STEM Education Trends: A Content Analysis of Three International STEM Journals

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This content analysis adds to STEM Education research by highlighting trends in the subfields of STEM education and identifying at what educational levels this research has been conducted. Since their start, all published articles were analyzed from three international STEM education research journals—IJEMST, IJSE, and J-STEM. After logging the relevant information on a spreadsheet, analyzing the data, and looking at the results, the authors identified that technology and engineering education are still underrepresented in STEM education; that more than 50% of the research focused on only one of the four STEM silos; and that most research occurred in higher education settings.

Keywords: STEM Education Research, STEM Silos, Integrated STEM (iSTEM), Directed Content Analysis

INTRODUCTION

Four doctoral students in an Exceptional Learning program focused on STEM education wanted to find out more information about STEM education research published in international, peer-reviewed journals for a course assignment. The students had each been enrolled in the program for approximately two years and had studied various research within STEM education. In a previous course, three of the four students mapped out a timeline of trends and issues for STEM in each of the silos and integrated STEM (iSTEM) over the past decade. These trends and issues from this timeline included calls for action in STEM education. The authors wanted to see if the published research in three international STEM journals revealed reactions from researchers trying to rise to the calls for action in their respective (i)STEM fields.

To accomplish this task, the authors analyzed published articles from 2013 to 2018 from three international STEM research journals: the *International Journal of Education in Mathematics, Science and Technology* (IJEMST), the *International Journal of STEM Education* (IJSE), and the *Journal of Research in STEM Education* (J-STEM). Cherrstrom et al. (2017) stated, "Academic publications provide insights into a discipline's history, knowledge base, and research norms, and thus analyzing publication activity provides learning about the field of study" (p. 3). Some of the trends identified in the previous course were for the United States to increase its visibility in the STEM arena (Bybee, 2013), for more students to be interested and involved in STEM education to persist in finding future STEM careers (Monhardt, 2003; Tai et al., 2006), and for the integration of the STEM silos in education (Sanders, 2008).

United States STEM Education Research

Emphasis on STEM education has grown since the launch of Sputnik by the Soviet Union in 1957 (Bybee, 2013). Since the launch of the first artificial satellite, which caused "strong feeling[s] of fear, astonishment, and insecurity" (Steeves et al., 2009, p. 73), the United States has increased the emphasis on STEM fields. The government and people of the United States felt that Sputnik caused them to look weak "scientifically, technologically, militarily, and economically" (Bybee, 1997, para. 2).

In 1983, the National Commission on Excellence in Education (1983) published *A Nation at Risk*. This publication critiqued the United States education system. An era followed focused on standards in the STEM silos (National Commission on Excellence in Education, 1983). The United States government began funding and developing educational policies for reforming schools and producing students that could meet the increased demands in STEM fields (Steeves et al., 2009). Further reforms such as *Rising Above the Gathering Storm* (Committee on Prospering in the Global Economy of the 21st Century, 2007), STEM 2026 (Tanenbaum, 2016), and the introduction and revisions of common STEM standards have occurred since Sputnik (Kohler et al., 2014). These initiatives continually expand and improve with global competition in mind.

STEM Careers

Vision statements are often published, providing predictions and goals that researchers could use as guidelines or topics of interest. Many vision statements have been published regarding STEM disciplines and STEM education, identifying paths in which research could be directed and areas to be targeted in the past years. For example, many identified issues that needed to be addressed were the underrepresentation of technology and engineering in K–12 education (National Academy of Engineering, 2004; Tanenbaum, 2016; The Royal Society, 2014).

Bybee (2010) stated that "although one can identify technology and engineering programs, the scale at which they are in schools is generally quite low" (p. 31). Research also supports this. Katehi et al. (2009) claimed that even though "an increasing number of states and school districts have been adding technology education to the mix, and a smaller but significant number have added engineering" (p. 2), there is still much work to do since "most efforts to improve STEM education have been concentrated on mathematics and science" (p. 2). In addition, the National Academy of Engineering (2004) suggested that technology and engineering should be integrated with mathematics and science in K–12 education content.

The Royal Society (2014) stated that computer science should begin early and be embedded in curricula from elementary education onwards. Tanenbaum (2016) predicted that there might be "potential benefits of extending the philosophies and principles of constructing knowledge from experience that occur[s] more typically in early childhood, elementary, and out-of-school and informal learning settings to all stages of the education continuum" (p. 11). Finally, Monhardt (2003) conducted a study on an elementary setting "because it is at this level that attitudes toward science and scientists are first formed, even though it is not until high school and college that the outcomes of these attitudes become most evident" (p. 28).

iSTEM Education Research

Nadelson et al. (2017) stated that educators had increased their efforts to teach integrated STEM subjects. Bybee (2018) discussed how teaching STEM in a more integrated manner would benefit students by providing them with "opportunities to learn to apply knowledge, skills, and abilities from STEM disciplines in contexts close to what they will experience in the future" (p. 110). Above and beyond this, students who are exposed to integrative STEM content would experience higher achievement in STEM subjects (Becker et al., 2011).

Breiner et al. (2012) stated, "it is well documented that mastery of science and mathematics is correlated to college success and retention, economic growth and development, national security and innovation, and competitiveness in the global market" (p. 4). Finally, integrative STEM education best

> resonates in several of the engineering accreditation standards that grew out of the engineering education reform efforts: (a) an ability to apply knowledge of mathematics, science, and engineering, (b) an ability to design and conduct experiments, as well as to analyze and interpret data, and (d) an ability to function on multidisciplinary teams. (Sanders, 2008, p. 23)

If the integration of STEM subjects supplies so many benefits to students and prepares them for their future careers, iSTEM education research also needs to support these integrative approaches.

STEM and iSTEM, Education Research

As Science, Technology, Engineering, and Mathematics (STEM) education has gained importance, research for STEM education has too. Sometimes, the definitions of STEM and STEM education found in the literature differ. The authors of this study took a general approach to these two terms. As defined by Ntemngwa and Oliver (2018), "STEM [is] an acronym for science, technology, engineering and mathematics contrasting with STEM education as the process of receiving or giving methodical instruction in the STEM disciplines" (p. 14).

Furthermore, STEM and STEM education research cover all four independent silos and possible integrative combinations. Using combinatorics (Table 1), the authors listed how STEM might be taught in educational settings. There are a total of 15 subfields that fall under the STEM umbrella. STEM might be taught as a fully integrated course (iSTEM), a partially integrated course (two or three STEM subjects), or a singular subject.

TABLE 1
COMBINATORICS OF STEM SUBFIELDS

STEM Combinatorics	STEM Subfields
$\binom{4}{4} = \frac{4!}{(4-4)!\cdot 4!} = 1$	iSTEM
$\binom{4}{3} = \frac{4!}{(4-3)!\cdot 3!} = 4$	STE, STM, SEM, TEM
$\binom{4}{2} = \frac{4!}{(4-2)!\cdot 2!} = 6$	ST, SE, SM, TE, TM, EM
$\binom{4}{1} = \frac{4!}{(4-1)!\cdot 1!} = 4$	S, T, E, M

RESEARCH QUESTIONS (RQS)

This analysis aimed to answer the main research question: What trends exist for STEM education research articles from 2013 to 2018? This question will be answered by addressing five sub-research questions. (RQ1.) Where have the most STEM education articles been conducted? (RQ2.) Has there been a change in the number of STEM education research articles from 2013 to 2018? (RQ3.) At what educational levels has STEM education research been conducted? (RQ4.) Is STEM education research more focused on STEM or iSTEM subjects?

METHODS

Content Analysis

Summative content analysis is instrumental "as the approach entails quantifying data initially, serving as the basis for comparisons and researcher interpretations" (Stroud et al., 2017, p. 196). Content analysis of texts can be conducted on "large sets of existing written or visual documentation which require analysis" (Grbich, 2013, p. 189). Content analysis can be used for determining more information about a specific area of interest across research in published journals to determine "the percentages of occurrences of 'X' words, events, types of approaches, etc... [in addition to finding] particular concepts used in context and why" (Grbich, 2013, p. 189). These insights can help researchers determine areas of need and strength among publications using a numerical overview.

For this content analysis, the authors first determined a focus for this research. Next, they selected three international STEM journals from predetermined guidelines. The authors collected all the articles from the selected journals, IJEMST (n = 146), IJSE (n = 113), and J-STEM (n = 37). They organized the data into a prearranged spreadsheet that contained categories such as *Country*, *Educational Level*, and *STEM Subfield*. Once the researchers had reviewed each article, they analyzed the data to answer the research questions. Further detail for each variable is provided below.

Categories

To find information for each category in the spreadsheet, the author read each article's title, abstract, keywords (if listed), ERIC descriptors (if available), and skimmed through the headings of the articles to find the pertinent information. If the researcher could not find a specific category's data, they would read more deeply through the article to find the needed information. After coding twenty articles each, the authors met to determine if they were consistently finding the required data and found that each author seemed to see and appropriately report the data within each category's column. After this meeting, the researchers divided the remaining articles equally and finished filling out the spreadsheet.

For this study, the researchers focused only on the columns for *Country*, *Educational Level*, and *STEM Subfield* to answer the research questions. Furthermore, the researchers found 35 practitioner articles and one literature review and chose not to include them in further analysis for this study. Two additional erratum articles left the researchers with 258 articles for further analysis.

For the category, *Country*, the researchers reported the location of the study found within the context of the article. If an article only reported a city, the author would find the corresponding country and report this information instead. In cases where the authors did not state the location of the study, the authors' countries were reported. In addition, several articles indicated that two or more countries were involved in the study and were reported accordingly.

Educational Level had multiple subcategories *Elementary*, *Middle*, *High*, and *Postsecondary*. The articles described these different levels using: (a) the ages of children/adults being researched, (b) grade levels, and (c) type of school. The authors defined the variables as *Elementary*, grades K–6; *Middle*, 7–8; *High*, 9–12; and *Postsecondary* as colleges and universities. In some cases, multiple grade levels occurred within the context of an article. These occurrences included a mix of elementary school, middle school, high school, and higher education. The authors identified these as *Mixed*.

To categorize the data for *STEM Subfield*, the authors reviewed the articles to see which STEM fields were covered within the article. If multiple domains were mentioned, the authors would further investigate the paper to determine whether the STEM subjects had been integrated or taught independently of each other. Typically, STEM content was independently taught if multiple STEM subjects were mentioned at a postsecondary level. For the most part, integrated content was commonly found in studies geared towards K–12 education or studies that included an additional subject such as medical education (postsecondary level) and art education (elementary level).

RESULTS

RQ1. *Where have the most STEM education articles been conducted?*

Overall, the United States had the most journal articles (Table 2). Turkey produced the second-largest number of published articles. The remaining articles coded in the database contained research locations with a much smaller number of articles published.

TABLE 2
ARTICLES IDENTIFIED BY COUNTRY

Location	Studies Conducted	Percentage of Studies
Abu Dhabi	1	0.4%
Australia	2	0.8%
Canada	5	1.9%
China	4	1.6%
Finland	2	0.8%
Germany	4	1.6%
Ghana	4	1.6%
India	1	0.4%
Israel	3	1.2%
Netherlands	2	0.8%
New Zealand	3	1.2%
Nigeria	3	1.2%
Puerto Rico	1	0.4%
South Africa	1	0.4%
Sweden	1	0.4%
Switzerland	1	0.4%
Taiwan	1	0.4%
Turkey	46	17.8%
Uganda	1	0.4%
United States	162	62.8%
Multiple Countries	10	3.9%

Some of the studies were completed over large databases collected over multiple countries or had participants from various countries (Table 3). These studies are represented in *Multiple Countries* in Table 2. There were ten studies completed in multiple countries (3.9%). Two of these studies were reported as internationally focused articles.

TABLE 3
ARTICLES IDENTIFIED AS CONDUCTING RESEARCH IN MULTIPLE COUNTRIES

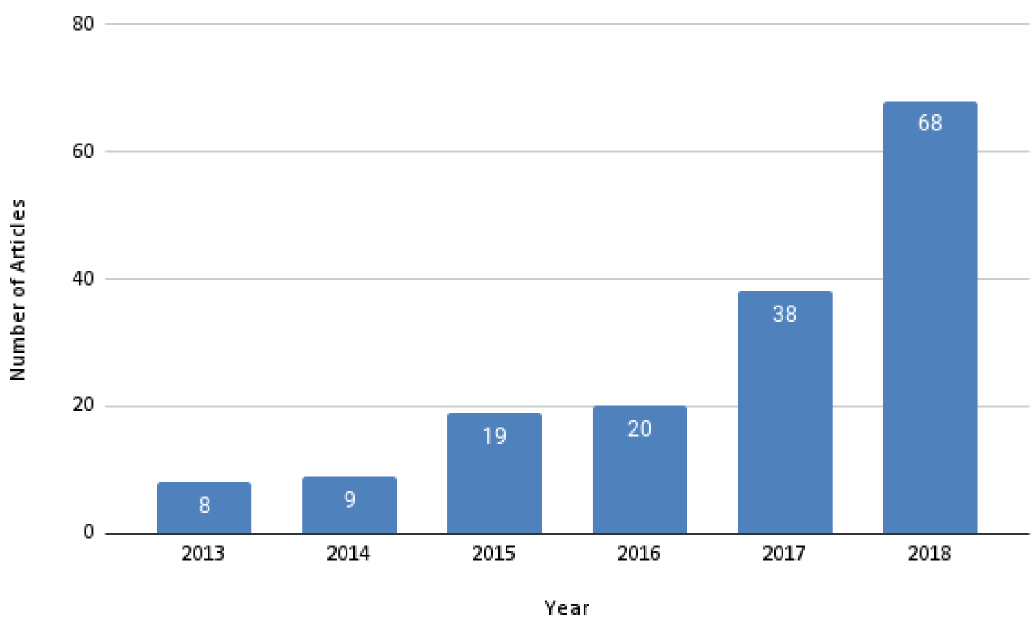
Location	Studies Conducted	Percentage of Studies
Austria, Belgium, Bulgaria, Croatia, Cyprus, Estonia, Germany, Greece, Hungary, Italy, The Netherlands, Portugal, Romania, Spain, & United Kingdom	1	1%
Australia, Austria, Azerbaijan, Croatia, Czech Republic, Finland, Georgia, Germany, Hong Kong, Hungary, Iran, Ireland, Italy,	1	1%

Lithuania, Malta, Morocco, North Ireland, Norway, Oman, Poland, Portugal, Qatar, Romania, Russian Fed., Saudi Arabia, Singapore, Slovak Rep., Slovenia, Spain, Sweden, Taiwan, & UAE		
China & U.S.	1	1%
Cyprus, Finland, & Ireland	1	1%
Cyprus & Spain	1	1%
International	2	2%
South Korea, Turkey, & Ireland	1	1%
U.S. & Turkey	2	2%

RQ2. *Has there been a change in the number of STEM education research articles from 2013 to 2018 in the United States?*

From 2013 to 2018, the number of articles appeared to increase exponentially. In addition, the number of articles almost doubled from 2014 to 2015, 2016 to 2017, and once again from 2017 to 2018. Overall, the number of articles grew from eight to 68 (8.5 times greater).

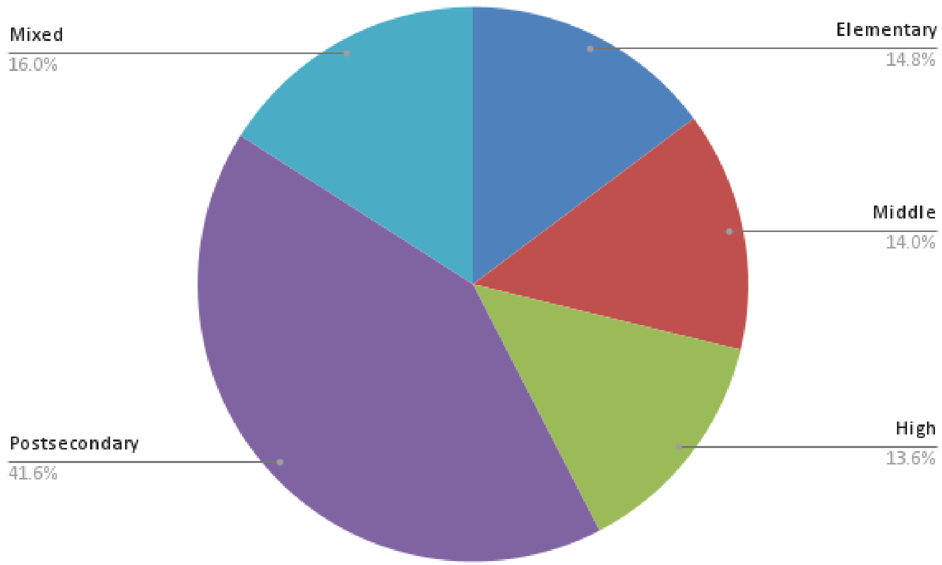
FIGURE 1
NUMBER OF STEM EDUCATION ARTICLES BY YEAR



RQ3. *At what educational levels has STEM education research been conducted?*

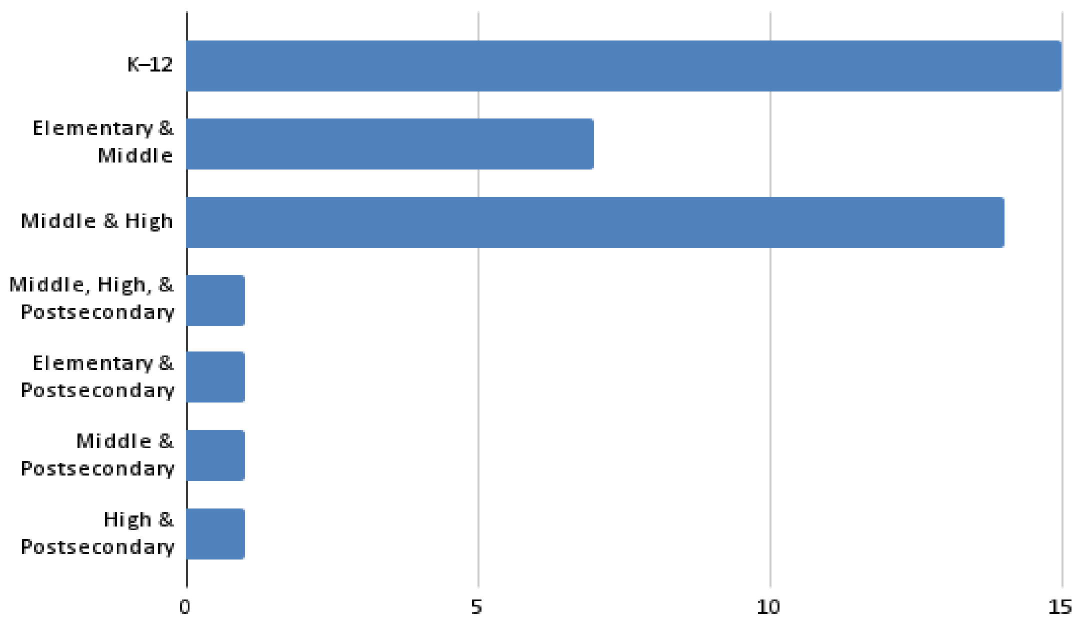
Figure 2 displays the percentages of each educational level. There were 37 Elementary, 35 Middle, 34 High, 104 Postsecondary, and 40 Mixed grades within the STEM education articles. Finally, eight articles did not publish their study's population's grade level or age level (n = 8). These articles were not included in these results.

FIGURE 2
PERCENTAGES OF GRADE LEVELS OF PARTICIPATING SCHOOLS



Mixed is a variable combination of grades (see Figure 3). If a study used a variety of elementary, middle, and high schools, it was re-labeled and categorized as *K–12* (*n* = 15). Additionally, seven studies included elementary and middle school participants; one with elementary and postsecondary participants; one with middle school and postsecondary participants; 14 with middle school and high school participants; one with middle school, high school, and postsecondary participants; and one more study with high school and postsecondary participants.

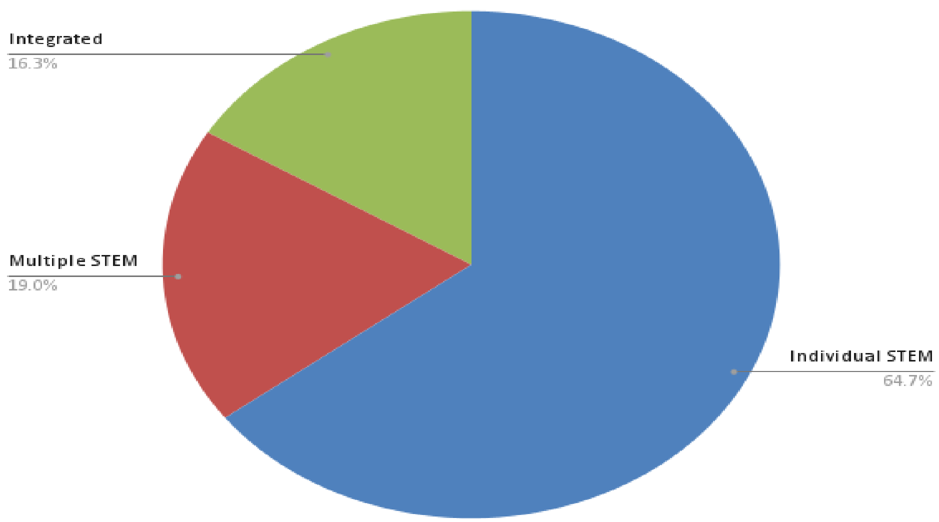
FIGURE 3
PERCENTAGES OF GRADE LEVELS OF PARTICIPATING SCHOOLS



RQ4. *Is STEM education research more focused on STEM or iSTEM subjects?*

Figure 4 depicts that over half of the articles were single-subject STEM education studies (n = 163). The second-largest group was multiple siloed STEM subjects (n = 48). Finally, iSTEM education research (n = 41) represents a minority. Finally, eight articles were not included for further analysis since they were not considered STEM education after further review.

FIGURE 4
PERCENTAGES OF STEM AND ISTEM EDUCATION ARTICLES



The following figures show how often each STEM code occurs for siloed STEM education research articles (Figure 5) and iSTEM education research articles (Figure 6). Science (56.4%) and mathematics (52.1%) education research articles are the most common among siloed STEM education research. Siloed research involving technology (21.3%) and engineering (27.5%) occurs less commonly.

FIGURE 5
FREQUENCIES OF SILOED STEM CODES

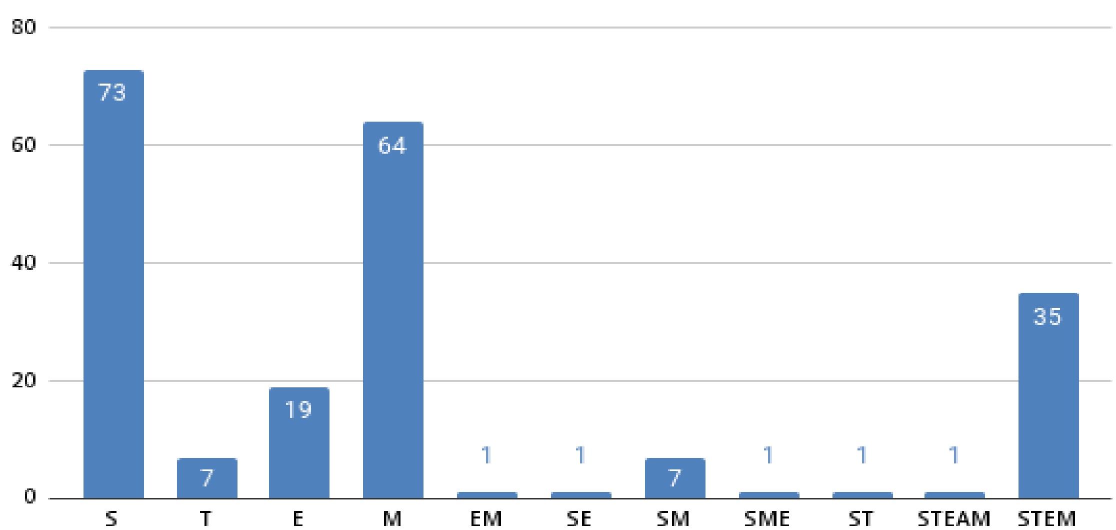
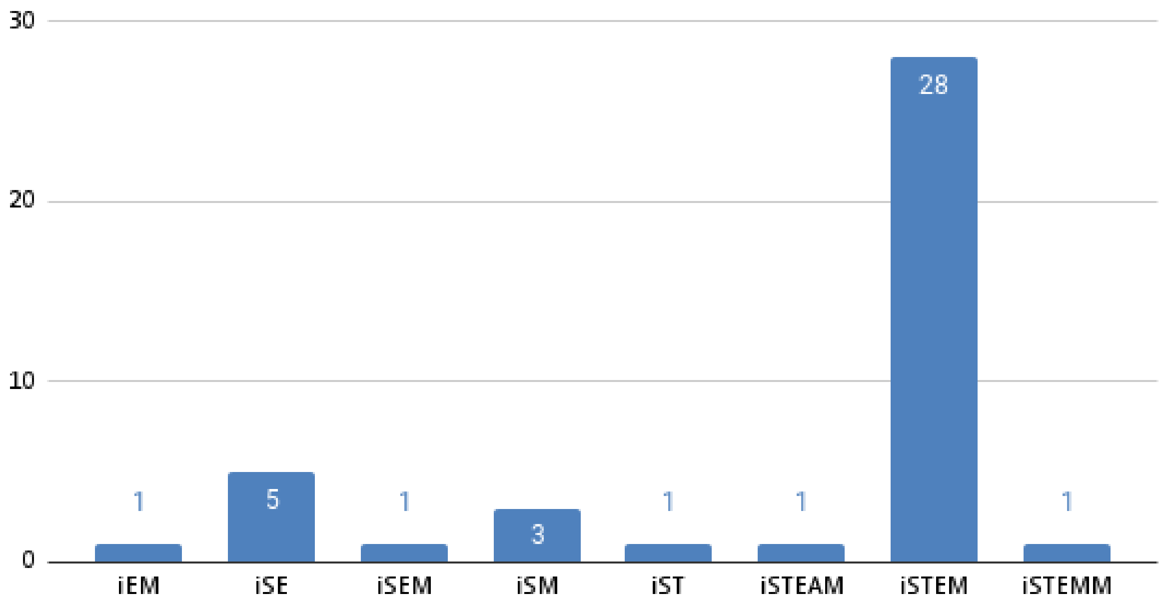


Figure 6 depicts the frequencies of iSTEM education research. In the case of iSTEM, science (97.6%) still occurs most often. However, engineering (87.8%) occurs more often than mathematics (85.4%) education research articles within iSTEM education. Finally, technology (75.6%) appears to occur least frequently within iSTEM education research.

FIGURE 6
FREQUENCIES OF ISTEM CODES



CONCLUSION

The focus of the analysis was on the United States. Many of the articles identified as being conducted within the United States also specified regions or states within the United States. In this case, these studies occurred in individual states such as Idaho (*n* = 1), Maryland (*n* = 1), Nebraska (*n* = 2), Pennsylvania (*n* = 1), Texas (*n* = 3), Tennessee (*n* = 1), and Virginia (*n* = 1). One study indicated they collected data from California, New York, North Carolina, Ohio, Tennessee, Texas, and Washington. The final 12 studies reported regions of the United States like Midwestern (*n* = 4), Northwest (*n* = 2), Southeastern (*n* = 4), Southern (*n* = 1), and Southwestern (*n* = 1). Further analysis could look more closely at these specific regions where populations are being studied to yield further insight into STEM education research being conducted in the United States.

Very few (*n* = 4) articles examined the connections between STEM education in K–12 and postsecondary education. Instead, the four postsecondary and K–12 focused on preservice teachers. None of the articles investigated STEM topics students might have learned in K–12 that might impact their achievement of STEM education at higher levels. Investigations involving this vertical alignment in STEM education and student achievement in STEM might better prepare future STEM students with the 21st-century skills they need to enter the STEM workforce successfully.

Furthermore, this study agreed with prior literature that most STEM education research had been conducted on siloed mathematics and science. However, engineering tends to be more prominent in iSTEM education research and occurs more frequently than mathematics in this field of study. Since engineering applies to multiple areas of science and mathematics, it tends to create a natural platform for integrating the other three STEM subjects. This could be a possible reason for the increased role of engineering in iSTEM education research.

In contrast, technology education research seems to fall behind its STEM counterparts. This lag could be due to the evolutionary nature of technology. This constantly changing field may make it challenging to teach in isolation, especially in K–12 schools that may not have the budget to keep up with the changing technologies or have qualified faculty who could teach technology classes. It is also possible that STEM education research does not consistently or correctly report technology education research. Some institutions might consider educational technology as technology education and mistakenly report it. Therefore, the numbers reported in this study might be inflated (despite the researchers' best efforts to catch any discrepancies in the literature). In either case, technology must be integrated into all the STEM subjects to help students become more proficient in using and learning about technology to meet the demands of the 21st-century workforce.

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