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The current state of the art in STEM research: A systematic review study

Aras Bozkurt*, Distance Education Department, Faculty Member, Anadolu University, Eskisehir, Turkey
Hasan Ucar, Distance Education, Bilecik Seyh Edebali University, Bilecik, Turkey
Gurhan Durak, Computer Education and Instructional Technology, Balıkesir University, Balıkesir, Turkey
Sahin Idin, The Scientific and Technological Research Council of Turkey, Ankara, Turkey

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Abstract

In the 21st century, when the knowledge-based economy is steering improvement and development, STEM education has gained increasing momentum and importance. This study aims to identify the current trends in STEM education, and also explores and identifies research trends and patterns in articles published between 2014 and 2016 on STEM education through a systematic review study. The research findings indicate that interest in STEM education in scholarly venues has witnessed a marked increase since 2014, with researchers preferring mostly quantitative, conceptual/descriptive, qualitative, mixed and practice-based research methods. In contrast, no interest is currently being shown in data mining and analytical methodologies. The patterns being in STEM education are identified as follows: (1) the scope of the STEM education, (2) the need for a new curriculum for the STEM in higher education, (3) gender studies in STEM education and (4) the need for student-centred future studies on the effectiveness of STEM education.

Keywords: STEM, research trends, systematic review, content analysis, text mining.

* ADDRESS FOR CORRESPONDENCE: **Aras Bozkurt,** Anadolu University, Yunus Emre Campus, Eskisehir, 26470, Turkey. *E-mail address*: arasbozkurt@gmail.com / Tel.: +90 222 335 0580

1. Introduction

In the 1990s, the business world stated that there had to be new approaches were needed if they were to be more successful in global economic competition. As an abbreviation of Science, Technology, Engineering and Math (Herschbach, 2011), STEM education is a teaching and learning approach that integrates the content and skills of science, technology, engineering and math (National Research Council, 1996). There is no precise definition for STEM, and therefore there are many opinions on how STEM education should be applied. For instance, according to Sanders (2009, p. 21), 'STEM education includes approaches that explore teaching and learning among any two or more of the STEM subject areas, and/or between a STEM subject and one or more other school subjects'. Gonzalez and Kuenzi (2012, p. 1), on the other hand, claim that the term 'STEM education refers to teaching and learning in the fields of science, technology, engineering and math, and typically includes educational activities across all grade levels—from pre-school to post-doctorate—in both formal and informal settings'. Taking both of these definitions into account, STEM can be defined as a method of teaching and learning that combine theory and practice in regard to the four named disciplines and real-world hands-on-experiences. Today, within the new knowledge-based economy, STEM education has become a crucial issue worldwide, making it important to understand the STEM phenomenon. Aiming to address this point, the goal of this study is to identify the current state of STEM research, research trends and the emerging trends in STEM education.

2. Related literature

This section presents a review of publications that cover STEM education in a holistic perspective. In a 2010 study entitled 'Advancing STEM Education: A 2020 Vision', Bybee (2010) examined the origin of STEM research and what the acronym really represents. He reported that the term was usually linked to 'stem cells' in biology but is used only loosely in the educational field. He indicated that educators usually use it when referring to science and math education, while technology and engineering are usually ignored, and proposed that rather than using the term STEM Education as a mere slogan, it should become a fundamental part of the curriculum. In a 2011 report, Carnevale, Smith and Melton (2011), rather than focusing on the educational perspectives of STEM, were more interested in those working in the STEM fields and highlighted that without a robust STEM workforce, the United States could expect to become less competitive in the global economy. They highlighted that 'the STEM workforce will remain central to [US] economic vitality, contributing to innovation, technological growth and economic development well into the future' (p. 74), and that the United States 'cannot win the future without a competent STEM workforce' (p. 78). In their report, Marginson, Tytler, Freeman and Roberts (2013) made a detailed comparison of STEM education in different countries and reported that countries develop productive strategies for STEM education and that many have drawn up a comprehensive STEM policy framework that integrates a holistic perspective.

In addition to the above studies, Jayarajah, Saat, Rauf and Amnah (2014) explored STEM education in Malaysia over a 14-year period and reported that information and communication technologies are the most covered research area in STEM education in the country. Confirming Bybee's (2010) findings, they also found that the disciplines of science and math take the lead in Malaysian STEM education, and their review of 56 publications revealed that quantitative (n = 25), mixed (n = 15) and qualitative (n = 15) were the most popular research methods in the country. Brown (2012) explored STEM research in an educational context by analysing articles published in eight journals focused on the STEM disciplines and reported that the use of research methods is finely distributed. He also noted that a large majority of the STEM education research sample participants were from K12-level education and that a lack of interest is apparent in higher education. As a follow-up study, Mizell and Brown (2016) covered the same parameters as Brown (2012) and reported that different research methods were used in a balanced weight. They also found that most research studies sampled participants from K12-level education, which confirms interest in primary and secondary education.

A large number of studies have been conducted on the concept of STEM. The fact that hundreds of studies have been indexed in Scopus related to this issue in just 3 years points to the importance of the concept and shows that it is viewed quite favourably among researchers. Content analysis is a technique that systematically reaches new results under a specific topic or title, and it can be said that one of the most important goals in this regard is to reveal the trends in the related subject or field. In this respect, conducting a systematic review related to such an important concept as STEM can reveal the current trends in this area.

3. Aim of the study

As a follow-up to previous studies of STEM, the main purpose of this study is to identify the current trends in STEM research. To this end, the study intends to provide answers to the following research questions:

- What are the current research trends, and
- What patterns have emerged in STEM education,

in papers published between 2014 and 2016.

4. Methodology

4.1. Method

This paper uses a systematic review (Gough, Oliver & Thomas, 2012) to identify research trends and patterns in STEM education. This type of study has proven to be effective in guiding future studies by summarising a large volume of literature (Petticrew & Roberts, 2008), and to this end, the researchers made use of the content analysis (Wilson, 2011) and text-mining (Hearst, 2003) approaches. In content analysis, a researcher adopts a quantitative approach to report on research findings through numerical expressions, while in a qualitative approach, researchers adopt a qualitative approach to report on research findings themes. In this study, the researchers made use of a quantitative approach, reporting on research methods and models/designs numerically. In text-mining, the titles, abstracts and keywords of the analyzed STEM articles and the lexical relationship is used to identify common themes on a concept map. The overall research flow is presented in Figure 1.

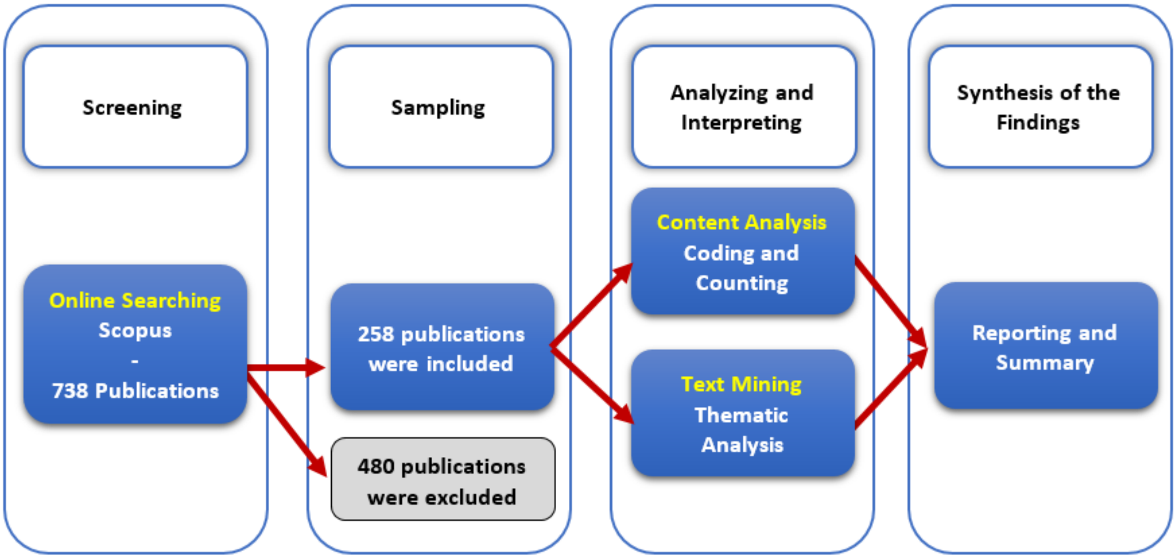

Figure 1. The overall research flow

4.2. Data collection procedure, sampling and analysis

For inclusion in the study, an article had to have selected keywords in their titles, to be written in English, to be published in a reviewed journal and to be indexed in the Scopus database. Scopus is the largest abstract and citation database of peer-reviewed literature, providing listings of scientific journals, books and conference proceedings (Scopus, 2018). Using the keywords 'STEM' and 'Science, technology, engineering and mathematics' in a search of the Scopus database, the researchers identified a total of 738 articles, although it was found that many were from the field of biology due to the keyword 'STEM' in its relation to stem cells. After analysing the titles and abstracts of the search findings, a total of 480 articles were excluded, leaving 258 articles for analysis. The earliest papers sampled in the study date back to 2014 (*n* = 59), and after a smooth increase in 2015 (*n* = 72), a peak was reached in 2016 (*n* = 127) (Figure 2).

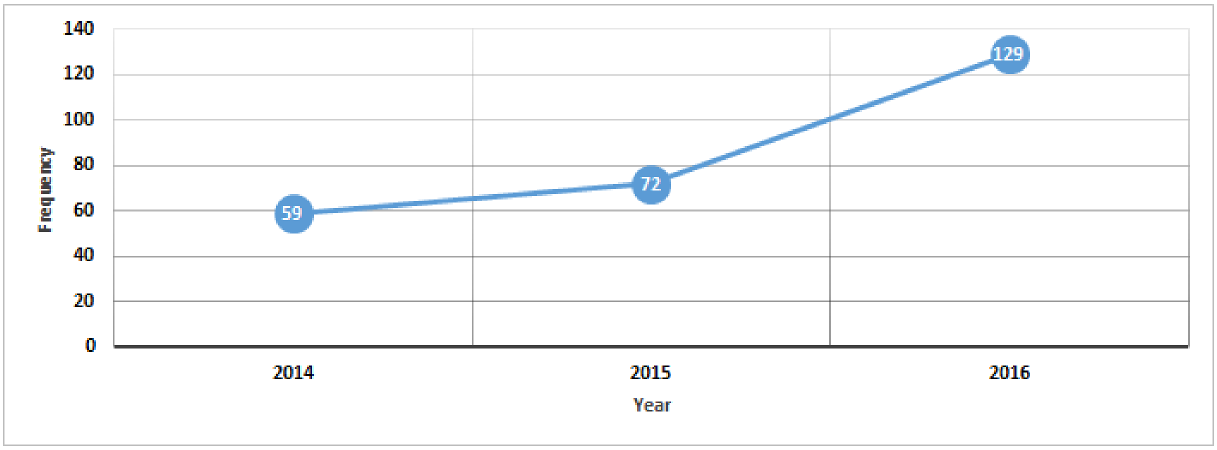

Figure 2. Time series by year for STEM publications

5. Results and discussions

This section deals with trends in research methods and model/designs, and patterns in keywords and in STEM research.

5.1. Research method and design

An analysis of the findings presented in Figure 3 reveals that researchers mostly preferred quantitative methods (37.7%), within which surveys (*n* = 55), causal-comparative studies (*n* = 18) and experimental (*n* = 17) research models were used mostly in quantitative STEM research. Conceptual/Descriptive methods (25%) were the second most preferred research paradigm, and among these studies, opinion papers (*n* = 18) and literature reviews (*n* = 14) were the most common in STEM research studies. Qualitative methods (22.7%) were the third most preferred research paradigm, within which case studies (*n* = 40) were the leading research model. Mixed method studies scored the next highest (9.7%), within which explanatory sequential (*n* = 9), embedded (*n* = 6), convergent parallel (*n* = 4) and exploratory sequential designs were almost equally distributed. Finally, it was revealed that practice-based research methods (5.4%) following design-based research (*n* = 11) and action research (*n* = 3) approaches were the least preferred method. In the sampled publications, none of the studies used data mining or analytical methods.

The findings of this study concur with Brown (2012), who reported that the methodology used in STEM publications is evenly dispersed among quantitative, qualitative and mixed methods, and it was revealed also that disciplines in STEM research tend to use a specific methodology, meaning that the nature of the discipline determines the type of methodology. Similarly, Jayarajah, Saat, Rauf and Amnah (2014), who explored STEM education in the Malaysian context, reported that, out of 56 publications, it was the quantitative (*n* = 25), mixed (*n* = 15), qualitative (*n* = 15), design and development, (5) and finally, unclassified (1) methods that are mostly preferred by researchers in STEM education. Their findings also indicate that the type of methodology differs according to the disciplines represented in STEM abbreviation—similar to Brown's (2012) findings.

Method	F	%	Model/Design	F	% CUM	% TOTAL
Quantitative	98	37,7	Survey	55	56,1	21,2
			Experimental	17	17,3	6,5
			Causal comparative	18	18,4	6,9
			Correlational	5	5,1	1,9
			Meta-analysis	3	3,1	1,2
Qualitative	59	22,7	Case Study	40	67,8	15,4
			Content Analysis	6	10,2	2,3
			Narrative	4	6,8	1,5
			Phenomenology	4	6,8	1,5
			Discourse analysis	3	5,1	1,2
			Ethnography	1	1,7	0,4
			Descriptive	1	1,7	0,4
			Delphi	0	0,0	0,0
			Grounded theory	0	0,0	0,0
			Meta-Synthesis	0	0,0	0,0
			Historical	0	0,0	0,0
			Heuristic	0	0,0	0,0
Mixed	24	9,7	Explanatory sequential	9	37,5	3,5
			Embedded	6	25,0	2,3
			Convergent parallel	4	16,7	1,5
			Exploratory sequential	4	16,7	1,5
			Multiphase	0	0,0	0,0
			Transformative	0	0,0	0,0
Conceptual/Descriptive/Other	65	25	Opinion paper	18	27,7	6,9
			Literature review	14	21,5	5,4
			Report	9	13,8	3,5
			Reflection paper	8	12,3	3,1
			Comparative	6	9,2	2,3
			Technical paper	5	7,7	1,9
			Position paper	3	4,6	1,2
			Field notes	2	3,1	0,8
			Systematic review	0	0,0	0,0
Practice based	14	5,4	Design-based research	11	78,6	4,2
			Action research	3	21,4	1,2
Data mining and analytics	0	0	Learning analytics	0	0,0	0,0
			Social network analysis	0	0,0	0,0
			Text mining	0	0,0	0,0
			Log analysis	0	0,0	0,0
			Internet and traffic ranks	0	0,0	0,0
			Sentiment analysis	0	0,0	0,0

Figure 3. Distribution of STEM publications by research method and model/design

5.2. Patterns in STEM research

This section presents the most important themes identified through text-mining (Figure 4). The four leading themes are given with their concept paths:

1. The scope of the STEM education (See the concept path *STEM—students—school—college—academic* in the school theme): STEM is an integrated educational model of different disciplines (Sanders, 2012), has a potential to provide interdisciplinary point of view to the students (Kubat and Guray, 2018), and therefore requires connectivity not only among disciplines but also at different levels of education. As revealed in this theme, the scope of STEM education covers primary, secondary and higher education, although it is problematic, in that there is a focus on STEM at the K12 level (Brown, 2012; Mizell and Brown, 2016). In order to surpass such a problem, countries with an interest in STEM education should develop national strategies that broaden the scope of STEM education at all educational levels.
2. The need for a new curriculum for STEM in higher education (See the concept path *curriculum—research—education—higher—STEM* in research theme): Classroom experiences and curriculum are critical and crucial for STEM education (Fairweather, 2008 Thibaut et al., 2018). Even though STEM education is provided effectively in K12 through the science curriculum (Sanders, 2009), there is a need to develop new strategies for teaching STEM (Winberg et al., 2018) and a need for reform for an integrated STEM implementation in higher education.
3. Gender studies in STEM education (See the concept path *career—STEM—science—women* in STEM and women themes): Related literature suggests that men value competitive environments, while women value collaborative environments. Considering the fact that STEM classrooms encourage competition to foster creativity, such a strategy can be invaluable for women who are human-oriented and prefer to be part of a team (Kulturel-Konak, D'Allegro & Dickinson, 2011). In terms of pursuing a career in STEM, there are some interesting findings. For instance, while women hold half of all jobs in the US economy, they hold fewer positions in STEM-related jobs (Beede et al., 2011). The research shows that the early years of education are an important indicator in this issue, that there is a lower retention of STEM career interest among females, and that greater difficulty is experienced in attracting females to STEM fields during high school (Sadler, Sonnert, Hazari & Tai, 2012). The state of the art revealed in this theme is consistent with similar studies (Lloyd, Gore, Holmes, Smith & Fray, 2018; O'Dea, Lagisz, Jennions & Nakagawa, 2018; Stoet & Geary, 2018; Wang & Degol, 2013; Wang, Eccles & Kenny, 2013). As highlighted in this theme, gender is an important factor in STEM education and careers, and so there is a need to develop strategies and policies to address this issue.
4. The need for student-centred future studies into the effectiveness of STEM education (see the concept path *perceptions—students—stem—experiences* in school and STEM themes): Active learning increases the performances of students in STEM education (Freeman et al., 2014; Han, Capraro & Capraro, 2015; Meyrick, 2011). It is also suggested that successful STEM education that takes into account the views of the stakeholders would lead to high-quality STEM education and will help students pursue a STEM career (National Research Council, 2011). Therefore, as revealed one of the major themes, implementing student-centred STEM education rather than merely focusing on technology or popular practices is considered to be very important.

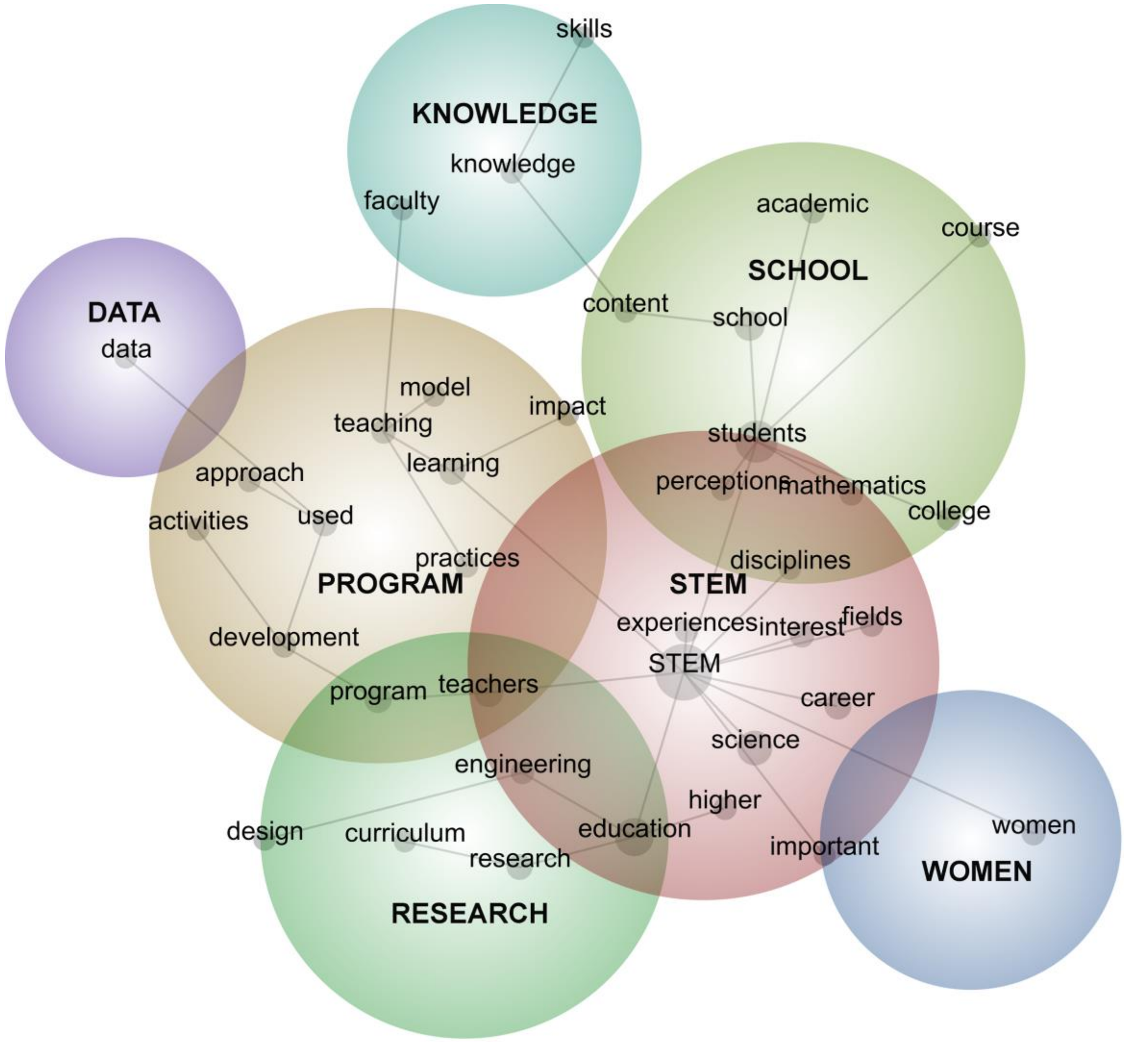

Figure 4. A thematic concept map based on a lexical analysis of the titles and abstracts in the sampled publications

6. Conclusion and future research directions

In a systematic review, this study explored 258 publications to identify trends and patterns in STEM education research. The findings revealed that from 2014 to 2016, an increasing interest was witnessed in STEM education research, as well as an apparent positive trend, which means that the number of publications that cover STEM education will continue to increase.

The trends in research methods, models and designs demonstrated that the quantitative research paradigm (37.7%) is the most commonly applied method. This trend is not surprising, given the popularity of quantitative research methods in the STEM disciplines (science, technology, engineering and math). This was followed by conceptual/theoretical methods (25%), which include opinion papers, literature reviews, position papers, reports, etc., and this type of studies outweigh when a research field emerging and pledge new, innovative grounds in the world of the research. Accordingly, it can be said that STEM education has gained sufficient maturity to focus on more empirical research methodologies. Qualitative studies (22.7%) are the third most preferred research paradigm, which is likely to be an outcome of efforts to gain a deeper understanding of the field. Though not as popular as the previous research paradigms, mixed methods (9.7%) are fourth on the list. Studies that adopt mixed methods tend to provide more comprehensive research findings, in that they benefit from both quantitative and qualitative methods. This supports the opinion that STEM education research is a mature research field. Fifth on the list is practice-based research methods (5.4%), which include design-based research and action research, as the least used research paradigm, although the contribution of these types of studies is not minor. Interestingly, none of the sampled studies used data-mining or analytical approaches (0%), which usually bring together massive volumes of data for analysis through innovative approaches and/or techniques. The absence of such studies indicates that STEM education practices ignore opportunities that can be harvested in online learning environments. Considering the potential of virtual laboratories and the capacity of online networks for communication and collaboration, the absence of this category can be considered a big loss for STEM education research.

In terms of research patterns, four themes were identified. First, *the scope of STEM education* relates to the issue of where to implement STEM education. It is known that STEM education is widely adopted at the K12 level, while interest in higher education is unsatisfactory. Considering that education is continuous progress and that lifelong learning is essential, the scope of STEM education should be broadened to transform it into sustainable practice. Supporting the first theme, the second theme is *the need for a new curriculum for STEM in higher education*. Accordingly, in addition to curriculum developments in primary and secondary education, instructional and curriculum designers need to make tangible efforts for the higher education curriculum. The third theme is *gender studies in STEM education*, which highlights an interesting issue. It is a known fact that disciplines such as engineering are male-dominated, and this unbalanced gender distribution can be considered as one of the STEM education's greatest handicaps. Based on this finding, measures to lessen the lack of balance should be taken by through the development of particular policies, and more efforts should be made in this regard. Finally, the final theme is *the need for student-centred future studies on the effectiveness of STEM education*. As can be seen in the concept map, the perceptions and experiences of students should be taken into consideration to ensure the sustainability of STEM education curriculums, although it should be also noted that to succeed in this regard, decisions should be developed that take into account the experiences of teachers, practitioners and policymakers. It is thought that the success of student-centred education can be accomplished only if all stakeholders contribute to the development of the STEM education curriculum.

Based on the findings of this research, the following suggestions can be considered for future study directions. First of all, STEM education practices may benefit more from online learning environments and analysing such practices through data mining and analytical approaches may lead to effective and efficient research findings. Secondly, there is a need for gender studies with a particular focus on addressing the gender imbalance in STEM education.

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