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Unravelling the Evolution of Mathematics Problem-Solving Research: A Bibliometric Analysis Using VOSviewer

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Abstrak

Keterampilan pemecahan masalah merupakan bagian yang sangat mendasar dalam pendidikan matematika karena mengembangkan kemampuan penalaran dan berpikir kritis siswa. Dalam dua dekade terakhir, pengetahuan dan kesadaran di bidang ini telah berkembang pesat hingga literatur yang ada menjadi kaya, beragam, dan seringkali sulit untuk dipahami. Dengan demikian, penelitian ini membahas perlunya pemetaan sistematis tren penelitian dan kerangka kerja intelektual dalam pemecahan masalah matematika. Penelitian ini bertujuan untuk mengidentifikasi perkembangan tema-tema utama, publikasi yang berpengaruh, dan jaringan kolaboratif di bidang ini. Sejumlah publikasi dari tahun 2000-2004 digunakan, yang diterbitkan dalam basis data ScienceDirect, dan dibatasi oleh kebijakan akses terbuka. Data yang digunakan dalam penelitian ini dianalisis melalui VOSviewer untuk menilai jaringan dalam kepenulisan bersama, sitasi bersama, dan kemunculan bersama kata kunci. Penelitian ini menunjukkan bahwa jumlah publikasi meningkat secara signifikan selama bertahun-tahun, topik penelitian yang sedang hangat diidentifikasi, serta area penelitian baru yang muncul, seperti pemodelan matematika dan optimasi. Temuan-temuan tersebut diprediksi akan memberikan informasi tentang arah penelitian di masa depan dan pendekatan pengajaran lainnya.

***Kata Kunci**: matematika; pemecahan masalah; bibliometrik; VosViewer; Science Direct.*

Abstract

Problem solving skill is a very fundamental part of mathematics education since it develops students' reasoning and critical thinking abilities. In the past 2 decades, knowledge and awareness of this field have expanded dramatically to the extent that the literature is now rich, diverse, and often difficult to wade through. Thus, this research addresses the necessity to systematically map the research trends and intellectual framework in mathematics problem-solving. This research aims to identify the development of key themes, influential publication, and collaborative networks within the area. A range of publications 2000-2004 was used, published in the ScienceDirect database, and was restricted by the open access policy. The data used in the study are analysed through VOSviewer to assess networks in co-authorship, co-citation and keyword co-occurrence. This research work demonstrates that the number of publications grows significantly over the years, that hot research topics are identified, as well as that new research area that emerge, such as mathematical modelling and optimization. Such revelations are predicted to inform future directions of research and other instructional approaches.

Keywords: mathematics; problem-solving; bibliometric; vosviewer; science direct.

I. INTRODUCTION

Problem-solving plays an essential part in mathematics and mathematics teaching and learning (Liljedahl et al., 2014; Maharani & Cesaria, 2024). In mathematics teaching and learning, problem-solving is addressed in two different ways, the first one is problem-solving as the aim of instructional activities to teach students all the problem-solving competencies, while the second one is as the instructional means used to enhance students' mathematics capabilities (de Ron et al., 2022). Students' understanding of mathematical concepts can be improved through mathematics problem solving, while students' abilities to effectively solve problems will improve their mathematical and critical thinking (Lithner, 2008; Afriansyah et al., 2020). Problem-solving involves logical reasoning, creativity, and persistence as the essential abilities that should be owned by students in their academic, daily, and professional lives (Schoenfeld, 2014; Indrajaya et al., 2025). Polya (1945) revealed that problem-solving abilities assist students to more develop their understanding of mathematics and allow them to apply their knowledge to a real-life situation. The implementation of problem-solving is not only narrowed in the mathematics classroom teaching and learning activities, but also usually used in various fields, for example in natural science, engineering, modelling, and economics (Niss, 2007; Musodiqoh & Jaelani, 2024). Therefore, it is crucial to foster students' mathematics problem-solving abilities to prepare them to face the more developed and technological-based world in the future (Amalia et al., 2017; Minggi, Arwadi, & Bakri, 2022).

In the past few years, the topic of mathematics problem-solving has been a popular discussion among academics. This fact is proven by the increased number of research articles, publications, conference themes, and other papers that explore every aspect related to mathematics problem-solving. Cai and Lester (2010) mentioned that the attention to mathematics problem-solving has been established considerably which represents its importance in academic and educational practice. A wide range of research topics discussed related to this domain is prominent, starting from the cognitive processes in problem-solving to the improvement of learning strategies, and the effect of technology towards problem-solving. For example, the study of Lester and Kehle (2003) discussed the process of cognitive and metacognitive in problem-solving, whereas the research of Hiebert and Grouws (2007) explored various instructional approaches and their effectiveness towards problem-solving abilities. Furthermore, the improvement of technology nowadays has established new methodologies for problem-solving learning, for instance, the utilise of eye-tracking to identify students' strategies (Holmqvist et al., 2011; Ulfa, Roza, & Maimunah, 2022). These developments not only strengthen the field but also highlight the multifaceted practice of mathematics problem-solving, demonstrating the relevance to theoretical engagement and practical implementation in education.

Because of these massive developments, a systematic mapping of

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research in mathematics problem-solving is crucial for knowledge improvement and future research development. As the number of research starts to increase, it remains way more difficult to keep track of the various research, numerous methodologies, and diverse topics within this field. Regarding Aria and Cuccurullo (2017), systematic mapping of research is pivotal for organising and synthesising existing knowledge, therefore presenting a clear outline of the current condition in the field. By doing bibliometric analysis and other systematic review studies, researchers could recognise key trends, well-known themes, and influential works that have formed the perspectives. In addition, systematic mapping is very valuable to state the gaps in the literature, where particular aspects of mathematics problem-solving may be overlooked or where contradictory findings may be found (Van Eck & Waltman, 2014; Ahmatika, Sulastri, & Aprilani, 2025). This systematic mapping will help to underscore the areas that need further investigation and assist in discovering the agenda for future studies. Furthermore, by identifying the gaps and trends, researchers, educators, and policymakers could determine the right decisions and effectively allocate resources to high-impact and relevant areas.

Bibliometric analysis is a statistical research technique that can be applied to investigate and assess research trends and outputs and the citation impact of published research (Riadi, Turmudi, & Juandi, 2024). Thus, the bibliometric analysis that studies citation and co-authorship patterns and occurrence of keywords offer a wealth of understanding of the structure and development of a particular area of research. Bibliometric analysis helps the researchers to find out the key authors, institutions, journals and articles for a particular domain and to study the intellectual basis of the collaboration network also (Zupic & Čater, 2015; Tupulu et al., 2024). For this reason, this approach is most helpful when looking at the evolution of research areas, the progression of topics and the identification of new domains. One among the advanced software commonly used for bibliometric analysis is VOSviewer developed by Van Eck and Waltman (2010) for constructing and visualizing co-authorship, co-citation and keywords co-occurrence maps that is suitable for researchers interested in finding relational and network characteristics of large data sets. With the help of VOSviewer, it is possible to build complex graphical maps of diverse scientific environments and better realise how ideas, collaboration, and publications relate to one another.

One of the main strengths of VOSviewer is the handling of large datasets with high precision and after updating the package there are more opportunities for detailed analysis when mapping vast research fields. In this specific technique of mathematics problem-solving, VOSviewer was selected from the different bibliometric analytical tools known for efficiency in producing simple and interactive graphics. According to Waltman et al. (2010) using the software to cluster terms and authors by citation histories can readily point to trends and major contributors in a given area of

research and this is in line with the study's objective of charting the progress of mathematics problem-solving research.

Specifically, this article aims to provide the first bibliometric analysis of the research progress of mathematics problem-solving by identifying key publications based on their citation impact. Consequently, the scope of the study is to outline the trends, the works that have shaped the development of this area, and the shift in the research focus in this area of interest. In line with the recommendations of Donthu et al. (2021), mapping research activities gives a clear perspective of how scholarly discussions on the subject evolve and therefore aids in identifying topics of significant emphasis and ideas that have not been fully discussed. To visualize these structural attributes, the study employs VOSviewer to create co-authorship network maps, co-citation maps and keyword maps which give insights into the collaborative and intellectual relations in the field. In line with this work, this study will review manuscripts containing research articles on mathematics problem-solving published over the last two decades, from 2000 to 2024, based on data prepared from the Science Direct database, which is widely acclaimed for its comprehensiveness of quality research outputs. Such a period was chosen to focus both on the historical trends and the modern state of the research area, allowing observing the evolution of the trends during the last twenty-four years.

The originality of the present study is in the fact that it is the first bibliometric overview of mathematics problem-solving research over the last 20 years (2000-2024). Unlike earlier studies which looked at problem solving in a theoretical or pedagogic manner, this paper uses VOSviewer to not only provide a structured look at intellectual structure, collaboration networks, and the emergent research topics of the field of study. The specificity of the research is that it examines the issue of mathematics problem-solving within such database as ScienceDirect; thus, any bibliometric review does not focus on the mathematics problem-solving issue and does not cover it. This research considers influential publications, key authors, and emerging subjects within the ScienceDirect database including optimization and mathematical modelling, so-far not evidenced in the previous bibliometric reviews. In this sense, this study not only enhances the theoretical dimension of mathematics education, but it also provides concrete information to future studies, as well as the design of curriculum and even designing policy.

It is possible to identify the set of anticipated contributions of this study as valuable for the field of mathematics education and research. Through structurally reviewing the advancements in research for mathematics problem-solving, this study provides an exposure to the development history of the current research area including the heat maps of trends, publications, and lacunas. According to Sugimoto and Larivière (2018), bibliometric investigations yield gross knowledge of a given area of study, they help elucidate the processes of knowledge development and indicate research directions that would deserve

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additional attention. Thus, the conclusion of this study could act as an important reference source to the various researchers. They reveal many arising trends and directions as well as the institutional and authorial foci that may invite further research. For educators sciences offered in this consideration could usefully be applied to the design of curricula and pedagogy in general and students' problem-solving skills in particular, which are critical to mathematics learning. Further, it will ease policymaker's decision-making process on the allocation of funds and support to future research in mathematics education that will potentially have a maximum impact on creativity. Therefore, the findings of this study enrich the theoretical development of mathematics education and provide instructions for subsequent research, practice, and public policymaking.

II. METHOD

The current research was conducted through a bibliometric analysis that revealed the history of mathematics problem-solving studies with the VOSviewer software. The retrieved data were obtained in the ScienceDirect database (https://www.sciencedirect.com) by using the keyword Mathematic Problem-Solving and setting the filter to open-access publications. The articles published after 2000 and before 2024 have been limited as the dataset, which provided a historical and a more current view of the research tendencies in this area.

Records retrieved were initially tabulated in Microsoft Excel and therefore exported in Research Information Systems (RIS) format. RIS files are universal bibliographic information files containing title, author, year, and publication, keywords, publisher, volume, issue and page number information. The publications where Mathematics Problem-Solving has been mentioned in the title, abstract or keywords have been used were the only ones included in the analysis.

Afterwards, RIS data have been analyzed with VOSviewer in order to produce bibliometric maps. The software collects the data and offers the visualizations that describe the connections between publications, authors, and keywords related to mathematics problem-solving (Fahimnia et al., 2015). Two methods of analysis were used including co-authorship analysis that reflects relationships between authors based on common publications and co-occurrence analysis determining relationships between keywords that occur often in same documents (Van Eck & Waltman, 2010).

III. RESULT AND DISCUSSION

A. Published Year of "Mathematics Problem-Solving" Research

According to the results of a search on Science Direct, research in "Mathematics Problem-Solving" has been moving toward open access since 2000. The number of documents that could be viewed online more easily in that year was up to 1,047. However, in 2001, it reached the lowest number of the documents appearing online as counted as 909 documents. After 2001,

the number of documents always increased almost every year, and it became 14,052 documents in 2023, almost 14 times increase compared to the initial year, where it is the highest number achieved after 23 years. The highest increase of the documents happened between 2021 and 2022, the number of documents in 2022 was 39% more than the number of documents in 2021. After that, the number of the documents was counted as 8,241 as of April 30th 2024. Table 1 provides more information on the trajectory of mathematics problem-solving research from year to year.

Table 1.
The Spread of Mathematics Problem-Solving Development from Year to Year

Year	Number of Documents	Year	Number of Documents
2024	8,241	2011	5,332
2023	14,052	2010	4,087
2022	11,075	2009	4,028
2021	7,941	2008	3,780
2020	6,194	2007	3,468
2019	7,255	2006	2,969
2018	6,822	2005	2,448
2017	7,261	2004	1,548
2016	6,719	2003	1,498
2015	7,036	2002	1,075
2014	5,991	2001	909
2013	5,547	2000	1,047
2012	5,568		

Table 1 showed an enormous rise in the number of publications concerning mathematics problem-solving including the period after 2010 with the highest rate between 2021 and 2023. Such sharp growth is indicative of mathematics problem-solving being a major theme in research work and practice since it has become critical in education and other aspects. Cai and Lester (2010) stressed that mastering of problem-solving in mathematics education develops the skills to reason and also readies students to confront real life situations with the help of mathematics. This stable increase observed in this bibliometric mapping supports the fact that the subject matter shows stability in terms of scholarly interest across several disciplines.

Also from Table 1, we can see vividly that there are a large number of mathematics problem-solving documents of research from year to year. This number of the research indicates that the Mathematics Problem-Solving theme is crucial to research. This topic is discussed in various disciplines and has a lot of advantages.

B. Types of Articles that Contain "Mathematics Problem-Solving" on the Research Development Map

There are several types of articles that discuss Mathematics Problem-Solving and mention it in their title, abstract, keyword, and content. The list of the types of articles is as follows.

Table 2.
Types of Articles that contain "Mathematics Problem-Solving"

Types of Articles	Number of Document	Types of Articles	Number of Document
Review Articles	5,321	Editorials	652
Research Articles	145,177	Errata	53
Book Chapters	22	Mini-Reviews	532
Conference Abstract	479	News	47
Book Reviews	788	Practice Guidelines	8
Case Reports	81	Product Reviews	2
Conference	92	Short	4,202

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Types of Articles	Number of Document	Types of Articles	Number of Document
Info		Communications	
Correspondence	183	Software Publications	241
Data-Articles	68	Video Articles	8
Discussion	228	Other	1,795

Data in Table 2 show that Research Articles are the most popular types of articles discussed in Mathematics Problem-Solving during this period. There are 145,177 documents published in the form of Research Articles followed by 5,321 Review Articles. Whereas, there are only 2 documents published in the form of Product Reviews. Thus, we can see that it has a big gap between the most and the least popular types of documents as shown in the table.

This data indicate that the field is quite research-oriented and it is maintained with empirical research studies being constantly published to address the problem-solving pedagogy. According to Hiebert and Grouws (2007), problem-solving activities are heavily divided by type of teaching in the classroom and since the research articles are numerous, it is clear that educators and researchers are determined to investigate teaching methods that lead to enhanced learning.

C. The Name of the Journal that has been published about "Mathematics Problem-Solving"

Several journals mentioned on the Science Direct website contain Mathematics Problem-Solving articles in their volume. The Mathematics Problem-Solving term is mentioned in the title, abstract, keywords, and content of the articles. The names of the journals and the number of articles that they have published are shown in Table 3.

Table 3.
Name of the Journal that Discussed "Mathematics Problem-Solving"

Name of Journal	Number of Document	Name of Jurnal	Number of Document
Journal of Computational and Applied Mathematics	9,113	Applied Mathematics Letters	2,420
Journal of Mathematical Analysis and Applications	8,261	International Journal of Solids and Structures	2,066
Computers & Mathematical with Applications	8,115	Alexandria Engineering Journal	2,019
Applied Mathematical Modelling	6,955	Heliyon	1,999
Procedia Computer Science	4,580	Advance in Mathematics	1,984
Discrete Applied Mathematics	4,219	Journal of Algebra	1,936
Journal of Differential Equations	3,996	Journal of Functional Analysis	1,792
Mathematical and Computer Modelling	3,772	Energy Reports	1,674
Linear Algebra and its Applications	3,732	Result in Physics	1,521
Theoretical Computer Science	3,096	Biophysical Journal	1,506
Discrete Mathematics	2,918	Case Studies in Thermal	1,415

Name of Journal	Number of Document	Name of Jurnal	Number of Document
		Engineering	
Procedia – Social and Behavioral Sciences	2,749	Energy Procedia	1,223
Procedia Engineering	2,601		

Based on the data from Table 3, it can be seen that the Journal of Computational and Applied Mathematics has the highest number of documents that discuss Mathematics Problem-Solving. 9,113 documents have been recorded and published in this journal. However, Energy Procedia is the journal with the lowest number of articles discussing Mathematics Problem-Solving.

D. Map of Mathematics Problem-Solving Co-Author

It was discovered that several authors wrote extensively about Mathematics Problem-Solving from thousands of articles. Through the Open Access articles on the Science Direct website, it was found that one author might write more than one article related to Mathematics Problem-Solving. Moreover, this research used a co-authorship type of analysis through VOSviewer and recorded the author who wrote and published at least 4 documents in Mathematics Problem-Solving. Consequently, 18 authors meet the criteria. Figure 1 displays the names of these authors along with the number of documents and total link strength. Total link strength shows the strength of the relationship between the author and other authors based on collaboration in the analysed documents.

Selected	Author	Documents	Total link strength
☑	sabir, zulqurnain	11	9
☑	bhat, shahid ahmad	5	8
☑	raja, muhammad asif zahoor	5	8
☑	alvarez-valdes, ramon	4	4
☑	bayat, sahar	5	4
☑	parreño-torres, consuelo	4	4
☑	tarmizi, rohani ahmad	8	3
☑	kazemi, farhad	4	1
☑	nisar, kottakkaran sooppy	7	1
☑	bashiri, mahdi	4	0
☑	kamel, salah	4	0
☑	katranci, yasemin	5	0
☑	khudair, ayad r.	4	0
☑	kroesbergen, evelyn h.	6	0
☑	puerto, justo	6	0
☑	tag-eldin, elsayed m.	4	0
☑	vidákovich, tibor	4	0
☑	yavuz, gunes	4	0

Figure 1. Author Name, Number of Documents, and Total Link Strength.

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Data in Figure 1 show that the author with the highest number of documents is Sabir, Zulqurnain who published 11 documents related to Mathematics Problem-Solving; he is the only author who wrote more than 10 documents. However, the other authors wrote less than 10 documents and most authors (9 out of 18) published 4 documents. Furthermore, Sabir, Zulqurnain is also the author who has the strongest link with the other authors; he gained 9 link strengths, while nine authors have no connection with the others and two authors in the name of Kazemi, Farhad, and Nisar, Kottakkaran Sooppy are the authors who only have one link strength.

Furthermore, that the co-authorship networks herein represented show a growing collaboration among universities and authors. It is noted by Liljedahl et al. (2014) that international collaboration is a crucial variable in moving mathematics education research forward. As indicated by the collaborations identified in this study, research in mathematics problem-solving has stopped being a local affair; it is increasingly becoming globalized within the academia. This is not only an echo of the joint problems that educators have to face but also an indication of the unity in what educators across borders want to achieve: enhance the quality of pedagogical practices.

E. Visualization of Author Network of Mathematics Problem-Solving

The network visualization of the author of Mathematics Problem-Solving can be seen in Figure 2. There are 1000 documents downloaded from the Science Direct Open Access database related to Mathematics Problem-Solving. After that, the downloaded documents were exported into RIS format and analysed by using VOSviewer. The VOSviewer analysis resulted in 18 authors who have at least 4 documents on Mathematics Problem-Solving, and some of them have networks or collaboration with other authors.

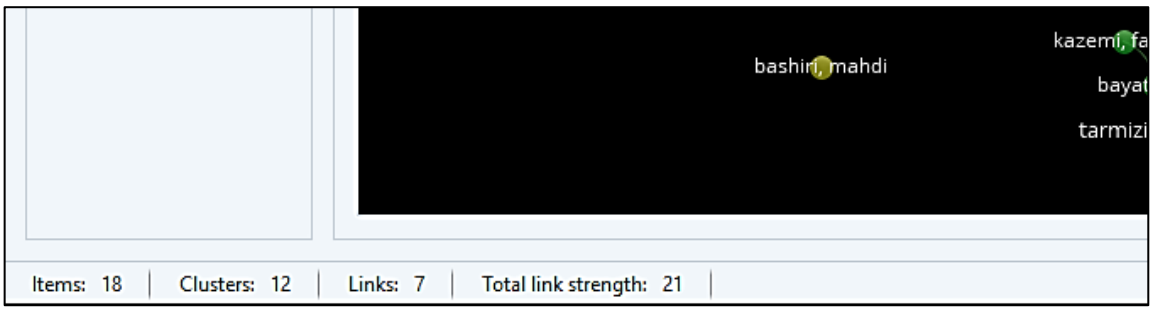

Figure 2. Author Network Visualization on Mathematics Problem-Solving.

From Figure 2, we can see the collaboration among authors who wrote Mathematics Problem-Solving. Some authors link to other authors, whereas some authors do not have links to others. In total, there are 18 authors with 12 clusters, 7 links, and 21 total link strengths created. The most linked authors are represented by the largest coil called cluster 1. A closer look at cluster 1 can be seen from Figure 3.

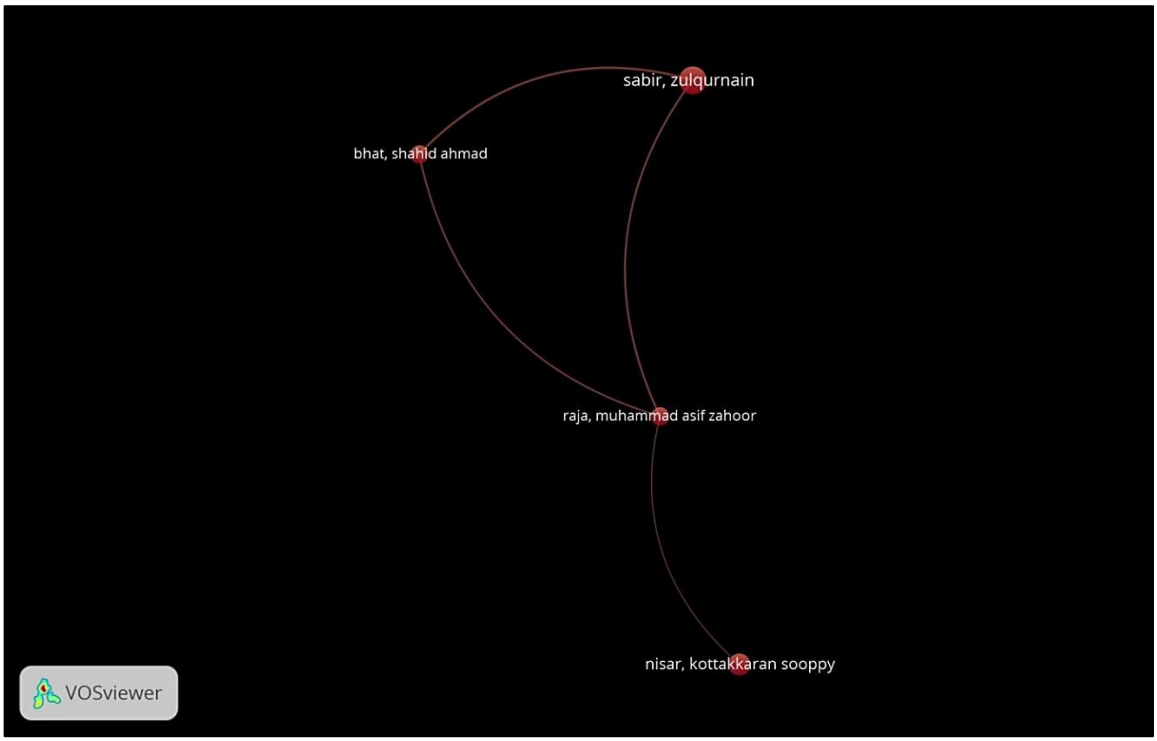

Figure 3. Author Network Visualization for Cluster 1.

It can be seen in Figure 3 that there are four authors listed in cluster 1 who at least have one connection with the other author. The author Nisar, Kottakkaran Sooppy links to Raja, Muhammad Asif Zahoor, while Raja, Muhammad Asif Zahoor links to Bhat, Shahid Ahmad and Sabir, Zulqurnain. After that, Sabir, Zulqurnain and Bhat, Shahid Ahmad are also linked to each other.

F. Topics of Research Development in Mathematics Problem Solving

Another type of VOSviewer analysis utilised in this study was the co-occurrence type of analysis. There are 3,622 keywords recorded in the documents which have a connection with Mathematics Problem-Solving. In this research, the minimum number of occurrences of keywords chosen to be analysed was 4. Thus, there are 92 research topics are recorded as the most often appearing with the highest total link strength being 27. It means that the highest number of documents that have two terms occurring together is 27 and 92 keywords which link each other at least four times. Table 4 shows 25 out of 92 of the most frequently researched topics discussed.

Table 4.
Research Topics on Mathematics Problem-Solving

Keywords	Occurrence	Percentage
Optimization	39	1.08%
Problem-Solving	36	0.99%
Mathematics Education	31	0.86%
Mathematics	27	0.75%
Mathematical Model	25	0.69%
Mathematical Modeling	23	0.64%
Scheduling	17	0.47%
Genetic Algorithm	17	0.47%
Metaheuristics	15	0.41%
Mathematical Programming	14	0.39%
Mathematical Modelling	13	0.36%
Multi-Objective Optimization	13	0.36%
Optimal Control	12	0.33%

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Keywords	Occurrence	Percentage
Stability	12	0.33%
Machine Learning	12	0.33%
Covid-19	11	0.30%
Sensitivity Analysis	11	0.30%
Problem-Solving	11	0.30%
Neural Networks	10	0.28%
Creativity	10	0.28%
Problem Posing	10	0.28%
Heuristics	9	0.25%
Simulation	8	0.22%
Mixed Integer Programming	8	0.22%
Inverse Problems	8	0.22%

Based on data in Table 4, it can be seen that the most appearing keywords that link together with Mathematics Problem-Solving are "Optimization" with 39 occurrences, followed by "Problem-Solving" and "Mathematics Education", whereas "Simulation", "Mixed Integer Programming", and "Inverse Problems" appeared 8 times linked with Mathematics Problem-Solving.

Optimization and mathematical modelling were noted by the co-occurrence analysis as emerging research themes. What this research result indicates is that the discipline of mathematics problem-solving is growing to other lines of applications and interdisciplinary directions. According to proposals made by Niss (2007), mathematics problem-solving is not only confined within the walls of classrooms since it is one of the important segments of engineering, economics and natural sciences. In much the same way, Lithner (2008) argued that creative reasoning is important in problem-solving and this elevated interest in modelling and optimization as a more realistic and sophisticated form of modelling more closely aligned with the real world of professional practice.

G. Visualization of Topics Network of Mathematics Problem-Solving

The data from 92 research topics which appeared together with Mathematics Problem-Solving can be visualized in Figure 4.

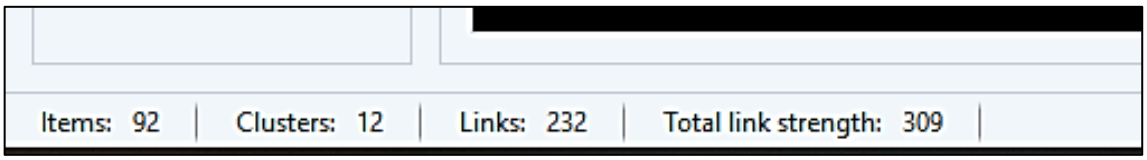

Figure 4. Visualization of Network Topics in Mathematics Problem-Solving.

Figure 4 shows that there are 12 clusters, 232 links, and 309 total link strengths created in the Mathematics Problem-Solving research development map. The clusters of the topics were divided into 12 different colours. The closer two circles are located to each other, the stronger their relatedness, the larger the circle and the label means that the higher the weight of the item. For example, the keyword "Problem Solving" is very close to "Mathematics", so it reveals that Problem Solving is often related to Mathematics. Furthermore, from Figure 4, we can see that "Optimization" has the largest circle and the label in red colour, followed by "Problem-Solving" and "Mathematics Education" in blue which are suitable to the data in Table 4 with the most frequently appeared keywords.

H. Density Visualization on the Topic of Mathematics Problem-Solving

There are two types of density visualization in the VOSviewer application, they are item density visualization and cluster density visualization (Van Eck & Waltman, 2010). The density visualization used in this study is item density visualization which shows each item by its label. It uses colours to represent the item density at each place. Colours are by default blue, green, and yellow. A point's colour approaches yellowness in direct proportion to the number of objects nearby and the higher the weights of those items. By focusing on the aspects of the items that are deemed significant for analysis, this section is highly helpful in providing an overview of the general layout of bibliometric maps. The most popular and thoroughly investigated keywords can be deduced from the findings displayed in this graphic. Conversely, we may determine which topics are uncommon or the least studied by using the Visualisation of topics in this density section. Figure 5 shows the visualization of the density of the co-word map of the improvement of Mathematics Problem-Solving research.

Figure 5 shows that the words "Optimization" and "Problem Solving" have the largest font and the most yellow colour. It means that the density of "Optimization" and "Problem Solving" are denser than the other words, and indicates that the topics have been extensively studied. However, the words "Convergence Analysis" and "Exact Solutions" have the smallest font and the least yellow colour or blue colour which shows that there hasn't been much research done on these topics.

Overall, not only has mathematics problem-solving research increased in mass, but the field of research has expanded. The subject has transformed itself with non-classroom-based research to more interdisciplinary approaches incorporating optimization, modelling and technological advances. The development illustrates the importance of the problem-solving concept as an alternate theory to education in mathematics as well as a practical method. Hence, the study serves to help shed light on the spiritual background of mathematics problem-solving and can be used as a basis of further research that should be aimed at shaping educational practice, as well as policy.

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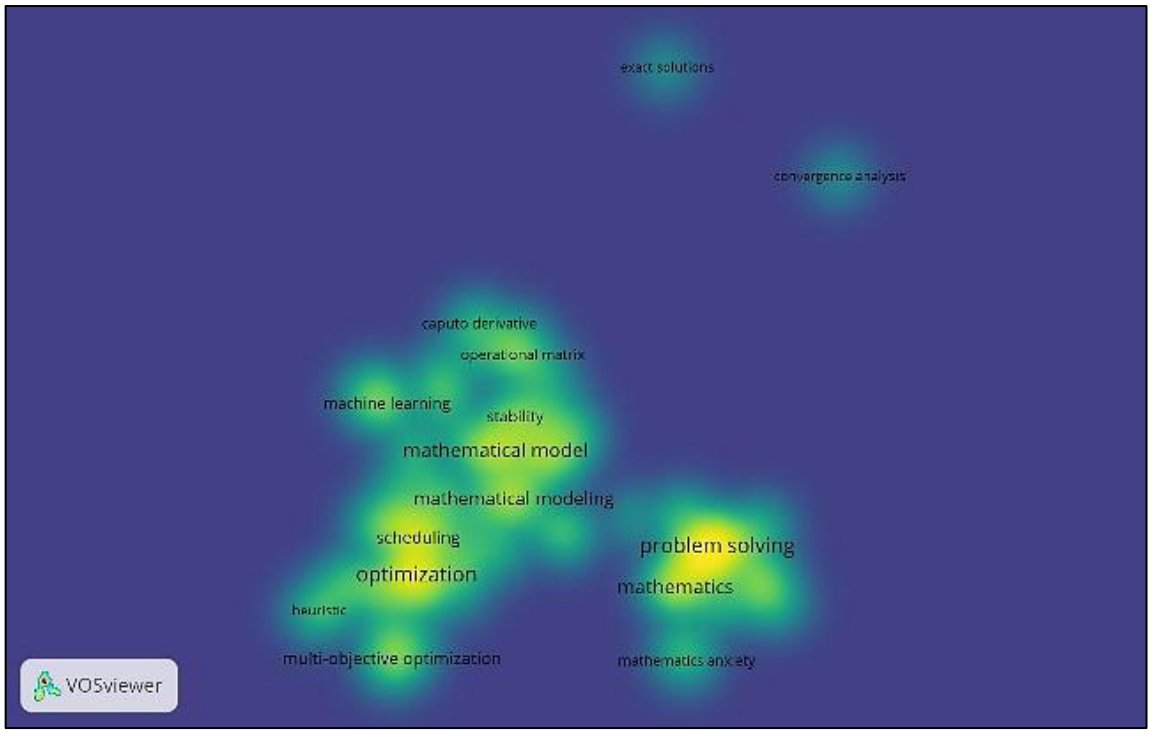

Figure 5. Density Visualization of Mathematics Problem-Solving.

IV. CONCLUSION

It is clear from the results and the discussion sessions that research on Mathematics Problem-Solving has been issued open access since 2000. In the initial year, the document recorded related to Mathematics Problem-Solving was 1,047 documents, while it expanded quickly from year to year, and reached the highest number in 2023 for 14,052 documents. Furthermore, the number of documents was counted as 8,241 as of April 30th 2024. The most common type of papers that addressed Mathematics Problem-Solving at this time was research articles. A total of 145,177 documents have been published as research articles, with 5,321 review articles coming next. Most publications that addressed Mathematics Problem-Solving were found in the Journal of Computational and Applied Mathematics; 9,113 documents have been published in this journal as of this writing. Moreover, there are a total of 18 authors, 12 clusters, 7 linkages, and 21 link strengths generated overall with the limited criteria of the authors who wrote at least 4 documents. With 11 publications about Mathematics Problem-Solving, Sabir Zulqurnain is the author with the most documents.

Furthermore, the minimum criteria were also implemented to analyse the frequent topics that come together with Mathematics Problem-Solving; there are at least 4 occurrences of keywords used in this study. This limitation resulted in 92 study topics that are known to appear most frequently, with 27 having the highest total connection strength, whereas the most frequently appearing topic is "Optimization," which occurs 39 times, followed by “Problem-Solving” and “Mathematics Education”. Moreover, 12 clusters, 232 links, and 309 total link

strengths were created regarding the visualization of network topics of Mathematics Problem-Solving research development. An item's weight is indicated by its larger circle and label, the closer two circles are to one another, the stronger their relationship. Given how closely the terms "Problem Solving" and "Mathematics" are related, it is clear that the two are frequently associated. Furthermore, the words "Optimization" and "Problem Solving" have denser densities than the other words, indicating that these subjects have been thoroughly researched.

The research has a contribution to the study of mathematics education by offering the first bibliometric mapping of problem-solving in mathematics research in the past twenty years. It provides a concise summary of publications of influence, promising authors and collaborative networks, as well as the emerging trends in the research. The findings will enhance theoretical knowledge of mathematics problem-solving and serve as a good source of information to educators, researchers and policymakers in curriculum design, advancing instructional practice and efficient resource allocation.

In accordance with the results, it is possible to suggest several recommendations. To start with, the application of problem-solving to optimisation, modelling, and technological innovations should be examined in future research as these areas are growing tendencies. Second, the cooperation of the researchers is to be enhanced further both nationally and internationally in order to guarantee the broader knowledge sharing and building. Third, researchers will be motivated to apply the findings of research on problem-solving to create pedagogical frameworks that would help improve the reasoning, creative, and critical thinking abilities of students. To conclude, policymakers are encouraged to focus on interdisciplinary research on mathematics problem-solving, which can be applied with great potential to educational quality and even wider application in science and technology.

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