# Systematic Analysis of Research Trends in STEAM/STEM Education Based on Big Data

Ying Zhao(✉)

Fuzhou Shangshan Education Consulting Co., Ltd., Fuzhou, China
vivi051314@gmail.com

**Abstract.** Over the past decade, big data has become a part of everyday life. Big data and big data analysis techniques are applicable in many fields, especially education. Combining science, technology, engineering, arts and mathematics, STEAM (Science, Technology, Engineering, Arts and Mathematics) competitiveness has always been the focus of the world. This paper uses network big data resources to obtain relevant types of research results; uses big data analysis methods to finally extract 495 STEM/STEAM education articles published in 16 top journals from 2016 to 2021 for analysis, in order to comprehensively understand the current STEM/Big data trends and academic trends in STEAM education. The authors conducted quantitative research on selected journals, including the number of articles published in the field each year, author nationality, citations of published articles, research methods, and research topics. The results vividly show that the international status of big data in the field of STEM/STEAM is expanding. At present, most big data applications are still dominated by STEM education, which is gradually realizing a clear identity. The field of STEAM research, which aims to bring artistic expression into STEM education, is in its infancy, but it is growing faster than STEM education.

**Keywords:** Big Data · Cloud Computing · STEAM Education · STEM Education · Network Technology

## 1 Introduction

Combined improvements in science and technology are required to address global challenges such as climate change, over-population, health, and the reduction of energy and water resources. Therefore, it is of great importance and urgent at the international level to develop comprehensive talents in science, technology, engineering and mathematics [32]. At the same time, some researchers are extending STEM to STEAM (incorporating the arts). STEAM is acquiring momentum to build student cooperation in STEM through personal expression, feel, and interdisciplinary projects to enhance student engagement, creativity, innovation, and problem-solving [3, 18, 26]. Basic Google searches for 'STEM instruction' and 'STEAM Education' return more than 3.5 billion and 1.8 billion outcomes, respectively. Such voluminous data shows the quick development and vibrant dynamic in the STEM/STEAM education field. In any area, it is


C. F. Peng et al. (Eds.): EIMT 2022, AHSSEH 3, pp. 155–168, 2023.
https://doi.org/10.2991/978-94-6463-012-1_18

essential to understand the current state and trends of academic research to support the development of the field, and this principle certainly applies to STEAM/STEAM education. Li et al. (2020) show that there has been intellectual improvement in science, technology, engineering, and math (STEM) from 2000 to 2018, by reviewing 798 papers published in STEM education. Nevertheless, the STEM field has gathered momentum over the recent six years. STEAM education is gaining traction, and such traction has prompted the crucial need to review the current research and trends of STEM/STEAM education research internationally through an analysis of the updated articles published in high-quality journals.

Systematic reviews to investigate a particular discipline's current research and trends in educational research are widespread. These studies critically evaluate and summarize the overall or specific focus of relevant research in this area. Since 2016, scholars have reviewed the STEM/STEAM education field both from whole and from its different branches. Some scholars examined the identity and the integration of STEM/STEAM education [23, 29, 30]. Some scholars focused on STEM teaching and learning direction [10, 21, 27] and others summarized comprehensively the STEM and STEAM education [15, 22, 28]. These related studies have incorporated different methods to identify, collect, and analyze relevant literature. There are differences in the purpose of literature, the scope of topic selection, time cycle, and selection methods of literature. In this review, the author will systematically analyze 16 selected high-quality journal publications in education research, in order to provide a comprehensive overview of STEM/STEAM research developments in education from January 2016 to December 2021.

## 2 Research Question

Since this paper reviews the updated year and authoritative academic journals based on Li et al. (2020), the research questions have also been modified. In particular, this paper will predominantly concentrate on the following four research questions:

1. What is the status and trend of journal-based STEM/STEAM education research from January 2016 to December 2021?
2. According to the author's country or region, which countries or areas publish STEM/STEAM educational journals?
3. What are the main topics of STEM/STEAM education research?
4. What research methods do STEM/STEAM article writers use in their educational research?

## 3 Method

In light of the above research questions, this study will initially search and identify high-quality STEM/STEAM journals and then continue to seek the corresponding STEM/STEAM-related educational research papers in these journals through keywords search. Finally, the research will concentrate on the four research objectives through qualitative and quantitative methods.

### 3.1 Selected Journal and Articles

This study uses the following three steps to search and identify journals to be included:

1. This study assumes that articles on STEM education research have been published in journals involving multiple traditional disciplines. Consequently, this study utilizes Google Scholar to search and identify all educational journals whose keywords incorporate 'STEM', 'Science, Technology, Engineering and Mathematics', 'STEAM', and 'Science, Technology, Engineering, Art and Mathematics' in their titles or keywords.
2. However, there is such a large number of publications. Yale college's Poorvu Center for Teaching and Learning provides a rundown of 16 kinds of published journals that cover the STEM education undergraduate course (see https://poorvucenter.yale.edu/FacultyResources/STEMjournals). Subsequently, only a portion of the published journals was chosen for this review.
3. Due to the requirement of journal quality, this study chose 16 final journals and 495 articles, by combining the above two conditions with Scimago Institutions Journal Rankings on Education (Table 1).

### 3.2 Data Analysis

To address research question two, this study analyzes the nationality of the authors in order to determine which countries/regions have contributed to STEM education research in the past years. Since each article may have one or more authors, the following method will analyze the corresponding author nationality. This study only considers the corresponding authors (or the first author, if no specific indication is given about the lettering author) and institution affiliation, if multiple institution affiliations are listed.

To address research question three, the author examined several sources of information, including a list of topics from the National Science Foundation STEM Education EHR Core Research in STEM education, several conferences in STEM education, and journal publication reviews in selected disciplines in STEM education [9, 19]. The author then selected the five topic categories listed below. Prior to formal characterization, this study tested 50 codes to ensure feasibility and observed that the examination could utilize these five theme classifications to group 495 articles through a pre-test.

(1) STEM/STEAM teaching, teacher and teacher education
(2) STEM/STEM learner, Learning, and learning environment
(3) STEM/STEAM goals, motivations, persistence, career selection, and evaluation
(4) Policy, curriculum, assessment, and nature of STEM and STEM education
(5) Culture, social, and gender issues

Lastly, to answer the four research questions, all 495 published papers are sorted and classified according to (1) qualitative methods, (2) quantitative methods, (3) mixed methods, and (4) non-empirical studies (including conceptual or theoretical papers and literature reviews). Each paper is assigned a research topic and a method. When more than one topic or method can be used in a publication, selecting and assigning one case or method is needed.

**Table 1.** Total of 16 selected journals

| No. | Selected Journals | | |
|---|---|---|---|
| | Journal name | Start year | Number of articles selected |
| 1 | American Educational Research Journal | 1964 | 6 |
| 2 | British Educational Research Journal | 1975 | 2 |
| 3 | British Journal of Educational Technology | 1970 | 3 |
| 4 | Computers & Education | 1976 | 12 |
| 5 | International Journal of Science and Mathematics Education | 2003 | 71 |
| 6 | International Journal of Science Education | 1979 | 42 |
| 7 | International Journal of STEM Education | 2014 | 139 |
| 8 | International Journal of Technology and Design Education | 1990 | 38 |
| 9 | Journal of Engineering Education | 1912 | 8 |
| 10 | Journal of Research in Science Teaching | 1963 | 20 |
| 11 | Journal of Science Education and Technology | 1992 | 69 |
| 12 | Research in Science Education | 1971 | 29 |
| 13 | Review of Education | 1974 | 6 |
| 14 | Science Education | 1916 | 29 |
| 15 | Studies in Science Education | 1974 | 4 |
| 16 | The Journal of Educational Research | 1920 | 17 |

## 4 Result

The answers to the four research questions listed above will be presented and discussed in the following sections.

### 4.1 Status and Trend of Journal-Based STEM/STEAM Education Research from January 2016 to December 2021

Figure 1 shows the quantity of STEM education and STEAM education publications from 2016 to 2021. Of the 495 chosen articles, only 41 were connected with STEAM education, representing approximately 8.5%. Over 91% of the articles center on STEM. As displayed in Fig. 1, the quantity of publications in the STEM field has been expanding, starting around 2016, and particularly from 2018 to 2021. Furthermore, STEAM

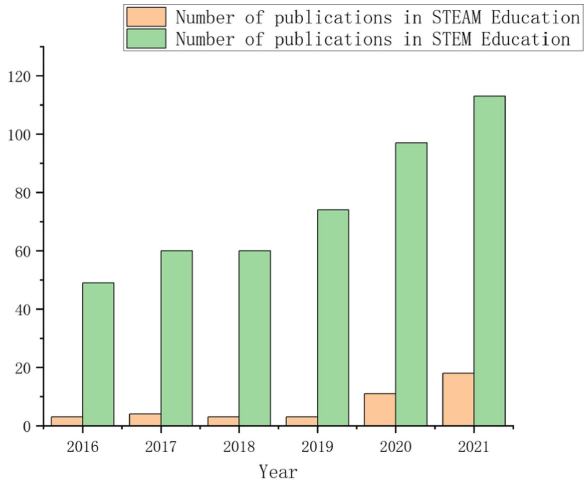


**Fig. 1.** The distribution of STEAM education publications over the years

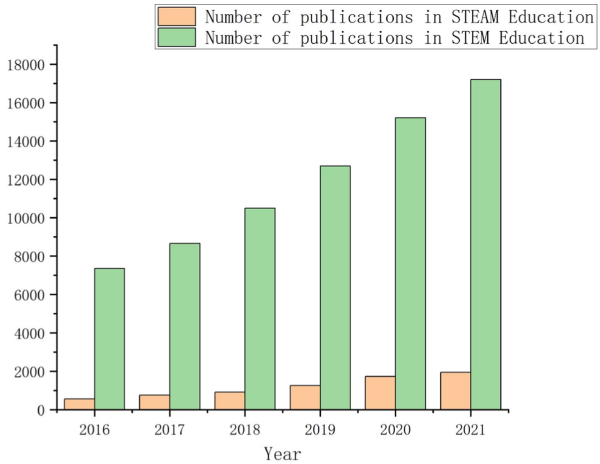


**Fig. 2.** The distribution of STEAM education publications over the years (Data from Google Scholar)

education saw only around three releases between 2016 and 2019, yet demonstrated significant growth in 2020 and 2021.

The results show that there has been a considerable increase in STEM education research since 2016, and a large number of STEM education publications also indicate that STEM education research has become a vital, much sought-after subject area. STEAM education, which coordinates art into STEM education, has not many publications at the earliest stages. Although there are few publications in these 16 journals, the development pace of STEAM education is many times that of publications in STEM education.

**Table 2.** Top 10 countries/regions where scholars contributed journal publications in STEM/STEAM education from 2016 to 2021

| Country | Numbers of publications | Percentage |
|---|---|---|
| USA | 292 | 59% |
| Australia | 34 | 7% |
| Taiwan | 21 | 4% |
| UK | 20 | 4% |
| Spain | 15 | 3% |
| China | 11 | 2% |
| Netherland | 11 | 2% |
| Israel | 10 | 2% |
| Turkey | 10 | 2% |
| Canada | 8 | 2% |

The small sample size of STEAM education is one of the limitations of this study. To demonstrate the exploration pattern of STEM Education and STEAM Education in a more prominent manner, the author applied 'STEM Education' and 'STEAM Education' as keywords in Google Scholar and plotted the number of publications in the two fields from 2016 to 2021. According to the data in Fig. 2 from Google Scholar, the research trend of STEM/STEAM education with that from Fig. 1. The quantity of publications on STEM education and STEAM education has expanded from 2016 to 2021. STEAM education presently has fewer publications, around one-tenth of the number of publications on STEM education. Still, it is growing faster than STEM education.

### 4.2 Top 10 Countries/Regions Where Scholars Contributed Journal Publications in STEM/STEAM Education

Table 2 shows the prominent nations/locales for the number of distributions, determined by those referenced previously. The outcomes showed that around 60% of the authors were from the United States, Australia, Taiwan, the United Kingdom, and Spain. There is a particular discrepancy between this result and that of Li, Y. et al. (2020). About 75% of the authors are from the United States, due to differences in journal selection. The British Educational Research Journal and British Journal of Educational Technology are selected in this study, as well as more articles published by European authors.

Simultaneously, the top five countries in terms of the number of publications per year from 2016 to 2021 are shown in Table 3, which shows that an ever-increasing number of nations are focusing more closely on STEM/STEAM instruction research. In 2016, the USA dominated the publication numbers, representing the majority of 76.92%, with just a small number of distributions from different nations. Beginning around 2016, the extent of USA distributions has gradually diminished to 48.09% in 2021. Like Australia, Taiwan, China, and the UK, various nations and regions have started to attach importance

**Table 3.** Top 5 countries/regions where scholars contributed journal publications in STEM/STEAM education from 2016 to 2021 By Year

| 2016 | 2017 | 2018 | 2019 | 2020 | 2021 |
|---|---|---|---|---|---|
| USA (77%) | USA (72%) | USA (62%) | USA (64%) | USA (51%) | USA (48%) |
| Australia (4%) | UK (8%) | Netherland (10%) | Australia (8%) | Australia (8%) | Australia (7%) |
| UAE (4%) | Australia (6%) | Australia (6%) | Taiwan (5%) | Taiwan (6%) | Taiwan (6%) |
| UK (4%) | Canada (3%) | Spain (5%) | Israel (4%) | UK (5%) | China (5%) |
| Germany (2%) | – | – | Spain (4%) | Spain (4%) | Turkey (4%) |

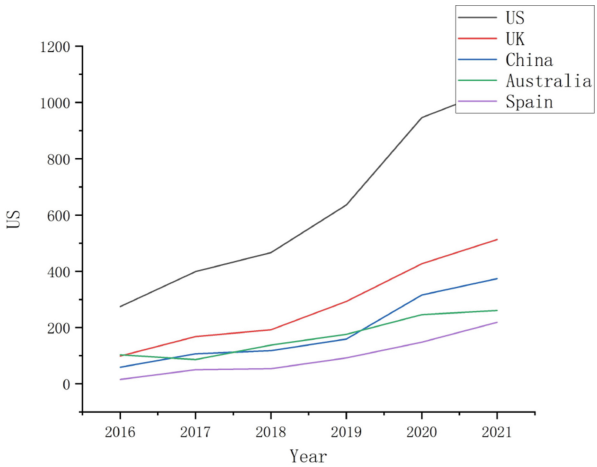


**Fig. 3.** Top 5 countries/regions where scholars contributed journal publications in STEAM education from 2016 to 2021 (Data from Google Scholar)

to STEM/STEAM education research and development. It is clear that STEM/STEAM education is acquiring worldwide consideration.

The example size is again one of the limits of this review. To reveal the STEM education and STEAM Education advancement in every country with a more indicative example, the author applied 'STEM Education', 'Country', and 'STEAM Education Country' as keywords in Google Scholar and plotted the number of distributions in the two fields from 2016 to 2021. Figures 3 and 4 show that the top four countries where scholars contributed journal publications in STEM education and STEAM education are the United States, the United Kingdom, China, and Australia. The United States and Australia developed slower, while the United Kingdom and China—especially the latter—grew faster.

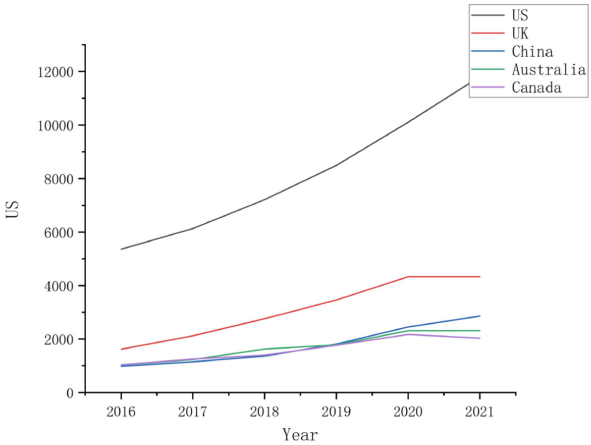


**Fig. 4.** Top 5 countries/regions where scholars contributed journal publications in STEM education from 2016 to 2021 (Data from Google Scholar)

**Table 4.** Published articles by research topics from 2016 to 2021

| Topic | Total number of publications | Total percentage |
|---|---|---|
| 1 | 94 | 19% |
| 2 | 87 | 18% |
| 3 | 136 | 27% |
| 4 | 122 | 25% |
| 5 | 56 | 11% |

1 = STEM/STEAM Teaching, Teacher and Teacher education
2 = STEM/STEAM Learner, Learning, and Learning environment
3 = STEM/STEAM Goals, Motivations, Persistence, Career selection, and evaluation
4 = *Policy, Curriculum, Assessment and Nature of STEM and STEM education*
5 = *Culture, social, and gender issues*

### 4.3 Published Articles on Research Topics

Table 4 shows the total number of publications in each of the five subject categories and the number published each year from 2016 to 2021. All things considered, the category "STEM/STEAM Goals, Motivations, Persistence, Career Selection, and Evaluation" had the most significant number of publications, accounting for 27% of total publications. The category with the second largest number of publications is "Policy, Curriculum, Assessment and Nature of STEM and STEM Education," accounting for 25%.

More specifically, it can be seen from the discounted line chart of published articles by research topic from 2016 to 2021 by year in Fig. 5 that, from 2016 to 2021, the number of published papers on each topic presented an upward trend. "STEM/STEAM Teaching, Teacher and Teacher education" and "STEM/STEAM Learner, Learning, and Learning environment" hold the fastest growth rate.

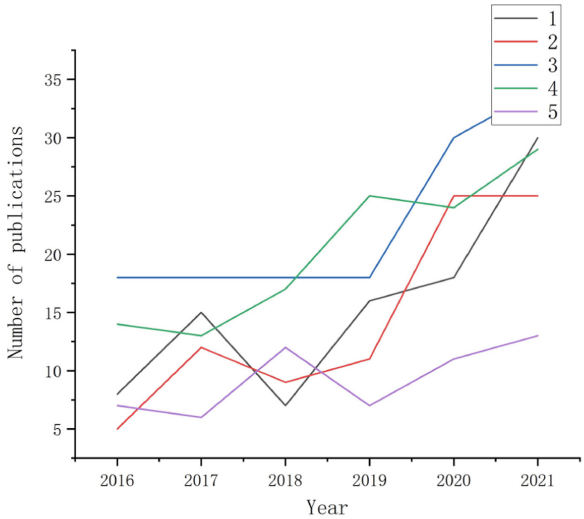


**Fig. 5.** Published articles by research topic from 2016 to 2021 by year

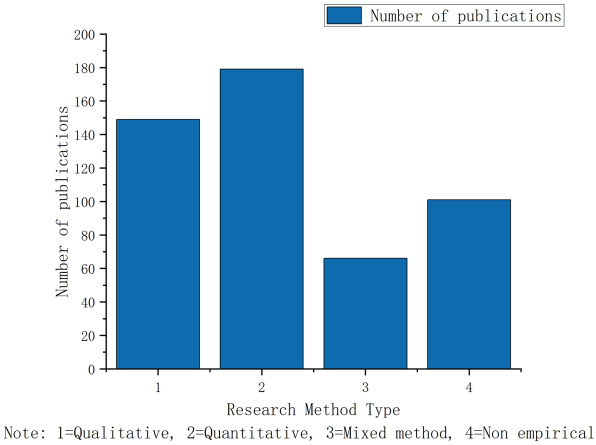


**Fig. 6.** Published articles by research methods from 2016 to 2021

### 4.4 Published Articles by Research Methods

Figure 6 shows the number of papers distributed each year by research method in empirical studies, where classes 1–3 are empirical studies and 4 is non-empirical studies.

As shown in Fig. 4, practical research publications account for 80%, substantially more than non-empirical research publications representing over 20%. Most researchers use qualitative or quantitative methods alone in empirical research, while a few use mixed methods. Figure 7 shows the published articles by research methods from 2016 to 2021 by year in greater detail. Publications of the four empirical and non-empirical

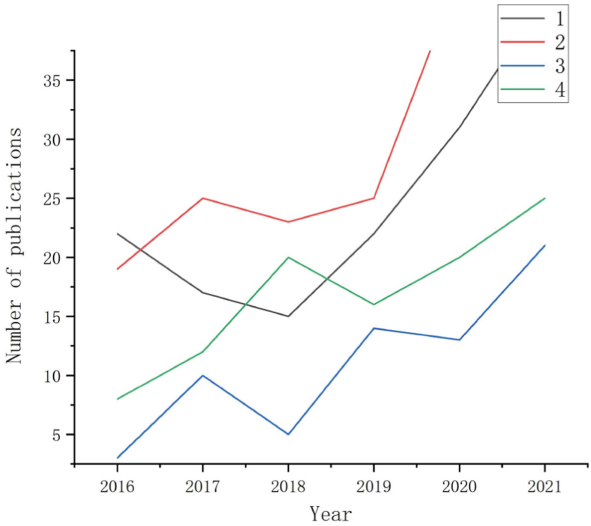


**Fig. 7.** Published articles by research methods from 2016 to 2021 by year

research methods are expanding year-by-year. The mixed method in empirical research has the fastest growth rate.

## 5 Discussion

The systematic analysis above of 495 distributions in 16 STEM/STEAM fields from 2016 to 2021, with data gathered from Google Scholar, showed critical development in STEM education and STEAM education over the past six years. The analysis in this paper indicates that STEM/STEAM education research has been increasingly recognized as an important subject area, with research published in many different journals. However, researchers have presented with various perspectives on defining research as STEM education or STEAM education [7]. In the past six years, authors have increasingly used 'STEM', 'STEAM', or related words in titles, abstracts, and keyword lists in order to differentiate their articles. STEAM education is growing significantly faster than STEM education, though it reached only one-tenth the number of publications. Researchers have investigated and discovered that incorporating unique aspects of the arts, such as innovation, critical thinking, students' creativity, into traditional STEM education can more effectively teach STEM education and develop integrated problem-solving skills, collaboration, and interpersonal communication skills [18, 33]. This promptly demonstrates the reason for STEAM education research's moderately rapid growth. However, scholars lack, first, the understanding about the profound history and variety of artistic expression and, second, the comprehension of measurable learning outcomes in enhancing creativity, problem-solving, and arts education [24]. Empirical research has also shown that many STEAM practitioners struggle with an integrated approach to art [8, 13], which may explain why the arts often take secondary priority to STEM subjects.

As for author and publication countries, most periodicals in STEM/STEAM education research are authors from the United States, the birthplace of STEM and STEAM education, followed by the United Kingdom, China, and Canada. In the meantime, researchers from a few Asian nations, including China, Japan, Taiwan, Hong Kong, and India, have become highly visible and recognized in this field in the past couple of years. Asian students, especially those from East Asia, have outperformed those from different locales, in math, science, and engineering over an extend period of time. Researchers have found that this may be due to the emphasis placed on education in Asian families [5], school curriculum design [31], teaching methods [14], "Tiger" education [6], and extensive extramural education [1] The rapid advancement of STEM/STEAM education research in Asia may also be attributed to the above factors, though further research is required.

With the rapid change in STEM education internationally, it is challenging for researchers to thoroughly understand what may be concerning topics in STEM/STEAM education, especially when STEM/STEAM education publications appear in countless journals in various fields. Up to this point, the "Motivations, Persistence, Career selection and evaluation" and "Strategy, Curriculum, Assessment and Nature of STEM and STEM education" categories are the most well-known. In terms of growth rate, STEM/STEAM teaching and learning have the highest, suggesting that the research community had a broad interest in teaching and learning, including teachers' professional development, learning environments, and teaching and learning challenges [4, 11, 12, 25].

## 6 Conclusions

The research trends in STEM/STEAM education uncovered in this study reveal the development of this field in the last six years. Understanding the current status of STEM/STEAM education research may provide possible directions for future research. This is particularly beneficial for new researchers at the beginning stage of their scholarly venture, and for the educators concerned; monitoring the issues featured in STEM/STEAM education might stimulate reflection and improvement in their teaching. To meet local educational needs, stakeholders may also employ information about international trends in STEM/STEAM education as a basis for their decisions.

In conclusion, studies and similar reviews that routinely screen and report on research trends provide guidelines for all participants in the STEM/STEAM education community, regarding research design, budget funding, and teaching practices. Simultaneously, there are still limits, including the selection of journals and small sample size. Only English journals were selected in this study, while journals in other languages such as Chinese and German were not considered. However, journals in other languages may also provide valuable STEM/STEAM educational research material. This may significantly impact the top 10 countries/regions where scholars contributed journal publications in STEM/STEAM education. Likewise, a small sample size makes it difficult to ascertain the trend, so Google SEO search results are added to assist in this study. However, the aftereffects of the Google Scholar SEO search are somewhat monotonous. For instance, some articles are repeated when using 'UK' or the 'US', which likewise impacts research results.

## References


1. Bray, M., and P. Kwok. 2003. Demand for private supplementary tutoring: Conceptual considerations, and socio-economic patterns in Hong Kong. *Economics of Education Review* 22 (6): 611–620. https://doi.org/10.1016/s0272-7757(03)00032-3.
2. Charette, R.N. 2013. The STEM crisis is a myth. *IEEE Spectrum* 50 (9): 44–59. https://doi.org/10.1109/mspec.2013.6587189.
3. Engelman, S., B. Magerko, T. McKlin, M. Miller, D. Edwards, and J. Freeman. 2017. Creativity in authentic STEAM education with EarSketch. In *Proceedings of the 2017 ACM SIGCSE technical symposium on computer science education*, March 8. https://doi.org/10.1145/3017680.3017763
4. English, L.D. 2017. Advancing elementary and middle school STEM education. *International Journal of Science and Mathematics Education* 15 (1): 5–24. https://doi.org/10.1007/s10763-017-9802-x.
5. Francis, B., and L. Archer. 2005. British-Chinese pupils' and parents' constructions of the value of education. *British Educational Research Journal* 31 (1): 89–108. https://doi.org/10.1080/0141192052000310047.
6. Fu, A.S., and H.R. Markus. 2014. My mother and me. *Personality and Social Psychology Bulletin* 40 (6): 739–749. https://doi.org/10.1177/0146167214524992.
7. 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
8. Herro, D., and C. Quigley. 2016. Exploring teachers' perceptions of STEAM teaching through professional development: Implications for teacher educators. *Professional Development in Education* 43 (3): 416–438. https://doi.org/10.1080/19415257.2016.1205507.
9. Hynes, M.M., C. Mathis, S. Purzer, A. Rynearson, and E. Siverling. 2017. A systematic review of research in P-12 engineering education from 2000–2015. *International Journal of Engineering Education* 33 (1): 453–462.
10. Ibáñez, M.-B., and C. Delgado-Kloos. 2018. Augmented reality for STEM learning: A systematic review. *Computers & Education* 123: 109–123. https://doi.org/10.1016/j.compedu.2018.05.002.
11. Kelley, T.R., and J.G. Knowles. 2016. A conceptual framework for integrated STEM education. *International Journal of STEM Education* 3 (1): 1–11. https://doi.org/10.1186/s40594-016-0046-z.
12. LaForce, M., E. Noble, H. King, J. Century, C. Blackwell, S. Holt, A. Ibrahim, and S. Loo. 2016. The eight essential elements of inclusive STEM high schools. *International Journal of STEM Education* 3 (1): 1–11. https://doi.org/10.1186/s40594-016-0054-z.
13. LaJevic, L. 2013. Arts integration: What is happening in the elementary classroom? *Journal for Learning through the Arts: A Research Journal on Arts Integration in Schools and Communities*, 9(1). https://doi.org/10.21977/d99112615
14. Leung, K.S.F. 2006. Mathematics education in East Asia and the West: Does culture matter? In Mathematics education in different cultural traditions-A comparative study of East Asia and the West, pp 21–46. Cham: Springer. https://doi.org/10.1007/0-387-29723-5_2
15. Li, Y. 2018. Four years of development as a gathering place for international researchers and readers in STEM education. *International Journal of STEM Education* 5 (1): 1–4. https://doi.org/10.1186/s40594-018-0153-0.
16. Li, Y., J. Froyd, and K. Wang. 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): 1–8. https://doi.org/10.1186/s40594-019-0176-1.

17. Li, Y., K. Wang, Y. Xiao, and J. Froyd. 2020. Research and trends in STEM education: A systematic review of journal publications. *International Journal of STEM Education* 7 (1): 1–16. https://doi.org/10.1186/s40594-020-00207-6.
18. Liao, C. 2016. From interdisciplinary to transdisciplinary: An arts-integrated approach to STEAM education. *Art Education* 69 (6): 44–49. https://doi.org/10.1080/00043125.2016.1224873.
19. Lin, T.-J., T.-C. Lin, P. Potvin, and C.-C. Tsai. 2018. 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.
20. Marginson, S., R. Tytler, B. Freeman, and K. Roberts. 2013. STEM: Country comparisons. Report for the Australian Council of Learned Academies. Retrieved 23 February 2019.
21. Margot, K., and T. Kettler. 2019. Teachers' perception of STEM integration and education: A systematic literature review. *International Journal of STEM Education* 6 (1): 1–16. https://doi.org/10.1186/s40594-018-0151-2.
22. Marín-Marín, J.-A., A.-J. Moreno-Guerrero, P. Dúo-Terrón, and J. López-Belmonte. 2021. STEAM in education: A bibliometric analysis of performance and co-words in Web of Science. *International Journal of STEM Education* 8 (1): 1–21. https://doi.org/10.1186/s40594-021-00296-x.
23. Martín-Páez, T., D. Aguilera, F.J. Perales-Palacios, and J.M. Vílchez-González. 2019. What are we talking about when we talk about STEM education? A review of literature. *Science Education* 103 (4): 799–822. https://doi.org/10.1002/sce.21522.
24. Perignat, E., and J. Katz-Buonincontro. 2019. STEAM in practice and research: An integrative literature review. *Thinking Skills and Creativity* 31: 31–43. https://doi.org/10.1016/j.tsc.2018.10.002.
25. Pierson, A., C. Brady, and D. Clark. 2019. Balancing the environment: Computational models as interactive participants in a STEM classroom. *Journal of Science Education and Technology* 29 (1): 101–119. https://doi.org/10.1007/s10956-019-09797-5.
26. Root-Bernstein, R. 2015. Arts and crafts as adjuncts to STEM education to foster creativity in gifted and talented students. *Asia Pacific Education Review* 16 (2): 203–212. https://doi.org/10.1007/s12564-015-9362-0.
27. Schreffler, J., E. Vasquez III, J. Chini, and W. James. 2019. Universal design for learning in postsecondary STEM education for students with disabilities: A systematic literature review. *International Journal of STEM Education* 6 (1): 8. https://doi.org/10.1186/s40594-019-0161-8.
28. Takeuchi, M.A., P. Sengupta, M.-C. Shanahan, J.D. Adams, and M. Hachem. 2020. Transdisciplinarity in STEM education: A critical review. *Studies in Science Education* 56 (2): 213–253. https://doi.org/10.1080/03057267.2020.1755802.
29. Tang, K., and P.J. Williams. 2018. STEM literacy or literacies? Examining the empirical basis of these constructs. *Review of Education* 7 (3): 675–697. https://doi.org/10.1002/rev3.3162.
30. Wang, C., J. Shen, and J. Chao. 2021. Integrating computational thinking in STEM education: A literature review. *International Journal of Science and Mathematics Education*, 24 (1). https://doi.org/10.1007/s10763-021-10227-5
31. Wu, X., J. Deshler, and E. Fuller. 2018. The effects of different versions of a gateway STEM course on student attitudes and beliefs. *International Journal of STEM Education* 5 (1): 1–12. https://doi.org/10.1186/s40594-018-0141-4.
32. Yildirim, B. 2016. An analyses and meta-synthesis of research on STEM education. *Journal of Education and Practice* 7 (34): 23–33.
33. Yoh, T. et al. 2021. STREAM: A new paradigm for STEM education. *Journal of STEM Education: Innovations and Research*, 22 (1).