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A bibliometric analysis of the structural equation modeling in mathematics education

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Abstract

Structural equation modeling (SEM) is well-known in statistics due to its flexibility and accessibility. In the Scopus database alone, there were more than 1,500 search results related to SEM in mathematics education. However, there is a lack of scientific reviews of mathematics education that use SEM. The purpose of this study was to investigate research trends related to SEM in mathematics education. The researcher used Biblioshiny and VOSviewer to conduct bibliometric analysis on 1,017 papers that have been published in the Scopus database. The result showed that the number of publications in the research area has continuously grown over the last few decades. The US was the most prolific country in terms of publication and international collaboration. Professor Herbert W. Marsh had the most publications and citations, while the most productive journal was Frontiers in Psychology. The most current keywords include STEM, technology acceptance model, control-value theory, and computational thinking. Hence, these findings may serve as a guide for future researchers to conduct relevant research using SEM.

Keywords: structural equation modeling, mathematics education, bibliometric analysis, VOSviewer, Biblioshiny

INTRODUCTION

Since more than two decades ago, structural equation modeling (SEM) has been widely used as a multivariate data analysis method in the field of education (Arthur et al., 2022; Cardona, 2020; Davadas & Lay, 2018; Lee & Kung, 2018; Somasundram, 2021). One of the reasons for such popularity is the complexity of the educational constructs in reality. Many educational researchers are finding it challenging to analyze the relationships between complex and latent variables (Khine, 2013). The presence of SEM tools such as AMOS not only makes it easier for researchers to measure and interpret complex relationships among variables but also speeds up SEM analysis process, which does not require programming skills for all researchers (Collier, 2020).

Despite the fact that there has been a wide range of educational review research focused on SEM (Karakaya-Ozyer & Aksu-Dunya, 2018; Sakaria et al., 2023; Xu et al., 2022; Yin & Huang, 2021) and bibliometric review focused on mathematics education (Phan et al., 2022; Suseelan et al., 2022; Xu et al., 2022), no bibliometric analyses on this topic have been published to the best of our knowledge. Therefore, the objective of this study is to fill the gap by providing a bibliometric description and analysis of the previous empirical studies related to SEM in mathematics education on

(a) the pattern of publications,
(b) the top-authors and journals,
(c) the contribution and collaboration among countries, and
(d) the key concepts in publications that use SEM in mathematics education.

METHODOLOGY

The data was collected on January 18, 2023, in accordance with the four steps of the preferred reporting of systematic reviews and meta-analysis (PRISMA) guidelines (Moher et al., 2009). In this study, we adopted Elsevier's Scopus database because it covers more than 27.1 thousand active titles and has about 84 million

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Contribution to the literature

- This research has identified the leading journals and authors that have used Structural Equation Modeling (SEM) in mathematics education.
- This research has mapped how different countries contribute and collaborate in publishing SEM studies in mathematics education.
- This research highlights that current keywords such as Science, Technology, Engineering, and Mathematics (STEM), Technology Acceptance Model (TAM), control-value theory, and computational thinking are getting more attention in recent academic research.

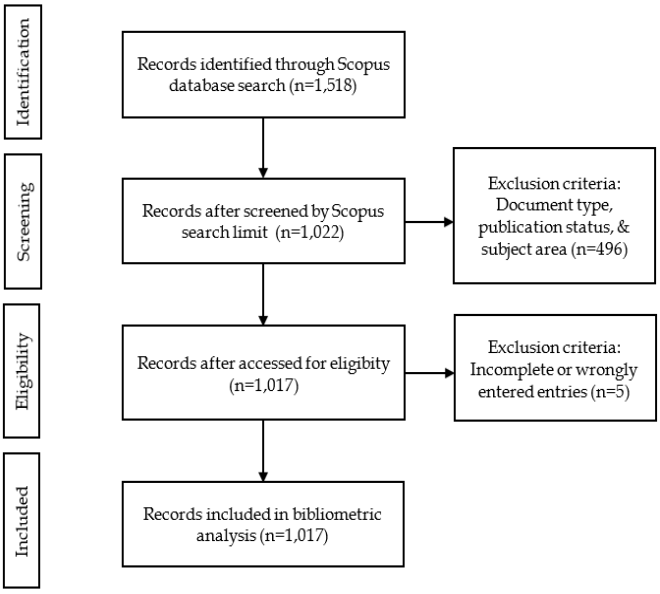

Figure 1. PRISMA flow diagram of literature search process (Source: Authors' own elaboration)

records (Scopus–Your Brilliance, Connected, 2022). Furthermore, it provides more high-quality social science publications than some other academic databases (Baas et al., 2020). **Figure 1** shows PRISMA flow diagram of the literature search process.

The first stage of PRISMA is called identification, where the researchers identify relevant publications that focus on using SEM in mathematics education. For an effective document search, the researchers conducted an advanced search with the search field code (TITLE-ABS-KEY). The use of the search field code (TITLE-ABS-KEY) enables the search engine in retrieving any publications that contain relevant phrases in the title, keywords, or abstract. The search phrases used in this study were "structural equation model*", "SEM", educat*, school*, teach*, learn* and math*. The asterisk (*) was used to replace multiple characters in a word (Grigg, 2023). For example, searches using educat* would return results for "education," "educate," "educating," "educated," "educators," and so on. On the other hand, double quotation marks ("…") was used to search for terms that have to be together, such as "structural equation modeling". As a result, prior to any filtering, the primary search yielded a total of 1,518 document results.

Subsequently, the researchers refined the search by using exclusion criteria to exclude irrelevant results. In this study, the exclusion criteria were limited to only journal papers in their final stage of publication and papers in the subject areas of social sciences, psychology, and mathematics. The rationale for such criteria was to improve comparability throughout the bibliometric analysis. The following search query TITLE-ABS-KEY (("structural equation model*" OR "SEM") AND (educat* OR school* OR teach* OR learn*) AND (math*)) AND (LIMIT-TO (PUBSTAGE, "final")) AND (LIMIT-TO (SUBJAREA, "SOCI") OR LIMIT-TO (SUBJAREA, "PSYC") OR LIMIT-TO (SUBJAREA, "MATH")) AND (LIMIT-TO (DOCTYPE, "ar")) was used to search and identify relevant studies. After refining based on the exclusion criteria, a total of 1,017 data results were recorded. The Scopus database was then downloaded and saved as a comma-separated values (.csv) file. This step is essential so that importing data into Biblioshiny application and VOSviewer software is trouble-free. Next, the data was opened in Microsoft Excel for "data cleansing," which involves removing any missing or incorrectly entered data. After cleaning the data, it was imported into Biblioshiny apps and VOSviewer software for analysis.

Bibliometric analysis is a widely used methodology for analyzing large amounts of scientific data (Block & Fisch, 2020; Donthu et al., 2021). There are two fundamental bibliometric analysis techniques: performance analysis and science mapping (Donthu et al., 2021). Science mapping looks into the relationships between the research constituents, whereas performance analysis explores the productivity and performance of the research constituents (Donthu et al., 2021). Examples of science mapping include co-authorship analysis, co-words analysis, bibliographic coupling, citation analysis, and co-citation analysis, whereas performance analysis includes the total number of publications, the total number of citations, the h-index, etc. (Donthu et al., 2021).

This study used Biblioshiny, an application of Bibliometrix R-package and VOSviewer for bibliometric analysis. Two of them are open-source and free software that can be downloaded from the internet. Biblioshiny is a web-based graphical interface of Bibliometrix R-package, which was released in 2019 (Moral-Muñoz et al., 2020). Unlike the older version of Bibliometrix R-package, Biblioshiny in the recent version of

Bibliometrix R-package is user-friendly and does not require coding skills to perform the bibliometric analysis (Ahmi, 2022). It can run bibliometric analysis in terms of performance analysis and science mapping. However, the researchers found that VOSviewer can construct and visualize bibliometric networks better than Biblioshiny application in certain conditions. For example, before VOSviewer co-authorship map is generated, we can preview the co-authorship data list. However, there is no such function in Biblioshiny. In addition, the value threshold is also customizable in VOSviewer (van Eck & Waltman, 2022; McAllister et al., 2021). For instance, we can modify the number of keywords that appear in VOSviewer visualization map but not in Biblioshiny visualization map. Thus, the researchers mostly use VOSviewer to perform scientific mapping in this study.

Apart from that, Scopus has its own basic performance analysis, which beats both Biblioshiny and VOSviewer. For instance, the top-countries analysis includes hyperlinks for every country listed. We can read the articles listed under a specific country by clicking on it. Furthermore, it displays two metrics (SCImago journal rank [SJR] and source normalized impact per paper [SNIP]) to assist us in understanding the citation impact of the sources.

RESULTS & DISCUSSION

This section presents the findings' results and discussions based on the four research questions. The results were generated from the two main bibliometric analysis techniques: performance analysis and science mapping. In this study, performance analysis helps determine the performance and productivity of the research topic, whereas science mapping helps demonstrate the co-authorship and co-occurrence of research constituents.

Research Question 1. What Is Pattern of Publications of Papers That Use SEM in Mathematics Education?

Figure 2 is a line graph that shows the relationship between the number of years and the number of articles published. This graph shows a rising trend with a total of 1,017 journal articles. The year 2021 was the year with the most articles published.

Table 1 displays the important facts about SEM publishing since 2008. According to the findings, there were 1,017 journal articles published on the topic of mathematics education using SEM since 1988. These articles were primarily from 420 sources, with an average of 32 citations per document. The publication's annual growth rate is 5.25%, indicating a positive, gradually increasing growth rate. However, a closer look shows that it began to rise sharply after 2011. One of the factors that contributed to the dramatic rise after 2011 could be the increasing number of publications that guide researchers on how to use SEM (e.g., Hair et al., 2010, 2011).

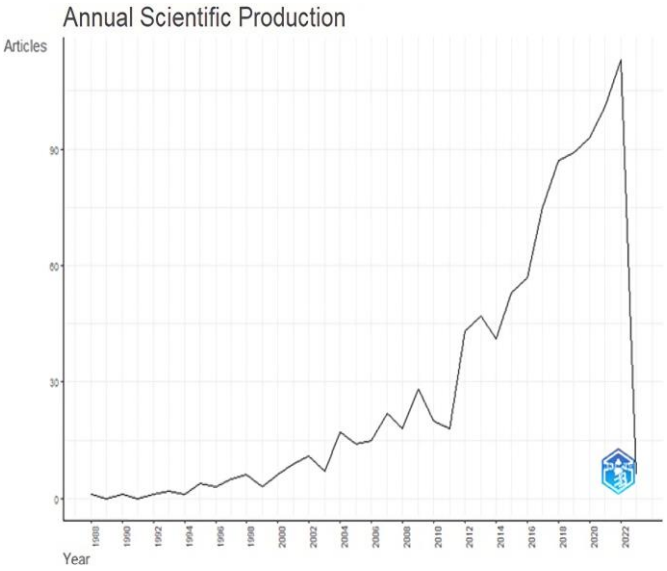

Figure 2. Distribution of mathematics education publications that used SEM from 1988 to January 18, 2023 (Source: Authors' own elaboration, using the Biblioshiny App)

Table 1. Main information about mathematics education that used SEM

Description	Results
Timespan	1988:2023
Sources (journals, books, etc.)	420
Documents	1,017
Annual growth rate (%)	5.25
Document average age	7.60
Average citations per document	32.23
References	58,903
Keywords plus (ID)	1,889
Author's keywords (DE)	2,485
Authors	2,619
Authors of single-authored docs	104
Single-authored docs	115
Co-authors per document	3.20
International co-authorships (%)	20.55
Article	1,017

Research Question 2. What Are Top-Journals & Top-Authors That Have Employed SEM in Mathematics Education Articles?

The two most prolific journals among all publications are 'Frontiers in Psychology' and 'Learning and Individual Differences,' which published 35 papers each. The following are the other top-10 journals: Journal of Educational Psychology (27), British Journal of Education Psychology (22), Contemporary Educational Psychology (22), International Journal of Science and Mathematics Education (17), Journal of Experimental Child Psychology (14), EURASIA Journal of Mathematics, Science and Technology (13), Journal of School Psychology (13), and Social Psychology of Education (11).

Table 2. Top-10 most prolific journals

Journal name	Publisher	Based on SEM in mathematics education articles		Based on all publications in journal	
		TP	TC	SNIP[a]	SJR[b]
Frontiers in Psychology	Frontiers Media	35	450	1.61	0.87, Q1
Learning & Individual Differences	Elsevier	35	951	1.20	1.55, Q1
Journal of Educational Psychology	APA	27	3,447	3.28	2.62, Q1
British Journal of Education Psychology	Wiley-Blackwell	22	977	2.00	1.29, Q1
Contemporary Educational Psychology	Elsevier	22	942	3.06	2.65, Q1
International Journal of Science & Mathematics Education	Springer Nature	17	257	2.12	1.15, Q1
Journal of Experimental Child Psychology	Elsevier	14	646	1.33	1.20, Q1
EURASIA Journal of Mathematics, Science, & Technology	Modestum Ltd.	13	82	1.42	0.57, Q2
Journal of School Psychology	Elsevier	13	1,034	2.78	1.95, Q1
Social Psychology of Education	Springer Nature	11	145	1.86	0.96, Q1

Note. TP: Total publication; TC: Total citation; SNIP[a]: Source normalized impact per paper for 2021 provided by Scopus; & SJR[b]: Scimago journal ranking for 2021 provided by Scopus

Table 3. Top-10 most prolific authors

Order	Author	Institution	Country	TP	TC	h-index
1	Marsh, H. W.	Australian Catholic University	Australia	14	2,281	122
2	Koller, O.	Leibniz Institute for Science & Mathematics Education	Germany	10	657	38
3	Martin, A. J.	University of New South Wales	Australia	9	431	57
4	Baumert, J.	Emeritus Group Educational Research Publications	Germany	7	2,272	46
5	Pekrun, R.	University of Essex	The UK	7	943	70
6	Kyriakides, L.	University of Cyprus	Cyprus	6	90	32
7	Ludtke, O.	Leibniz Institute for Science & Mathematics Education	Germany	6	708	62
8	Niklas, F.	University of Munich	Germany	6	193	20
9	Schneider, W.	University of Wurzburg	Germany	6	193	45
10	Skaalvik, E. M.	Norwegian University of Science & Technology	Norway	6	281	34

Note. TP: Total publication & TC: Total citation

We can observe from **Table 2** that four journals among the top-10 journals belong to the Elsevier publisher, and two belong to the Springer Nature publisher. The remaining journals are published by Frontiers Media S.A., APA, Wiley-Blackwell, and Modestum Ltd. In the Scopus database, these journals are classified as quartile 1 (Q1), quartile 2 (Q2), quartile 3 (Q3), and quartile 4 (Q4) based on the value from SJR, with Q1 being the top-25% most influential Scopus-indexed journal (Krauskopf, 2018). It was discovered that all of the top-10 journals are ranked Q1 except EURASIA Journal of Mathematics, Science and Technology (Q2). This shows that the best places to find good-quality SEM-based articles in the field of math education are in top-notch journals.

We can also see another important journal metric known as SNIP score in **Table 2**. SNIP metric is a ratio between the number of citations per paper and the citation potential of the subject field (Colledge et al., 2010). If SNIP for a journal is 1.00, it indicates the journal has received more citations than average in its field compared to other journals (Baker et al., 2020). The findings in **Table 2** show that all the top-journals have SNIP scores over one, with 1.20 being the minimum. This means that all of these top-10 journals have a great citation impact on their subject areas. Besides that, this could also help explain why EURASIA Journal of Mathematics, Science, and Technology is listed top-10 while being ranked only Q2 in SJR. The reason for this is the journal's strong citation impact in the field.

Table 3 shows information about the top-10 authors who have used SEM the most in their research on mathematics education. Professor Herbert W. Marsh has the most publications and citations, with 14 publications and 2,281 citations. The writer is now a distinguished professor at Australian Catholic University. His focus is on SEM for longitudinal studies. Professor Olaf Koller is the second-most-cited researcher in this field. The author is a professor at Germany's Leibniz Institute of Science and Mathematics Education, where he specializes in both educational and psychological research. Large-scale educational evaluation and measurement are his primary areas of study.

Professor Andrew Martin is the third most productive author, with 10 articles to his name. Currently, the author holds the position of Scientia Professor at Australia's University of New South Wales. His research interests include quantitative research methodologies, especially those using SEM, as well as the study of motivation, engagement, and achievement.

The next two authors in the top-10 are Professor Jurgen Baumert and Professor Reinhard Pekrun, each of whom has published seven papers. Professor Reinhard Pekrun teaches psychology at the University of Essex in the UK, and Professor Jurgen Baumert is the director emeritus of Emeritus Group Educational Research

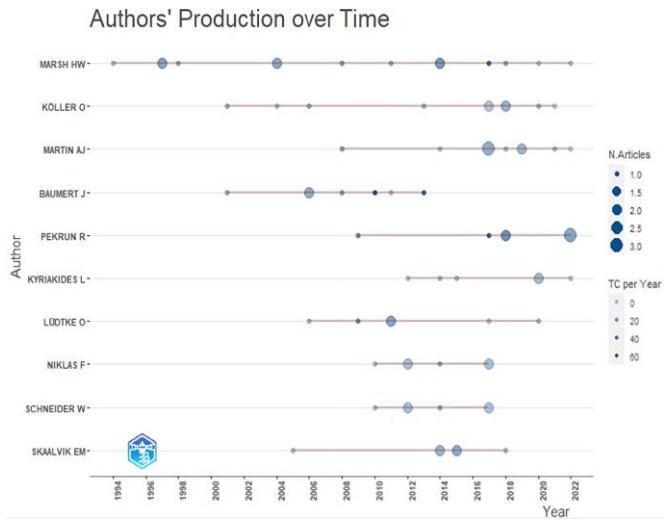

Figure 3. Annual publication of top-10 most prolific authors between 1988 & January 2023 (Source: Authors' own elaboration, using the Biblioshiny App)

Publications in Germany. The other five authors in the top-10 are Professors Leonidas Kyriakides, Einar M. Skaalvik, Frank Niklas, Oliver Ludtke, and Wolfgang Schineider. Professor Leonidas Kyriakides works at the University of Cyprus as a professor of educational research and evaluation. Einar M. Skaalvik is a retired professor at Norway's Norwegian University of Science and Technology. Professor Frank Niklas is a psychologist at the University of Munich who studies how people develop and learn. Professor Wolfgang Schineider is also a retired professor at the University of Wurzburg, and Professor Oliver Ludtke is a professor of educational measurement at the Leibniz Institute for Science and Mathematics Education.

Figure 3 shows the total number of articles produced annually by authors in this area over the years. The red line represents the timeline, the node represents the number of papers produced each year, and the color intensity represents the total number of citations produced each year by the top-10 authors. **Figure 3** shows that the majority of the top-10 writers have consistently conducted mathematics education research with SEM throughout the years. Professor Jurgen Baumert, Professor Wolfgang Schineider, and Professor Einar M. Skaalvik, on the other hand, have not been active in this area of publication for many years. Based on a search of their academic job title, this could be due to the fact that they have retired as a professor emeritus.

Research Question 3: How Is Contribution & Collaboration of Various Countries to Publication of SEM in Mathematics Education?

According to the findings, researchers from 79 countries have utilized SEM to analyze their results in mathematics education. Top-10 most prolific SEM-using countries in mathematics education research are shown in **Table 4**. These top-10 countries contributed more than

Table 4. Distribution of top-10 leading countries from 1988 to 18 January 2023

Country	TP	TP (%)	TC
The US	354	26.8	15,590
Germany	107	8.1	5,676
Australia	74	5.6	3,704
China	68	5.2	640
Taiwan	45	3.4	1,201
The UK	44	3.3	2,164
Spain	42	3.2	830
Turkey	41	3.1	714
Hong Kong	32	2.4	830
Malaysia	31	2.4	150

Note. TP: Total publication & TC: Total citation

63.5% of the overall publication. In the previous 34 years, the US has maintained its number one position in this study field with 26.8% of total publications. With a total publication rate of 8.1%, Germany ranked second in the field on SEM in mathematics education. Followed by Australia, China, Taiwan, the UK, Spain, Turkey, Hong Kong, and Malaysia, as shown in **Table 4**. It is important to note that, the total number of publications based on country distribution (1,322) differed from the total number of publications (1,017). It could be due to the fact that certain research papers were conducted by multiple researchers from various countries.

To get a greater understanding of the international collaboration amongst researchers, we used VOSviewer to create a science mapping to show the co-authorship networks. Each node in the co-authorship network represents a different country, whereas each node's size indicates the total number of papers written by researchers from that particular country. The larger the node size, the more publications there are in that country. In addition, a co-authorship between researchers from two countries was shown by a line between two nodes. The thicker the line, the more documents were written collaboratively by countries. **Figure 4** depicts a network of collaboration, with the US leading as the biggest node and having the most lines of collaboration originating from it. There were 34 connections to this major node, while Australia ranked second with only 25 connections. It indicates that, compared to Australia's 25 countries of collaboration, the US has collaborated with 34 countries in the field of mathematics education research that uses SEM.

The co-authorship analysis in **Figure 5** not only showed the co-authoring patterns of various countries and authors, but the overlay visualization mode also helps us understand the recent co-authoring trends. A deeper purple node indicates that country have been working on this topic prior to 2010. In this study, the US has the biggest and darkest purple node. With an average publication year of 2013 is .85, it was one of the first countries to use SEM in math education research. Interestingly, the node with yellow coloring represents countries such as China, Malaysia, Indonesia, South

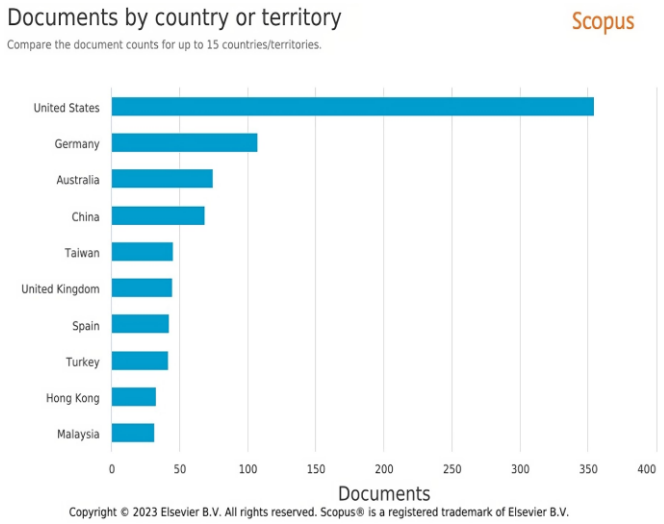

Figure 4. Number of publications by country (Source: Authors' own elaboration, using the Scopus)

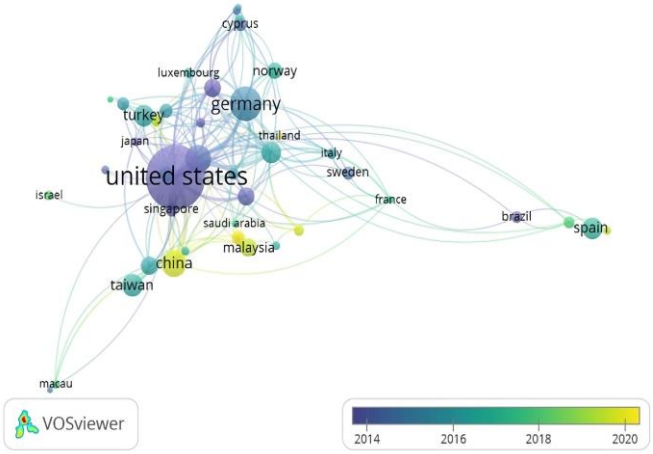

Figure 5. Overlay visualization of co-authorship among countries (Source: Authors' own elaboration, using the Vosviewer software)

Africa, and Thailand that have been involved in the research area in recent years. Despite having fewer publications than the US, China, and Malaysia have had more active collaboration with other countries in recent years.

Research Question 4: What Are Key Concepts That Are Explored in Previous Publications That Use SEM in Mathematics Education?

Figure 6 displays VOSviewer-analyzed keyword co-occurrence network. In this context, author keyword co-occurrence refers to the use of the same author keywords in previous published papers. A total of 2,485 authors' keywords were identified through VOSViewer analysis. By using a keyword threshold of 20, we were able to narrow down and focus on the list of keywords to 15 in the visualization map. The distance between each term on VOSviewer map indicates how closely they are connected to one another. A closer distance between those terms indicates a stronger connection between

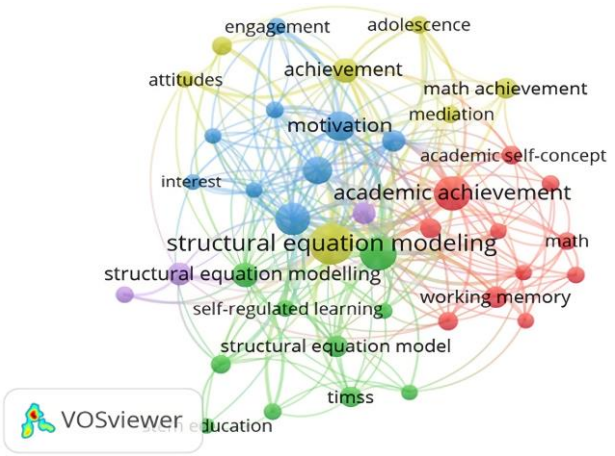

Figure 6. Network visualization of co-occurrence of author keywords (Source: Authors' own elaboration, using the Vosviewer software)

them. The larger the node, the greater the amount of research conducted with that particular keyword.

Based on **Figure 6**, the author's keywords can be grouped into five main clusters. "Academic achievement," "structural equation modelling," "self-efficacy," "mathematics," and "STEM" were the most prominent keywords in each of the five clusters. In the red cluster, the main keyword "academic achievement" was linked to words like "longitudinal," "working memory," "intelligence," and etc. In the blue cluster, the main keyword "self-efficacy" was linked to words like "motivation," "self-concept," "interest," "intrinsic motivation," and etc. We can see that both of these clusters are related to psychological matters. However, the blue cluster is more related to social psychology, whereas the red cluster is more related to cognitive and brain processes.

Apart from that, the green cluster's primary term, "mathematics," was connected with "TIMSS" and "PISA." This indicates that the researchers in this cluster were interested in studying international assessment developments such as TIMSS and PISA in the field of mathematics using SEM. The purple cluster's primary term was "STEM," which has links to the gender and technology acceptance models (TAMs). The researchers in this cluster were interested in understanding gender inequality in STEM fields. This was due to the fact that women were much less likely to graduate with a STEM degree or work in a STEM field compared to men (McCabe et al., 2020; Wall, 2019). Finally, the yellow cluster links "structural equation modeling" to concepts like "adolescent," "mediation," "attitudes," "achievement," and other smaller nodes. This may suggest that researchers in this group were particularly interested in the mediation effect on students' behaviors towards their academic success.

The results of the co-occurrence analysis assist us in determining not only the previous but also the current research trend in the research area. Based on the overlay

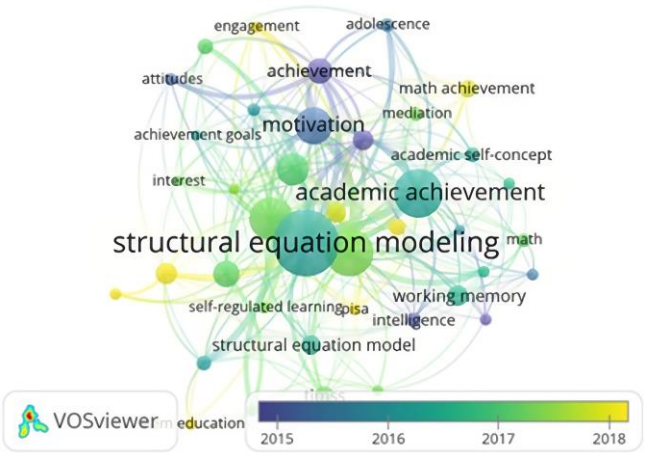

Figure 7. Overlay visualization of co-occurrence of author keywords (Source: Authors' own elaboration, using the Vosviewer software)

visualization map shown in **Figure 7**, the keywords in the yellow cluster have only shown up around the year 2018. Some of the noticeable keywords in the yellow cluster are STEM education, TAM, the control-value theory, and computational thinking. This may suggest that they are among the newest topics that have received increasing attention from researchers in recent years.

CONCLUSIONS

In conclusion, we have conducted a bibliometric analysis of mathematics education publications that use SEM. We looked at how SEM-based mathematics education research has developed over time. From the Scopus database, a total of 1,017 publications were selected from January 1988 through January 2023. The development of SEM in mathematics education indicates that it has received increasing attention from researchers in recent years, especially after 2012. It is predicted that the field of mathematics education that employs SEM will continue to expand.

We further analyzed the Scopus dataset of this study to find out the most prolific journal and how the countries and authors contributed and collaborated together. According to the ranking, the most productive journal was Frontiers in Psychology, followed by Learning and Individual Differences and the Journal of Educational Psychology. In terms of both publication production and international collaboration, the US stood out as the most prolific nation. Professor Herbert W. Marsh has published the most articles on the topic of SEM in mathematics education, and his work is ongoing. He has published a total of fourteen papers on the topic. These findings may serve as a guide for future researchers to conduct relevant research using SEM. We believed that the findings of this paper may help researchers in improving the quality of their studies by identifying the current trend of relevant literature and comparing their work to other researchers identified in this study. Thus, these results may also be useful for policymakers in their search for the "relevant" researchers to consult.

In addition to this, we also used visualization maps from VOSviewer to explore the keywords involved in the study's research field. Based on the author's keyword analysis, the most current keywords in mathematics education research using SEM include STEM, TAM, control-value theory, and computational thinking. Hence, future researchers may take these keywords trend into consideration when conducting mathematical education research using SEM approach.

Based on the current STEM research trend, there is a growing concern about interdisciplinary integration, project-based learning, and personalized learning in the classroom. This type of study generally involves complex relationships among different academic disciplines. Thus, it is predicted that SEM tools will continue to be beneficial tools for modeling complicated STEM research relationships, as they enable researchers to explore the connections between variables from multidisciplinary fields.

Apart from that, the results of the keyword trend also suggested control-value theory as the future research direction in mathematics education. Further research into the connection between students' control beliefs, value beliefs, and math abilities is expected. Students' self-efficacy, self-concept, intrinsic motivation, growth mindset, and perceived usefulness of mathematics concepts may all play a role in the impact of students' control and value beliefs on their mathematical achievement. These psychological constructs are commonly referred to as latent variables as they are not able to be measured directly. Therefore, SEM may be the preferred method to explore the connections among these psychological constructs due to its strength in analyzing latent variables.

As the world gets more technologically advanced, it is also predicted that the future trend for mathematics education will be technology-rich. Therefore, TAM will continue to be an important research framework in determining the levels of acceptance of students and teachers towards digital mathematics educational tools. It is also expected that computational thinking skills will continue to be important for helping students solve mathematics problems. In addition, there is a possible future trend, where mathematics education research will incorporate the integration of STEM, TAM, control-value theory, and computational thinking methodologies. Hence, SEM tools will be beneficial in testing such complex theoretical models.

Limitations

Considering that this research relied only on the Scopus database to search for papers, it means that any articles published in journals not indexed by Scopus

were excluded from analysis. Similar studies may be performed in the future using a combination of databases, such as ProQuest, Science Direct, and Web of Science. Secondly, the bibliometric analysis itself has certain characteristic limitations. In fact, the bibliometric analysis only looks at metadata and not the actual content of the documents. In order to overcome this limitation, future researchers may use content analysis in their bibliometric analysis study.

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Declaration of interest: No conflict of interest is declared by authors.

Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author.

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