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Mathematics education and technology: Bibliometric analysis and systematic review (2000-2024)

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Abstract

The objective of the present study is to obtain an updated perspective of the state of education in mathematics and technology, as well as the emerging veins of research in these areas. The study began by selecting articles in the database Scopus, between 2000-2024, with the search criteria of "mathematics," "education" and "technology." 6,215 registries of articles were found. The analysis of the records was performed using data mining in R language. The United States is the leading country in publications and the University of California is the one with the highest production of articles. Three emerging lines of research were obtained. The first line of the investigation is related to gender and science, technology, engineering, and mathematics (STEM) graduate studies. The second line of research is related to motivation and permanence in STEM, including studies with secondary students' parents. The third emerging line of research is on mathematical identity in primary and secondary education.

Keywords: education, mathematics, STEM, data mining

INTRODUCTION

Future educational practices will include virtual classrooms, artificial intelligence, learning analytics, mobile applications, smart devices, extended reality, open educational resources, gamification, cloud computing, networked societies, the post-truth era, digital learning objects, and online collaboration. On the other hand, according to Simsek (2024), the use of social media, the metaverse, and portable technologies in education will decrease. Research in science, technology, engineering, and mathematics (STEM) focuses on the beliefs, experiences, and self-efficacy perceptions of participants, as well as on the effects of educational technology on learning. Furthermore, project-based learning and problem-solving are the teaching methods that stand out (Kondrashev et al., 2024).

STEM education comprises six components: disciplinary integration, the use of multiple representations, real and relevant problems, the application of engineering design, active collaboration, and student-centered learning approaches (Nugraha et al., 2024). However, Singh et al. (2024) found that university students have difficulty applying previously learned mathematical knowledge to solve mathematical problems. Similarly, they lack the skills to validate solutions and to face basic mathematical problems heuristically.

In an initiative involving secondary schools to promote STEM careers through fieldwork and conversations with scientists to enrich learning, a positive change in STEM aspirations was observed (Hale et al., 2024). Similarly, it has been found that in integrated STEM teaching, addressed topics are regularly limited, without considering the diversity of student interests. On the contrary, projects where students have autonomy in their choice are scarce, as stated by Tang et al. (2024). Furthermore, the greater the autonomy granted to students in project selection, the greater the degree of STEM integration, as the boundaries between areas are blurred by solving significant problems with an impact on the community.

Interdisciplinary projects influence students' collaborative skills, such as positive interdependence,

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Contribution to the literature

- Four clusters were formed in the bibliographic coupling: minorities in STEM, factors for choosing a career in STEM, STEM teaching in primary and secondary school, and integrated STEM education and teacher training to carry it out.
- In the network analysis carried out the seminal documents are about learning theories and contributions to statistics in behavioral sciences: Vygotsky's (1978) sociocultural theory, Papert's (1980) constructionist theory, Bandura's (1986) social learning theory, Lave and Wenger's (1991) situated learning theory and Cohen's (1988) work on the size of the effect when implementing a didactic proposal.
- The most recent research in the field is about: STEM area, information and communication technology (ICT) for teaching and learning, underrepresented groups and gender studies. In the bibliographic coupling and in the emerging lines of research, common actions were identified in primary and secondary school. The studies in primary and secondary school are aimed at motivating children and adolescents to study STEM degrees.

responsibility, promoting interaction, group processing, and social skills that contribute to STEM workforce training (Seo et al., 2024). In addition, training mentors in the development of scientific communication skills benefits students in both sociopsychological and behavioral aspects, as well as in scientific identity, communication fluency, and reconsidering STEM degrees (Cameron et al., 2024).

STEM education in early childhood has increased due to methods involving digital technology. However, it is necessary to implement STEM where the child perceives reality in a complex way, such as in an outdoor environment. Also, more reliable and valid digital and quantitative measurement instruments need to be developed (Revák et al., 2024). In addition, didactic sequences with a STEM focus in early childhood promote disciplinary integration, inquiry through the solution of real-life problems, and active interdisciplinary learning. However, the development of resources for the effective implementation of STEM didactic sequences must be increased, as well as specialized teacher training promoted (Rúa et al., 2024).

In science, technology, engineering, art, and mathematics (STEAM) education, teachers' experience and prior knowledge influence teaching and learning. In addition, teachers' attitudes contribute to innovation and student learning outcomes (Chu et al., 2024). However, in teacher training for STEAM, training programs lack courses that allow for the integration of sustainability and STEAM, with an interdisciplinary focus, and interventions are concentrated on mathematics and statistics. On the other hand, in-service teachers express difficulties in relating theory to real-life problems. Similarly, in educational strategies, teachers focus on problem-based or research-based learning, escape rooms, robotics, or flipped classrooms (Álvarez & Olatunde-Aiyedun, 2024).

Teachers have different strategies for integrating STEM disciplines in the classroom, such as inquiry and problem-solving based learning, through practical activities or by emphasizing real-life applications. However, the connection of concepts between disciplines is deficient, indicating the need for teacher training in STEM subjects (Ismail et al., 2024). Also, Flanagan et al. (2024) found difficulties in teachers' understanding of STEM education integrated at the elementary level. On the other hand, structured training, technology-based certification programs, and postgraduate studies in STEM improve teachers' skills in teaching STEM subjects (Mansour et al., 2024).

In online learning environments where teaching is student-centered, self-regulated learning is fundamental. Huh et al. (2024) point out that self-regulated learning is teachable, however, in a study of K-12 online schoolteachers in the United States, it was found that teachers provided direct guidance instead of supporting them in developing self-regulated learning. Similarly, Jarrah et al. (2024) determined that elementary mathematics teachers are willing to use technology for remote teaching, however, they prefer traditional teaching. In addition, difficulties were identified in achieving the projected student performance. In turn, Bandoh et al. (2024) mention that the factors that positively influence the use of technology by pre-university mathematics teachers are performance and effort expectations, as well as the availability of technological infrastructure. On the contrary, social influence negatively affects teachers' intention to adopt technology for teaching mathematics.

The representation of women is low in STEM areas. The choice and permanence of women in a STEM career face obstacles related to the balance between work, personal life, and professional development (Dori et al., 2024). In a study of African women leaders in STEM, it was found that they needed to balance family and work life, set goals, solve problems, be open to innovative ideas, recognize diversity, as well as collaborate, have research knowledge, and mentoring skills (Babalola et al., 2024). On the other hand, Akar et al. (2024) express that the professional development of women in the areas of information and communication technologies is influenced by irrational beliefs about employment,

Table 1. Criteria for Scopus search

Criteria	Selection
Years	2000-2024
Date of consultation	4 May 2024
Kind of documents	Articles
Kinds of journals	All kinds
Field of search	Article title, abstract, & keywords
Search equation	"mathematics" and "education" and "technology"
Registries	6,215

which is counteracted by fostering professional optimism and employability, thus contributing to a labor market where women have ambitious careers.

The importance of mathematics in the skills required in today's life leads to the objective of this study being to determine the current state of education in mathematics and technology, as well as to identify emerging lines of research.

METHODOLOGY

To carry out this research we began by consulting a database in which documents were selected in keeping with specific criteria (see **Table 1**). Later software was used for bibliometric analysis, analysis of the network and emerging lines of investigation.

The database where the search was carried out was Scopus, which is one the main hubs of academic publications (Schotten et al., 2017; Zhu & Liu, 2020).

The information was exported to BibTex and CSV files, including the information of citation, bibliography, abstract, keywords and references for bibliometric analysis. In the network analysis and to find emerging lines of research, the 500 most cited articles were obtained from the 6,215 in the file with RIS (research information systems) extension.

Bibliometric Analysis

We used the method of analysis proposed by Zupic and Cater (2015) to carry out an objective evaluation of the scientific literature, thus increasing the rigor of the research. This method consists of citation analysis, co-citation analysis, co-author analysis, co-word analysis, and bibliographic coupling analysis. The network of co-citations was obtained in the citation analysis. The co-author analysis determined the networks of collaboration among authors. The analysis of co-words shows the most used terms as keywords. The bibliographic coupling analysis identified the articles which share references.

The database analysis was carried out using data mining with Bibliometrix (https://www.bibliometrix.org/), an open coding tool for quantitative research in Scientometrics and Bibliometrics, to perform a comprehensive mapping of scientific literature. This tool was developed in R language (https://www.r-project.org/), a free programming language and environment focused on statistical analysis. Also, Bibliometrix (Aria & Cuccurullo, 2017) was used, which is a web application included in Bibliometrix and allows non-programmers to use Bibliometrix. In addition, VOSviewer software (https://www.vosviewer.com) was used to obtain the co-citation network, the co-word analysis and the bibliographic coupling. The VOSviewer software is a free tool to build and visualize bibliometric networks.

Network Analysis and Emerging Lines of Investigation

The network analysis was carried out with the proposal of Valencia-Herandez et al. (2020) and adaptations for using Scopus made by Robledo et al. (2020) by means of the graph theory proposed the creation of the tree of science (ToS). The platform created for the scientific analysis of the literature made by Zuluaga et al. (2022) was called the ToS (https://tos.coreofscience.com/). The analysis was carried out by means of the citation networks, considering three indicators as per Robledo et al. (2014), in-degree, betweenness, and out-degree. Articles with a high in-degree and zero out-degree are called the roots of the tree and are known as seminal articles. Moreover, the articles with a high degree of betweenness would form the trunk and correspond to the structure. The articles that make up the perspectives are called branches and formed of clusters. Finelly, the leaves of the tree are articles with a high out-degree and zero in-degree, representing the most recent research in the field.

The results of ToS identified in the roots and the trunk 20 documents in each, and from these the five documents with the most citations were chosen for analysis. Three branches with 15 documents each were obtained for each, recovering the 10 articles with the most citations for each branch for analysis. The leaves consisted of 50 articles of which the 21 most recent articles were chosen, that is, those from between 2020 and 4 May 2024 (the date of our consultation).

RESULTS

The bibliometric citation analysis study obtained the number of publications per year, the journals with the most articles, the main authors, countries, institutions, co-citations, co-authors, co-words and bibliographic coupling. The ToS analysis obtained three emerging lines of investigation.

Publications per Year

The results of the number of publications per year on mathematics, education and technology are shown in **Figure 1**. The analysis of the publications begins in the year 2000 and goes through 2024 (4 May 2024, the date

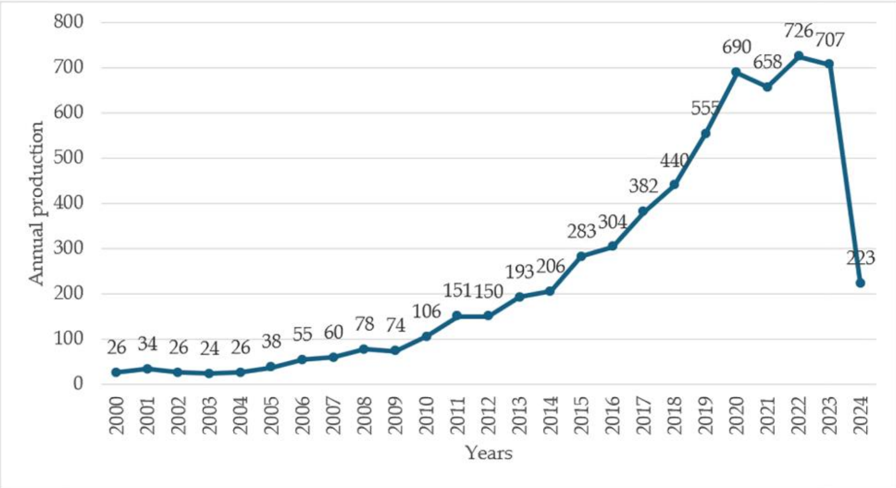

Figure 1. Number of articles published per year (Source: Authors' own elaboration)

Table 2. Journals with the largest production between 2000 and 2024

Journal	Articles	Quartile	SJR (2023)	h-index	Country
CBE–Life Sciences Education	170	Q1	1.318	90	United States
Education Sciences	107	Q2	0.669	53	Switzerland
Eurasia Journal of Mathematics, Science and Technology Education	88	Q2	0.451	56	Turkey
Sustainability	83	Q2	0.672	169	Switzerland
International Journal of Technology and Design Education	81	Q1	0.812	56	Netherlands
Frontiers in Education	77	Q2	0.627	40	Switzerland
Computers and Education	75	Q1	3.651	232	United Kingdom
Education and Information Technologies	62	Q1	1.301	76	United States
International Journal of Mathematical Education in Science and Technology	62	Q2	0.634	42	United Kingdom
International Journal of STEM Education	61	Q1	2.035	50	Switzerland

on which we consulted Scopus), giving as results a total of 6,215 articles. In 2000 26 publications were registered, with a slight annual increase each year until 2010 when the increase is greater, with a total of 547 articles for the years 2000 to 2010. The ascending tendency continued through the period, accumulating 5,668 publications from 2011 to 2024 with the largest number of publications in 2022 with 726 articles. The lower number of publications in 2024 is due to the date of our search on 4May 2024, with 223 articles written in the first four months of 2024.

Analysis of the Journals

The journals with the largest number of publications are presented in **Table 2**, which shows information on the 10 most important journals. The number of articles per journal. The quartile to which it belongs, the SJR index (2023), the h-index and the country of origin are also indicated. The quartile is an indicator to identify the importance of a journal with respect to the total number of journals in its area. The total number of journals in the area ordered from highest to lowest impact index is divided into four, thus integrating the quartiles. Quartile Q1 contains the journals with the highest impact index. **Table 2** shows that the journals belong to quartiles Q1 and Q2 (five in each quartile), showing that they are the most important in their area of knowledge.

The SCImago Journal Rank (SJR) index is an indicator developed by the SCImago research group with information from the Scopus database (Elsevier). This indicator determines the quality of scientific journals according to the citations obtained, weighing the importance of the journals from which these citations come. The index is calculated with the citations that the journals received in the last three years. The higher the SJR index, the more citations the journal has received from other prestigious journals, showing a higher level of influence and impact on the scientific community. **Table 2** shows that the Eurasia Journal of Mathematics, Science and Technology Education has the lowest SJR index with .451 and the highest SJR index (3.651) is the journal Computers and Education. In addition, **Table 2** shows that the journals with the highest SJR index are those belonging to the Q1 quartile.

The h-index is a bibliometric indicator used to measure research activity and the impact on dissemination. In journals, it is calculated by ordering the articles from the highest to the lowest number of citations and the h-index would be the number in which the order number coincides with the number of citations.

Table 3. Authors with the most production for 2000 to 2024

Author	Articles	Citations	h-index	Affiliation	Country
Lavicza, Z.	25	654	13	Johannes Kepler University Linz	Austria
Drijvers, P. H. M.	14	1,483	24	Freudenthal Institute	Netherlands
Capraro, M. M.	13	1,983	24	Texas A&M University	United States
Bouck, E. C.	12	2,509	27	Michigan State University	United States
Capraro, R. M.	12	2,077	24	Texas A&M University	United States
Houghton, T.	12	97	8	Johannes Kepler University Linz	Austria
Ng, O. L.	12	448	13	Chinese University of Hong Kong	Hong Kong
Wang, X.	12	1,308	17	University of Wisconsin-Madison	United States
Abramovich, S. M.	11	247	9	SUNY Potsdam	United States
Henderson, C. R.	11	4,367	32	Western Michigan University	United States

The h-index does not consider the quality of the journals, which is why **Table 2** shows journals with a high h-index that belong to the Q1 or Q2 quartile.

On the other hand, Switzerland is the country of origin of four journals, followed by the United States and the United Kingdom with two journals each. Although the United States contributes only two journals among the top-10, both journals are in the Q1 quartile and have an SJR index greater than one.

Analysis of Authors

The authors with the most articles published are shown in **Table 3**. The author with the most publications is Lavicza, Z. with 25 articles, followed by Drijvers, P. H. M. with 14, and Capraro, M. M. with 13. However, it is Henderson, C. R., who has the highest h-index (32) and at the same time the most citations with 4,367, among the 10 main authors.

Regarding the institutions where the 10 most prolific authors are affiliated (**Table 3**), it can be observed that both Johannes Kepler University Linz (Austria) and Texas A&M University (United States) are represented by two authors each. Furthermore, the United States is the country that dominates with six authors and, in second place, Austria with two authors.

Analysis of Countries or Regions

In the analysis of countries or regions with the greatest production of articles on the matter, the United States stands out with 5,965 contributions by institutions located in this country (see **Table 4**), representing 44% of the total number of contributions (13,553). The country in second place is China with 752 participations. As can be seen in **Table 4**, after the United States the rest of the countries or regions contributed less than 6% each. The United States and Canada, the two countries which make up North America are among the top-10 countries. In contrast, Latin America is represented only by Brazil and Africa only by South Africa.

In the network of collaboration of countries (see **Figure 2**), four clusters can be observed. The main cluster is red, led by the United States, which shows greatest collaboration with Canada and China. In contrast, Nigeria and the Philippines have the least collaboration within the cluster. Besides, this cluster is made up of countries from all continents, among them Japan, Turkey, Austria, Serbia, Iran, Israel, Saudi Arabia, Korea, New Zealand, India, United Arab Emirates, Thailand, Indonesia, Malaysia, Hong Kong and Singapore.

Table 4. Countries or regions with the most publication between 2000 and 2024

Country or region	Articles	Percentage (%)
United States	5,965	44.01
China	752	5.55
Spain	580	4.28
United Kingdom	496	3.66
Australia	489	3.61
Turkey	434	3.20
Malaysia	305	2.25
Canada	303	2.24
Brazil	265	1.95
South Africa	241	1.78
Other countries (106)	3,723	27.47
Total	13,553	100

The second most important cluster in green is made up mainly of European countries or regions (see **Figure 2**). The strongest collaboration is between the United Kingdom, Germany, Italy, Australia and South Africa. The countries with the weakest collaboration Are Slovenia and Kazakhstan. Within this cluster we also find the Netherlands, Finland, Greece, Belgum, France, Portugal, Denmark, Norway, Ireland, Switzerland, Poland and Cyprus.

Another cluster which is shown in blue is made up of Spanish-speaking countries, with the exception of Brazil. Although in this cluster there are only six countries, the collaboration among Colombia, Chile, Mexico, Brazil and Spain is important. In this cluster we find Peru which has weaker collaboration (**Figure 2**).

The purple cluster is made up of three countries (**Figure 2**), the Czech Republic, Slovakia and Ukraine which all have common borders. The first two countries are in Central Europe and the third is in Eastern Europe. The strongest collaboration is between the Czech Republic and Slovakia while Ukraine has less collaboration.

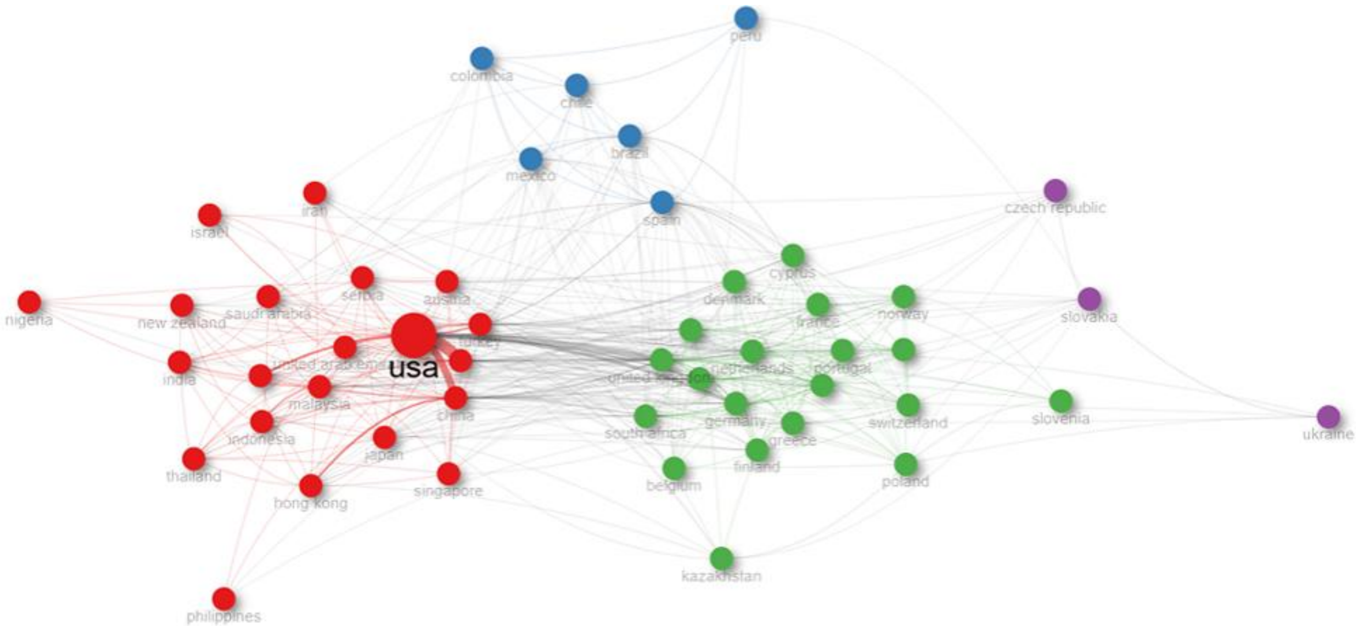

Figure 2. Network of collaboration among countries or regions (Source: Authors' own elaboration)

Table 5. Institutions with the greatest production between 2000 and 2024

Affiliation	Articles	Percentage (%)	Country
University of California	178	1.31	United States
Purdue University	115	0.85	United States
Michigan State University	78	0.57	United States
University of Michigan	74	0.54	United States
University of Georgia	63	0.46	United States
Vanderbilt University	62	0.46	United States
Northwestern University	59	0.43	United States
Arizona State University	56	0.41	United States
Texas A&M University	54	0.40	United States
University of Minnesota	53	0.39	United States
Other institutions (5,070)	12,823	94.18	
Total	13,615	100	

Analysis of Institutions

Table 5 presents the ten institutions with the highest number of published articles. All ten affiliations are universities in the United States, with the University of California listed in first position with 178 articles (1.31% of total production). Also, it can be observed that the rest of the universities are below 1%, with Purdue University being the closest to the University of California with 115 publications.

In relation to the collaboration between institutions, various clusters were identified (see **Figure 3**). The most important cluster, marked in green, is led by the University of California and is made up of 15 institutions, all in the United States. In addition, greater collaboration is shown between the University of California, Northwestern University, Columbia University, the University of Wisconsin-Madison, Stanford University, Cornell University, Michigan State University and Vanderbilt University. In contrast, Pennsylvania State University is the one with weakest relation within the cluster.

The purple cluster is made up of 13 institutions in the United States (see **Figure 3**). Purdue University predominates the cluster and has established close collaboration with the University of Pittsburgh and the University of Colorado. The weakest relationship of collaboration is with Clemson University. Also, in this cluster we find the University of Michigan, Iowa State University, the University of Florida, Ohio State University, George Mason University, the University of South Florida, Oregon State University, Indiana University and North Carolina State University. However, we may observe important collaboration between the university of Michigan and Michigan State University, which are found in different clusters. Likewise, Purdue University has a close collaboration with Arizona State University which is another cluster.

Anther relevant cluster is the brown one which is made up of only three institutions, Arizona State University, the University of Washington and Florida State University, all in the United States. Within this cluster we may observe the great collaboration between

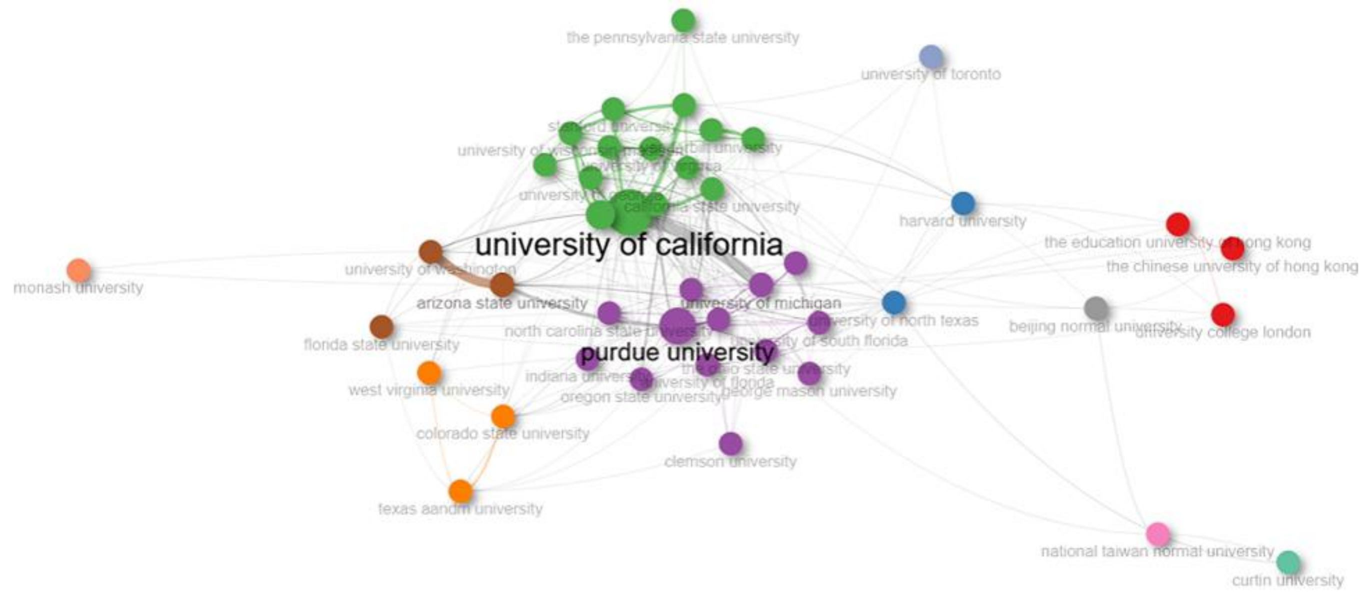

Figure 3. Network of collaboration among institutions (Source: Authors' own elaboration)

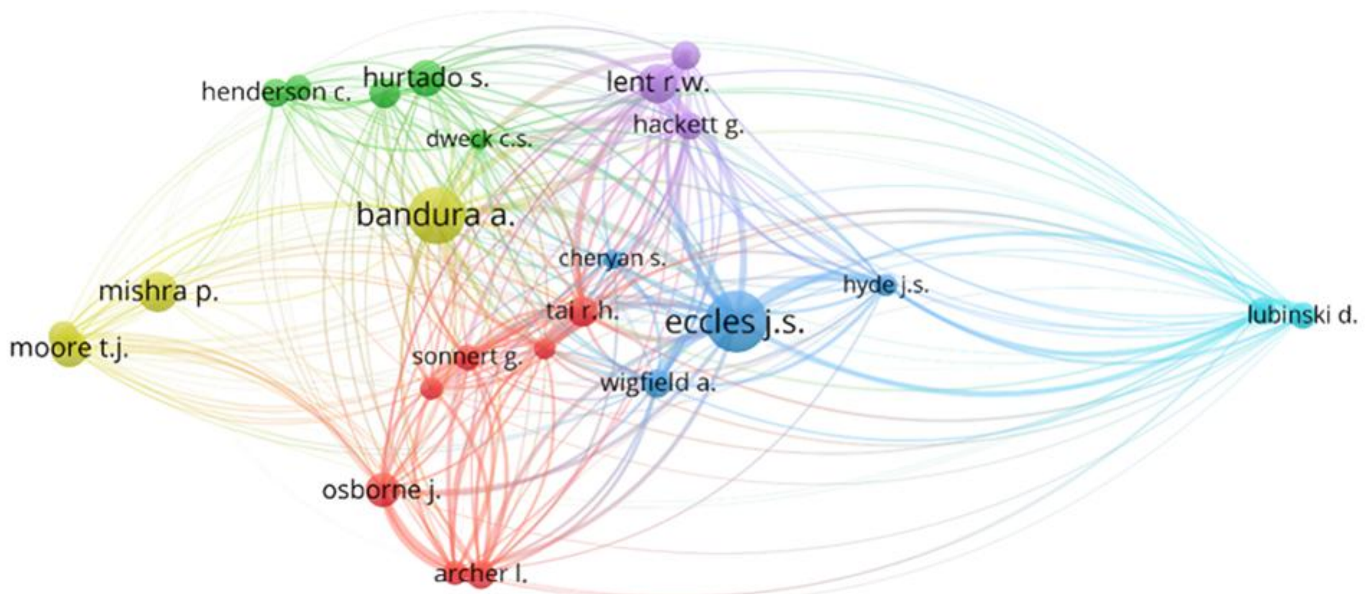

Figure 4. Network of co-citations (Source: Authors' own elaboration)

Arizona State University and the University of Washington, shown by the thick line which joins the circles (see **Figure 3**).

The red cluster in **Figure 3** is made up of three universities, one in England (University College London) and two in China (The Chinese University of Hong Kong and The Education University of Hong Kong). The relationship of collaboration among these three institutions is similar; there is not one that dominates.

It is important to point out that there are institutions in various countries which are not included in the clusters, but which share important collaboration with the aforementioned clusters. Among these are Curtin University (Australia), Monash University (Australia), National Taiwan Normal University (Taiwan), University of Toronto (Canada) and Beijing Normal University (China).

Analysis of Co-Citations

A network of 25 authors was obtained in the analysis of co-citations with the most co-citations (see **Figure 4**). In the network each node represents an author, and the larger the node and the author's name, the more citations it indicates.

The author who stands out in the network of co-citations (**Figure 4**) is Eccles, J. S. from the University of California (United States), who conducts research on gender roles, teacher expectations, the influence of the classroom environment on student motivation, and social development in the school and family context. In addition, we find her contribution to the expectancy-

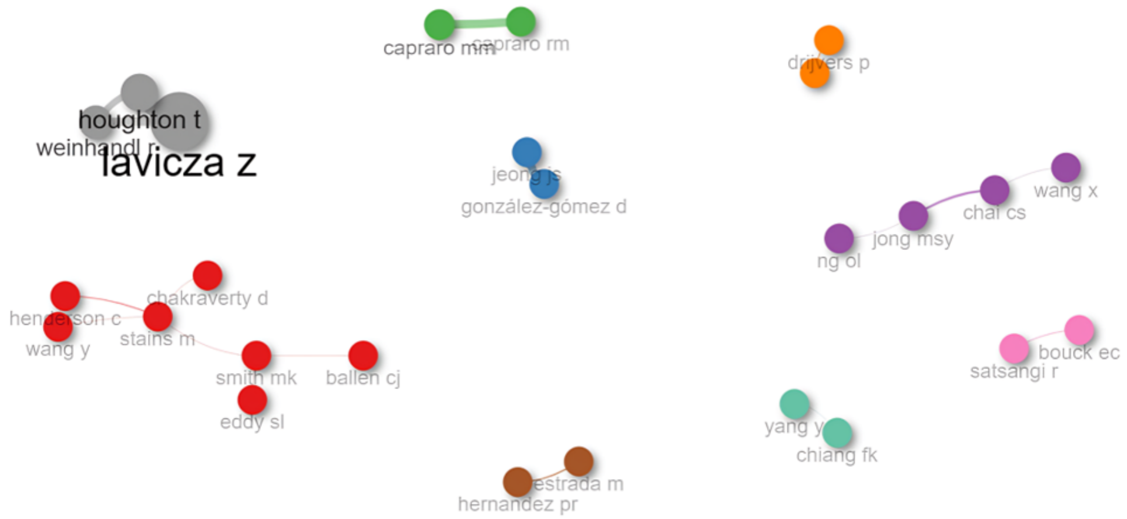

Figure 5. Network of collaboration among authors (Source: Authors' own elaboration)

value theory of motivation and her concept of setting-scenario are the most important models on academic performance (Eccles, 2014; Eccles & Wigfield, 2023, 2024; Eccles et al., 2015; Wigfield & Eccles, 2023, 2024). The second most outstanding author is Bandura, A. from Stanford University (United States) who developed the theory of social learning, studied self-efficacy, cognitive processes in behavioral changes, and reinforcement (Bandura, 1976, 1977, 1978a, 1978b, 1982; Bandura & Adams, 1977; Bandura et al., 1977).

Analysis of Co-Authors

Figure 5 shows the collaboration network among authors, where three groups stand out, two for their impact and the third for the number of authors who collaborate. The most important collaboration group is the one made up of Lavicza, Z., Houghton, T., and Weinhandl, R. all three from Johannes Kepler University Linz in Austria. In addition, two of the authors belong to the 10 authors with the highest number of publications (see **Table 3**), occupying the first and sixth positions.

The second group that stands out in terms of collaboration between authors (see **Figure 5**) is that formed by Capraro, M. M. and Capraro, R. M., both from Texas A&M University in the United States. The two researchers are among the 10 authors with the highest number of published articles (see **Table 3**), ranking third and fifth. Also, Texas A&M University is one of the ten universities with the highest production of articles (see **Table 5**). Likewise, the two authors are affiliated with universities in the United States, which is the leading country in published articles (see **Table 4**). However, the third group gains relevance due to the number of authors who collaborate with each other. The group consists of Wang, X. (University of Wisconsin-Madison), Henderson, C. R. (Western Michigan University), Stains, M. (University of Virginia), Eddy, S. L. (University of Minnesota Twin Cities), Ballen, C. J. (Auburn University), Smith, M. K. (Cornell University), and Chakraverty, D. (Indian Institute of Management Ahmedabad). In this group, the first two authors are among the top-10 authors with the most publications (see **Table 3**). Furthermore, six of the seven authors have affiliations with universities in the United States, and only one is from a university in India.

Analysis of Co-Words

The co-word network corresponds to the keywords of each article. Using data mining analysis, a network is created that is shown in **Figure 6**. In the co-word network, seven groups are identified with different colors. The size of the circle represents the number of repetitions of that word. The larger the circle, the greater the repetition of that keyword; on the contrary, the smaller the circle, the less that keyword is present.

In the co-word network (see **Figure 6**), the largest group is the red one, called group 1, and includes the keywords: mathematics education, engineering education, curriculum, STEM technologies, teaching and learning, STEM, and professional aspects. Group two (green) includes mathematics, humans, learning, adolescents, male, female, child, and psychology. Group three (blue) is about minority groups, mentors, career choice, decision making, diversity, and equity. Group four (yellow) includes engineering, science, students, universities, research, curriculum, human, and technology. Cluster five (purple) comprises the terms education, gender, academic performance, sustainability, perception, science and technology. Cluster six (blue-green) deals with high school, achievement, academic motivation, competition, family and parents. Cluster seven (orange), the smallest cluster refers to students and underrepresented groups, community college, socioeconomic status, social status and employability.

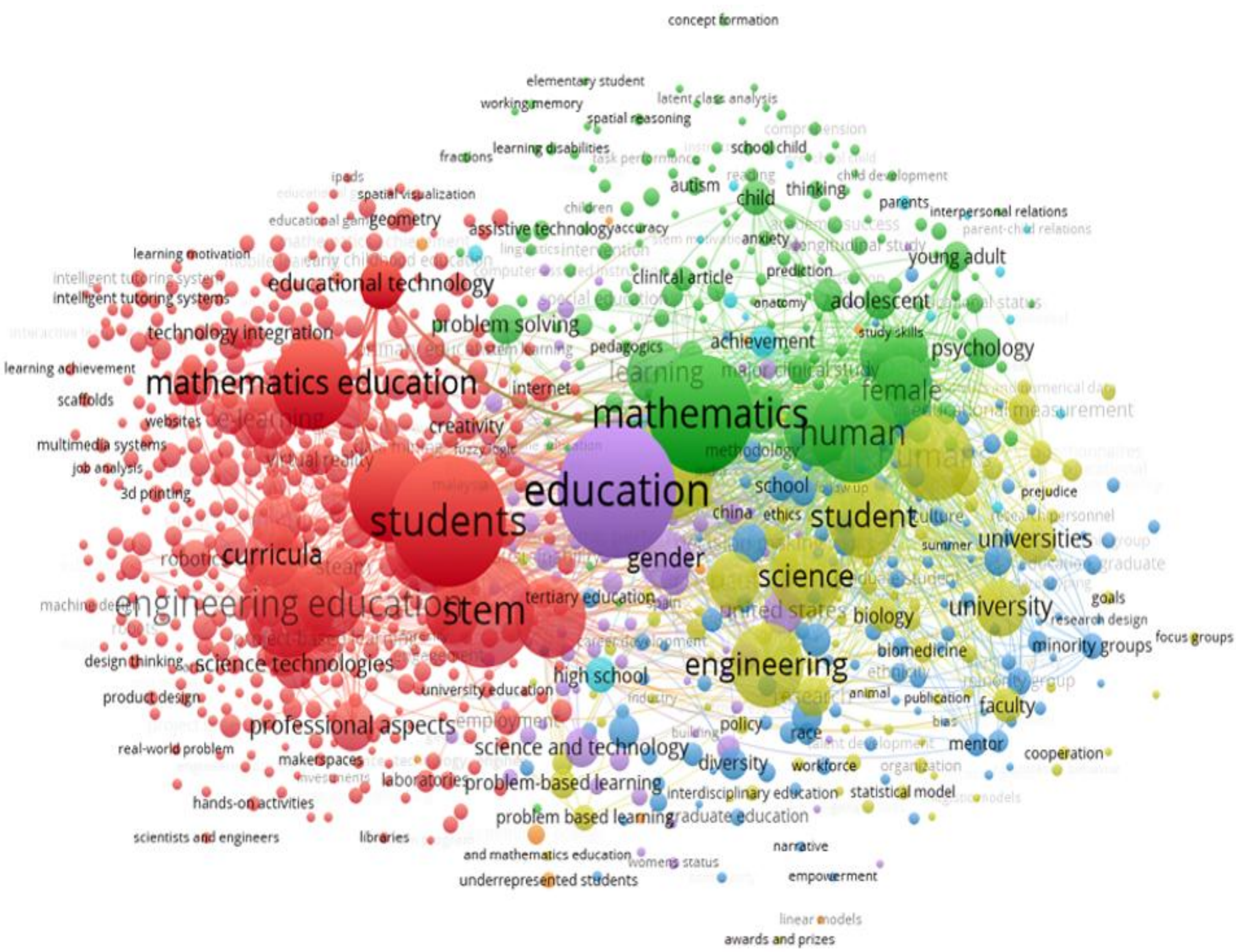

Figure 6. Network of co-words (Source: Authors' own elaboration)

Bibliographic Coupling

In bibliographic coupling, articles that share references are identified. **Figure 7** shows the bibliographic coupling network that was created in which four groups were formed. Each group is identified with a different color and the larger the circle, the greater the bibliographic coupling.

In the bibliographic coupling network (see **Figure 7**), group one is identified in yellow and is about minorities in STEM. In this group, work by Freeman et al. (2014) stands out. They conducted a meta-analysis with 225 studies where they compared the performance of students with traditional learning and active learning. The results indicated that grade point averages improved by about 6% with active learning and students with traditional learning had 1.5 times more failure rates than students with active learning. Another article that emerges is Estrada et al. (2016) where they study how to improve persistence in minority students in STEM programs. Estrada et al. (2016) propose eliminating institutional barriers to admission and identifying interventions that increase students' interest, commitment, and ability to continue in STEM programs. In addition, Estrada et al. (2018) in a longitudinal investigation determined that quality mentoring and research experiences in junior and senior years favor the integration of underrepresented minorities in STEM programs. Similarly, Eagan et al. (2013) present a study on the impact of undergraduate research programs on minority groups and how these significantly influence the possibility of continuing with a STEM graduate degree. Also, Ong et al. (2018) conducted work on marginalized groups, specifically women of color and their persistence in STEM.

Group two (green color) covers the reasons for choosing a STEM career. Maltese and Tai (2011) stand out with an investigation on school factors that influence students to choose a STEM program. In the results they found that the decision is made by students during high school and is based on their interest in mathematics and science, rather than on enrollment and performance in advanced courses. Likewise, another important study in this group is Wang (2013) who investigates the reasons that students have for choosing a STEM program. The findings show that choosing a STEM major is directly related to math performance in 12th grade, taking math and science courses, and the belief in math self-efficacy.

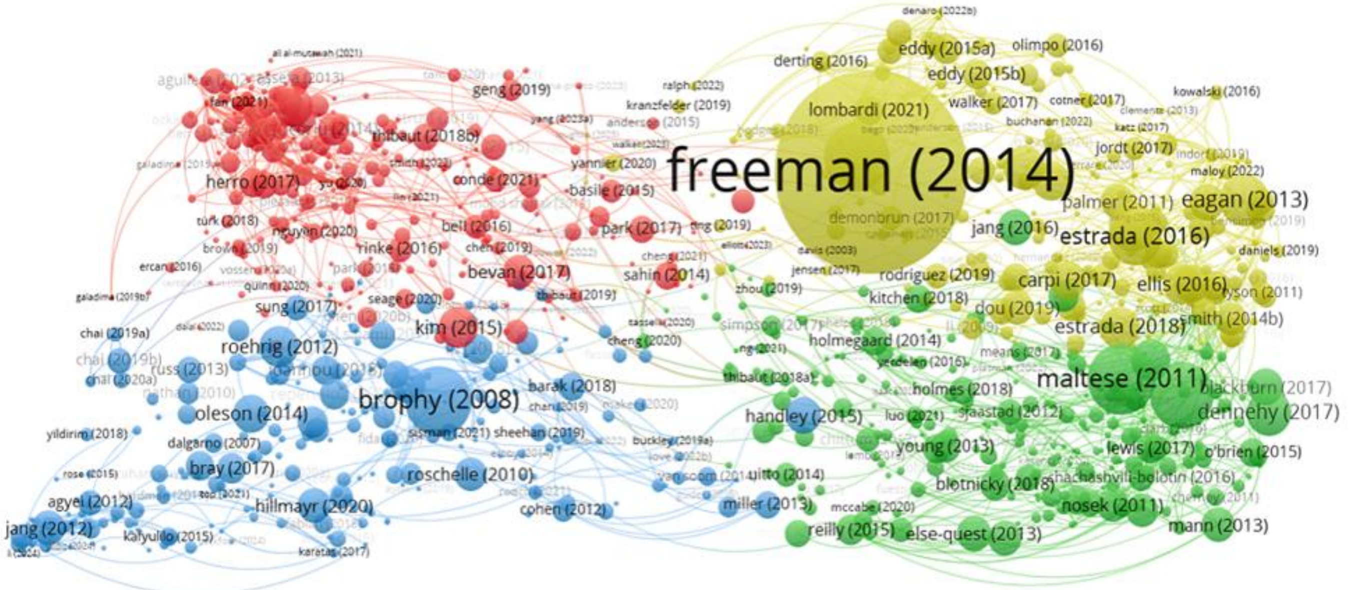

Figure 7. Bibliographic coupling (Source: Authors' own elaboration)

The positive impact of these factors accumulates mainly in white students and less in underrepresented minority students. Dennehy and Dasgupta (2017) point out that peer mentors at the beginning of college positively increase the experience and retention of women in engineering. Also, Hernandez et al. (2013) conducted a longitudinal study of interventions that motivate the participation of underrepresented students in STEM. In turn, Jang (2016) investigates the competencies that students should develop in STEM.

Group three (blue) is about STEM teaching in primary and secondary school. Brophy et al. (2008) stands out with the research where they present instructional models to teach engineering in K-12 classes. Also, Roehrig et al. (2012) is important with the study on the integration of STEM education by secondary school teachers during a school year. Similarly, Oleson and Hora (2014) through qualitative methods study how STEM teachers teach. On the other hand, Handley et al. E2015) study the gender bias against women in STEM areas. In turn, Hillmayr et al. (2020), conducted a meta-analysis on the use of digital tools in the learning of mathematics and science in secondary school. Similarly, Jang and Tsai (2012) investigate the technological pedagogical content knowledge model at the primary level in mathematics and science teachers with the use of interactive whiteboards.

Group four (red) includes integrated STEM and teacher training. It is represented by several studies such as that of Shernoff et al. (2017) on assessment in teacher training and professional development in integrated STEM education. Another research is that of Corlu et al. (2014) who propose a model for STEM education emphasizing integrated knowledge of the teacher. Integrated STEM education is also studied by Maass et al. (2019), where they point out that mathematics is underestimated within STEM and propose three interdisciplinary approaches to promote it. In turn, Herro and Quigley (2017) carried out research on teacher perspectives and practices before and after participating in professional development for STEAM integration. Kim and Bolger (2017) stand out with the study on the change in attitudes of primary school students toward teachers in the integration of STEAM pedagogy to develop lesson plans.

Network Analysis and Emerging Lines of Research

Network analysis selected articles with the highest number of citations on the results of ToS and thus constructed the tree diagram presented in **Figure 8**. The tree shows the articles that correspond to the root (seminal articles), the trunk (articles that cite the seminal documents and are cited by recent studies), the branches (the research perspectives) and the leaves (recent research). To select the documents that make up the tree, the most cited documents were identified from the list obtained in ToS for each category, in the roots (5 documents), in the trunk (5 articles), in the branches (10 articles in each of the three branches), and in the leaves (21 articles). The research perspectives or emerging lines were called gender and STEM postgraduate studies, motivation and permanence in STEM, and the third, mathematical identity.

Roots

The first document reviewed in the roots is that of Vygotsky (1978). This book is a compendium of manuscripts and conferences where concepts about what would later be known as Vygotsky's (1978) theory are presented. This theory states that social and cultural interaction influences people's thinking and behavior and is therefore fundamental for cognitive development.

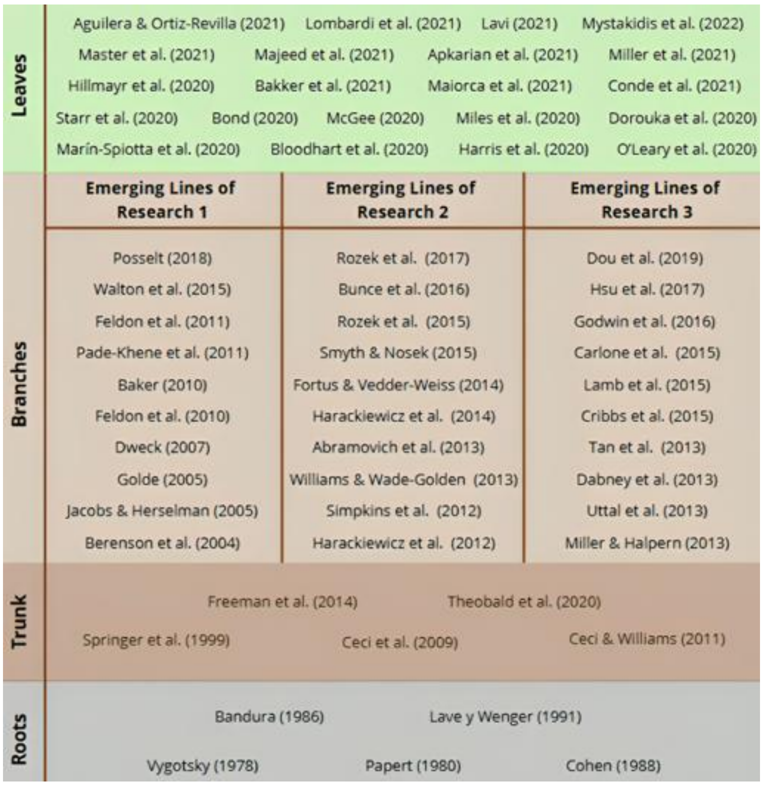

Figure 8. ToS tree diagram (Source: Authors' own elaboration)

In addition, it states that learning is a process that takes place in a social and cultural context, and not individually.

Another of the seminal documents is that of Papert (1980), where the basic ideas of learning are presented through constructionism. In this theory it is stated that one learns by doing, where motivation and interest contribute as essential elements for learning. He also states that technology is a tool that allows constructions to be made. Likewise, he points out that each individual is responsible for his own learning.

On the other hand, Cohen (1988) joins the seminal documents in this research with contributions on statistics for behavioral sciences. This book describes and proposes statistical parameters to measure the strength of a phenomenon, that is, the size of the effect. Also, criteria are established to define whether the size of the effect is small, medium, large or very large.

The fourth seminal document is by Bandura (1986) and presents the theory of social learning. This theory states that children learn through social contexts, that is, through observation and imitation of behavior. Likewise, it indicates that the learning process is affected by the mental state, however, when something is learned this does not mean that a change in behavior will occur.

Finally, there is the seminal document by Lave and Wenger (1991) where they present the theory of situated learning. This theory mentions that learning occurs in a real context, where the student interacts with the environment. In addition, it is mentioned that practice, trial and error are required to obtain skills that arise with experience. Additionally, collaborative work, where individuals interact with each other and with their surroundings is essential for learning.

Four learning theories emerged as seminal articles in the roots. These theories address learning from childhood and are taken up at all educational levels. In addition, to determine the size of the effect in the studies or didactic proposals, Cohen's (1988) contribution emerges as a seminal study.

Trunk

The trunk includes studies that cite the documents of the roots and, in turn, are cited by research that makes up the branches and leaves. The trunk of the tree is made up of five studies, the first to be reviewed is that of Springer et al. (1999) who develop a meta-analysis on the effects on learning by small undergraduate groups in STEM. The study shows that diverse small learning groups in addition to improving academic achievement, favor the attitude towards learning and increase persistence in undergraduate courses in STEM.

On the other hand, Ceci et al. (2009) present research on the underrepresentation of women in intensive mathematics. In the study, they indicate that, although biological and sociocultural causes are mentioned, these are not conclusive. However, they expose factors that contribute to the underrepresentation of women in the field of mathematics, one of which is that women with a good command of mathematics prefer other areas and, in addition, are more likely to abandon careers with a program requiring many studies in mathematics.

Another factor is that men obtain higher scores in exams or control tests in mathematics. A third factor is that women with high mathematical competence also have a high verbal competence and therefore have a greater range of professions to choose from. A fourth factor is that women with children are penalized when obtaining promotions at work. Finally, they mention that a secondary factor is that performance in control tests is due to sociocultural rather than biological causes.

Another study that is part of the structural documents is Ceci and Williams (2011) and also addresses the underrepresentation of women in mathematics-intensive fields. In the research, they review data from the last 20 years of complaints about discrimination and the arguments presented and conclude that some of these claims no longer correspond to the current situation. Therefore, options are proposed to contribute to gender equity based on current and not historical findings.

An article that forms the core is that of Freeman et al. (2014), where through a meta-analysis of 225 studies, they compare the performance of undergraduate students in STEM with traditional teaching and active learning.

In the study, they found that exam performance increases with active learning and that failure in traditional classes increases by 55% compared to active learning. In the analysis, they also determined that the results are similar in all STEM disciplines and that active learning is effective for all class sizes, but a greater effect is obtained in classes of 50 students or less.

The fifth article that makes up the trunk of the tree is the study by Theobald et al. (2020) where the performance of underrepresented and overrepresented students is compared with education using active learning and traditional teaching. The analysis included 15 studies with test scores and 26 studies with student failure data. The results show that with active learning the gap in performance with test scores was reduced by 33% and in terms of passing, the gap was reduced by 45%. However, they point out that only classes where high-intensity active learning was applied with inclusive teaching reduced the performance gaps.

Branches

The emerging lines of research are reflected in the branches of the tree. In the analysis using ToS, three branches were obtained, from which ten of the most cited articles in each branch were analyzed. In turn, with the analysis of the articles that make up each emerging line, a name was designated according to the theme, identifying them as gender and STEM postgraduate studies, motivation and permanence in STEM, and mathematical identity.

Emerging line: Gender and STEM graduate studies: The first article reviewed is that of Walton et al. (2015), who conducted a randomized controlled trial of short interventions to reduce the cold atmosphere faced by women in engineering. The results of the proposal had a greater effect in careers where women represented less than 20% and, in addition, grade point averages increased for women, eliminating gender differences. In turn, women acquired skills to cope with daily adversities and improved their attitudes toward academic activities. Similarly, Dweck (2007) investigated the gender difference in learning mathematics. In the study, she proposes that it is due to a gender difference in the way of dealing with difficulties and confusion, and not due to mathematical ability. On the other hand, Berenson et al. (2004) conducted a study on collaboration between women in an advanced software course. The findings identified the importance of face-to-face meetings, increased confidence in product quality, and a reduction in the amount of time required for tasks.

Another line of research is formed by several studies, such as Baker (2010), who, through development networks and sociocultural perspectives on learning, proposes an approach to analyze doctoral studies as a path for teachers. Through the approach, the relationship between what students learn during postgraduate studies, including their role as teachers and the formation of their professional identity, is determined. On the other hand, Golde (2005) studies the dropout rate of doctoral students. He establishes that poor academic integration is the cause of dropout. In addition, he points out that both universities and institutes, as well as national organizations in each discipline, lack adequate academic integration. Similarly, Posselt (2018) investigates the role of teacher mentoring in doctoral education. Teacher support promotes intellectual growth, professional socialization, and independence. It is also stated that teachers can prevent students from confusing difficulties at school with their ability to achieve success.

Feldon et al. (2011) studied the methodological research skills of graduate students in STEM areas. The results showed that students who are teaching improved significantly in generating testable hypotheses and designing valid experiments. Therefore, they conclude that teaching experience can favor research skills. In this same line of research, Feldon et al. (2010) conducted a study to determine the influence of instruction on scientific research skills in STEM students. To do so, they provided instruction based on cognitive task analysis to a group of students (treatment) and another group with traditional instruction (control). The results indicate that students with traditional instruction are almost six times more likely to drop out of the course compared to the treatment group. On the other hand, students in the treatment group showed significantly higher performance in formulating conclusions, with alternative explanations, exposing design limitations and implications for research.

On the other hand, in this line of research, support with ICT in rural communities also emerges. The study by Pade-Khene et al. (2011) proposes a model for managing ICT projects in rural areas of developing countries. The model includes sustainability criteria that involve the implementation of information and communication technologies in mathematics education. In turn, Jacobs and Herselman (2005) propose establishing centers that provide integrated ICT services in rural communities, a physical center with infrastructure to provide advice on desktop publishing, business support, application development, training and information services to the community. In this way, the rural community can manage its own development because they have ICT.

Emerging line: Motivation and permanence in STEM: Names such as Brunce et al. (2016) who studied the consumer orientation of students in higher education and the relationship with academic performance appear. They found that the greatest consumer orientation is associated with lower academic performance. Abramovich et al. (2013) studied the educational insignias as an alternate evaluation to increase student motivation. The study was carried out using insignias in an intelligent tutorial system for learning applied mathematics at the secondary school level. The results showed that the insignias could have a positive effect on students' motivation. The patterns for obtaining insignias varied among the students with varying levels of previous knowledge. They point out that the educational insignias should be developed considering students' capabilities and motivations. Moreover, there are studies such as those by Williams and Wade-Golden (2013) which focus on the directives of diversity in higher education. In the study they define the necessary skills, knowledge and experience the directive of diversity should have in order to be effective.

Another line of investigation emerges with Simpkins et al. (2012) on the associations between the parents' beliefs and the behavior toward the young people's achievements. In the study, they determined that mothers' beliefs in sports, music, and mathematics positively predicted youths' motivational beliefs in these areas. In turn, Harackiewicz et al. (2012) conducted an intervention with parents of high school students to convey to them the importance of selecting STEM courses. The results indicated that students whose parents participated in the experimental group opted on average for almost one more semester of science and mathematics compared to the control group. Similarly, Rozek et al. (2015) analyzed the results obtained with a utility-value intervention that was implemented with parents of high school students to motivate their children to study advanced science and mathematics courses. The findings showed that the intervention to motivate taking STEM courses was more effective in high-achieving girls and low-achieving boys. However, an increase in STEM courses was not obtained in low-achieving daughters. Rozek et al (2017) also evaluated the long-term effects of parents' intervention with secondary students to help them transmit the importance of mathematics and science courses. Findings showed that intervention managed to improve the grades in standardized tests in mathematics and science, which is an exam for university preparation. Besides, improved preparation in STEM during secondary education is associate with a better search for STEM areas of university studies. Therefore, they conclude that a motivational intervention by the parents can improve students' STEM secondary preparation and their continuing on to university education in STEM.

A line of research on student motivation and retention in STEM areas is created with studies such as that of Fortus and Vedder-Weiss (2014) on the continuous motivation of students for learning science. Continuous motivation can be reflected in carrying out extracurricular activities on science that are not related to school or other requirements. In the study, they develop an instrument to measure continuous motivation in learning science and its relationship with school, grades and gender. In the results during its implementation, they found less continuous motivation in women. Similarly, Harackiewicz et al. (2014) conducted a study on how to promote STEM courses for students and their permanence in them. The work focuses on students' perceptions of the value of academic tasks and personal values during the school stage. In the analysis of different interventions, they conclude that motivational processes must be specific to be effective with specific groups or contexts. On the other hand, Smyth and Nosek (2015) investigate whether the variation in the proportions of women in scientific disciplines is related to explicit or implicit stereotypes that favor men. In the research, they hypothesize that stereotypes of science as masculine are weaker where women are better represented. In the results, they obtained that the explicit stereotype confirms the hypothesis, but the implicit stereotype is related to the scientific values of women in the disciplines.

Emerging lines: Mathematical identity: Along this line, studies on mathematics identity emerge, such as that of Godwin et al. (2016) on identities in mathematics and physics, as well as students' beliefs about the ability of science to improve the world can predict the choice of a career in engineering. In the results, they found that both the identities and beliefs of students are significant predictors for the choice of an engineering career. Similarly, Dou et al. (2019) studied the relationship between STEM experiences in childhood, STEM identity and the intention to study a university career. The findings indicate that STEM identity is a predictor for studying a STEM career. In turn, carrying out informal activities about STEM were also predictive for STEM identity during university.

In the same line of research, Cribbs et al. (2015) studied students' beliefs about their competence in mathematics. The results showed that self-perceptions about competence and performance in mathematics are not sufficient for the development of mathematical identity. However, the association between students' interest and external recognition in mathematics and mathematical identity stands out. On the other hand, Dabney et al. (2013) analyze family influence and students' initial interest in the study of science. The findings indicate that family interest fosters initial interest in science. They later determined that parents' occupation was previously the influence, while currently it is occupation, fun or hobby and approval.

Other contributions are those of Lamb et al. (2015) who review the relationship between cognition, the affective aspect and the STEM content integrated into the primary and secondary school curriculum. The findings showed differences between experimental and control groups in the constructs of self-efficacy, scientific interest, spatial visualization and mental rotation. The evidence found suggests that the inclusion of integrated STEM learning in primary school is significantly important as students' progress in school. Also, Hsu et al. (2017) analyze the incorporation of augmented reality of students to explore surgery. The results indicated a positive perception in the lessons and simulators. In turn, motivation and commitment were also high, which is why it is concluded that interest in studying for a career in STEM increased.

In addition, Uttal et al. (2013) studied spatial thinking and how it can improve achievement in STEM areas. In the results they obtained that the effect of spatial training could last for months in similar tasks and they also found works that indicate an increase in learning in STEM. In addition, Miller and Halpern (2013) investigated the benefits of spatial training in students of STEM careers. The results showed improvement in spatial skills in talented students, in turn reducing gender differences. Also, an increase of one third of the grade in the physics course was obtained. However, no differences were detected eight months after training. The researchers suggest carrying out spatial activities for several semesters or years to reduce gender gaps in STEM.

On the other hand, Tan et al. (2013) investigate the low representation of non-white girls in STEM. In the study, they analyze the identities of non-white high school girls whose goals are STEM-related fields. In the results, they obtained both the obstacles and the support structures that girls require to follow a path in STEM. In addition, Carlone et al. (2015) study gender as a discursive performance. In the research, they analyzed the data of girls in science and found that gender, race, and class structures stand out over time. In addition, the thematic positions in the classroom are narrow, leaving no room to be both feminine and scientific.

Leaves

The leaves in the science tree correspond to the most recent and cutting-edge articles in this area. The ToS analysis identified 50 leaves, from which the most recent articles were selected, from the year 2020 to May 4, 2024 (21 articles).

In relation to STEM, the study by Lavi (2021) was found, which investigates the development of 21st century skills in STEM students. In turn, Majeed et al. (2021) analyze the impact of STEM education on creative thinking and performance in mathematics. Also, Bakker et al. (2021) study what topics educational research in mathematics should focus on in the next decade. On the other hand, Maiorca et al. (2021) investigate the influence of a STEM educational experience in high school students on their interest in studying a STEM career. Similarly, Aguilera and Ortiz-Revilla (2021) analyze educational interventions with STEM and STEAM to determine their ability to develop creativity in students.

Regarding the use of technology for teaching and learning, several studies were identified, such as that of Mystakidis et al. (2022) who carry out a systematic review on the use of augmented reality applications in STEM at a higher level. In turn, Dorouka et al. (2020) investigate smart mobile devices and applications for early childhood education. Also, we find Hillmayr et al. (2020) through a meta-analysis study how technology can improve learning in mathematics and science at the secondary level.

Now, in reference to teaching-learning approaches, there are works such as that of Starr et al. (2020) who study the scientific practices in the classroom of STEM students in relation to motivation, identity and academic performance. On the other hand, Bond (2020) conducts a systematic review on the flipped learning approach in primary and secondary education. In relation to active learning, Lombardi et al. (2021) analyze its construction in STEM. Likewise, Apkarian et al. (2021) study active learning in introductory STEM courses. Also, Conde et al. (2021) carried out a systematic mapping to identify how active learning in robotics and mechatronics is applied in STEAM education.

Studies on underrepresented groups are presented by Harris et al. (2020) who investigate the abandonment of underrepresented groups from STEM careers. In turn, Miles et al. (2020) analyze racial microaggressions in black STEM PhD students. Also, McGee (2020) studies the racialized structure of higher education in STEM. Similarly, Marín-Spiotta et al. (2020) review the historical structures of exclusion in geosciences and other STEM fields. On the other hand, O'Leary et al. (2020) consider teacher training as an alternative to transform STEM classrooms into more inclusive areas.

In research on gender, there is Master et al. (2021) who study the social stereotype that girls are less interested in computer science and engineering than boys. In addition, Miller et al. (2021) analyze educational experiences with minoritized sexual and/or gender identities in STEM. Also, Bloodhart et al. (2020) investigate gender biases in STEM careers.

CONCLUSIONS

The objective of this research is to first establish the current state of education in mathematics and technology, and for this purpose a bibliometric study was carried out. Subsequently, to obtain the emerging lines of research, a ToS analysis was carried out.

In the bibliometric analysis, the number of articles per year was determined, where the year 2022 stands out with 726 documents, followed by the year 2023 with 707 studies. Regarding the journals with the highest production, the first 10 journals belong to quartile 1 or quartile 2. The journal with the most articles published is CBE–Life Sciences Education from the United States with 170 studies. In second place is the journal Education Sciences from Switzerland, with 107 articles.

The author with the greatest production on the subject is Lavicza, Z. from Johannes Kepler University Linz in Austria with 25 articles. In second place is Drijvers, P. H. M. from Freudenthal Institute in the Netherlands with 14 articles. In third place with 13 studies is Capraro, M. M. from Texas A&M University in the United States.

As for the most prolific countries, the United States leads with 44% of the production, and in second place is China with 5.55%. In turn, the collaboration network between countries exposes four clusters, where the main cluster is the United States and is made up of countries from all over the world, however, the strongest relationship of the United States is with Canada and China.

In relation to the institutions, the first ten with the greatest production of articles belong to the United States. The University of California with 178 articles and Purdue University with 115 studies are the most prolific institutions. In the network of collaboration between institutions, several clusters were formed, however, the two most important clusters are led by the University of California and the other by Purdue University.

In the network of co-citations, six clusters were formed. The most outstanding author is Eccles, J. S. from the University of California in the United States. On the other hand, in the network of co-authors, nine clusters were integrated. The strongest cluster is made up of three authors from the Johannes Kepler University Linz in Austria, and the most prolific author belongs to this cluster, Lavicza, Z.

The network of co-words showed seven clusters. The largest group corresponds to mathematics in engineering, while group two is about mathematics in children and adolescents. Group three is about minority groups, diversity and equity. Group four refers to engineering and universities. In turn, group five is about gender, academic performance and perception. In group six it is about high school, motivation and parents. Finally, cluster seven includes underrepresented students and employability.

Four clusters were formed in the bibliographic coupling. One of the clusters is about minorities in STEM. Another cluster is about the factors for choosing a career in STEM. A third cluster refers to STEM teaching in primary and secondary school. The fourth cluster brings together research on integrated STEM education and teacher training to carry it out.

In the network analysis carried out through ToS, the seminal documents that correspond to the roots of the tree were obtained. In this study, the seminal documents are about learning theories and contributions to statistics in behavioral sciences. The theories that make up the roots are Vygotsky's (1978) sociocultural theory, Papert's (1980) constructionist theory, Bandura's (1986) social learning theory, and Lave and Wenger's (1991) situated learning theory. Finally, there is Cohen's (1988) work on the size of the effect when implementing a didactic proposal.

The ToS core is the central column of collective knowledge, it is based on the roots and is where new research emerges. The articles that make up the core are Springer et al. (1999) with a meta-analysis of the effect on STEM undergraduate learning. Likewise, Freeman et al. (2014) present a meta-analysis that compares performance between traditional and active learning in STEM undergraduate. On the other hand, Ceci et al. (2009) address the underrepresentation of women in intensive mathematics. Likewise, Ceci and Williams (2011) analyze the last 20 years of complaints about discrimination against women in mathematics areas. In turn, Theobald et al. (2020) carry out a meta-analysis where they contrast the performance of underrepresented and overrepresented students between traditional and active learning.

The emerging perspectives or lines of research are identified with the ToS branches. Three lines of research were obtained in this study. The first emerging line of research was called gender and STEM postgraduate studies, which also includes the use of technology in rural communities. Regarding gender, Walton et al. (2015) work on the hostile climate faced by women in engineering. Also, Dweck (2007) studies gender differences in learning mathematics. Likewise, Berenson et al. (2004) analyze collaboration between women in advanced software courses. On the other hand, in the doctoral area, there is Baker (2010) who presents the doctorate as a route to teaching. In addition, Golde (2005) analyzes the desertion of doctoral students. In the same sense, Posselt (2018) investigates teacher mentoring in doctoral studies. In turn, Feldon et al. (2010) investigate the influence of scientific research skills in STEM undergraduate studies, and methodological research skills in STEM postgraduate studies are examined by Feldon et al. (2011). Another area of research is on ICT in rural communities, where Pade-Khene et al. (2011) propose a model for managing ICT projects and Herselman (2005) suggests establishing centers that provide integrated ICT services.

These findings coincide with Dori et al. (2024), who express that the representation of women in STEM areas is low. They also mention that both the choice and the permanence of women in a STEM career are affected by the balance between personal life, professional development, and work. In addition, Akar et al. (2024) point out that beliefs about employment affect the professional development of women in STEM. Now, Mansour et al. (2024) state that structured training, technology-based certification programs, and STEM graduate studies strengthen the skills of teachers who teach STEM subjects. On the other hand, the development of scientific communication skills for mentors also benefits students, not only in sociopsychological and behavioral aspects, but also in scientific identity, communication, and considering STEM degrees (Cameron et al., 2024).

A second emerging line of research is on motivation and retention in STEM, where the influence of parents of high school students on the choice of STEM careers is also investigated. In the area of student motivation, Bunce et al. (2016) analyze the consumer orientation of universities, while Abramovich et al. (2013) study educational badges as an alternative assessment in high school. Similarly, Williams and Wade-Golden (2013) investigate diversity directors in higher education. In the area of parents of high school students, there is the work of Simpkins et al. (2012) on parents' beliefs about youth achievement. Also, Harackiewicz et al. (2012) implement an intervention with parents to instruct them on the importance of STEM courses. In addition, Rozek et al. (2015) analyzed the results of an intervention in parents to motivate their children in STEM courses. Similarly, Rozek et al. (2017) evaluated the long-term effects of intervention of parents. The area of motivation and belonging in STEM is made up of studies such as that of Fortus and Vedder-Weiss (2014) who study the continuous motivation for learning science. In turn, Harackiewicz et al. (2014) study how to promote entry and permanence in STEM. On the other hand, Smyth and Nosek (2015) analyze stereotypes in STEM.

This research perspective agrees with the work of Hale et al. (2024), who obtained a positive change in the STEM aspirations of secondary school students through fieldwork and conversations with scientists. Similarly, interdisciplinary projects provide students with collaboration skills, responsibility, group processing, and social skills that contribute to STEM workforce training (Seo et al., 2024). In addition, didactic sequences with a STEM focus in early childhood favor disciplinary integration, the solution of real-life problems, and active interdisciplinary learning (Rúa et al., 2024). Also, the autonomous choice of projects by secondary school students stimulates the integration of STEM areas by solving real problems in their communities (Tang et al., 2024).

The third emerging line of research is about mathematical identity during childhood and high school. Godwin et al. (2016) work on mathematical identity in high school students, while Dou et al. (2019) analyze STEM experiences during childhood and the relationship with STEM identity. Also, Cribbs et al. (2015) investigate students' beliefs about their competence in mathematics. On the other hand, Dabney et al. (2013) review the family influence on the choice of studying science. Similarly, Lamb et al. (2015) examine the relationship between cognition, affective aspects and STEM content integrated into primary and secondary curricula. In turn, Hsu et al. (2017) use augmented reality to increase interest in STEM careers. On the other hand, Uttal et al. (2013) and Miller and Halpern (2013) present work on spatial thinking in STEM students. Regarding the scarce representation of non-white girls in STEM, it is addressed by Tan et al. (2013), while Carlone et al. (2015) conduct gender studies analyzing data from girls in science.

This line of research concurs with the study by Revák et al. (2024), who express that STEM education has increased in early childhood due to digital technology. However, they argue that the child should be in a natural environment where they face reality. The integration of STEM areas in the classroom is carried out with different strategies, according to Ismail et al. (2024), such as inquiry-based learning, problem-solving, practical activities, or real-life applications. However, it is complex to achieve the connection between disciplines, indicating the need for teacher training in STEM. Similarly, Flanagan et al. (2024) determined that primary school teachers have deficiencies in their understanding of integrated STEM education. In addition, in STEAM education, the experience, prior knowledge, and attitude of teachers favor innovation and student performance (Chu et al., 2024). On the other hand, during teacher training for STEAM, there is a lack of an interdisciplinary approach, primarily considering interventions in mathematics and statistics, according to Álvarez & Olatunde-Aiyedun (2024). Similarly, in-service teachers express conflicts in relating theoretical concepts to real-life situations.

The most recent research in the field is located in the ToS leaves. In the STEM area, the studies by Lavi (2021), Majeed et al. (2021), Bakker et al. (2021), Maiorca et al. (2021) and Aguilera and Ortiz-Revilla (2021) were identified. In the use of ICT for teaching and learning, there are articles by Mystakidis et al. (2022), Dorouka et al. (2020), Hillmayr et al. (2020), Starr et al. (2020), Bond

(2020), Lombardi et al. (2021), Apkarian et al. (2021) and Conde et al. (2021). Regarding underrepresented groups, the works of Harris et al. (2020), Miles et al. (2020), McGee (2020), Marín-Spiotta et al. (2020), and O'Leary et al. (2020). In gender studies, there are the investigations of Master et al. (2021), Miller et al. (2021), and Bloodhart et al. (2020).

In the bibliographic coupling and in the emerging lines of research, common actions were identified in primary and secondary school. The studies in primary and secondary school are aimed at motivating children and adolescents to study STEM degrees. The research is diverse, there are studies where the proposal is to have an integrated STEM curriculum, train teachers to integrate STEM, as well as workshops or interventions with parents to make them aware of the advantages of their children choosing STEM subjects. In addition, didactic proposals were identified with technology to visualize objects in 3D whose purpose is to motivate students to choose STEM degrees.

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REFERENCES

Abramovich, S., Schunn, C., & Higashi, R. M. (2013). Are badges useful in education?: It depends upon the type of badge and expertise of learner. *Educational Technology Research and Development, 61*, 217-232. https://doi.org/10.1007/s11423-013-9289-2

Aguilera, D., & Ortiz-Revilla, J. (2021). STEM vs. STEAM education and student creativity: A systematic literature review. *Education Sciences, 11*(7), Article 331. https://doi.org/10.3390/educsci11070331

Akar, N., Yörük, T., & Tosun, Ö. (2024). Predicting women's career decisiveness in the ICT sector: A serial multiple mediation model among MIS students. *PLoS ONE, 19*(12), Article e0316154. https://doi.org/10.1371/journal.pone.0316154

Álvarez, J., & Olatunde-Aiyedun, T. G. (2024). A systematic literature review on STEAM pre- and in-service teacher education for sustainability: Are teachers ready? *Eurasia Journal of Mathematics, Science and Technology Education, 20*(9), Article em2498. https://doi.org/10.29333/ejmste/14982

Apkarian, N., Henderson, C., Stains, M., Raker, J., Johnson, E., & Dancy, M. (2021). What really impacts the use of active learning in undergraduate STEM education? Results from a national survey of chemistry, mathematics, and physics intructors. *PLoS ONE, 16*(2), Article e0247544. https://doi.org/10.1371/journal.pone.0247544

Aria, M., & Cuccurullo, C. (2017). Bibliometrix: An R-tool for comprehensive science mapping analysis. *Journal of Informetrics, 11*(4), 959-975. https://doi.org/10.1016/j.joi.2017.08.007

Babalola, O. O., du Plessis, Y., & Babalola, S. S. (2024). Power of shared success: How can sharing success and roles of others motivate African women in STEM? *International Journal for Educational and Vocational Guidance, 24*, 1-27. https://doi.org/10.1007/s10775-023-09583-1

Baker, V. L. (2010). Developmental networks and learning: Toward an interdisciplinary perspective on identity development during doctoral study. *Studies in Higher Education, 35*(7), 807-827. https://doi.org/10.1080/03075070903501887

Bakker, A., Cai, J., & Zenger, L. (2021). Future themes of mathematics education research: An international survey before and during the pandemic. *Educational Studies in Mathematics, 107*, 1-24. https://doi.org/10.1007/s10649-021-10049-w

Bandoh, S. O., Akweittey, E., Lotey, E. K., Gordon, J. F., & Appiagyei, E. (2024). Using UTAUT model to assess the factors influencing the use of ICT in Ghanaian pre-tertiary mathematics education. *Journal of Digital Educational Technology, 4*(1), Article ep2407. https://doi.org/10.30935/jdet/14297

Bandura, A. (1976). Self reinforcement: Theoretical and methodological considerations. *Behaviorism, 4*(2), 135-155.

Bandura, A. (1977). *Social learning theory*. Prentice Hall.

Bandura, A. (1978a). Reflections on self-efficacy. *Advances in Behavior Research and Therapy, 1*(4), 237-269. https://doi.org/10.1016/0146-6402(78)90012-7

Bandura, A. (1978b). Self-efficacy: Toward a unifying theory of behavior change. *Advances in Behavior Research and Therapy, 1*(4), 139-161. https://doi.org/10.1016/0146-6402(78)90002-4

Bandura, A. (1982). Self-efficacy mechanism in human agency. *American Psychologist, 37*(2), 122-147. https://doi.org/10.1037/0003-066X.37.2.122

Bandura, A. (1986). *Social foundations of thought and action: A social cognitive theory*. Prentice Hall.

Bandura, A., & Adams, N. E. (1977). Analysis of self-efficacy theory of behavioral change. *Cognitive Therapy and Research, 1*(4), 287-310. https://doi.org/10.1007/BF01663995

Bandura, A., Adams, N. E., & Beyer, J. (1977). Cognitive processes mediating behavioral change. *Journal of Personality and Social Psychology, 35*(3), 125-139. https://doi.org/10.1037/0022-3514.35.3.125

Berenson, S. B., Slaten, K. M., Williams, L., & Ho, C. W. (2004). Voices of women in a software engineering course: Reflections on collaboration. *Journal on Educational Resources in Computing, 4*(1). https://doi.org/10.1145/1060071.1060074

Bloodhart, B., Balgopal, M. M., Casper, A. M. A., Sample, L. B., & Fischer, E. V. (2020). Outperforming yet undervalued: Undergraduate women in STEM. *PLoS ONE, 15*(6), Article e0234685. https://doi.org/10.1371/journal.pone.0234685

Bond, M. (2020). Facilitating student engagement through the flipped learning approach in K-12: A systematic review. *Computers & Education, 151*, Article 103819. https://doi.org/10.1016/j.compedu.2020.103819

Brophy, S., Klein, S., Portsmore, M., & Rogers, C. (2008). Advancing engineering education in P-12 classrooms. *Journal of Engineering Education, 97*(3), 369-387. https://doi.org/10.1002/j.2168-9830.2008.tb00985.x

Bunce, L., Baird, A., & Jones, S. E. (2016). The student-as-consumer approach in higher education and its effects on academic performance. *Studies in Higher Education, 42*(11), 1958-1978. https://doi.org/10.1080/03075079.2015.1127908

Cameron, C., Lee, H. Y., Anderson, C. B., Dahlstrom, E. K., & Chang, S. (2024). Helping mentors address scientific communication in STEM research training helps their mentees stay the course. *International Journal of STEM Education, 11*, Article 40. https://doi.org/10.1186/s40594-024-00497-0

Carlone, H. B., Johnson, A., & Scott, C. M. (2015). Agency amidst formidable structures: How girls perform gender in science class. *Journal of Research in Science Teaching, 52*(4), 474-488. https://doi.org/10.1002/tea.21224

Ceci, S. J., & Williams, W. M. (2011). Understanding current causes of women's underrepresentation in science. *PNAS, 108*(8), 3157-3162. https://doi.org/10.1073/pnas.1014871108

Ceci, S. J., Williams, W. M., & Barnett, S. M. (2009). Women's underrepresentation in science: Sociocultural and biological considerations. *Psychological Bulletin, 135*(2), 218-261. https://doi.org/10.1037/a0014412

Chu, I. T., Lin, H. H., & Wei, J. J. (2024). Application of multi-criteria decision-making in STEAM teaching in design innovation at the university. *Eurasia Journal of Mathematics, Science and Technology Education, 20*(12), Article em2359. https://doi.org/10.29333/ejmste/15653

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences.* Lawrence Erlbaum Associates.

Conde, M. A., Rodríguez-Sedano, F. J., Fernández-Llamas, C., Goncalves, J., Lima, J., & García-Peñalvo, F. J. (2021). Fostering STEAM through challenge-based learning, robotics, and physical devices: A systematic mapping literature review. *Computer Applications in Engineering Education, 29*(1), 46-65. https://doi.org/10.1002/cae.22354

Corlu, S. S., Capraro, R. M., & Capraro, M. M. (2014). Introducing STEM education: Implications for educating our teachers for the age of innovation. *Education and Science, 39*(171), 74-85.

Cribbs, J. D., Hazari, Z., Sonnert, G., & Sadler, P. M. (2015). Establishing an explanatory model for mathematics identity. *Child Development, 86*(4), 1048-1062. https://doi.org/10.1111/cdev.12363

Dabney, K. P., Chakraverty, D., & Tai, R. H. (2013). The association of family influence and initial interest in science. *Science Learning in Everyday Life, 97*(3), 395-409. https://doi.org/10.1002/sce.21060

Dennehy, T. C., & Dasgupta, N. (2017). Female peer mentors early in college increase women's positive academic experiences and retention in engineering. *PNAS, 114*(23), 5964-5969. https://doi.org/10.1073/pnas.1613117114

Dori, Y. J., Refaeli-Mishkin, H., Wengrowicz, N., Yoel, S. R., & Dori, D. (2024). Exploring career choice and retention among engineering undergraduate students and systems engineers: A gender perspective. *Eurasia Journal of Mathematics, Science and Technology Education, 20*(11), Article em2527. https://doi.org/10.29333/ejmste/15483

Dorouka, P., Papadakis, S., & Kalogiannakis, M. (2020). Tablets and apps for promoting robotics, mathematics, STEM education and literacy in early childhood education. *International Journal of Mobile Learning and Organization, 14*(2), 255-274. https://doi.org/10.1504/IJMLO.2020.106179

Dou, R., Hazari, Z., Dabney, K., Sonnert, G., & Sadler, P. (2019). Early informal STEM experiences and STEM identity: The importance of talking science. *Science Education, 103*(3), 623-637. https://doi.org/10.1002/sce.21499

Dweck, C. S. (2007). Is math a gift? Beliefs that put females at risk. In S. J. Ceci, & W. M. Williams (Eds.), *Why aren't more women in science?: Top researchers debate the evidence* (pp. 47–55). American Psychological Association. https://doi.org/10.1037/11546-004

Eagan, M. K., Hurtado, S., Chang, M. J., Garcia, G. A., Herrera, F. A., & Garibay, J. C. (2013). Making a difference in science education: The impact of undergraduate research programs. *American*

Educational Research Journal, 50(4), 683-713. https://doi.org/10.3102/0002831213482038

Eccles, J. S. (2014). Gender and achievement choices. In E. T. Gershoff, R. S. Mistry, & D. A. Crosby (Eds.), *Societal contexts of child development: Pathways of influence and implications for practice and policy* (pp. 19-34). Oxford University Press.

Eccles, J. S., & Wigfield, A. (2023). Expectancy-value theory to situated expectancy-value theory: Reflections on the legacy of 40 years of working together. *Motivation Science, 9*(1), 1-12. https://doi.org/10.1037/mot0000275

Eccles, J. S., & Wigfield, A. (2024). The development, testing, and refinement of Eccles, Wigfield, and colleagues' situated expectancy-value model of achievement performance and choice. *Educational Psychology Review, 36*, Article 51. https://doi.org/10.1007/s10648-024-09888-9

Eccles, J. S., Fredricks, J. A., & Baay, P. (2015). Expectancies, values, identities, and self-regulation. In G. Oettingen, & P. M. Gollwitzer (Eds.), *Self-regulation in adolescence* (pp. 30-56). Cambridge University Press. https://doi.org/10.1017/CBO9781139565790.003

Estrada, M., Burnett, M., Campbell, A. G., Campbell, P. B., Denetclaw, W. F., Gutiérrez, C. G., Hurtado, S., John, G. H., Matsui, J., McGee, R., Okpodu, C. M., Robinson, T. J., Summers, M. F., Werner-Washburne, M., & Zavala, M. E. (2016). Improving underrepresented minority student persistence in STEM. *CBE–Life Sciences Education, 15*(3), 1-10. https://doi.org/10.1187/cbe.16-01-0038

Estrada, M., Hernandez, P. R., & Shultz, P. W. (2018). A longitudinal study of how quality mentorship and research experience integrate underrepresented minorities into STEM careers. *CBE–Life Sciences Education, 17*(1), 1-13. https://doi.org/10.1187/cbe.17-04-0066

Feldon, D. F., Peugh, J., Timmerman, B. E., Maher, M. A., Hurst, M., Strickland, D., Gilmore, J. A., & Stiegelmeyer, C. (2011). *Science, 333*(6045), 1037-1039. https://doi.org/10.1126/science.1204109

Feldon, D. F., Timmerman, B. C., Stowe, K. A., & Showman, R. (2010). Translating expertise into effective instruction: The impacts of cognitive task analysis (CTA) on lab report quality and student retention in the biological sciences. *Journal of Research in Science Teaching, 47*(10), 1165-1185. https://doi.org/10.1002/tea.20382

Flanagan, B., Hourigan, M., & Leavy, A. (2024). Primary teachers' learning experiences of integrated STEM education. *Journal of Early Childhood Research, 22*(4), 556-569. https://doi.org/10.1177/1476718X241257335

Fortus, D., & Vedder-Weiss, D. (2014). Measuring students' continuing motivation for science learning. *Journal of Research in Science Teaching, 51*(4), 497-522. https://doi.org/10.1002/tea.21136

Freeman, S., Eddy, S. L., McDonough, M., Smith, M. K., Okoroafor, N., Jordt, H., & Wenderoth, M. P. (2014). Active learning increases student performance in science, engineering, and mathematics. *PNAS, 111*(23), 8410-8415. https://doi.org/10.1073/pnas.1319030111

Godwin, A., Potvin, G., Hazari, Z., & Lock, R. (2016). Identity, critical agency, and engineering: An affective model for predicting engineering as a career choice. *Journal of Engineering Education, 105*(2), 312-340. https://doi.org/10.1002/jee.20118

Golde, C. M. (2005). The role of the department and discipline in doctoral student attrition: Lessons from four departments. *The Journal of Higher Education, 76*(6), 669-700. https://doi.org/10.1080/00221546.2005.11772304

Hale, J., Harkess, A., & Könyves, K. (2024). The Jersey Daffodil Project: Integrating nanopore sequencing into classrooms improves STEM skills, scientific identity and career development. *Plants People Planet, 6*(6), 1293-1298. https://doi.org/10.1002/ppp3.10550

Handley I. M., Brown, E. R., Moss-Racusin, C. A., & Smith, J. L. (2015). Quality of evidence revealing subtle gender biases in science is in the eye of the beholder. *PNAS, 112*(43), 13201-13206. https://doi.org/10.1073/pnas.1510649112

Harackiewicz, J. M., Rozek, C. S., Hulleman, C. S., & Hyde, J. S. (2012). Helping parents to motivate adolescents in mathematics and science: An experimental test of a utility-value intervention. *Psychological Science, 23*(8), 899-906. https://doi.org/10.1177/0956797611435530

Harackiewicz, J. M., Tibbetts, Y., Canning, E., & Hyde, J. S. (2014). Harnessing values to promote motivation in education. In S. A. Karabenick, & T. Urdan (Eds.), *Advances in motivation and achievement. Motivational interventions, volume 18* (pp. 71-105). Emerald Publishing. https://doi.org/10.1108/S0749-742320140000018002

Harris, R. B., Mack, M. R., Bryant, J., Theobald, E. J., & Freeman, S. (2020). Reducing achievement gaps in undergraduate general chemistry could lift underrepresented students into a "hyperpersistent zone". *Science Advances, 6*(24). https://doi.org/10.1126/sciadv.aaz5687

Hernandez, P. R., Schultz, P. W., Estrada, M., Woodcock, A., & Chance, R. C. (2013). Sustaining optimal motivation: A longitudinal analysis of interventions to broaden participation of underrepresented students in STEM. *Journal of*

Educational Psychology, 105(1), 89-107. https://doi.org/10.1037/a0029691

Herro, D., & Quigley, C. (2017). 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

Hillmayr, D., Ziernwald, L., Reinhold, F., Hofer, S. I., & Reiss, K. M. (2020). The potential of digital tools to enhance mathematics and science learning in secondary schools: A context-specific meta-analysis. *Computer & Education, 153*, Article 103897. https://doi.org/10.1016/j.compedu.2020.103897

Hsu, Y.-S., Lin, Y.-H., & Yang, B. (2017). Impact of augmented reality lessons on students' STEM interest. *Research and Practice in Technology Enhanced Learning, 12*, Article 2. https://doi.org/10.1186/s41039-016-0039-z

Huh, Y., Lee, D., & Reigeluth, C. (2024). Teacher supports and technology needs to develop students' self-regulated learning at U.S. K-12 online schools. *Contemporary Educational Technology, 16*(3), Article ep523. https://doi.org/10.30935/cedtech/14956

Ismail, M. H., Fadzil, H. M., Salleh, M. F. M., Saat, R. M., Kurniawan, C., & Hariyono, E. (2024). Science teachers' instructional practices: A need analysis for preparing integrated STEM practices through scientist-teacher-student partnership. *Asian Journal of University Education, 20*(3), 630-644.

Jacobs, S. J., & Herselman, M. E. (2005). An ICT-hub model for rural communities. *International Journal of Education and Development using Information and Communication Technology, 1*(3), 57-93.

Jang, H. (2016). Identifying 21st century STEM competencies using workplace data. *Journal of Science Education and Technology, 25*, 284-301. https://doi.org/10.1007/s10956-015-9593-1

Jang, S., & Tsai, M. (2012). Exploring the TPACK of Taiwanese elementary mathematics and science teachers with respect to use of interactive whiteboards. *Computers & Education, 59*(2), 327-338. https://doi.org/10.1016/j.compedu.2012.02.003

Jarrah, A. M., Fayez, K., Almarashdi, H., & Fidalgo, P. (2024). Enhancing mathematics education in the UAE: Elementary teachers' views on distance education methods. *Contemporary Educational Technology, 16*(3), Article ep516. https://doi.org/10.30935/cedtech/14714

Kim, D., & Bolger, M. (2017). Analysis of Korean elementary pre-service teachers' changing attitudes about integrated STEAM pedagogy through developing lesson plans. *International Journal of Science and Mathematics Education, 15*, 587-605. https://doi.org/10.1007/s10763-015-9709-3

Kondrashev, S. V., Vavulskaia, E. I., Burenina, V. I., Prokopyev, A. I., Ibraeva, G. R., & Nikitina, S. A. (2024). Research trends in engineering education research through bibliometric analysis. *Eurasia Journal of Mathematics, Science and Technology Education, 20*(7), Article em2476. https://doi.org/10.29333/ejmste/14760

Lamb, R., Akmal, T., & Petrie, K. (2015). Development of a cognition-priming model describing learning in a STEM classroom. *Journal of Research in Science Teaching, 52*(3), 410-437. https://doi.org/10.1002/tea.21200

Lave, J., & E. Wenger (1991). *Situated learning. Legitimate peripheral participation.* Cambridge University Press. https://doi.org/10.1017/CBO9780511815355

Lavi, R., Tal, M., & Dori, Y. J. (2021). Perceptions of STEM alumni and students on developing 21st century skills through methods of teaching and learning. *Studies in Educational Evaluation, 70*, Article 101002. https://doi.org/10.1016/j.stueduc.2021.101002

Lombardi, D., Shipley, T. F., Bailey, J. M., Bretones, P. S., Prather, E. E., Ballen, C. J., Knight, J. K., Smith, M. K., Stowe, R. L., Cooper, M. M., Prince, M., Atit, K., Uttal, D. H., LaDue, N. D., McNeal, P. M., Ryker, K., St. John, K., van der Hoeven Kraft, K. J., & Docktor, J. L. (2021). The curious construct of active learning. *Psychological Science in the Public Interest, 22*(1), 8-43. https://doi.org/10.1177/1529100620973974

Maass, K., Geiger, V., Romero, M., & Goss, M. (2019). The role of mathematics in interdisciplinary STEM education. *ZDM Mathematics Education, 51*, 869-884. https://doi.org/10.1007/s11858-019-01100-5

Maiorca, C., Roberts, T., Jackson, C., Bush, S., Delaney, A., Mohr-Schroeder, M. J., & Soledad, S. Y. (2021). Informal learning environments and impact on interests in STEM careers. *International Journal of Science and Mathematics Education, 19*, 45-64. https://doi.org/10.1007/s10763-019-10038-9

Majeed, B. H., Jawad, L. F., & Alrikabi, H. T. S. (2021). The impact of teaching by using STEM approach in the development of creative thinking and mathematical achievement among the students of the fourth scientific class. *International Journal of Interactive Mobile Technologies, 15*(13), 172-188. https://doi.org/10.3991/ijim.v15i13.24185

Maltese, A. V., & Tai, R. H. (2011). Pipeline persistence: Examining the association of educational experiences with earned degrees in STEM among U.S. students. *Science Education, 95*(5), 877-907. https://doi.org/10.1002/sce.20441

Mansour, N., Said, Z., Çevik, M., & Abu-Tineh, A. (2024). Science and mathematics teachers' integration of

TPACK in STEM subjects in Qatar: A structural equation modeling study. *Education Sciences, 14*(10), Article 1138. https://doi.org/10.3390/educsci14101138

Marín-Spiotta, E., Barnes, R. T., Berhe, A. A., Hastings, M. G., Mattheis, A., Schneider, B., & Williams, B. M. (2020). Hostile climates are barriers to diversifying the geosciences. *Advances in Geosciences, 53*, 117-127. https://doi.org/10.5194/adgeo-53-117-2020

Master, A., Meltzoff, A. N., & Cheryan, S. (2021). Gender stereotypes about interests start early and cause gender disparities in computer science and engineering. *PNAS, 118*(48), Article e2100030118. https://doi.org/10.1073/pnas.2100030118

McGee, E. O. (2020). Interrogating structural racism in STEM higher education. *Educational Researcher, 49*(9), 633-644. https://doi.org/10.3102/0013189X20972718

Miles, M. L., Brockman, A. J., & Naphan-Kingery, D. E. (2020). Invalidated identities: The disconfirming effects of racial microaggressions on Black doctoral students in STEM. *Journal of Research in Science Teaching, 57*(10), 1608-1631. https://doi.org/10.1002/tea.21646

Miller, D. I., & Halpern, D. F. (2013). Can spatial training improve long-term outcomes for gifted STEM undergraduates? *Learning and Individual Differences, 26*, 141-152. https://doi.org/10.1016/j.lindif.2012.03.012

Miller, R. A., Vaccaro, A., Kimball, E. W., & Forester, R. (2021). "It's dude culture": Students with minoritized identities of sexuality and/or gender navigating STEM majors. *Journal of Diversity en Higher Education, 14*(3), 340-352. https://doi.org/10.1037/dhe0000171

Mystakidis, S., Christopoulos, A., & Pellas, N. (2022). A systematic mapping review of augmented reality applications to support STEM learning in higher education. *Education and Information Technologies, 27*, 1883-1927. https://doi.org/10.1007/s10639-021-10682-1

Nugraha, M. G., Kidman, G., & Tan, H. (2024). Interdisciplinary STEM education foundational concepts: Implementation for knowledge creation. *Eurasia Journal of Mathematics, Science and Technology Education, 20*(10), Article em2523. https://doi.org/10.29333/ejmste/15471

O'Leary, E. S., Shapiro, C., Toma, S., Sayson, H. W., Levis-Fitzgerald, M., Johnson, T., & Sork, V. L. (2020). Creating inclusive classrooms by engaging STEM faculty in culturally responsive teaching workshops. *International Journal of STEM Education, 7*, Article 32. https://doi.org/10.1186/s40594-020-00230-7

Oleson, A., & Hora, M. T. (2014). Teaching the way they were taught? Revisiting the sources of teaching knowledge and the role of prior experience in shaping faculty teaching practices. *Higher Education, 68*, 29-45. https://doi.org/10.1007/s10734-013-9678-9

Ong, M., Smith, J. M., & Ko, L. T. (2018). Counterspaces for women of color in STEM higher education: Marginal and central spaces for persistence and success. *Journal of Research in Science Teaching, 55*(2), 206-245. https://doi.org/10.1002/tea.21417

Pade-Khene, C., Mallinson, B., & Sewry, D. (2011). Sustainable rural ICT Project management practice for developing countries: Investigating the Dwesa and RUMEP projects. *Information Technology for Development, 17*(3), 187-212. https://doi.org/10.1080/02681102.2011.568222

Papert, S. (1980). *Mindstorms: Children, computers, and powerful ideas*. Basic Books.

Posselt, J. (2018). Normalizing struggle: Dimensions of faculty support for doctoral students and implications for persistence and well-being. *The Journal of Higher Education, 89*(6), 988-1013. https://doi.org/10.1080/00221546.2018.1449080

Revák, I. M., Csernoch, M., Szilágyi, K. C., Dávid, Á., Tóth, B. K., Malmos, E., Sütő, É., & Kurucz, D. (2024). A systematic review of STEM teaching-learning methods and activities in early childhood. *Eurasia Journal of Mathematics, Science and Technology Education, 20*(8), Article em2481. https://doi.org/10.29333/ejmste/14779

Robledo, S., Osorio, G., & López, C. (2014). Networking en pequeña empresa: Una revisión bibliográfica utilizando la teoría de grafos [Networking in small businesses: A literature review using graph theory]. *Revista Vínculos, 11*(2), 6-16.

Robledo, S., Zuluaga, M., Valencia, L. A., Arbelaez-Echeverri, O., Duque, P., & Alzate-Cardona, J. D. (2022). Tree of Science with Scopus: A shiny application. *Issues in Science and Technology Librarianship*, (100). https://doi.org/10.29173/istl2698

Roehrig, G. H., Moore, T. J., Wang, H., & Park, M. S. (2012). Is adding the E enough? Investigating the impact of K-12 engineering standards on the implementation of STEM integration. *School Science and Mathematics, 112*(1), 31-44. https://doi.org/10.1111/j.1949-8594.2011.00112.x

Rozek, C. S., Hyde, J. S., Svoboda, R. C., Hulleman, C. S., & Harackiewicz, J. M. (2015). Gender differences in the effects of a utility-value intervention to help parents motivate adolescents in mathematics and science. *Journal of Educational Psychology, 107*(1), 195-206. https://doi.org/10.1037/a0036981

Rozek, C. S., Svoboda, R. C., Harackiewicz, J. M., Hulleman, C. S., & Hyde, J. S. (2017). Utility-value intervention with parents increases student's STEM preparation and career pursuit. *PNAS, 114*(5), 909-914. https://doi.org/10.1073/pnas.1607386114

Rúa, F. J., Merchán, M. A., & Camacho-Tamayo, E. (2024). Teaching sequences based on the STEM approach for the development of inquiry in early childhood education: A systematic review. *Eurasia Journal of Mathematics, Science and Technology Education, 20*(10), Article em2517. https://doi.org/10.29333/ejmste/15207

Schotten, M., Aisati, M. Meester, W., Steiginga, S., & Ross, C. (2017). A brief history of Scopus: The world's largest abstract and citation database of scientific literature. In F. J. Cantu-Ortiz (Ed.), *Research analytics: Boosting university productivity and competitiveness through scientometrics* (1st ed.). Auerbach Publications. https://doi.org/10.1201/9781315155890

Seo, S., Van Orman, D. S. J., Beattie, M., Paxson, L. C., & Murray, J. (2024). Transforming learning orientations through STEM interdisciplinary project-based learning. *Education Sciences, 14*(11), Article 1154. https://doi.org/10.3390/educsci14111154

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*, Article 13. https://doi.org/10.1186/s40594-017-0068-1

Simpkins, S. D., Fredricks, J. A., & Eccles, J. S. (2012). Charting the Eccles' expectancy-value model from mothers' beliefs in childhood to youths' activities in adolescence. *Developmental Psychology, 48*(4), 1019-1032. https://doi.org/10.1037/a0027468

Simsek, A. (2024). How will education look like in the future? *Contemporary Educational Technology, 16*(3), Article ep518. https://doi.org/10.30935/cedtech/14794

Singh, P., Nasir, N. A., M., & Hoon, T. S. (2024). The cognitive gap in the mathematical thinking abilities of high school leavers for college: Are they ready? *Eurasia Journal of Mathematics, Science and Technology Education, 20*(11), Article em2529. https://doi.org/10.29333/ejmste/15577

Smyth, F. L., & Nosek, B. A. (2015). On the gender-science stereotypes held by scientists: Explicit Accord with gender-ratios, implicit Accord with scientific identity. *Frontiers in Psychology, 6*. https://doi.org/10.3389/fpsyg.2015.00415

Springer, L., Stanne, M. E., & Donovan, S. S. (1999). Effects of small-group learning on undergraduates in science, mathematics, engineering, and technology: A meta-analysis. *Review of Educational Research, 69*(1), 21-51. https://doi.org/10.3102/00346543069001021

Starr, C. R., Hunter, L., Dunkin, R., Honig, S., Palomino, R., & Leaper, C. (2020). Engaging in science practices in classrooms predicts increases in undergraduates' STEM motivation, identity, and achievement: A short-term longitudinal study. *Journal of Research in Science Teaching, 57*(7), 1093-1118. https://doi.org/10.1002/tea.21623

Tan, E., Barton, A. C., Kang, H., & O'Neill, T. (2013). Desiring a career in STEM-related fields: How middle school girls articulate and negotiate identities-in-practice in science. *Journal of Research in Science Teaching, 50*(10), 1143-1179. https://doi.org/10.1002/tea.21123

Tang, K. S., McLure, F., Williams, J., & Donnelly, C. (2024). Investigating the role of self-selected STEM projects in fostering student autonomy and self-directed learning. *Australian Educational Researcher, 51*(5), 2355-2379. https://doi.org/10.1007/s13384-024-00696-2

Theobald, E. J., Hill, M. J., Tran, E., Agrawal, S., Arroyo, E. N., Behling, S., Chambwe, N., Cintrón, D. L., Cooper, J. D., Dunster, G., Grummer, J. A., Hennessey, K., Hsiao, J., Iranon, N., Jones, L., Jordt, H., Keller, M., Lacey, M. E., Littlefield, C. E., …, & Freeman, S. (2020). Active learning narrows achievement gaps for underrepresented students in undergraduate science, technology, engineering, and math. *PNAS, 117*(12), 6476-6483. https://doi.org/10.1073/pnas.1916903117

Uttal, D. H., Miller, D. I., & Newcombe, N. S. (2013). Exploring and enhancing spatial thinking: Links to achievement in science, technology, engineering, and mathematics? *Current Directions in Psychological Science, 22*(5), 367-373. https://doi.org/10.1177/0963721413484756

Valencia-Hernandez, D. S., Robledo, S., Pinilla, R., Duque-Méndez, N. D., & Olivar-Tost, G. (2020). SAP algorithm for citation analysis: An improvement to Tree of Science. *Ingeniería e Investigación, 40*(1), 45-49. https://doi.org/10.15446/ing.investig.v40n1.77718

Vygotsky, L. S. (1978). *Mind in society. The development of higher psychological processes*. Harvard University Press. https://doi.org/10.2307/j.ctvjf9vz4

Walton, G. M., Logel, C., Peach, J. M., Spencer, S. J., & Zanna, M. P. (2015). Two brief interventions to mitigate a "chilly climate" transform women's experience, relationships, and achievement in engineering. *Journal of Educational Psychology, 107*(2), 468-485. https://doi.org/10.1037/a0037461

Wang, X. (2013). Why students choose STEM mayors: Motivation, high school learning, and postsecondary context of support. *American Educational Research Journal, 50*(5), 1081-1121. https://doi.org/10.3102/0002831213488622

Wigfield, A., & Eccles, J. S. (2023). What is next for situated expectancy-value theory? A reply to our commentators. *Motivation Science, 9*(1), 19-20. https://doi.org/10.1037/mot0000282

Wigfield, A., & Eccles, J. S. (2024). The relevance of situated expectancy-value theory to understanding motivation and emotion in different contexts. In G. Hagenauer, R. Lazarides, & H. Järvenoja (Eds.), *Motivation and emotion in learning and teaching across educational contexts* (pp. 3-18). Routledge. https://doi.org/10.4324/9781003303473-2

Williams, D. A., & Wade-Golden, K. C. (2013). *The chief diversity officer. Strategy structure and change management.* Taylor & Francis.

Zhu, J., & Liu, W. (2020). A tale of two databases: The use of Web of Science and Scopus in academic papers. *Scientometrics, 123*, 321-335. https://doi.org/10.1007/s11192-020-03387-8

Zuluaga, M., Robledo, S., Arbelaez-Echeverri, O., Osorio-Zuluaga, G. A., & Duque-Méndez, N. (2022). Tree of Science-ToS: A web-based tool for scientific literature recommendation. Search less, research more! *Issues in Science and Technology Librarianship*, (100). https://doi.org/10.29173/istl2696

Zupic, I., & Cater, T. (2015). Bibliometric methods in management and organization. *Organizational Research Methods, 18*(3), 429-472. https://doi.org/10.1177/1094428114562629