. *International Journal of Science Education*, *38*(15), 2346-2366. https://doi.org/10.1080/09500693.2016.1242818

Zawacki-Richter, O., Kerres, M., Bedenlier, S., Bond, M., & Buntins, K. (2020). *Systematic reviews in educational research: Methodology, Perspectives and application*. Springer. https://doi.org/10.1007/978-3-658-27602-7