Mapping the Evolution of Cultural and Problem-Based Approaches in Mathematics Education: A Bibliometric Review from 2000 to 2024

Wahyuni Mailili[1,*], Ijirana[2], Muhammad Rizal[3], & Windia Hadi[4]
[1]Doctoral Program in Science Education, Universitas Tadulako, Indonesia
[2]Department of Chemistry Education, Universitas Tadulako, Indonesia
[3]Department of Mathematics Education, Universitas Tadulako, Indonesia
[4]Doctoral School of Education, University of Szeged, Hungary

Abstract: This study is a literature review that aims to analyze research trends on Problem-Based Learning (PBL), Mathematical Communication, Ethnomathematics, and Problem Solving in mathematics education, and to provide recommendations for variables with potential for future research. Bibliometric analysis was used to identify relevant research articles. Search data were obtained from Google Scholar from 2000 to 2024 using the keywords problem-based learning, mathematical communication, ethnomathematics, and problem solving, with publication types limited to journals, articles, and conference papers. From a total of 72 articles initially screened, the refinement process yielded 52 relevant articles published between 2007 and 2024. To analyze the data comprehensively and achieve the research objectives, data analysis was conducted using Harzing's Publish or Perish, Excel, and VOSviewer. The benefit of this research is that it can help researchers who will conduct further research on problem-based learning, mathematical communication, ethnomathematics, and problem-solving by identifying the opportunities identified in this study. The results of this study show a continuous and developing research trend and provide recommendations for variables that have the potential to be studied in the future related to the integration of the keywords problem-based learning, ethnomathematics, and mathematical communication as a proposed strategic approach to simultaneously strengthen mathematical literacy and mathematical problem-solving skills in the context of modern learning. This study is expected to provide a roadmap and outline new opportunities for researchers interested in exploring topics related to the keywords, serve as an important reference, and inspire new research with greater novelty, thereby supporting the development of 21st-century skills through mathematics education.

Keywords: problem-based learning, mathematical communication, ethnomathematics, problem solving, bibliometric analysis, VOSviewer.

▪ **INTRODUCTION**

Education in the 21st century should ideally not only produce academically excellent graduates but also equip students with relevant skills to address complex challenges in the future. Students are not only expected to understand subject content but also to possess critical thinking skills, creative problem-solving abilities, information and digital literacy, collaborative communication skills, and the ability to take initiative in various social and professional contexts (Yanuarto et al., 2025)

In modern mathematics education, one of the main challenges is to develop students' problem-solving and mathematical communication skills simultaneously so that they cannot only solve problems but also explain mathematical ideas in a clear, precise, and contextual manner. Learning is more teacher-centered, with lecture methods that do not provide opportunities for students to develop critical and creative thinking skills, especially in solving mathematical problems (Ijirana et al., 2025). Problem-based

learning (PBL) has long been considered an effective strategy for stimulating problem-solving and critical thinking. For example, research by Fatimah (2013) shows that PBL can improve students' problem-solving skills, although improvements in mathematical communication are not always greater than those with conventional methods.

Ethnomathematics, the integration of local culture into the mathematics learning process, is becoming increasingly popular as a way to make mathematics more meaningful and relevant to students. This approach not only helps students relate mathematical concepts to their daily lives but also strengthens cultural engagement and identity in mathematics learning. The concept of "culture" in ethnomathematics studies reinforces the argument that a culturally sensitive approach to mathematics education can help students bridge their everyday experiences with more abstract academic concepts (Nasrum et al., 2025). A quasi-experimental study by Wulandari et al. (2024) shows that ethnomathematics-based learning has a significant positive effect on students' comprehension of mathematical concepts and problem-solving abilities. Ethnomathematics itself uses mathematical concepts broadly related to mathematical activities. That is, Ethnomathematics is not fixated on a single theoretical study but rather on many, such as agriculture, architecture, clothing motifs, weaving, ornaments, kinship, and spiritual relations (Marleny et al., 2020).

Problem-Based Learning with an ethnomathematical nuance provides an interesting, broad, and meaningful learning experience, thereby enabling students to increase their mathematical communication skills. (Yuningsih et al., 2024). The PBL model, combined with ethnomathematics, can develop students' creative thinking skills through problems arising from the surrounding environment (Amalia et al., 2021). However, a study showed that the ethnomathematics-based PBL model significantly improved students' mathematical abilities, particularly critical thinking and problem-solving skills. However, it had a smaller impact on students' mathematical communication and representation skills, as evidenced by lower effect sizes in these domains. (Maulida et al., 2025). The National Council of Teachers of Mathematics (NCTM) (Planas & Pimm, 2023) emphasizes communication as one of the essential standards for mathematics learning, as it enables students to express their ideas, justify their reasoning, and participate in mathematical discourse that fosters deeper comprehension.

To improve students' mathematical communication skills, teachers need to provide practice problems in the form of contextual or PISA-style story problems. In Addition, teachers also need to choose learning strategies that involve students actively. So that the teacher can assess students' mathematical communication skills and their understanding of the material taught (Na'im & Mukhlis, 2024), this empirical study demonstrates that the combination of problem-based learning and ethnomathematics has the potential to enrich the mathematics learning process with a more contextual and reflective approach as a strategic approach to simultaneously strengthen mathematical literacy and mathematical problem-solving skills in modern learning contexts. However, to more systematically understand how research trends in this area are evolving, a broader literature review is needed.

There have been many bibliometric studies in the field of mathematics education, but research specifically mapping the combination of PBL, ethnomathematics, mathematical communication, and problem solving is still limited. This is an important

research gap, given the importance of cultural integration and active teaching strategies in building 21st –century mathematical competencies. In this context, bibliometric analysis emerges as a highly relevant method. The bibliometric analysis spans five main methods: citation analysis, co-citation analysis, bibliographic coupling, co-author analysis, and co-occurrence (co-word) analysis. Each provides distinctive insights to map the current state of knowledge by highlighting interconnections among contributions (Donthu et al., 2021). SLR involves a qualitative analysis of academic documents to build a consistent picture of a specific body of knowledge, emphasising discrepancies, inconsistencies, and knowledge gaps to develop new theoretical frameworks for analysing phenomena (Breslin & Gatrell, 2020). At the intersection of bibliometric analysis and SLRs, the BSLR combines quantitative and qualitative approaches to analyse the literature, relying on metrics of interconnections among contributions and meeting the replicability and transparency tenets that distinguish SLRs, ultimately creating space for theorisation (Marzi et al., 2025).

Through bibliometric analysis, researchers can map research trends, popular topics, and scientific collaborations in specific domains. Bibliometric analysis is a quantitative method often used in analyzing bibliographic data in articles or journals (Öztürk et al., 2024). A similar view holds that bibliometrics is a set of methods for tracking, measuring, and analyzing scientific articles using mathematical or statistical approaches (Roemer & Borchardt, 2015). This analysis is also useful for identifying trends and developments in scientific publications over time (Lam et al., 2022). The VOSviewer tool is one of the most widely used in bibliometric research due to its ability to map and group publications based on citations, co-authors, or keywords. This allows for the identification of major research themes and potential research gaps. For example, Julius et al. (2021) conducted a bibliometric analysis of global research on mathematics education over four decades using Scopus data. They visualized the results with VOSviewer, providing an overview of journal distribution, country collaboration, and major research topics.

Thus, a bibliometric analysis using VOSviewer of the literature on cultural approaches to mathematics learning aims to provide insight into how the research community incorporates these concepts. Novelty refers to the need to introduce a fresh perspective or a new framework to tackle an unsolved issue. The research question should thus challenge existing paradigms or propose unexplored angles on a familiar topic, thereby contributing to the evolution of the scholarly conversation within a discipline (Marzi et al., 2025). To provide an understanding of how research combines map concepts and explores topics from keywords that can inspire new research with higher novelty, which supports the development of 21st-century skills through mathematics education, several research questions are presented as follows:

RQ1: How is the distribution of publications, and which articles contribute to the development of approaches in mathematics teaching?
RQ2: What trends and potential pedagogical developments will occur in this theme in the future?
RQ3: What gaps are identified through keyword mapping, and what are the implications for 21st-century mathematics education?

▪ **METHOD**

Research Design

The method used in this study is a bibliometric analysis using VOSviewer software. A basis for bibliometrics is the identification of a five-stage process (Fitria et al., 2022; Liu et al., 2025; Zhang et al., 2023; Liu et al., 2025; Passas, 2024). With stages such as determining keywords from exploration with problem-based learning, mathematical communication, ethnomathematics, and problem solving, thus providing a comprehensive picture of research developments during the period 2000–2024. the results of the initial exploration, improvements to the exploration results, compiling initial data graphs, and data analysis with the following explanations (Fitriani & Soebagyo, 2022),

Search Strategy

Search data is sourced from Google Scholar and analyzed using tools such as Harzing's Publish or Perish, Excel, and VOSviewer to visualize networks of keywords, authors, or institutions. This literature exploration was conducted using the keywords problem-based learning, mathematical communication, ethnomathematics, and problem solving, and data were collected using Harzing's Publish or Perish. In the initial exploration, 72 articles were identified from the search results, covering the period from 2000 to 2024, as discussed in the discussion section.

Inclusion and Exclusion Criteria

The results were refined by filtering the articles obtained. The filtering process was divided into two stages. The first stage involved removing BOOK, HTML, DOC, and Citation articles from the list. In the second stage, Articles were excluded if the full text could not be obtained through a systematic search of recognized academic databases such as Scopus, Web of Science, and DOAJ, or through institutional library resources, which prevented verification of the study's content. The filtered results were downloaded and imported into Mendeley for further data analysis, allowing articles to be easily grouped by publisher, year, and publication source. Based on Harzing's Publis Or Pairish (POP), 52 journal articles were obtained from 2007 to 2024. The results of this metadata search are exported in RIS format for subsequent import into the VOS viewer.

Data Analysis

After the data screening process was complete, the VOSviewer software was used to open RIS format files obtained from PoP. In this step, terms related and unrelated to "problem-based learning, "mathematical communication," and "ethnomathematics" will be selected in the Title Field option. After a series of steps, an analysis was performed on the visualizations generated by the VOS viewer. The visualizations produced by the VOS viewer consist of three displays: network, overlay, and density (Irkhamiyati & Kurniawan, 2024). Network functions to visualize the network of generated keywords. If the network from the bibliometric analysis is printed in bold, it indicates a fairly strong relationship between the analyzed keywords. Conversely, if the relationship between keywords is printed in thin with small circles, it indicates that the relationship between the analyzed keywords is weak. The second visualization is an overlay that visualizes the historical trail of writing. If the visualization appears darker, it indicates that the writing is older. Conversely, if the writing is done more recently, the visualization is depicted in light colors. The third visualization is density, which shows the density between research

groups. Density visualization can show research subjects that are still rarely conducted or those that have been done too often or too much.

▪ **RESULT AND DISSCUSSION**

The results of the initial exploration using PoP and the Google Scholar database, with the keywords problem-based learning, mathematical communication, ethnomathematics, and problem solving, produced 125 articles for the period 2000 - 2025. Then, 13 articles were automatically excluded because access was denied. Furthermore, 40 articles published in 2025 were also excluded because they risked introducing publication bias.

Table 1. Citation

Data	Results
Publication year	2007-2024
Year of Citation	17(2007-2024)
Article	72
Citations	1024
Citations/Year	60.23
Article Citation	14.22

measurement results

Citation analysis shows that between 2007 and 2024, 72 articles were compiled, totaling 1,024 citations over the 17 years. The average annual citation rate reached 60.23, indicating that the scientific works during this period had considerable visibility and influence within the academic community. Furthermore, the average citation rate per article of 14.22 indicates that each publication made a significant contribution to the field of research. Overall, these data demonstrate the consistent and relevant scientific impact of these publications over nearly two decades. The types Book, HTML, Citation, and PDF were also excluded to avoid the risk of journals that did not undergo the review process.

Table 2. Screening results

Screening Results	Number of Articles
Book, HTML, DOC, and Citation documents are excluded.	20
Remaining articles	52

The bibliometric exploration is depicted in the PRISMA 2020 Flowchart (Haddaway et al., 2022) in Figure 1. How is the distribution of Publications, and Which Articles Contribute to the Development of Approaches in Mathematics Teaching?

Distribution of Publications

The publication trend can be depicted as in Figure 2. Data show that the publication trend experienced a fairly long period of stagnation from 2007 to 2020, with only 1 publication per year and none in 2021. However, starting in 2022, there was a significant surge, with seven publications, followed by a sharp increase in 2023 to 13 publications, and reaching a peak of 25 publications in 2024. This pattern demonstrates a shift from a
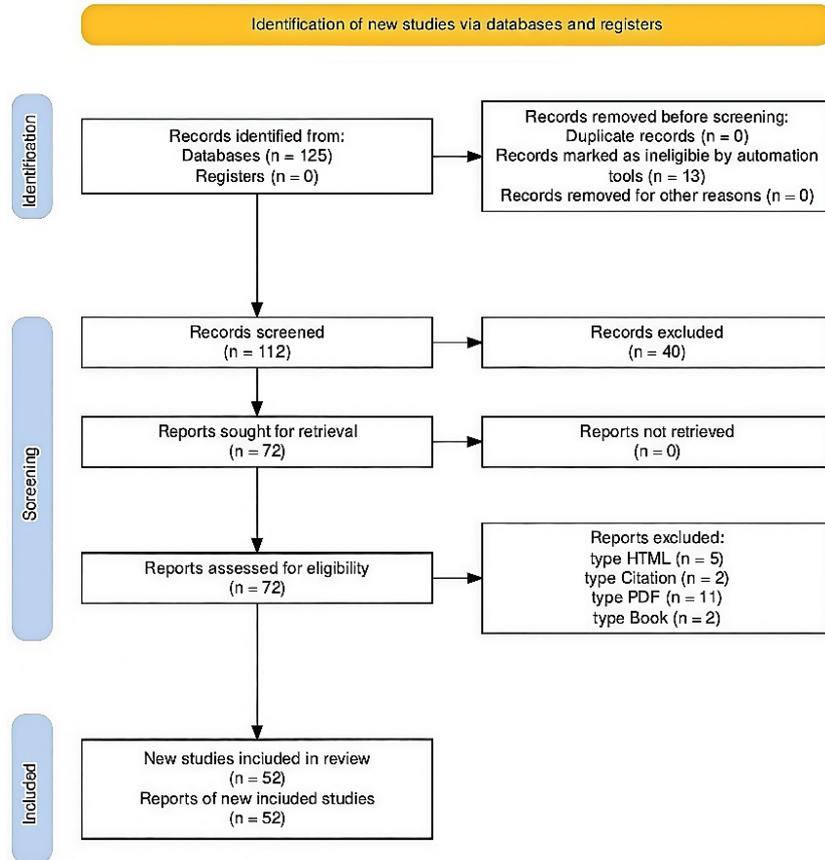
Figure 1. The bibliometric exploration in the PRISMA 2020 flowchart

period of very low research interest to rapid growth over the past three years, indicating increased research attention and productivity on the topic.
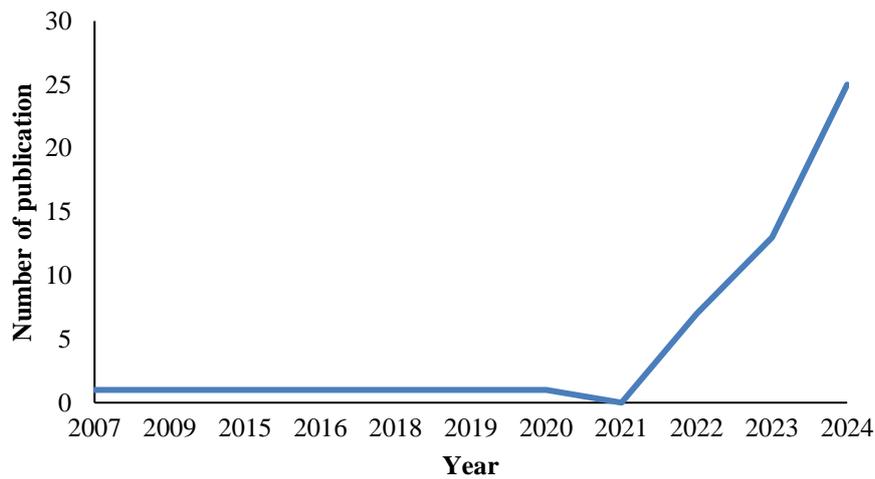
Figure 2. Publication trends from year to year

Further analysis focused on the frequency of publications on *problem-based learning, mathematical communication, ethnomathematics, and problem solving*, as shown in Figure 3. Publications were dominated by two publishers, with the rest being evenly distributed. This information may be helpful to publishers who want to accommodate research on problem-based learning, mathematical communication, ethnomathematics, and problem-solving.
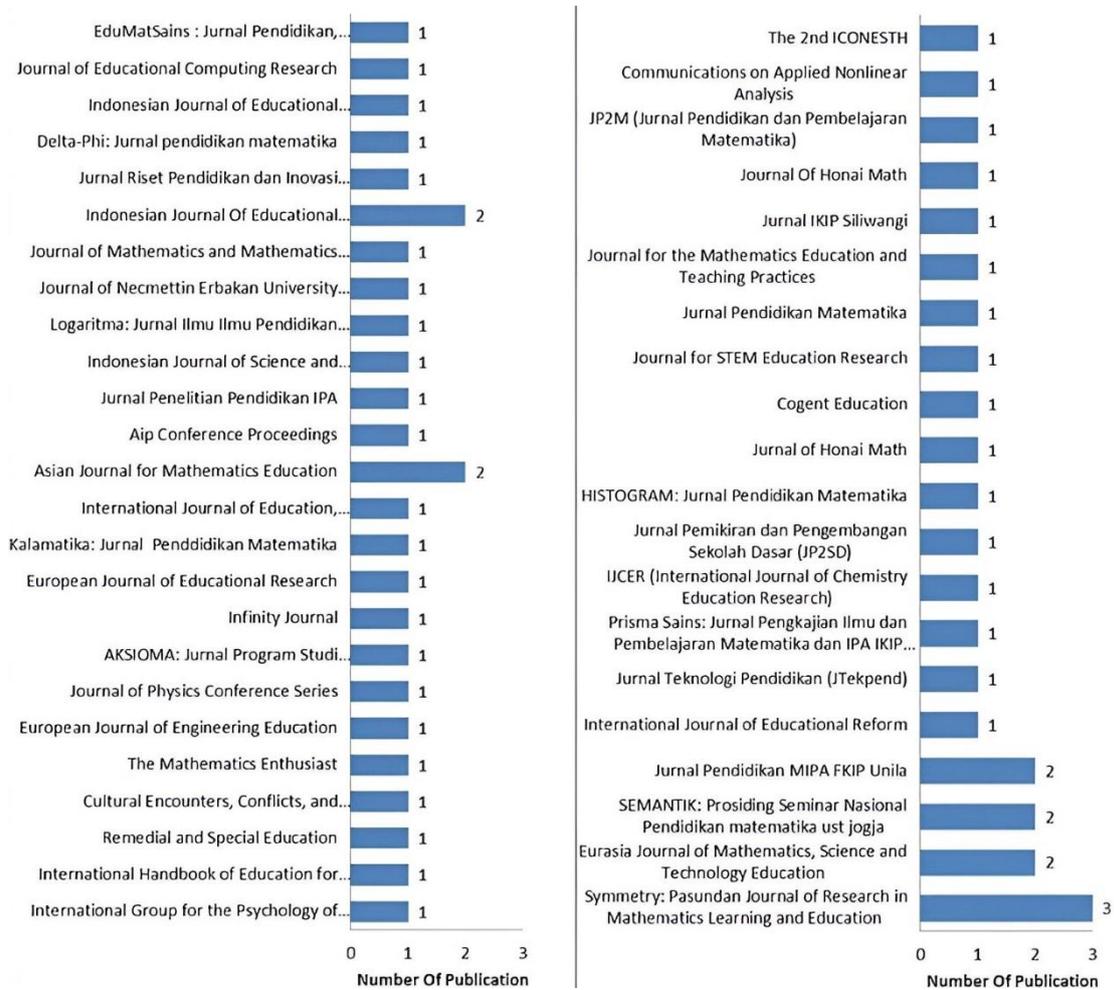
Figure 3. Frequency of article publication

The "Number of Citations" graph shows a highly fluctuating pattern from 2015 to 2024. The highest peak in citations occurs in 2022 (nearly 200), followed by significant increases in 2016 (around 145), and then in 2023 and 2024 (both above 150), indicating that publications from those years only began to gain high citation traction in a relatively short time. Meanwhile, citations are very low, even approaching zero, between 2017 and 2021 (except for a small spike in 2019 and 2020), which may be due to a lack of publications in those years or a long lag time before the work is cited. The decline in citations in 2023 and 2024 (compared to the peak in 2022) could be due to several factors, including Topic Saturation, which may have become a popular citation base, and researchers shifting to newer topics in 2023.
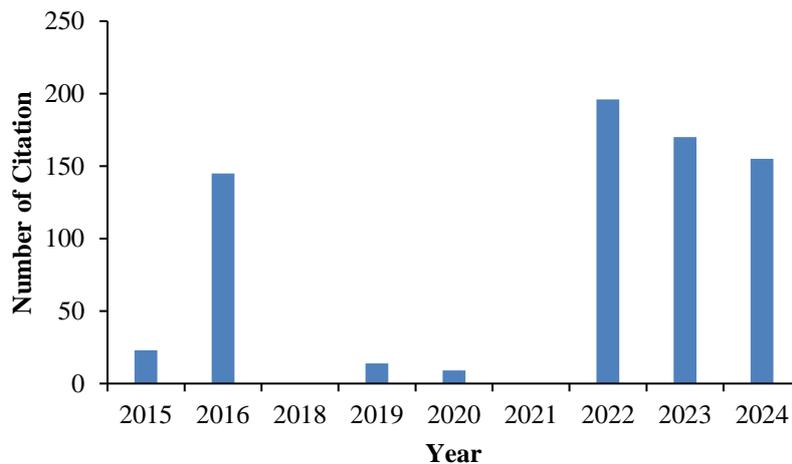
Figure 4. Number of citations

Articles Contribute to the Development of Approaches in Mathematics Teaching

Research on the development of various mathematics learning methods is greatly influenced by contributions and research results published in scientific articles. The three articles with the highest number of citations in Table 3 are as follows.

Table 3. Highest number of citations

Name	Article Title	Year Publication	Journal Name	Number Citation
Shin, M; Bryant, DP	Fraction intervention for students struggling to learn mathematics: A research synthesis	2015	Remedial and Special Education	145
Lidinillah D A M; Rahman R; Wahyudin W	Integration of Sundanese ethnomathematics into mathematics curriculum and teaching: A systematic review from 2013-2020	2022	Infinity Journal	85
Chan, S W; Looi, C K; Ho, W K	Tools and approaches for integrating computational thinking and mathematics: A scoping review of current empirical studies	2022	Journal of Educational Computing Research	63

These articles advance approaches to mathematics teaching. The article by Lidinillah et al. (2022) directly focuses on ethnomathematics by integrating Sundanese culture into the curriculum, making an important contribution to research on the link between formal mathematics and local cultural contexts. This approach supports mathematical problem-solving and communication by providing students with a familiar and relevant context. In contrast, the article by Shin & Bryant (2015) reviews fraction interventions as crucial for improving numeracy skills, which are fundamental to effective problem solving. Meanwhile, Chan et al. (2022) conducted a study on integrating computational thinking tools and new approaches to complement teaching strategies such

as PBL and to improve students' mathematical communication skills through algorithmic representation and reasoning. Overall, these articles encourage a shift towards more contextualized, culturally integrated (ethnomathematics), and skills-focused critical mathematics teaching practices (problem-solving, mathematical communication) through the application of innovative learning strategies (including the potential implementation of PBL enhanced by computational thinking).

What Trends and Potential Pedagogical Developments Will Occur in this Theme in the Future?

Analysis of recent literature trends shows a significant shift in the focus of mathematics education research, with an exploration of emerging trends to increase student engagement and self-motivation.

Trends and Pedagogical Developments

Keyword mapping on Co-occurrence shows 180 keywords, but only 135 keywords are relevant to the subject. Results of keyword processing of articles using VOS viewer. The keywords that appear in relation to the subject are problem-based learning (appears 7 times), mathematical communication (appears 7 times), ethnomathematics (appears 9 times), and problem solving (appears 6 times).

Table 4. Frequency table keywords articles appearing related to the subject

id	Keyword	Occurences	Total link strength
43	Ethnomathematics	9	22
84	Mathematical communication	7	17
118	Problem solving	6	17
119	problem-based learning	7	19

The network visualization resulting from the exploration mapping is grouped/divided into several clusters. Each cluster has a different color and several members, each containing several keywords. In each of these Research clusters, there is a primary keyword (with the largest node) and related keywords (with smaller nodes). Based on Figure 5, 8 clusters were identified from keywords. A complete list of the article exploration clusters is shown in Table 5.

Table 5. Clusters/Groups of keyword occurrence exploration results

Cluster and Theme	Number of Keywords	Keyword
Mathematics Education Innovation Based on STEAM, Digital Technology, and Project-Based Learning	31	3d printing; adult; affective domain; computer-aided design; curriculum reform; curriculum resources; discipline;discourse; game-based learning; games; gamification; geometry; implementation research; indonesia; lifelong; maker; mathematical thinking;mathematics education; movement; overview; philosophy; pjbl; professional development; professional knowledge; scoping review;steam education; students' prior knowledge; study topics;

		systematic literature review.; teacher noticing; video clubs
STEM-Oriented Mathematics Learning with Cultural Contexts and Geometric Problem Solving	19	batik motifs; cognitive ability; competence; geometric transformation; islamic values; learning style; lesson study; mathcitymap; mathematical representation; mathematics and science; mathematics teaching material; problem solving; project-based learning model; promising resources; reputable journals; research and development; stem; systematic literature review; writing error
Mathematical and Quantitative Literacy through Learning Design and Project-Based Approaches	19	learning design; adult literacy; international adult literacy survey; kreativitas; literature; mathematical literacy; mathematics learning; motivation to learn; numeracy skill; probing prompting; problems; project-based learning; quantitative literacy; school;school mathematics classroom;self efficacy.; teacher perception; teacher practice; tinjauan pustaka sistematis
Technology-Enhanced Ethnomathematics and Contextual Learning in School Geometry	18	android application; approach; castellan analysis; contextual learning model; culture; ethnomathematics; exercise stage; geogebra; geometri; interviews; learning and learning model; mathematic teaching; mathematics instructional; numeracy literacy; research stage; school mathematics; secondary mathematics; students
Technology-Supported Learning for Critical, Creative, and Numeracy Skills in Mathematics	18	berpikir kreatif; berpikir kritis; collaborative; creative thinking; critical thinking; cross curriculum; curriculum 2013; derivative; educational technology; kolaboratif; learning; learning media; learning model; literacy; mathematics; numeracy; student errors; teknologi pendidikan
Problem-Based and Ethnoscience-Oriented Learning for Mathematical Critical Thinking and Communication	17	21st-century learning skills; analysis bibliometric; chemistry learning; conceptual learning; discourses; ethnoscience approach; indicators of critical; influence; learning design; literature review; local wisdom; mathematical communication; mathematical critical thinking; mathematical learning; mathematical problems; problem-based learning; systematic
Culturally Responsive and Reflective Practices for Equity-Oriented STEM Mathematics Education	9	active learning; crp framework; culturally-responsive; equity; mathematics teacher educator; practice; reflective; research review; stem education research

Cluster 1 demonstrates the modernization of mathematics education through the integration of the STEAM approach and Project-Based Learning, supported by digital technologies such as 3D printing and gamification. The key concepts are interconnected to engage students' affective aspects, while teacher professional development and

curriculum reform serve as the foundation for transforming abstract mathematical concepts into practical experiences. Consequently, future research trends will increasingly focus on interdisciplinary learning, the use of cutting-edge digital tools, and the strengthening of relevant mathematical thinking for learners.

In cluster 2, the integration of STEM education with local wisdom and religious values in geometry learning is discussed. Keywords such as batik motifs, Islamic values, and geometric transformations are interconnected to demonstrate how cultural context can help students develop cognitive and problem-solving abilities. The implication is that research trends in this area are directed towards the development of research-based teaching materials that explore cultural identity to enhance students' mathematical competence within a global STEM framework.

Cluster 3 focuses on learning design to improve numeracy and quantitative literacy through a project-based approach. The interconnectedness of project-based learning, mathematical literacy, and numeracy skills suggests that literacy mastery depends not only on the school curriculum but also on psychological factors such as self-efficacy and motivation to learn. Research trends in this cluster imply the importance of effective teacher practices and learning designs that accommodate adult literacy in mapping the success of probing-prompting and creativity methods in education.

Cluster 4 narrates the role of digital technology in mediating the relationship between formal mathematics and ethnomathematics. Keywords such as Android application, GeoGebra, and ethnomathematics are interconnected in a contextual learning model to facilitate the understanding of geometry concepts in secondary schools. The trend's implications suggest that future research will increasingly rely on mobile applications and dynamic software to bridge cultural artifacts with school materials, using in-depth interviews and Castellan analysis to measure improvements in students' numeracy literacy in digital learning ecosystems.

In Cluster 5, the important role of educational technology is in developing students' higher-order competencies within the curriculum framework. Keywords such as educational technology, learning media, critical thinking, and creative thinking are interconnected, indicating that the use of digital learning media aims to facilitate collaborative learning and minimize students' errors in understanding mathematical concepts such as derivatives. The implication is that future research trends will increasingly focus on the effectiveness of integrating digital tools in curriculum design to strengthen numeracy literacy.

This cluster 6 integrates an ethnoscience approach with a problem-based learning model to develop mathematical communication and critical thinking skills. The relationship between keywords such as ethnoscience approach, local wisdom, problem-based learning, and mathematical communication reflects researchers' efforts to contextualize mathematics learning through local wisdom relevant to students' real lives. This trend has implications for increasing bibliometric research and literature reviews exploring how ethnoscience can meet the indicators of 21st-century learning skills.

Cluster 7 focuses on social justice in mathematics education through a culturally responsive learning framework. The interconnectedness of the keywords Culturally Responsive Pedagogy, equity, active learning, and reflective practice emphasizes the crucial role of mathematics teacher educators in creating inclusive learning environments. The implications for research trends are a shift toward reflective practice in STEM

education research that focuses not only on cognitive outcomes but also on equal access and respect for students' backgrounds.

Cluster 8 narrates the exploration of mathematical creativity at the higher education level, particularly in engineering disciplines. The close association between the keywords mathematical creativity, engineering, and higher education demonstrates a highly specific research focus on developing innovation and solving complex problems at the university level. This research trend implies the need for stronger integration between pure mathematics and practical engineering applications to spark student creativity in facing future industrial challenges.

Potential Pedagogical Developments

Exploration of new scientific potential can now be carried out systematically using the VOSviewer software. By mapping keyword density and inter-topic relationships bibliometrically, it is clear that the development of future learning models will be greatly influenced by the integration of artificial intelligence and data literacy.

This VOSviewer network visualization in Figure 5 depicts a comprehensive landscape of mathematics education research, dominated by a strong focus on core areas such as ethnomathematics, cultural integration, and technology. The primary pedagogical approaches reflect problem-based learning and enhanced mathematical communication, often explored through systematic literature reviews and reinforced by the concepts of indigenous wisdom and responsive culture. At the same time, research strongly focuses on student learning outcomes, particularly in improving mathematical literacy, self-efficacy, creative thinking, and problem-solving skills, demonstrating a concerted effort to make mathematics teaching more contextual, problem-based, and oriented toward the development of critical competencies.

Figure 5. Network visualization of vos viewer mapping results from explored keywords

The overlay visualization in Figure 6 shows that problem-based learning, ethnomathematics, and mathematical communication problem-solving are trending topics from 2022 to 2024. It is interesting to discuss all four in a single research title. This VOS viewer network visualization, with color overlays showing the evolution of trends over time, illustrates the dynamic shift in focus in mathematics education research. While foundational topics such as mathematics education, geometry, and games have been

established focuses between 2020 and 2022, current research trends are strongly driven by ethnomathematics approaches and the use of GeoGebra in 2024.

Figure 6. Overlay visualization related to the research subject

Pedagogical strategies of problem-based learning and enhancing mathematical communication have remained a stable and dominant research focus from 2022 to 2024, serving as the primary mechanism for testing new interventions aimed at improving problem-solving skills. Overall, this map demonstrates a collective shift toward more contextual, culturally responsive, and technology-enabled studies, while maintaining a strong commitment to proven methods for enhancing students' critical competencies.

The density visualization results in Figure 7 show research trends in Binary Counting Density Visualization, which consists of eight clusters related to these themes. The density map shows that core research has been established in mathematics education and basic subjects such as geometry, with recent trends moving intensively toward ethnomathematics and the implementation of technologies such as GeoGebra.

The main pedagogical strategies that remain stable and solid are problem-based learning and enhancing mathematical communication, which serve as key mechanisms for implementing a renewed focus on local wisdom and culturally responsive teaching. Therefore, this Synergy aims to develop the 4C skills (Communication, Collaboration, Critical Thinking, and Creativity) as 21st-century core competencies. It is predicted that future research will focus on Strengthening Mathematical Communication, a skill needed to enhance problem-solving abilities through a Problem-Based Learning approach with contextual innovation to achieve more relevant and impactful mathematical literacy.

Mathematical communication and problem-solving abilities are strengthened through the use of digital technologies such as Android-based media or GeoGebra. Thus, mathematics education does not focus solely on technical mastery of numeracy, but also

Figure 7. Density visualization related to the research subject

on developing students' character to be digitally literate, creative in solving complex problems, and remain grounded in cultural identity amid dynamic global challenges.

What Gaps are Identified Through Keyword Mapping, and What are the Implications for 21st-Century Mathematics Education?

On the conceptual and empirical interconnections between the main clusters: ethnomathematics, problem-based learning, and mathematical communication appear dominant and closely related.

Gaps Through Keyword Mapping

A prominent research gap is the need to further explore the interconnections among the main clusters, particularly with a focus on practical implementation and specific outcomes. In particular, there is room to more deeply connect topics such as mathematics education and ethnomathematics with outcome-focused clusters (such as creative thinking and mathematical literacy) through robust research methods such as problem-based learning, which can lead to the development of innovative learning models that effectively integrate cultural elements that mediate the improvement of mathematical communication and thus improve problem-solving skills.

The current approach to mathematics learning emphasizes the development of higher-order thinking skills, including problem-solving. Problem-solving not only trains students to solve mathematical problems but also develops critical, creative, and reflective thinking skills. In the context of learning, these skills provide students with a foundation for understanding mathematical concepts in depth and applying them in real-life situations. One important aspect that supports the success of the problem-solving process is mathematical communication skills.

Implications for 21st-Century Mathematics Education

These skills include students' ability to express ideas, explain solution steps, interpret mathematical symbols or models, and interact effectively with teachers and peers. Through mathematical communication, students not only convey the final result but also explain the reasoning behind the solution. This makes mathematical communication a bridge between conceptual understanding and practical application in problem solving.

Fundamentally, the research findings support Lev Vygotsky's social constructivism theory and David Ausubel's theory of meaningful learning (Amineh & Asl, 2015; Arends, 2012; Joyce et al., 2025; Schunk, 2020), which emphasize that mathematical knowledge is constructed through active interaction with the cultural environment and students' prior knowledge. The emergence of ethnomathematics and Problem-Based Learning (PBL) in the bibliometric visualization groups of this study demonstrates a shift in perspective toward learning that prioritizes meaningful context and cultural identity to address low mathematical literacy. More deeply, this trend suggests that current research seeks to bring mathematics from everyday life and community traditions by bridging abstract concepts through local wisdom integrated into active learning models to hone students' problem-solving skills. The implication for teaching practice is that teachers must transform into culturally responsive curriculum developers. For curriculum policy, these data reinforce the urgency of implementing literacy-based assessment and character-building aligned with the Independent Curriculum, where mathematics is no longer taught in isolation but as a tool for understanding and preserving societal values.

To integrate these three aspects, the problem-based learning (PBL) model is an effective approach. PBL encourages students to learn by solving challenging, real-world problems relevant to their life contexts. In this process, students actively construct knowledge through discussion, exploration, and reflection, while the teacher acts as a facilitator. When applied alongside an ethnomathematics approach, PBL enables students to solve problems rooted in local cultural contexts, fostering authentic and meaningful learning. Furthermore, collaborative activities in PBL also strengthen mathematical communication skills, as students need to argue, discuss, and explain their ideas to others.

Thus, integrating problem-solving, mathematical communication, ethnomathematics, and problem-based learning can form a holistic model of mathematics learning. This model not only enhances students' cognitive abilities but also develops their social, cultural, and communication skills, supporting 21st-century learning.

▪ **CONCLUSION**

The Bibliometric analysis shows a significant increase in publications on problem-based learning, mathematical communication, ethnomathematics, and problem-solving from 2022 to 2024, indicating growing interest in contextual, culturally responsive, and 21st-century-oriented mathematics education. Keyword analysis and VOSviewer identified these four themes as closely interconnected and supported by the integration of educational technology.

These findings concretely demonstrate that PBL serves as a methodological bridge, operationalizing the previously theoretical concept of ethnomathematics into classroom activities that stimulate students' communication and problem-solving skills. This

integration reinforces Vygotsky's social constructivist theory and Ausubel's meaningful learning, using local wisdom as a medium to address low mathematical literacy.

However, research gaps remain, particularly the lack of empirical studies integrating ethnomathematics and problem-based learning with mathematical communication as a key or mediating variable. Future research should focus on how the practical implementation of a locally based PBL syntax can effectively improve mathematical literacy scores at a higher cognitive level, aligned with the demands of the Independent Curriculum. These findings suggest opportunities to develop holistic learning models that incorporate cultural context, problem-solving, and mathematical communication to strengthen students' mathematical literacy and competence.

▪ **REFERENCES**

Al Husaeni, D. F., & Nandiyanto, A. B. D. (2021). Bibliometric using Vosviewer with Publish or Perish (using Google Scholar data): from step-by-step processing for users to the practical examples in the analysis of digital learning articles in pre and post covid-19 pandemic. *ASEAN Journal of Science and Engineering*, *2*(1), 19–46. https://doi.org/10.17509/ajse.v2i1.37368

Albanese, V., Adamuz-Povedano, N., & Bracho-López, R. (2017). The evolution of ethnomathematics: Two theoretical views and two approaches to education. *ICME-13 Monographs*, 307–328. https://doi.org/10.1007/978-3-319-59220-6_13

Amalia, S. R., Purwaningsih, D., & Fasha, E. F. (2021). *Penerapan problem-based learning berbasis etnomatematika terhadap bepikir kreatif matematis* [Implementation of ethnomathematics-based problem-based learning to mathematical creative thinking]. *Aksioma: Jurnal Program Studi Pendidikan Matematika*, 10(4), 2507-2514. https://doi.org/10.24127/ajpm.v10i4.4255

Amineh, R. J., & Asl, H. D. (2015). Review of Constructivism and Social Constructivism. *Journal of Social Sciences, Literature and Languages*, *1*(1), 9–16.

Arends, R. I. (2012). *Learning to teach* (9th ed.). New York, NY: McGraw-Hill.

Alexander, P. A. (2020). Methodological guidance paper: The art and science of quality systematic reviews. *Review of Educational Research*, *90(1)*, 6–23. https://doi.org/10.3102/0034654319854352.

Azid, N., Ali,Md,R., Khuluqo, E.I., Purwanto, E.S., & Susanti, N.E. (2022). Higher order thinking skills, school-based assessment and students' mathematics achievement: Understanding teachers' thoughts. *International Journal of Evaluation and Research in Education (IJERE)*, *11*(1), 290–302. https://doi.org/10.11591/ijere.v11i1.22030

Breslin, D., & Gatrell, C. (2020). Theorizing through literature reviews: The miner-prospector continuum. *Organizational Research Methods*, *26*(1), 139–167. https://doi.org/10.1177/1094428120943288

Chan, S.-W., Looi, C.-K., Ho, W. K., & Kim, M. S. (2022). Tools and approaches for integrating computational thinking and Mathematics: A scoping review of current empirical studies. *Journal of Educational Computing Research*, *60*(8), 2036–2080. https://doi.org/10.1177/07356331221098793

D' Ambrosio, U. (2018). The program ethnomathematics: Cognitive, anthropological, historic, and socio-cultural bases. *PNA. Revista de Investigación en Didáctica de la Matemática*, *12*(4), 229–247. https://doi.org/10.30827/pna.v12i4.7851

Deda, Y. N., Disnawati, H., Tamur, M., & Rosa, M. (2024). Global trend of ethnomathematics studies of the Last Decade: A Bibliometric analysis. *Infinity Journal*, *13*(1), 233–250. https://doi.org/10.22460/infinity.v13i1.p233-250

Dockendorff, M., & Solar, H. (2017). ICT integration in mathematics initial teacher training and its impact on visualization: The case of GeoGebra. *International Journal of Mathematical Education in Science and Technology*, *49*(1), 66–84. https://doi.org/10.1080/0020739x.2017.1341060

Donthu, N., Kumar, S., Mukherjee, D., Pandey, N., & Lim, W. M. (2021). How to conduct a bibliometric analysis: An overview and guidelines. *Journal of Business Research*, *133*, 285–296. https://doi.org/10.1016/j.jbusres.2021.04.070

Fatimah, F. (2013). *Kemampuan komunikasi MATEMATIS Dan Pemecahan Masalah melalui problem-based learning* [Mathematical communication skills and problem solving through problem-based learning]. *Jurnal Penelitian Dan Evaluasi Pendidikan*, *16*(1), 249–259. https://doi.org/10.21831/pep.v16i1.1116

Fitriani, R., & Soebagyo, J. (2022). *Kajian Bibliometrik: Mathematical communication Dalam Pembelajaran matematika* [Bibliometric Study: Mathematical Communication in Mathematics Learning]. *JKPM (Jurnal Kajian Pendidikan Matematika)*, *8*(1), 45–54. https://doi.org/10.30998/jkpm.v8i1.13680

Fouze, A. Q., & Amit, M. (2019). Ethnomathematics and Geometrical Shapes in Bedouin women's traditional dress. *Creative Education*, *10*(07), 1539–1560. https://doi.org/10.4236/ce.2019.107112

Haddaway, N. R., Page, M. J., Pritchard, C. C., & McGuinness, L. A. (2022). PRISMA 2020 : An R package and shiny app for producing Prisma 2020-compliant flow diagrams, with interactivity for optimised digital transparency and Open synthesis. *Campbell Systematic Reviews*, *18*(2), 1–12. https://doi.org/10.1002/cl2.1230

Hamdiyanti, M., Rodiana, I., Laelasari, & Subroto, T. (2024). Systematic literature review: Mathematical literacy skills in terms of mathematics learning motivation. *IJCER (International Journal of Chemistry Education Research)*, *8*(2), 104–112. https://doi.org/10.20885/ijcer.vol8.iss2.art3

Ijirana, Kristina, & Nurmi. (2025*). Meningkatkan kemampuan pemecahan masalah pada mata pelajaran matematika siswa kelas V menggunakan pendekatan tarl dan media konkret* [improving problem-solving skills in mathematics subjects of fifth grade students using the TaRL approach and concrete media]. *Media Eksakta*, *21*(1), 1–13. https://doi.org/10.22487/me.v21i1.4577

Irkhamiyati, & Kurniawan, B. D. (2024). *Pemetaan bibliometrik dengan vosviewer terhadap tesis program studi kebidanan program magister universitas 'AISIYAH tahun 2019-2022* [bibliometric mapping using vosviewer on midwifery study program theses, master's program, AISIYAH university, 2019-2022]. *BACA: Jurnal Dokumentasi Dan Informasi*, *45*(1), 65–78. https://doi.org/10.55981/baca.2024.904

Joyce, B. R., Weil, M., & Calhoun, E. (2025). *Models of teaching* (10th ed.). New York, NY: Routledge.

Julius, R., Abd Halim, M. S., Abdul Hadi, N., Alias, A. N., Mohd Khalid, M. H., Mahfodz, Z., & Ramli, F. F. (2021). Bibliometric analysis of research in Mathematics Education using Scopus Database. *Eurasia Journal of Mathematics,*

Science and Technology Education, *17*(12), 1–12. https://doi.org/10.29333/ejmste/11329

Lam, W. H., Lam, W. S., Jaaman, S. H., & Lee, P. F. (2022). Bibliometric analysis of Information Theoretic Studies. *Entropy*, *24*(10), 1–13. https://doi.org/10.3390/e24101359

Lidinillah, D. A., Rahman, Wahyudin, & Aryanto, S. (2022). Integrating Sundanese ethnomathematics into Mathematics Curriculum and teaching: A systematic review from 2013 to 2020. *Infinity Journal*, *11*(1), 33–54. https://doi.org/10.22460/infinity.v11i1.p33-54

Liu, H., Yu, J., Wu, B., Ren, Y., & Liu, Q. (2025). Bibliometric analysis and content analysis of Digital Entrepreneurship: Utilizing the WOS and Scopus databases. *Humanities and Social Sciences Communications*, *12*(1), 1–26. https://doi.org/10.1057/s41599-025-04440-8

Liu, Q., Ali, N. L., & Lee, H. Y. (2025). Applying Vosviewer in a bibliometric review on English language teacher education research: An analysis of narratives, networks and numbers. *Cogent Education*, *12*(1), 1–18. https://doi.org/10.1080/2331186x.2025.2449728

Marleny, A. S., Somakim, Aisyah, N., Darmawijoyo, & Araiku, J. (2020). Ethnomathematics-based learning using oil palm cultivation context. *Journal of Physics: Conference Series*, *1480*(1), 1–8. https://doi.org/10.1088/1742-6596/1480/1/012011

Marzi, G., Balzano, M., Caputo, A., & Pellegrini, M. M. (2024). Guidelines for bibliometric-systematic literature reviews: 10 steps to combine analysis, synthesis and theory development. *International Journal of Management Reviews*, *27*(1), 81–103. https://doi.org/10.1111/ijmr.12381

Maulida, Fajriah, N., & Hidayanto, T. (2025). The effectiveness of the ethnomathematics-integrated problem-based learning (PBL) model on students' mathematical abilities: A meta-analysis study. *Journal Focus Action of Research Mathematic (Factor M)*, *8*(1), 68–80. https://doi.org/10.30762/f_m.v8i1.5037

McAllister, J. T., Lennertz, L., & Atencio Mojica, Z. (2021). Mapping a discipline: A guide to using VOSviewer for Bibliometric and visual analysis. *Science & Technology Libraries*, *41*(3), 319–348. https://doi.org/10.1080/0194262x.2021.1991547

Nasrum, A., Salido, A., & Chairuddin. (2025). Unveiling emerging trends and potential research themes in future Ethnomathematics Studies: A global bibliometric analysis (from inception to 2024). *International Journal of Learning, Teaching and Educational Research*, *24*(2), 206–226. https://doi.org/10.26803/ijlter.24.2.11

Na'im, Z. N., & Mukhlis, M. (2024). Exploration of students' mathematical communication abilities. *Jurnal Riset Pendidikan Matematika*, *11*(1), 41–52. https://doi.org/10.21831/jrpm.v11i1.66639.

Öztürk, O., Kocaman, R., & Kanbach, D. K. (2024). How to design bibliometric research: An overview and a framework proposal. *Review of Managerial Science*, *18*(11), 3333–3361. https://doi.org/10.1007/s11846-024-00738-0

Passas, I. (2024). Bibliometric Analysis: The main steps. *Encyclopedia*, *4*, 1014–1025. https://doi.org/10.3390/encyclopedia4020065

Planas, N., & Pimm, D. (2023). Mathematics Education Research on language and on communication including some distinctions: Where are we now? *ZDM – Mathematics Education*, *56*(1), 127–139. https://doi.org/10.1007/s11858-023-01497-0

Roemer, R. C., & Borchardt, R. (2015). *Meaningful metrics : a 21st century librarian's guide to bibliometrics, altmetrics, and research impact*. Chicago, IL: The Association of College & Research Libraries, a division of the American Library Association.

Scheiner, T., & Bosch, M. (2025). Dialogues between theoretical approaches in Mathematics Education Research: A systematic review. *ZDM – Mathematics Education*, *57*(4), 711–725. https://doi.org/10.1007/s11858-025-01687-y

Schunk, D. H. (2020). *Learning theories: An educational perspective* (8th ed.). New York, NY: Pearson.

Sukestiyarno, Y. L., Nugroho, K. U., Sugiman, & Waluya, B. (2023). Learning trajectory of non-Euclidean geometry through ethnomathematics learning approaches to improve spatial ability. *Eurasia Journal of Mathematics, Science and Technology Education*, *19*(6), 1–17. https://doi.org/10.29333/ejmste/13269

Shin, M., & Bryant, D. P. (2015). Fraction interventions for students struggling to learn mathematics. *Remedial and Special Education*, *36*(6), 374–387. https://doi.org/10.1177/0741932515572910

Trimurtini, Waluya, S.B., Zaenuri, Dwidayati, N.K., Kharisudin, I. (2023). *Ethnomathematics Challenges and Opportunities in Mathematics Research and Learning: A Bibliometric Study Using the VosViewer*. ISET: International Conference on Science, Education and Technology, 7(1), 620–624.March 2023.Semarang, Indonesia: UNNES

Vankúš, P. (2021). Influence of game-based learning in mathematics education on students' affective domain: A systematic review. *Mathematics*, *9*(986), 1–10. https://doi.org/10.3390/math9090986

Wulandari, R., Lubis, M. S., & Siregar, T. J. (2024). *Pengaruh pembelajaran berbasis etnomatematika terhadap kemampuan pemahaman konsep dan pemecahan masalah matematis siswa. Relevan: Jurnal Pendidikan Matematika*, *4*(6), 1–11.

Yanuarto, W. N., Setyaningsih, E., & Zakaria, M. I. (2025). The 21st Century skills model of mathematics students today's instruction age. *JPI:Jurnal Pendidikan Indonesia*, *14*(2), 467–476. https://doi.org/10.23887/jpi-undiksha.v14i2.85109

Yuningsih, Y, Zaenuri, Z,, Walid, W., & Mariani, S. (2024). *Problem based learning bernuansa etnomatematika untuk meningkatkan kemampuan komunikasi matematis siswa. Jurnal Cendekia : Jurnal Pendidikan Matematika*, *8*(1), 655–666. https://doi.org/10.31004/cendekia.v8i1.2978

Zhang, J., Quoquab, F., & Mohammad, J. (2023). Plastic and sustainability: A bibliometric analysis using VOSviewer and CiteSpace. *Arab Gulf Journal of Scientific Research*, *42*(1), 44–67. https://doi.org/10.1108/agjsr-10-2022-0225