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Tendencies in Research on Attitudes towards Learning Mathematics: A Bibliometric Analysis

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Abstract

The objective of this study is to analyze the present-day state of attitudes towards learning mathematics and to identify new lines of research being developed. For this purpose, first articles were elected in the Scopus database for the years 1970-2024 using the search criteria “mathematics” and “attitudes.” 4160 articles were found and data mining in the R language was carried out to analyze the registries. The country leading in the number of publications is the United States and the University of California the institution with the most articles. The author with the most publications is Ma X. They study the relationship between attitudes, anxiety and academic performance. Bibliographic coupling reflets the lines of research focused on affective aspects and gender in the educational context. There were three emerging perspectives of this research. One focuses on the factors which influence preparation for academic and professional success. Another is related to active methodologies in mathematics. The last one centers on the measurement of attitudes.

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Introduction

Research on students' attitude is ever more important in mathematics due to its influence on academic performance (Suherman & Vidákovich, 2024). In this sense, changes in teaching and learning processes have led to focusing on the use of active methodologies. For example, collaborative learning represents a positive impact on mathematics' performance and a significant influence on students' attitudes towards the subject, reducing mathematics anxiety, promoting a more positive perception and providing more confidence in the subject (Siller & Ahmad, 2024). Similarly, learning based on research suggests improved attitudes, since this methodology allows students greater participation in the learning process, supporting each other, allowing for autonomy in their learning which significantly improves their enjoyment and value of students' homework as they feel they have greater control and responsibly on the results of learning (Robinson & Aldridge, 2022). Also, the use of manipulative materials in mathematics promotes students' interest in the subject, improving their perceived enjoyment and competence. However, it is important that students understand the context and content in which these materials are used, besides familiarizing themselves with the use of these objects in their learning in order to obtain favorable results (Quane, 2024).

Another change in education took place between 2019 and 2021, during the COVID 19 pandemic. This forced teachers and students to adapt to new technological skills and affected the dynamics of teaching/learning. Virtual schooling was now (UNICEF, 2021), along with long-distance learning part of education. This new way of learning depended on several elements among which was the use of on-line platforms that in and of themselves depend on various factors which resonated on students' motivation such as: access, ease of use, comfort, graphic design and satisfaction (Schmitt-Cerna et al., 2024). Pereira and Gomes (2022) achieved positive evaluation on the functioning of an on-line support platform, as well as a positive attitude of both teachers and students. Reddy et al. (2021) explored students' perceptions of assistive technology (AT) on learning mathematics, which proved effective in improving students' learning and confidence and reduced anxiety in the face of mathematics.

It can be seen that students' attitude towards mathematics may be influenced by the materials used in the class, teaching methods, lack of interaction with the teacher and technological challenges, among others. However, it may also be affected by other cognitive, affective and behavioral variables, something that is reflected in academic achievement (Fernández-Cézar et al., 2021). According to Alvarenga (2024) another factor of influence is the socio-economic level of the student in an unfavorable context, a student's attitude arises as a crucial factor which can mold their educational career.

Added to this is the surge in gender equity in the areas of science, technology, engineering and mathematics (STEM) which leads to the study of the influence of this variable on attitudes. Opstad (2021) analyzed the factors which influence students' attitudes towards mathematics, focused on gender, personality traits and mathematics formation. In relation to gender, they concluded that there is no significant influence in attitudes towards mathematics, although some results indicated a slightly more positive tendency towards women's attitudes, this being weak. On the other hand, other factors which were studied do show a greater impact on attitudes in this discipline.

Methodology

Scientific mapping was carried out in this research in search of establishing a relationship between the information in various documents with respect to attitudes and mathematics. To this end, the consultation of literature in Scopus database was begun. Scopus is one the most well-recognized databases with the greatest range of publications in the world. For the bibliographic revision, the considerations of criteria described in Table 1 were used. The first search resulted in 6090 articles. Using the search criteria this number was reduced to 4160 publication. These files were exported to BibTex and CSV with information on citations, bibliography, abstract, keywords and references. A bibliometric analysis was made using these files and the RIS (Research Information Systems) was also exported to carry out network analysis and the identification of emerging lines.

Table 1. Search Criteria

Criteria	Scopus
Time range	1970-2024
Date consulted	September 26, 2024
Type of journals	All types
Field of search	Article title, abstract & keywords
Equation of search	“Mathematics” and “Attitude”
Total Findings	4160

Bibliometric Analysis

The objective of this analysis is to quantitatively discover the impact and development of scientific production of attitudes towards mathematics. The methods recommended by Zupic and Cater (2015) were used for citation analysis. This provides information on the impact of publications and allows for evaluating the influence of researchers or institutions in the area, through the history of publications, journals, authors, countries and institutions which lead the production of the subject. The second method is co-word analysis which identifies the most repeated terms or words in titles and abstracts and of keywords in articles, allowing for finding the most widely studied areas in literature. The following method is the analysis of co-citations. This consists of counting the frequency with which two articles are quoted together in other papers, thus allowing for grouping documents which shared thematic relevance and show a network of co-citations and collaborations. The fourth analysis, co-authors, presents the collaboration among different authors through a network of co-authors. Finally, there is the bibliographic coupling through which the perspectives that arise in research based on coupling of reference registries shared in the research are identified.

Bibliometrix (https://www.bibliometrix.org/) was used with data mining to process the database. This is a tool developed in Language R https://www.r-project.org/) in relation to free programing and focused on statistical analysis. However, there is Biblioshiny, an interface web for those who do not know how to program and can use Bibliometrix (Arias & Cuccurullo, 2017). VOSviewer (https://www.vosviewer.com/) was also used. VOSviewer is free, open coded and allows for building and visualizing bibliometric networks.

Network Analysis and Research Perspectives

To perform the network analysis, the Tree of Science (ToS) platform (https://tos.coreofscience.com/) was used. This platform was created for the analysis of scientific literature and is based on graph theory, allowing the visualization of research in a specific area of knowledge. Analogous to a tree, it takes classic articles, which it calls seminal, as the roots. The trunk is formed by documents that allow the area to grow, followed by the branches, which are articles grouped into distinct subfields or specialized areas of research. These represent research lines and/or study perspectives that connect various areas of a determined field. Finally, the leaves are considered to be documents that are 5 years old or less and represent research that has not been cited by other articles (Zuluaga et al., 2022). In the ToS results, 20 documents were identified in both the roots and the trunk. For this report, the five most cited documents for each were chosen for analysis. Regarding the branches (research lines), three were obtained, each with 15 documents. Similarly, the selection of articles was based on the most cited documents, selecting 10 articles from each branch. For the selection of the leaves, the most recent articles were chosen, specifically from 2022 to September 26, 2024 (search date). Thus, from 50 articles provided by the program, 30 were selected for analysis.

A thematic map was also generated using Bibliometrix in R, with the aim of identifying the main research areas and their development in the analyzed literature. This type of analysis allows for the identification of key themes based on their centrality (i.e., relevance in the research network) and their density (the level of internal development). The graph representing this analysis shows the themes organized according to two dimensions: the X-axis represents the importance of a theme in the research network, that is, its connection with other themes in the analyzed dataset, and the Y-axis indicates the degree of internal development of a theme, that is, how much it has been worked on and consolidated in literature. Each quadrant of the graph has a specific interpretation. In the first quadrant are the motor themes, which are highly relevant and developed themes in the area of study. In the second quadrant are the niche themes, which are highly developed themes but with low levels of connection to others, indicating that they are very specialized areas of study. In the third quadrant are the emerging or declining themes, which have low centrality and low density, suggesting that they may be in decline or still under development. Finally, in the fourth quadrant are the fundamental themes with high centrality but low density, meaning that they are connected to other themes but are not specialized or developed within the thematic network (López-Robles et al., 2019).

Results

Number of Publications Per Year

The analysis of publications related to attitudes and mathematics during the period from 1970 to September 2024 shows a turning point; from 1970 to 2004, the number of publications remained stable, showing a slight increase starting in 1993. However, the surge is evident from 2005 onwards, where there is a significant increase, reaching a maximum of 309 publications in the year 2021. Figure 1 shows the evolution of publications over this time period.

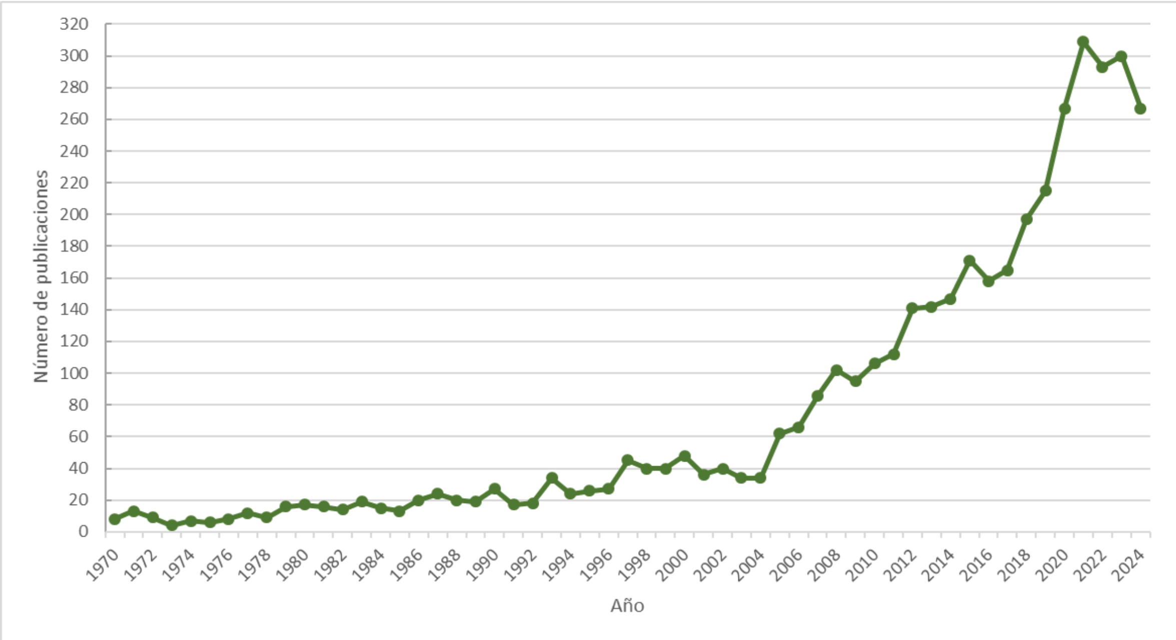

Figure 1. Number of Publications Per Year

In the early years of the 1970-1992 period, the number of publications was relatively low and remained stable, with an average of 14 articles per year. In the 1993-2004 period, there was a slight increase, with an average of 35 publications per year. Finally, the peak period occurred from 2005 onwards, during which the increase was 82% compared to the previous period. From that date on, the average annual increase was 12%. On the other hand, the last 10 years account for 60% of the total publications, highlighting the researchers' interest in the topic.

In the initial stage, some publications stand out for their influence, reflected in the number of citations received. For example, Aiken (1970), with "Attitudes toward mathematics," has 174 citations. Likewise, the work of Betz and Hackett (1983), with 507 citations, is positioned as an impactful contribution in the academic field. In the 1993-2004 interval, there are two publications that stand out for their large number of citations in that period: Eccles et al. (1993) shows its influence with 1130 citations, as does Springer et al. (1999) with 1333 citations. Finally, in the period of greatest production, the publication by Else-Quest et al. (2010) stands out, although with fewer citations (1011). Overall, research in the area has increased over time, highlighting the continued interest in this field of study.

Analysis of Journals

In the citation analysis, the 10 journals with the highest number of related publications in the area were identified. Table 2 shows information about these journals, the number of articles per journal, their country of origin, impact indicators such as the h-index (which indicates how influential the articles published in the journal are; a high h-index suggests that the journal publishes widely cited studies, although it does not distinguish whether the citations come from influential or less relevant articles). Another indicator is the quartile, which indicates the position of a journal relative to other journals in its field, with Q1 journals having the highest impact factors. The SCImago Journal Rank (SJR) indicator is also shown, which measures the impact and prestige of scientific journals based on citations, taking into account the quality of those citations.

Table 2 shows that the journals with the highest SJR indicators in the review are Educational Studies in Mathematics with 1,476 and the journal Computers and Education with 3.651; both also belong to the Q1 quartile.

Table 2. Most Outstanding Journals between 1970 and 2024

Journal	**Articles**	**Quartile**	**SJR (2023)**	**h-index**	**Country/Region**
International Journal of Mathematical Education in Science and Technology	113	Q1	0.634	42	United Kingdom
Educational Studies in Mathematics	61	Q1	1.476	83	Netherlands
Eurasia Journal of Mathematics, Science and Technology Education	60	Q2	0.451	56	Turkey
International Journal of Science and Mathematics Education	59	Q1	1.038	56	Netherlands
School Science and Mathematics	57	Q1	0.415	54	United States
Journal of Educational Research	48	Q2	0.645	90	United States
Sustainability (Switzerland)	42	Q2	0.677	169	Switzerland
Computers and Education	40	Q1	3.651	232	United Kingdom
Mathematics Education Research Journal	36	Q1	0.86	41	Netherlands
Education Sciences	32	Q2	0.669	53	Switzerland

The journal with the most publications in this research area is the International Journal of Mathematical Education in Science and Technology, with 2.72% of the total publications. The Netherlands journal has a total share of 3.75%, divided between the journals Educational Studies in Mathematics, International Journal of Science and Mathematics Education, and Mathematics Education Research Journal, which have the highest Q1 and SJR indicators after Computers and Education. Meanwhile, the journals Sustainability of Switzerland and Computers and Education stand out with h-index indicators of 169 and 232, respectively.

Author Analysis

The authors with the greatest number of publications in the database are analyzed. It allows us to identify opinion leaders in the field and to recognize the significant contributions and trends driven by these researchers (Zupic & Čater, 2015). Table 3 shows the 10 authors with the highest number of citations, and provides information on the number of publications, the number of citations each one accumulates, the h-index, affiliation and country.

Table 3. Main Authors in the Field from 1970 to 2024

Author	Articles	Citations	h-index	Affiliation	Country
Ma, X.	14	815	28	University of Kentucky	USA
Tong, D.H.	12	88	6	Can Tho University	Vietnam
Fraser, B.J.	11	494	52	University of Curtin	Australia
Uyen, B.P.	11	88	6	Can Tho University	Vietnam
Wang, X.	11	965	16	The University of Texas Rio Grande Valley	USA
Geary, D.C.	10	666	78	University of Missouri	USA
Zhang, Y.	10	327	1	Tilburg University	Netherlands
Liu, X.	9	44	1	Cleveland State University	USA
Wang, J.	9	102	13	Beijing Institute of Technology	China
Wang, S.	9	166	28	Beijing Normal University	China

In these results, authors Ma, X., and Tong, D.H., stand out with 14 and 12 publications, representing the greatest contributions to the field according to the literature found in the database. Ma, X. belongs to the University of Kentucky in the United States, and Tong, D.H. belongs to Can Tho University in Vietnam. On the other hand, the author with the highest number of citations is Wang, X., with 965 citations from his 11 publications, followed by Ma, X. with 14 publications and 815 citations.

Co-citation Analysis

Co-citation analysis seeks to identify the main thematic areas and influential authors in the field of study on attitudes and mathematics. Figure 2 presents the author co-citation network, in which the largest nodes represent the authors with the highest number of citations. Furthermore, the different colors between the clusters allow for grouping each author according to thematic similarity.

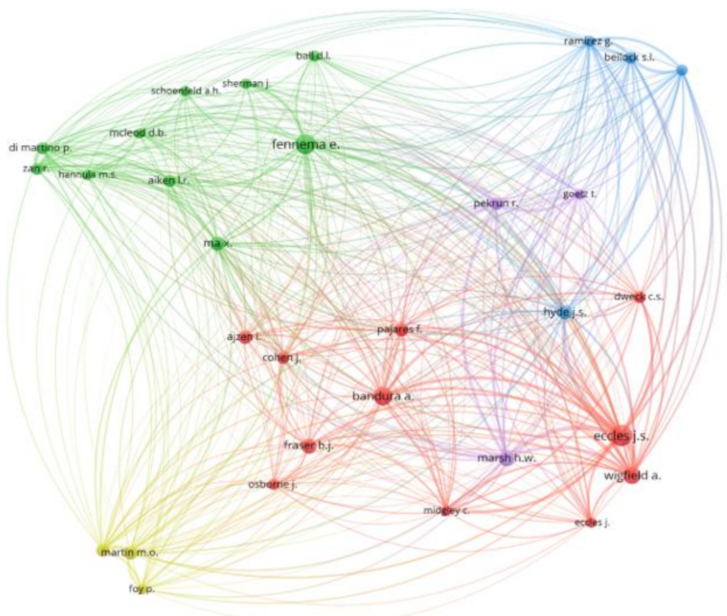

Figure 2. Co-Citation Network of Authors in the Field

Table 4 shows the information collected according to the number of citations, taking the 10 authors with the most citations as a reference. The list is led by author Jacquelynne Sue Eccles with 892 citations. Her most cited works are related to theories of motivation, expectancy and values, self-efficacy and beliefs, among others, in both educational and developmental contexts (Wigfield and Eccles, 2000; Eccles and Wigfield, 2002; Eccles et al., 2013). Figure 2 shows that this author is in the red cluster, which shows a larger number of authors who stand out due to their number of citations. Within this cluster are five of the 10 most cited authors, including Albert Bandura with 666 citations. His work explores how self-efficacy expectations, derived from prior achievements, experiences, and physiological states, influence the initiation, persistence, and success of behavior in the face of challenges (Bandura, 1977; 1982; 1999).

Another author with a large number of citations is Elizabeth Fennema, who has 761 citations in this analysis. In her research, she examined factors in the mathematics classroom that could be associated with gender. Among her most cited articles, she studies gender differences in attitudes toward mathematics (Hyde et al., 1990a; 1990b). She is located in the green node, the node with the second highest number of authors, and Fennema, in turn, has connections to the other nodes. Thus, the set of clusters reflects key authors leading lines of research related to motivation, attitudes and gender, among others, in addition to showing an approach that involves both psychological and pedagogical theories applied to education.

Table 4. Co-Citations of Authors in the Field

Author	Citations
Eccles J.S.	892
Fennema E.	761
Bandura A.	666
Wigfield A.	567
Marsh H.W.	450
Fraser B. J.	435
Hyde J. S.	390
Ma X.	367
Pajares F.	348
Martin M. O.	334

Co-Author Analysis

In this analysis, four clusters appear. Figure 3 shows that the largest node on the map is in the red cluster, indicating that the author Barry Fraser has strong connections with other researchers in this line of research. Fraser was a professor at Curtin University in Australia and made contributions to the field of education, particularly in science teaching, with research on learning environments and educational measurement. He influenced educational practices and outcomes. He explored how students' perceptions of learning environments influence attitudes towards science, and developed and validated questionnaires such as the Science Laboratory Environment Inventory (SLEI) (Fraser et al., 1995; Fraser & McRobbie, 1995), Classroom Environment Scale (CES) (Fisher

& Fraser, 1983), and Test of Science-Related Attitudes (TOSRA). The latter measured attitudes related to science, such as enjoyment, interest, and adoption of scientific attitudes, among others (Fraser, 1981).

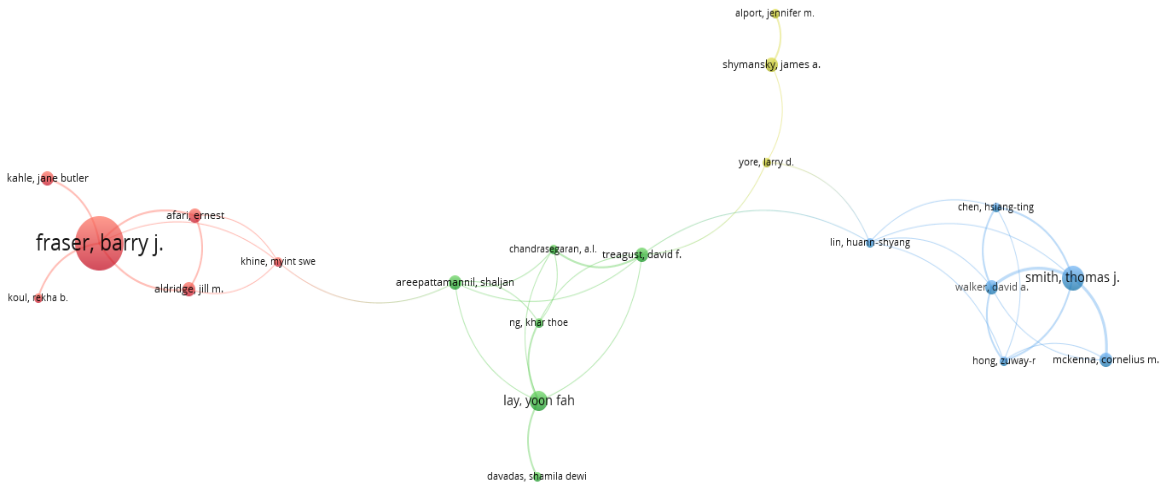

Figure 3. Network of Co-Authors of Research in the Area

On the other hand, Fraser investigated innovative teaching methods, examining how environmental characteristics affect students' attitudes and performance. Through his book "Educational environments: Evaluation, antecedents, and consequences" (Fraser and Walberg, 1991), he provided information for creating educational environments that promote positive attitudes to improve learning experiences. Within this cluster are five other authors who have co-citations with the central node constituted by Fraser. One of these is Jane Butler Kahle, a prominent researcher in the field of science education who worked at Purdue University and the University of Miami in the United States. Her focus areas were related to gender equity, highlighting that the lack of female role models has a negative effect on adolescent girls, and also mentioning that girls have fewer experiences with scientific materials or techniques (Kahle, 2004; Kahle, 2012; Hewson et al., 2001).

Furthermore, she investigated how educational reforms impact the area of science (Supovitz et al., 2000; Kahle, 2013). Fraser and Kahle have an academic relationship based on research related to learning environments. For example, they explored the influence of the classroom, home, and peer environment on students' academic performance and attitudes, with the classroom environment being the strongest predictor for both performance and attitude (Scantlebury et al., 2001). They also worked together on the Third International Mathematics and Science Study, which combined the analysis of educational environments and international data. Fraser and Kahle (2007) explored the effects of having multiple environments on students' academic outcomes—classroom, home, and peers—highlighting the importance of investigating this in relation to students' attitudes. However, only the classroom environment showed a statistically significant influence on students' academic performance.

Another author participating in this cluster is Rekha Rekha Koul, who is the Deputy Director and Discipline Lead of the STEM Research Group in the Faculty of Education at Curtin University (Australia). Her research focuses on the development and validation of questionnaires, the impact of classroom environments on student performance, the evaluation of educational programs, and curriculum evaluation, with her interests being learning environments in classrooms, schools, and STEM education. Her most cited article in Scopus (Koul & Fisher, 2005) provides information on the relationships between students' cultural background, perceptions of their teachers' interpersonal behavior, and the classroom learning environment. She also has publications regarding Makerspace, a collaborative environment equipped to foster innovation and active learning (Blackley et al., 2018; Sheffield et al., 2017; Blackley et al., 2018). Her academic relationship develops in research centered on educational environments and their impact on student learning and attitudes, highlighting research on the importance of understanding and improving the emotional climate in STEM learning environments, something key to fostering positive attitudes and interest in these areas. Additionally, gender disparities and how these types of supports impact all students are addressed (Fraser et al., 2021; Koul et al., 2018; Koul et al., 2023).

Dr. Ernest Afari is an adjunct professor of Mathematics Education in the Department of Mathematics, Science, and ICT Education at the University of Bahrain, Kingdom of Bahrain. His research focuses on structural equation modeling, psychometrics, and the application of statistical procedures to education to investigate constructs such as the attitudes and competencies of students and teachers towards learning and teaching.

Afari and Fraser have used structural models to analyze how various dimensions of the school environment influence students' behaviors and well-being. For example, the article by Aldridge et al. (2018) investigates the relationships between school climate, bullying victimization, and delinquency. On the other hand, he studied how perceptions of school climate affect students' well-being, resilience, and moral identity (Riekie, 2017). Regarding studies with teachers, he has publications where his interest is to understand and optimize the use of technology in education from the perspective of teachers, in the search to prepare educators for the effective integration of technology into their practices (Eksail & Afari, 2020; Afari et al., 2012).

Ernest Afari has conducted research on school climate and its effects on both learning and students' attitudes. Using structural models, he has analyzed how learning environments influence students' psychosocial and attitudinal variables. Among his most cited articles is Aldridge et al. (2016), which explores how school climate relates to students' well-being, life satisfaction, resilience, and ethnic and moral identity. On the other hand, Afari et al. (2013) evaluated the impact of using games in mathematics classes on perceptions of the learning environment and attitudes towards mathematics.

Jill Aldridge is a research professor in the School of Education at Curtin University in Western Australia. Her research interests are related to classroom learning environments, and her studies include a variety of qualitative and quantitative research methods, as well as the development and validation of questionnaires to assess students' perceptions. Another line of her work is collaborative action research for school improvement, which serves as a form of teacher professional development and a tool for school improvement. Additionally, she emphasizes multicultural learning environments, conducting research with students and teachers examining aspects of classroom life and investigating a variety of teaching practices that demonstrate the effectiveness of strategies for creating appropriate learning environments for students from non-dominant backgrounds.

Among Aldridge's most cited articles is a systematic review in which she analyzed studies on the relationship between psychosocial school climate and adolescent mental health. She notes that the results lacked causal evidence due to the scarcity of experimental and longitudinal studies and recommends further research on social safety and the academic environment (Aldridge et al., 2018). In collaboration with Fraser and other authors, she worked on studies about the learning environment in educational contexts, analyzing various factors that influence school climate, providing information to improve it, and suggesting that administrators consider this factor and how it could be enhanced (Aldridge and Fraser, 2016). In her more recent work, Aldridge conducts research on school climate, highlighting the importance of measuring and adjusting school climate to improve student experiences, using validated instruments and innovative approaches such as person-environment fit (Aldridge & McLure, 2024; Aldridge & Blackstock, 2024; Aldridge et al., 2024). She has also worked on the validity of questionnaires, ensuring their reliability and factorial validity (Aldridge et al., 1999; Aldridge et al., 2000).

The second most representative cluster (in blue) is led by Smith, Thomas J. This provides a useful framework for investigating how to optimize learning and participation in STEM. Research focuses on the relationship between educational variables such as school belonging (Smith et al., 2020), group work (Smith et al., 2014), and teacher characteristics, analyzing how these factors influence positive attitudes towards mathematics and science. The influence of parental education and cultural contexts on academic performance and attitudes is also highlighted (Smith et al., 2022). Furthermore, he utilizes statistical methodologies for educational analysis with the aim of examining complex relationships in the data, making use of the McNemar test and the weighted Bowker test to analyze changes in students' attitudes towards mathematics (Smith & McKenna, 2011).

The research reported in the green cluster analyzes the influence of various factors on students' attitudes towards mathematics, such as teachers' affective support, the quality of classroom instruction, and the family environment. The influence of these factors varies between urban and rural contexts, and they also impact students' academic performance (Davadas & Lay, 2018, 2020; Finau et al., 2018). Factors such as motivation, self-efficacy, and positive perceptions towards mathematics act as key mediators, showing positive effects on academic performance. For this reason, it is proposed to use pedagogical approaches designed to improve cognitive skills (Areepattamannil et al., 2015; Ng et al., 2012). The use of structural equation modeling and multilevel analyses in research such as that of Davadas and Lay (2020) and Areepattamannil (2014) allows the identification of contextual and cultural differences between countries such as Malaysia, the United Arab Emirates, and India.

Analysis by Country

Table 5 shows the countries with the largest number of publication in the subject of attitudes towards learning mathematics. Heading up the list is the United States with 3,239 (29.1%), followed by China with 9.5% and Turkey with 5.1%.

The clusters of collaboration networks among countries shows that the United States (USA) represents the central node with strong connections (see Figure 4) to China, Canada, Germany and Turkey, besides 12 other countries with direct connections. This suggests that this country is an intermediary between various geographical regions, having a dominant role in producing scientific knowledge. Having multiple connections with other countries implies efficient, well-established collaboration, the country acting as a bridge in facilitating the transference of knowledge among countries.

Table 5. Countries with the Most Publications for the Period 1970-2024

Country	Articles	Articles %
United States	3239	29.1
China	1053	9.5
United Kingdom	569	5.1
Australia	556	5.0
Turkey	535	4.8
Spain	503	4.5
Malaysia	349	3.1
Canada	280	2.5
Indonesia	274	2.5
Germany	264	2.4
Other countries (95)	3159	28.4
Total	11140	100

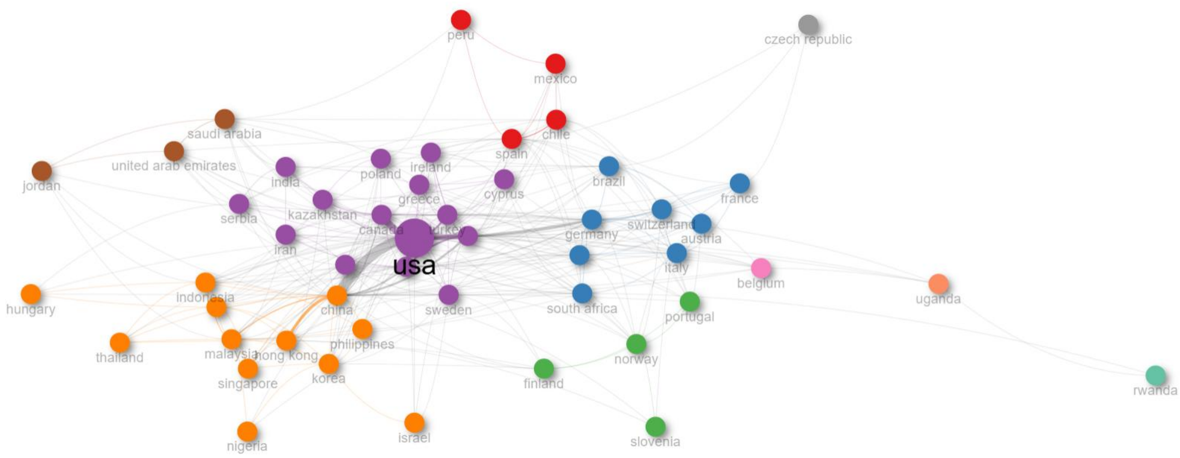

Figure 4. Network of Collaboration among Countries on Attitudes and Mathematics

The second largest cluster, orange, is mainly made up of Asian countries Eastern (China, Hong Kong and Korea) and Southeaster Asia (Thailand, Indonesia, Malaysia, Singapore and the Philippines), as well as the European country and the county of the Middle East, Hungary and Israel. In this collaboration network, China represents the direct link to the United States, besides being the country with the second largest number of publications on the topic. On the other hand, in the European continent a solid network of collaboration can be found, Germany standing out as the key link with the United States. Within this cluster (blue) are countries such as Switzerland, Austria, France and Italy, which also have significant connections to countries beyond the continent, among these Brazil and South Africa.

It is important to point out the presence of Spanish-speaking countries that form a network of collaboration between Mexico, Peru, Chile and Spain, the latter is generally the bridge between Latin American counties and Europe. It must also be pointed out that counties such as the Czech Republic, Belgium, Uganda and Rwanda appear only once on the network map, reflecting a peripheral position to the global network of scientific collaboration. However, this could represent opportunities for future collaboration that would allow for broadening their integration in consolidated scientific networks.

Analysis of Affiliation

Table 6 presents the 10 most prominent institutions associated with the publications, indicating the number of articles published by each institution and the country of origin. The analysis highlights the work done by the United States, which has two institutions on the list: the University of California leads the list with 62 publications, representing 14% of the total top 10, and Lawrence Technological University with 42 publications, both institutions accounting for 24% of the publications. Australia is similarly positioned, with Monash University ranking second with 49 articles, and Curtin University with 46 publications.

Table 6. Institutions with the Greatest Production in the Field for the Period of 1970-2024

Institution	Articles	Percentage (%)	Country
University of California	62	0.75	United States
Monash University	49	0.59	Australia
Beijing Normal University	48	0.58	China
Curtin University	46	0.55	Australia
National Taiwan Normal University	44	0.53	Taiwan
University of Limerick	42	0.51	Irlanda
Lawrence Technological University	41	0.49	United States
University of Cambridge	35	0.42	UK
University Putra Malaysia	33	0.4	Malaysia
University of Granada	33	0.4	Spain
Other institutions (2666)	7,868	94.23	
Total	8,301	100	

It is worth noting that, although Ireland and Taiwan are not among the countries with the highest number of publications, they are represented in the list of affiliated institutions. This could indicate that, while their contribution in terms of total publication volume may be limited, their contribution as a country may be through specific institutions with significant impact in the field, thus highlighting their capacity to participate in collaborative networks or strategic partnerships with international institutions.

Thematic Map

The thematic map (see Figure 5) reveals that the central themes in the analyzed research are mathematics, educational measurement, methodology, and psychological aspects, which are well developed and have a significant impact on literature. Topics such as students, teaching, problem- solving, and decision-making are fundamental but less specialized. Areas such as computer simulation, sustainable development, and uncertainty analysis appear as highly developed niches, but with less connection in the general network. Finally, topics such as e-learning and bifurcation (mathematics) are categorized as emerging or declining, suggesting that they are in the process of development or have lost relevance in this dataset.

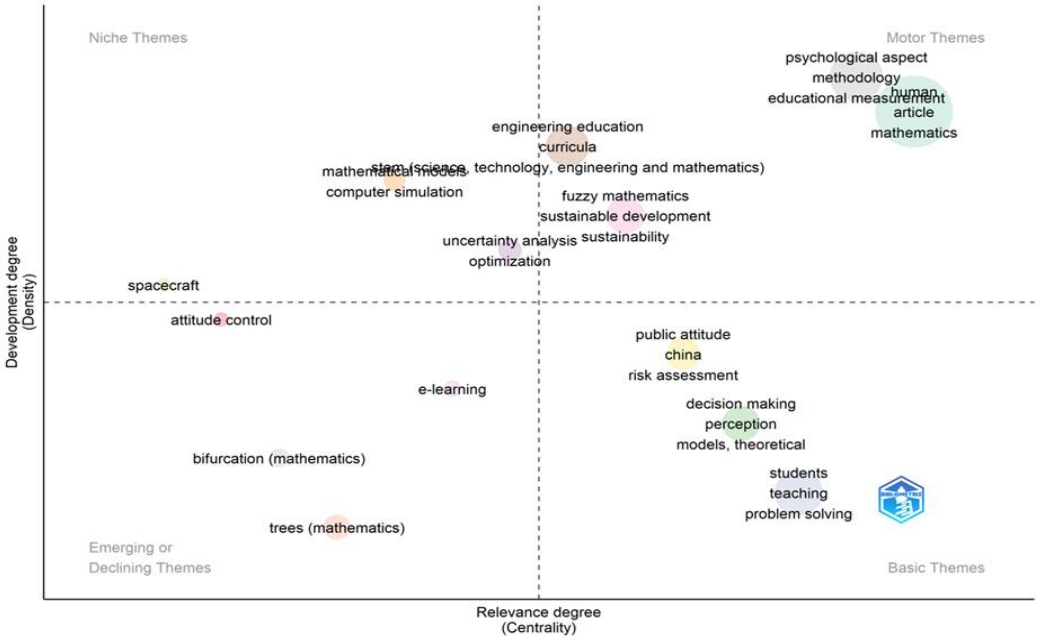

Figure 5. Map of Central Themes of This Research

Bibliographic Coupling

The analysis of bibliographic coupling provides information about the relationship between documents based on the citations made among them. This type of analysis allows for understanding how research fields develop and how certain documents or authors influence scientific production in the area. In Figure 6, 4 clusters with larger circles stand out, indicating that those documents have greater bibliographic coupling.

In the bibliographic coupling network, a yellow cluster is identified. The work of Springer (1999) stands out in this cluster. Their study conducted a meta-analysis on undergraduate STEM research since 1980, concluding that learning in small groups favors attitudes towards learning, promotes academic performance, and supports persistence in STEM courses and programs. Another prominent document is Nosek et al. (2002), which points out that gender stereotypes affect attitudes towards mathematics and science, particularly in women, influencing their identification with the discipline, which leads to paying attention to the opportunities or limitations posed by personal beliefs about the area.

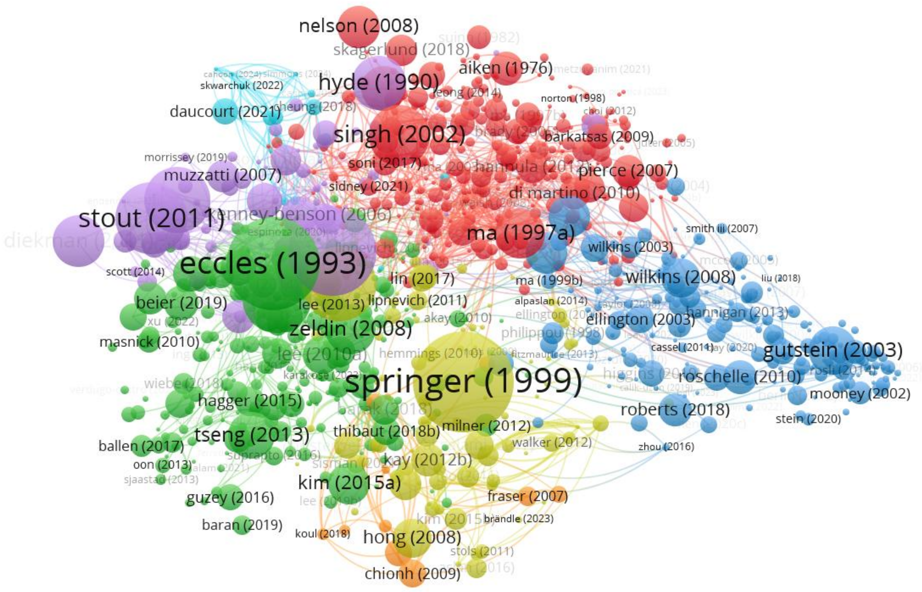

Figure 6. Bibliographic Coupling of Documents on Attitudes and Mathematics

In the green cluster, the four studies that stand out analyze how factors such as perceived competence, self-efficacy, and perceived usefulness influence attitudes towards STEM. Eccles et al. (1993) examined the development of competence perceptions in young children (7 to 10 years old) and the value they place on different activities in areas such as mathematics, reading, sports, and instrumental music, with respect to gender. On the one hand, they found that positive attitudes decreased in older children, and on the other hand, that boys had more positive competence beliefs and values than girls for sports and mathematics activities, while girls had more positive competence beliefs and values in reading and music activities.

Another relevant study is Wang (2013), which showed that the choice of a career in STEM fields is linked to mathematics performance, mathematical self-efficacy, and experiences with mathematics and science courses in secondary education, suggesting that positive attitudes can favor the choice of STEM careers. On the other hand, Zeldin et al. (2008) explored personal histories of men who chose STEM careers with the aim of understanding how their self-efficacy beliefs were formed and how this influenced their academic choices. The results suggest that there are different sources that predominate in the creation and development of self-efficacy for men and women who pursue STEM careers. While men's confidence is based on mastery experiences, women's depends on social persuasion and vicarious experiences.

Finally, Tseng et al. (2013) examined an activity that integrated STEM areas into the project-based learning (PjBL) methodology to understand students' perceptions regarding the integration of STEM areas in education. They found that this integration significantly improves students' attitudes towards engineering and that students recognized that having scientific knowledge in STEM areas is useful in their professional future.

The studies that stand out in the purple cluster conduct research on gender differences in participation in STEM fields. Else-Quest et al. (2010) analyzed two international datasets, results from 493,495 students aged 14 to 16, with the aim of estimating gender differences in performance, attitudes, and the affective domain towards mathematics. The results of the analysis indicated that gender equity can paradoxically affect the mathematics gap, highlighting the need to increase the empowerment of girls and women globally.

Diekman et al. (2011) mention that attraction to STEM fields is predicted by social cognitions such as working with or helping others and ability stereotypes. They mention that women prioritize community service more than men, perceive that STEM careers do not favor this type of work, and therefore show less interest in these areas. One strategy that could contribute to this gap is the one highlighted in the study by Stout et al. (2011). They conducted two cross-sectional and one longitudinal experiment in a calculus class, exposing students to female STEM role models and interacting with them to analyze the influence on students' attitudes, self-efficacy, and commitment to the disciplines. After this analysis, they suggest that seeing female experts in the field predicts greater self-efficacy, identification, and commitment to STEM careers, despite the fact that negative stereotypes about their gender and STEM remained active.

On the other hand, the study by Stoet and Geary (2018) explored how differences in academic strengths and sociocultural factors influence the choice of STEM fields. The results indicate that in two out of three countries, girls achieve equal or better results than boys in science. However, contrary to what would be expected in countries with greater gender equality, the differences between men and women in terms of academic strengths and the proportion of those who choose STEM careers are wider.

Finally, the studies with the greatest fit in the red cluster investigate the relationship between affective variables and academic performance. On the one hand, Ma and Kishor (1997) conducted a meta-analysis to evaluate this relationship in 113 studies, finding that several contextual variables, such as grade level and ethnic origin, lead to variations in the relationship. On the other hand, the study by Singh et al. (2002) used structural equation modeling to analyze the impact of motivation, attitude, and academic engagement on students' mathematics performance, showing that these have positive effects and indicated a stronger effect on academic time spent on tasks.

Network Analysis

From the results of the network analysis performed using ToS software, the articles with the highest number of citations were selected. From these, a tree was constructed with the citations of the documents represented in Figure 7. The tree consists of the roots, 5 seminal documents; the trunk, 5 documents that cite seminal documents and are cited by recent articles. The branches with the research perspectives that emerged are also represented, each represented by 10 articles. Finally, 30 articles were selected for the leaves, which are recent documents in the field of research.

Figure 7. Tos Tree Diagram

Roots

This section describes the main documents considered seminal or classics. The selection was made from articles with the largest number of citations. There is research on the methodological aspect of conducting research, and studies that analyze affective variables and how they influence the academic performance and attitudes of students and teachers.

In this line of research, statistical rigor is key to determining whether research related to behavioral variables such as attitude, performance and beliefs, among others, has sufficient power to find significant effects. In this sense, one of the most cited documents is Cohen's book (1988). This represents a key reference, as it provides a methodological basis for assessing the statistical power of analyses, evaluating whether sample sizes are adequate to identify changes in variables, and analyzing whether the results are significant and whether they have practical relevance. Cohen describes that statistical power depends on three parameters: first, the significance criterion, which represents the risk of rejecting the null hypothesis by mistake or proof that the phenomenon being studied exists; and second, the reliability of the sample results, which refers to the approximation of the sample to the corresponding population value. The most commonly used method for measuring this is the standard error. Finally, the effect size, which aims to provide a practical value to the relevance of the results, is a quantitative measure of the intensity of the relationship between variables or the difference between groups.

Another work identified as seminal in this analysis is that of Bandura (1977), which is considered fundamental to human behavior. He defines self-efficacy as the ability to believe in oneself to succeed. He indicates that those with high self-efficacy expectations are healthier, more effective, and, in general, more successful, as opposed to those with low self-efficacy expectations. In the educational field, this construct influences motivation, persistence, and performance. In the mathematical context, self-efficacy is closely related to students' attitudes, effort, and performance (Pajares & Miller, 1994; Hannula, 2002).

Pajares's (1992) study is another landmark document in the study of attitudes. This paper examines the meaning that prominent researchers give to the beliefs of teachers and teacher candidates. It indicates that teachers' beliefs can and should become an important focus of educational research, as they inform teachers' educational practice. To achieve this, clear conceptualizations, consistent understandings, precise meanings and adequate assessment and research of beliefs are required.

Hembree's (1990) work has been widely cited and recognized in the literature on math anxiety and its relationship to academic performance. This paper synthesizes a large number of previous studies on the topic through a meta-analysis. It provides a comprehensive overview of its nature, effects, and mitigation strategies, and provides information on its influence on affective and cognitive variables related to mathematics learning. The variable math anxiety is generally associated with lower academic performance and negative attitudes toward mathematics (Dowker & Sheridan, 2022).

McLeod (1992) also analyzes the role of the affective component in mathematics education. He does so based on a review of research in the area and proposes a new conceptualization to address this area, highlighting not only the cognitive component of teaching but also affective factors such as emotions, beliefs, and attitudes. In the study, the author comments that the cognitive component has been studied in isolation from the affective component, a point he criticizes, as he believes educators should be aware of the impact the affective component has on learning. He also suggests the design of strategies that foster positive beliefs about mathematics. As this is a research project that interrelates emotions, attitudes, and beliefs toward mathematics, it is essential to establish a conceptual basis for the study of the affective component of mathematics education.

Trunk

These documents are the backbone of research on the topic, opening the door to new lines of work. For their selection, the algorithm determines those documents that represent the shortest path between the leaves, which represent the most recent research, and the roots, which represent the classic studies.

Aiken (1970) conducted a systematic review of attitudes toward mathematics and their impact on academic performance. His particular interest was to analyze what information was available on the influence of factors such as a student's biological heritage and family environment; teacher attitudes and training; and curriculum content, organization, objectives, and adaptation in the teaching of mathematics. He also reviewed the methods used to measure attitudes, such as questionnaires, observations, and experimental and correlational studies. The author defines attitudes toward mathematics as a mix of emotions and feelings; affective components; and beliefs and perceptions about the usefulness of the discipline; and cognitive factors.

Furthermore, he indicated that a positive attitude toward mathematics is correlated with better academic performance, suggesting the need to improve attitudes toward mathematics through educational interventions with more dynamic and personalized teaching methodologies. Thus, their research remains relevant today as it allows us to understand how affective and cognitive components interact in the teaching and learning processes of mathematics.

On the other hand, the meta-analysis by Hyde et al. (1990a) is a key reference in research on gender and mathematics education. This study examines gender differences in attitudes and affect towards mathematics, using statistical techniques to calculate gender differences in different aspects related to mathematics. Several constructs are analyzed, such as math anxiety, confidence in learning mathematics, the usefulness of mathematics, the attitudes of mothers, fathers, and teachers (reported by students), and mathematics as a masculine domain, among others.

In general, the authors state that gender differences in mathematical attitudes are small, with women displaying more negative attitudes toward mathematics. Furthermore, there is a greater difference among students at advanced levels of study, which can have repercussions on their educational and professional careers. On the other hand, men tend to view mathematics as a field associated with their gender. Thus, this study serves as a benchmark for understanding how affective and sociocultural factors influence the academic and career decisions of men and women.

Another landmark document in the study of attitudes toward mathematics is that of Aiken (1976). In this work, the author updates his previous work (Aiken, 1970), expanding the analysis with new research. He emphasizes the need for ongoing reviews to keep the educational community informed about new methodologies and findings and stresses the importance of understanding the existing literature to inform future research. In this work, he reports on the research, classifying it into different categories. He begins by analyzing the various measurement instruments used at different educational levels. For math anxiety, he mentions that despite advances, the accuracy of these instruments still needs to be improved by creating tools that are more sensitive to individual and contextual differences.

It also reports studies on gender differences in attitudes toward mathematics, finding significant differences between men and women, with men displaying positive attitudes, greater interest, and confidence in their mathematical performance, which is mostly present at higher educational levels. Related to this, Aiken presents evidence from studies suggesting a low but significant positive correlation: students with more favorable attitudes tend to perform better in mathematics. Furthermore, it describes research on teachers and mathematics anxiety, which describes how teachers' attitudes, expectations, and teaching methods can significantly influence students' perceptions of the subject. Based on this analysis, it recommends reducing mathematics anxiety with more dynamic and motivating teaching methods, as well as building confidence in students' abilities regardless of their gender.

The study by Di Martino and Zan (2010) links educational psychology and mathematics education by investigating affective factors in mathematics learning based on a narrative analysis, using qualitative methodologies such as the holistic method, which focuses on an individual's life story, and the focus on the content presented in the narrative. Through these accounts, the conceptualization of attitude is redefined and complements previous approaches of psychometric and quantitative studies. The author identifies that attitude is not a unidimensional construct but rather the product of the interaction between emotions, past experiences, and perceptions about the usefulness of mathematics. Furthermore, it highlights that attitudes are formed over time, influenced by social and educational factors. This research moves away from traditional measurements and emphasizes the importance of students' opinions.

Another investigation that uses an unconventional methodology for the study of attitudes is that of Ma and Xu (2004), which conducted a longitudinal study. For this purpose, they employ a structural equation model to analyze a large-scale longitudinal dataset, analyzing the interaction between affective (attitude) and cognitive (performance) factors in mathematics education. The authors mention that it is important to examine these relationships over time, emphasizing secondary education where changes in attitudes occur and can stabilize and influence students' performance in mathematics. This study investigated the causal relationship between attitude towards mathematics and performance in the subject. Their findings highlight that performance has a stronger impact on attitude, contrary to the traditional idea that improving attitude leads to better academic results. In contrast, it suggests that ensuring successful experiences in mathematics is fundamental for the development of positive attitudes.

Emerging Perspectives from the Bibliometric Analysis of Attitudes towards Mathematics

Factors Influencing Preparation for Academic and Professional Success

This category describes various factors, including the development of self-regulation skills and cognitive competencies. Schunk and Zimmerman (2011) provide a broad and detailed overview of self-regulation processes in various educational contexts. Conley (2010) focuses on how these skills should influence preparation for higher education and the world of work, as this not only refers to basic academic knowledge but goes beyond, implying the development of advanced cognitive skills, autonomous work habits, learning strategies, and knowledge about how to navigate the educational and professional system. In addition to these, Roderick et al. (2009) mention other essential areas for university preparation: non-cognitive skills, such as behavior and attitudes. They also analyze the difficulties faced by urban high schools in preparing all students for college. For his part, Conley (2007) analyzes the differences in preparation between high schools and the academic expectations of institutions of higher education, proposing strategies to address the gap and thereby achieve a successful transition to higher education.

On the other hand, another factor influencing academic performance is the use of technology, particularly online assignments, which impact both performance and students' attitudes towards mathematics. The reviewed studies suggest that the use of digital tools such as online assignment platforms improves students' overall performance, helps them understand concepts, and increases their level of satisfaction with that classroom work system (Zerr, 2007). Furthermore, the studies by Leong and Alexander (2013; 2014) and Wooten and Dillard-Eggers (2013) indicate that low-performing students seem to benefit more compared to higher-performing ones. In this regard, Brewer (2009), through an exploratory analysis, showed that students who repeated courses and had low skill levels received passing grades, unlike those taking them for the first time.

Active Methodologies

The articles analyzed in this branch explore various pedagogical methodologies to improve the teaching and learning of mathematics, in addition to identifying whether these influence students' attitude and academic performance. Among these is the flipped classroom, which shows benefits for students such as increased in-class time for tasks, integration of new knowledge, and real-time feedback, although challenges also appear, such as students' lack of familiarity with flipped learning and a significant initial effort on the part of instructors (Lo et al., 2017).

On the other hand, studies by Oluwatimilehin and Owoyele (2012) and Siller and Ahmad (2024) explore strategies that influence students' academic performance. The first author analyzes the relationship between various aspects of study habits and performance, finding that consultation with the teacher is the most influential factor. The second study analyzes collaborative learning, which shows a positive impact on student performance and attitudes compared to traditional teaching. Also, the problem-solving method suggests it improves motivation and academic performance by using challenging problems (Bishara, 2016). This highlights the importance of communication, whether through teacher support or peer collaboration, to improve students' attitudes and academic performance.

Other strategies that positively influence students, especially in distance education contexts, include the use of e-learning. Compared to an expository teaching method. E-learning shows improvement in students' autonomy, participation, results, and motivation (Moreno-Guerrero et al., 2020), as does the distance learning modality in teaching and learning processes, which positively impacts these processes (Pereira & Gomes, 2022).

The process of computational thinking (CT) plays an important role in the areas of science, technology, engineering, and mathematics (STEM). However, there is limited information on the relationship between learning attitude towards STEM and students' CT skills. In this regard, the studies by Richado et al. (2023) and Sun et al. (2021) address this topic, analyzing the relationship between computational thinking (CT) and students' attitudes. Richado et al. (2023) identified that female students show better skills in mathematical problem-solving compared to male students. Regarding CT attitude, no gender differences were observed, and there is a significant relationship and influence of CT attitudes on CT skills. For their part, Sun et al. (2021) examined the relationship between learning attitude in STEM and CT skills in students, concluding that a positive attitude towards STEM predicts better CT development. They also indicate that female students show a greater inclination towards STEM than male students. Both studies suggest that gender difference can influence students' development and highlight the importance of fostering computational thinking from an early age.

Finally, other perspectives supported by these methodologies include the transformation of education through the restructuring of curricula, using project-based learning (Korkmaz and Kalayci, 2019), taking into account factors that influence students' mathematical performance such as family support, self-efficacy, and attitudes towards mathematics (Animasaun & Oyadeyi, 2023). This highlights the importance of external factors, such as the educational context, attitudes, and support received, in the effectiveness of learning.

Measurement of Attitudes

The studies analyzed are within the framework of the line of investigation on measuring attitudes towards mathematics and science. Specifically, the works address the development and validation of instruments for measuring attitudes, such as the Attitudes Toward Mathematics Inventory (ATMI), evaluating its factorial structure, reliability, and validity. It was found that several variables correlated with others and were eliminated without affecting the properties of the instrument. The enjoyment and motivation scales showed a high correlation, which suggested the elimination of motivation, showing good internal consistencies for the abbreviated ATMI (Lim & Chapman, 2013). Other scales, such as the Trends in International Mathematics and Science Study and the High School Longitudinal Study of 2009, were also used to measure attitudes towards mathematics (Thomson et al., 2012; Middleton, 2013).

The Fennema-Sherman Mathematics Attitudes Scales are used in various studies, including that of Mkhize and Maistry (2017). This research identified demographic aspects in attitudes towards mathematics. In general, positive results towards mathematics were found in students who felt more supported by their parents and teachers. Similarly, the study by Alibraheim (2020) found a statistically significant relationship between students' demographic characteristics regarding mothers' educational levels and their motivation in mathematics. Factors such as gender were also explored using this scale. Alibraheim and Fowler (2019) examined the differences between male and female students' attitudes towards mathematics and found no gender differences in their mathematical attitudes, but they did find an influence of maternal education level on mathematical motivation.

Various aspects of teaching mathematics at different educational levels were also analyzed by questionnaires, of both pre and post design and the use of modeling of structural equations to analyze data. Muthomi et al. (2012) investigated teachers’ disposition towards the use of scientific calculators, concluding that they have positive attitudes towards integrating their use into teaching. Michaluk et al. (2018) examined the beliefs and attitudes of primary school teachers on the Nature of Science (NoS) and learning mathematics and science, finding that following a curricular intervention perceptions may improve. Finally, Yun Y Ah’s study analyzes the relationship between primary school teachers’ knowledge, attitude towards mathematics and efficacy and ability in problem solving, through a modeling of structural equations to identify a way to strengthen the capability of problem solving.

Leaves

The leaves of the tree of science represent the most recent articles in the field. ToS analysis identified 50 leaves, of which the articles from the last two years were selected, from 2022 to September 6, 2024 (30 articles). In these articles various subjects on attitudes towards mathematics were analyzed, one of them being the influence of teaching based on pedagogic strategies. Wakhata et al (2024) highlighted the heuristic framework of active learning as a bridge between attitude and performance. Quane (2024) evaluated the impact of the use of manipulatives with primary school children. Romero and Angeles (2023) used the flipped classroom method. With respect to structural factors, Sun and Xiao (2023) explored the relationship between experimental learning and basic competencies in mathematics. Stone-Johnstone (2023) explored the impact of academic support with resources, pointing out the need to investigate the atmosphere in the classroom as a key factor in forming attitudes towards mathematics. In the context of distance learning, Pereira and Gomes (2022) evaluated learning mathematics in the distance modality. Mengstie (2022) analyzed the application of the Elaboration Likelihood Model of Persuasion in mathematics education, suggesting that these strategies can improve a pro-mathematics attitude in the early years of schooling. These studies highlighted the influence of various pedagogical approaches and contexts of learning in attitudes and academic performance.

The evaluation of attitudes is a recurring subject matter nowadays, highlighting the use of standardized questionnaires as fundamental tools for understanding attitudes towards mathematics at various educational levels and socio-cultural contexts. These instruments include validated scales that analyze dimensions such as self-efficacy, enjoyment of mathematics, perceived usefulness, math anxiety, among others. Ozimek et al (2024) utilized a scale encompassing multiple subscales, such as growth mindset, meaning-seeking, and the nature of responses in mathematics. Dingel and Ayebo (2022), on the other hand, employed mathematical autobiographical essays to analyze students' confidence, value, and enjoyment of mathematics. Meanwhile, Wakhata et al. (2022) adapted the short version of the Attitude Toward Mathematics Inventory (ATMI-SF) to evaluate Ugandan students' attitudes toward linear programming problems.

Beyond questionnaires, advanced statistical analyses were used to explore relationships between variables. Moliner and Alegre (2020) investigated teachers' knowledge, perceptions, and attitudes toward peer tutoring to determine implications for practice and policy. They concluded that female teachers are more sensitive than male teachers in regard to student inclusion and active learning. Sánchez-Mendías et al. (2024) also analyzed teacher opinions, studying prospective teachers' perceptions of their primary school teachers' attitudes toward mathematics. They indicated that these variables have a significant relationship: those who perceived more favorable attitudes from their teachers tended to show higher levels of mathematical competence. Schmitt-Cerna et al. (2024) measured attitudes toward mathematics and perceptions of virtual education during the COVID-19 era. Their findings showed that students had low affection toward both variables, but a significant positive correlation was found, suggesting that negative perceptions toward virtual teaching and attitudes toward mathematics are linked.

Moussa and Saali (2022) adapted the Mathematics Attitude Questionnaire (MAQ) to examine factors influencing university students' attitudes in the United Arab Emirates. They concluded that the level of mathematics study is a significant factor influencing these attitudes, while gender did not have a relevant impact. Segarra and Juliá (2022) used the Attitudes Toward Mathematics Scale (AMS) along with the Mathematics Teaching Efficacy Belief Instrument (MTEBI) to analyze the relationship between teacher self-efficacy, their attitude toward mathematics, and mathematical performance in prospective teachers. Their findings indicated that personal efficacy in teaching mathematics was the most determining factor. Similarly, Kiwanuka et al. (2020) examined the temporal relationship between these two variables with first-year secondary students, with results suggesting a reciprocal relationship between them. Quaye & Pomeroy (2022) investigated intergenerational inequalities between attitudes and mathematics learning with secondary students, concluding that attitudes toward mathematics are strongly influenced by their parents' perceived attitudes. Furthermore, Hernández de la Hera et al. (2023) examined the relationship between mathematical attitudes and emotional dimensions, noting that anxiety has a negative impact on attitudes, while self-efficacy positively influences them.

In some cases, questionnaire use requires adaptation to the language of application. For instance, Saputra and Tania (2024) adapted the Attitude Toward Mathematics Inventory (ATMI) and examined its Indonesian version. Their results showed good structural validity, high internal consistency, and no significant gender differences in attitude toward mathematics. Ovat et al. (2024) analyzed the psychometric properties of two instruments on attitudes toward mathematics and mathematical creativity. The author deduced that mathematical self-efficacy is a strong predictor of mathematical creativity in its dimensions of fluency, flexibility, and originality. Ávila-Toscano et al. (2023) examined these properties in the Scale of Attitudes Toward Mathematics (EAHM-U).

Recent research also includes studies on the role of gender in Science, Technology, Engineering, and Mathematics (STEM), focusing on how attitudes, stereotypes, and mathematical self-efficacy influence the participation of girls and boys in these fields. A key factor in motivating girls has been identified as knowing other women who serve as sources of inspiration in STEM areas. Gutiérrez-Aguilar and Tejada (2024) identified the association between gender stereotypes and students' attitudes toward mathematics, finding that barriers related to gender stereotypes persist. Geary et al. (2023) conducted longitudinal studies that showed girls tend to experience higher math anxiety and less positive attitudes than boys. Xie et al. (2023) explored the role of attitude toward mathematics and mathematical self-concept in relation to gender stereotypes in mathematics and the mathematical performance of males and females. They found that for women, stereotypes do not directly affect their mathematics performance but negatively influence how they perceive themselves in this area, whereas for men, stereotypes do not have a clear impact on either their attitude or self-concept. Along this line, Óturai et al. (2023) investigated the relationships between students' secondary mathematics education and their current study program, concluding that advanced mathematical foundations are related to positive attitudes and improved performance in higher education. They also analyzed differences in attitudes between STEM and non-STEM students but found that these do not differ significantly between the two groups.

Regarding teachers, Franco-Buriticá et al. (2023) analyzed the attitudes and anxiety of prospective teachers studying in rural and urban environments. Results show that gender is a differentiating factor in math anxiety, potentially affecting their future practices. In this context, according to Robinson and Aldridge (2022), fostering more positive and participatory learning environments, such as Inquiry-Based Learning (IBL), has proven effective in improving girls' perceptions of the learning environment and promoting more positive attitudes toward mathematics. Thus, these investigations, through their results, underscore the importance of educational interventions that reduce stereotypes and promote gender equity in STEM.

Finally, studies are emerging on the mediating role of parental involvement in the development of students' attitudes toward mathematics, highlighting its influence on creativity, interest in learning, and academic performance. Suherman and Vidákovich (2024) conducted a cross-sectional study exploring secondary students through an ethno-mathematics-based test of mathematical creative thinking (MCT) and questionnaires. They found that parental education and creative style influenced secondary students' mathematical creative thinking. On the other hand, Zhao et al. (2024) analyzed the mediating parental influence on the development of learning interest in children, finding that parents' attitudes toward their own abilities in mathematics and reading had effects on children's academic interests. Finally, Simmons et al. (2024) explored the relationship between parents' math anxiety and attitudes with their children's math performance in elementary school. A strong association was highlighted between maternal anxiety and academic performance in girls compared to boys.

Conclusion

To achieve the objective of this research, a bibliometric analysis was conducted to examine academic production by year. This analysis revealed that 309 articles were published in 2021, marking the highest productivity period, followed by 2023, with 300 articles. Regarding the journals with the highest production in the field, six were identified as being in the first quartile, while another four belong to the second quartile, indicating their high quality in terms of academic evaluation. Among these is the International Journal of Mathematical Education in Science and Technology, from the United Kingdom, with 113 published articles, followed by Educational Studies in Mathematics, from the Netherlands, with 61 studies.

The authors with the greatest contributions in this area of study come from various global institutions. Author Ma, X. from the University of Kentucky in the United States has the largest output on the subject with 14 studies. Among the topics of his research is how math anxiety and negative attitudes can affect academic performance in mathematics. Tong, D. H. and Uyen, B. P. from Can Tho University in Vietnam point out that implementing technology-supported pedagogical strategies fosters positive attitudes toward learning abstract concepts and improves mathematical skills. Meanwhile, Fraser, B. J., in her research, points out that the classroom environment contributes significantly to the development of attitudes, showing that the school climate and active methodologies are key to fostering a better disposition toward mathematics in students.

In the co-citation analysis, 5 clusters were created, among which author Eccles, J. S. from the University of California in the United States stands out. Her work, Expectancy-value theory of achievement motivation, is highly cited, indicating that it has an impact in the area of attitudes. Furthermore, his most cited works are in collaboration with Wigfield A., which suggests a strong connection between their theoretical and methodological approaches. The structure of collaboration within this research area is demonstrated through the co-author network, within which four clusters were identified. Among these are influential authors in scientific production, such as Fraser Barry J. of Curtin University in Australia, who represents a central node in the network, having connections with other research groups.

Regarding the countries with the highest scientific production, the United States accounts for 29.1% of the production, followed by China with 9.5%. Likewise, the collaboration network places the United States as the central node, with relationships with countries around the world; however, it presents a stronger relationship with China and Turkey. Regarding the institutions with the highest production, the top ten were considered. Two of these belong to the United States: the University of California, leading with 62 articles, and Lawrence Technological University with 41 documents. Australia also has two universities among the most prolific: Monash University with 49 articles and Curtin University with 46 documents.

The bibliographic coupling analysis identified seven clusters, with four standing out due to their greater representativeness. These clusters reflect research lines focused on affective and gender aspects within the educational context. One cluster addresses gender stereotypes and their influence in academia, while another centers on how affective factors impact attitudes toward STEM disciplines. A cluster analyzing gender differences in participation in these areas also stands out. Finally, there is a cluster focused on the relationship between affective variables and academic performance. This information highlights the importance of considering both affective aspects and social gender constructions as key points in improving student participation and performance in the STEM field.

The thematic map in the area of attitudes and mathematics reveals some widely recognized areas in the literature, such *as mathematics, educational measurement, methodology, and psychological aspects.* Emerging themes identified include e-learning, bifurcation (mathematics), and trees *(mathematics).*

The network analysis conducted with the Tree of Science (ToS) platform identified several seminal documents (roots). Cohen's (1988) study, providing a methodological basis, is widely cited. Bandura's (1977) book is considered crucial in studies of human behavior, and Pajares (1992) is a reference in research on teachers' beliefs. In the study of attitudes, affective factors are crucial; Hembree's (1990) work is a key source on the relationship between math anxiety and academic performance. Additionally, McLeod (1992) provides a framework for studies on the affective component in mathematics education. In the analogy of a tree, the trunk represents the central axis of the analyzed documents, supported by seminal works and giving rise to new investigations. This includes studies like Aiken (1970) with a systematic review on attitudes toward mathematics and their impact on academic performance, later updated by Aiken (1976). Hyde et al. (1990b) address gender and mathematics education. Di Martino and Zan (2010) and Ma and Xu (2004) discuss the relationship between affective factors and performance in mathematics education.

Based on the analysis, attitudes are influenced by various cognitive, affective, and contextual factors. The analysis identified emerging research lines, one of which highlights the importance of self-regulation as a key process for academic development in diverse educational environments (Schunk & Zimmerman, 2011). Likewise, Roderick et al. (2009) emphasize the importance of non-cognitive skills such as motivation and self-confidence in the holistic development of students transitioning to higher education from urban high schools. Conley (2007) also contributes by providing information on the differences between the preparation provided by high schools and the academic demands of higher education, which affect students' ability to face university challenges.

Additionally, another determining factor in student preparation is the availability of technological resources. As

Zerr (2007) mentions in their research, the use of technological tools can facilitate academic performance, thus strengthening the necessary competencies for students' academic future. Similarly, research by Leong and Alexander (2013; 2014) and Wooten and Dillard-Eggers (2013) highlights that the benefits of the use of technology can be especially significant for low-performing students, allowing them access to new learning methods that enhance their performance.

The constant changes in the educational environment over the past years have led to rethinking the methods of teaching and learning in order to improve students' experiences and results. That is why subjects such as active methodology have emerged as an effective solution since they promote students' participation, autonomy and commitment. This methodology highlights the importance of transforming the traditional approach of education into a more dynamic, student-centered education. Collaborative learning, for example, has shown that it favors the interaction and development of positive attitudes among students (Siller y Ahmad, 2024). Lo et al. (2017) mention that the flipped classroom has showed improvement in students' autonomy and allows them to spend more time in class on practical activities. Similarly, the use of challenging problems has been identified as a key factor in increasing students' motivation and promoting active learning (Bishara, 2016).

Technology has significantly impacted education, promoting innovative approaches such as e-learning and distance learning, which positively impact both academic outcomes and student motivation (Moreno-Guerrero et al., 2020; Pereira & Gomes, 2022). Computational thinking (CT) has also become a necessary skill for students, significantly influencing attitudes toward STEM disciplines, which in turn favors the development of CT skills (Richado et al., 2023; Sun et al., 2021). On the other hand, Korkmaz and Kalayci (2019) and Animasaun and Oyadeyi (2023) highlight active learning in problem-solving using project-based learning; however, this is influenced by external factors.

In recent years, the measurement of attitudes toward mathematics has gained momentum in educational research, not only due to its influence on academic performance from a cognitive perspective but also from an affective perspective. As Suherman and Vidákovich (2024) point out, affective variables have a considerable impact on mathematical performance, justifying the increase in studies focusing on this approach. The development and validation of instruments, such as the Attitudes Toward Mathematics Inventory (ATMI), demonstrates the need for solid certainty when measuring constructs. For example, Lim and Chapman (2013) decided to eliminate the motivation construct from the ATMI instrument due to its high correlation with other factors, highlighting the complexity of the phenomenon.

In turn, studies such as those by Mkhize and Maistry (2017) and Alibraheim (2020), which analyzed the Fennema-Sherman Mathematical Attitudes Scale, identified that demographic variables also significantly influence how students approach mathematics. While research such as that by Alibraheim and Fowler (2019) suggests that gender does not represent a significant difference in attitudes toward this discipline, which leads to rethinking certain traditional assumptions. Another factor that contributes to academic performance is teachers' attitudes. Research such as that by Michaluk et al. (2018) and Yun & Ah (2016) indicates that a positive attitude toward mathematics contributes significantly to improved teaching processes. In this sense, measuring teachers' attitudes through scales can be a useful tool for identifying areas for strengthening pedagogical practices.

Recent research on attitudes and mathematics is becoming increasingly broader. Among the documents studied, there is a growing interest in investigating how pedagogical strategies can influence positive attitudes towards mathematics, as demonstrated in recent studies that integrate innovative approaches (Wakhata et al., 2024; Quane, 2024; Romero & Angeles, 2023; Sun & Xiao, 2023; Stone-Johnstone, 2023). Furthermore, research on the influence of affective, academic, and contextual variables on the subject has allowed for greater knowledge about the area and paid attention to factors that were previously seldom considered (Moliner & Alegre, 2020; Schmitt-Cerna et al., 2024; Sánchez-Mendías et al., 2024). This line of work is complemented by the development and validation of instruments to measure these variables in a more precise and meaningful way (Ozimek et al., 2024; Dingel & Ayebo, 2022; and Wakhata et al., 2022).

There have also been more studies on the influence of gender on attitudes towards this discipline, studies which show that while differences persist, changes in the way attitudes towards mathematics in men and women have transformed (Gutiérrez-Aguilar y Tejada, 2024; Geary et al., 2023; Xie et al., 2023 y Óturai et al. (2023). Research in the area is dispersed and identifies a wide variety of variables that influence attitudes toward mathematics, ranging from parental involvement (Suherman & Vidákovich, 2024; Zhao et al., 2024; Simmons et al., 2024), learning environments (Robinson & Aldridge, 2022; Fraser & Kahle 2007), gender (Xie et al., 2023; Gutiérrez-Aguilar & Tejada, 2024), and affective variables (Dingel & Ayebo, 2022; Franco-Buriticá et al., 2023).

Analyzing collaboration networks suggests the existence of consolidated research nodes, as well as emerging lines of research exploring new theoretical and methodological perspectives in the study of attitudes towards mathematics. In this context, the positive results found in the research in which active methodologies are used highlight the importance and potential of interventions to improve teaching mathematics. Besides continuing the validation and development of scales that allow for better understanding the influence of these factors on attitudes, it may contribute to improving educational processes in this discipline.

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