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LOCAL LEARNING TRAJECTORY WITH MULTIMODAL APPROACH THROUGH MATHEMATICAL TRANSFER: BIBLIOMETRIC ANALYSIS 2015 – 2025

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ABSTRACT

The fundamental challenge in analyzing learning trajectory in geometry learning using mathematical transfer needs to be done. The problem of geometry learning focuses on the condition of students who often have difficulty constructing conceptual understanding and connecting it with various mathematical representations. This study aims to comprehensively analyze research trends on local learning trajectories with a multimodal approach through mathematical transfer in the time span of 2015 to 2025. Research questions are 1) What are the annual publication trends related to local learning trajectories using a multimodal approach through mathematical transfer from 2015 to 2025, based on data from Scopus, 2) Who are the most influential country and journals, and the research trend in this field? The method used is bibliometric analysis with the help of Biblioshiny to map publication trends, identify research gaps, and find keywords and topics that have not been widely explored. The data for this study will be analyzed using bibliometric methods, involving the identification of publication trends, collaboration networks, and thematic clusters of relevant from relevant articles sourced from Scopus databases between 2015 and 2025 using 221 documents. The results of the research novelty search are Publications on local learning trajectories with multimodal approaches and mathematical transfer increased rapidly from 2020 to 2022, according to Scopus data. The United States and the United Kingdom were major contributors, and journals such as the Journal of Mathematical Behavior became important platforms. Overall, this study highlights the growing interest in adaptive learning trajectory models and learning technologies, providing guidance for future educational research and practice.

Keywords: local learning trajectory, understanding geometry concepts, interactive multimodal approach, , mathematics transfer.

INTRODUCTION

The fundamental problem in learning geometry often lies in students' difficulties in constructing a deep and flexible understanding of concepts (Canducci et al., 2021; Noor & Alghadari, 2021). The

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dominant teaching approach is often less interactive, and does not fully exploit the potential of multimodal representation (Guo et al., 2019; Manzoor et al., 2023; O'Halloran, 2015). Furthermore, there are not many studies that systematically explore how the mechanisms of literal and figural mathematical transfer simultaneously contribute to geometric understanding. This deficiency creates a significant gap between the presentation of materials and students' ability to internalize and apply geometric concepts in various contexts. Therefore, the writing of this article is very urgent to present the essential novelty of the research plan that focuses on "Local Learning Trajectory with Interactive Multimodal Approach to Construct Understanding of Geometric Concepts Through Literal and Figural Mathematical Transfer".

Designing a Local Learning Trajectory (LLT) to promote mathematical transfer in geometry involves creating instructional stages that connect students' prior experiences to formal geometric concepts, which promotes understanding and adaptability (Orón & Lizasoain, 2023). One effective strategy is to use realistic, context-rich problems that are closely related to students' everyday experiences, as this approach increases motivation and helps students see the relevance of geometry in real life (Clements & Sarama, 2004). This can begin by giving students previously completed tasks and gradually guiding them toward more abstract and formal geometric reasoning. Teachers can help students build a strong conceptual foundation that supports transfer to new problems and contexts. The inclusion of cultural or local elements, such as traditional art forms, can increase engagement and make learning more meaningful, supporting the development of critical thinking and problem-solving skills.

A structured Learning Trajectory (LT) combines open-ended tasks and collaborative discussions to help students develop operational definitions, recognize relationships among concepts, and construct logical arguments. (Shamsutdinova, 2021; Simon & Tzur, 2004). For example, the use of flowchart proofs and open-ended problems can guide students to think forwards and backwards, planning the steps of their reasoning and deepening their understanding of geometric proofs (Zbiek et al., 2024). This process not only strengthens geometric reasoning but also prepares students to apply their knowledge flexibly in unfamiliar situations.

Effective instructional design for reinforcing geometric reasoning can blend literal and figurative transfer by combining hands-on constructivist activities with visual and conceptual modeling tools. (Nathan & Alibali, 2021; Rebello et al., 2017). For example, the use of dynamic software such as GeoGebra allows students to transfer geometric properties (Moore, 2021). Literally, it can be used for a variety of problems by constructing, manipulating, and verifying shapes, which strengthens their procedural and conceptual understanding through direct application and reasoning. At the same time, encouraged figural transfer involves developing students' ability to form and use visual images, analogies, and artistic representations of geometric concepts, helping to move from concrete everyday experiences to more abstract and complex mathematical ideas (Kiselnikov, 2020). This dual approach

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not only supports the development of accurate mathematical reasoning but also fosters flexible thinking, allowing students to recognize patterns, make connections, and apply geometric principles in new contexts.

Previous research focused on cross-modality mapping (gesture, speech, action) for transfer (Nathan & Alibali, 2021), while Kaminski focused on the advantages of visual representations over symbolic formats (Kaminski, 2017). Krause and Abrahamson's research focused on the role of sign language and gesture in supporting mathematical transfer, particularly for students with disabilities through the application of modal continuity (Krause & Abrahamson, 2021). Ulum and Pujiastuti's research investigated individual learning styles (visual, auditory, kinesthetic) and found no significant effect on mathematical concept understanding (Ulum & Pujiastuti, 2020). This means that not all modal differences have an impact on conceptual understanding. Fuchs et al.'s research shows that collaborative and interactive modalities (peer-assisted strategies) can enhance acquisition and transfer, especially for students with diverse learning histories (Fuchs et al., 1995). Thus, this research has novelty where the bibliography is still quite rare discussing the Local Learning Trajectory with Multimodal Approach through Mathematics Transfer. This research will have a comprehensive, longitudinal, and bibliometric synthesis of how multimodal strategies affect mathematics transfer. In contrast to previous research that focuses on a particular modality or population, this study aims to map the trends, gaps, and evolution of multimodal approaches in mathematics transfer over a decade, providing a broader and integrative perspective.

The primary purpose of this research novelty paper is to identify, validate, and clearly articulate the innovations offered by the proposed research plan. Research questions are 1) What are the annual publication trends related to local learning trajectories using a multimodal approach through mathematical transfer from 2015 to 2025, based on data from Scopus? 2) Who are the most influential country and journals, and the research trend in this field?

This bibliometric study has significant impact by mapping the research landscape on local learning trajectories, multimodal approaches, and mathematical transfer from 2015 to 2025. The study will identify key researchers and institutions, as well as thematic and methodological trends, helping emerging researchers identify research gaps and facilitate collaboration. Practically, the results can inform the development of more adaptive curricula and learning strategies, ultimately improving the quality of mathematics teaching and student learning outcomes.

METHODS

This research method uses bibliometric analysis of local learning trajectory, multimodal approach, and mathematical transfer. The bibliometric method is intended as an analysis of scientific publications where the components included include writing trends, themes that can be developed, authors, and references used (Firmansyah et al., 2022; Pei et al., 2023). The main purpose of this bibliometric use is

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to identify publication trends, emerging themes, and novelties of research on LLT with an Interactive Multimodal Approach to Constructing Geometry Concept Understanding Through Literal and Figural Mathematics Transfer.

The bibliometric search strategy was centered on the Scopus database and used a combination of relevant and specific keywords related to "learning trajectory". Possible keywords include, but are not limited to, "multimodality", "mathematics transfer" with Boolean operators (AND, OR) to expand the scope and precision of the search.

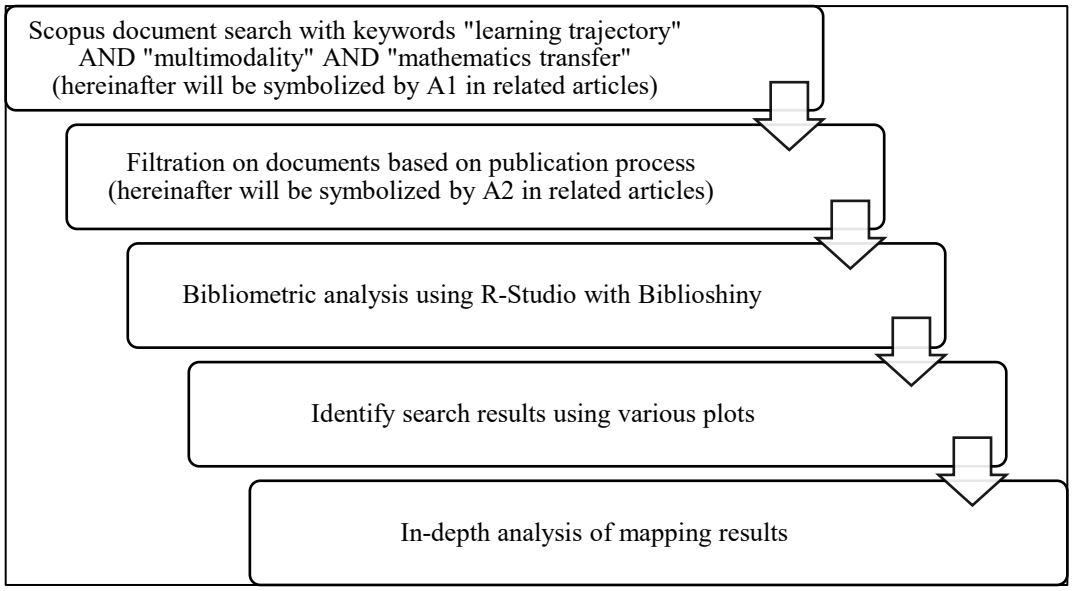

Figure 1. Stages of Bibliometric Analysis

Figure 1 shows the stages of bibliometric analysis carried out. The first stage is to open the official Scopus website and search and filter the data that is included or excluded. With the aim of achieving the relevance and quality of the analyzed data, inclusion and exclusion criteria will be applied. Articles or documents included are those published in journals, conference proceedings, or books and explicitly discuss local learning trajectory, multimodality, and mathematics transfer. The publication period is limited to 10 years so that it focuses on the latest developments in the topic. On the other hand, excluded documents can include non-peer-reviewed articles (eg, preprints without review), or documents that are not directly related to the core topic even though they contain one of the keywords.

The data that has been collected from Scopus according to the search strategy and criteria set, data analysis is carried out systematically. This process involves the use of bibliometric software Bibliometrix, VOSviewer, and R-package to perform various quantitative and qualitative analyzes. Vos Viewer is used to visualize bibliographies, or datasets containing keywords and abstracts from references exported from Scopus. The purpose of using VOSviewer is to analyze bibliometrics, find topics that provide research opportunities, and identify how recent the selected topics are. Bibliometrix

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with the R-Studio application is used to display data visualizations, manipulate descriptive data, and provide conceptual monitoring of the collected data sets.

The analysis carried out includes:

1. Publication Analysis: Calculating the number of publications per year to see the growth trend of topics, relevant publication journals, countries that focus on research on the specified topic
2. Citation Analysis: Identifying the most cited articles, showing influential works.
3. Key Author Analysis: Identifying the most productive and influential researchers.
4. Keyword Analysis: Identifying frequently occurring themes and emerging topics.
5. Research topic trend analysis

Through these steps, this study aims to present a comprehensive picture of the Local Learning Trajectory academic landscape with a multimodal approach and mathematical transfer. This will be used to demonstrate the novelty of this research direction.

FINDINGS

The annual publication trends related to local learning trajectories using a multimodal approach through mathematical transfer from 2015 to 2025, based on data from Scopus

Scopus document search was conducted using several stages of selected keywords. The first keyword is “learning trajectory” AND “mathematics”. As many as 472 Scopus documents were found using these keywords. Furthermore, filtration was carried out by excluding English, so that 472 documents were obtained. The results of the first keyword search were then exported to a file with the bibTEX type and named “LT_mathematics”. As many as 121 Scopus documents with computer science exclusion elements. Furthermore, the data was exported in BibTeX format. The next search uses the keyword “transfer in mathematics” and produce 9 Scopus documents related to transfer in mathematics. Furthermore, this document was exported in BIB file format. Based on the 3 BibTeX files obtained, the files were combined using the Notepad+++ application by copying and pasting the entire contents of each file to be combined into one file. The second keyword search used "multimodality" AND "learning" AND "multimodal learning". So that, so there are 562 Scopus documents (A1).

VOSviewer Results

The VOSviewer results show the results of mapping the main topics of this study, namely learning trajectory, multimodality and mathematical transfer. The references used were extracted from the Scopus website and combined using Publish or Perish with a time span of 2015 - 2025. The resulting mapping is as follows.

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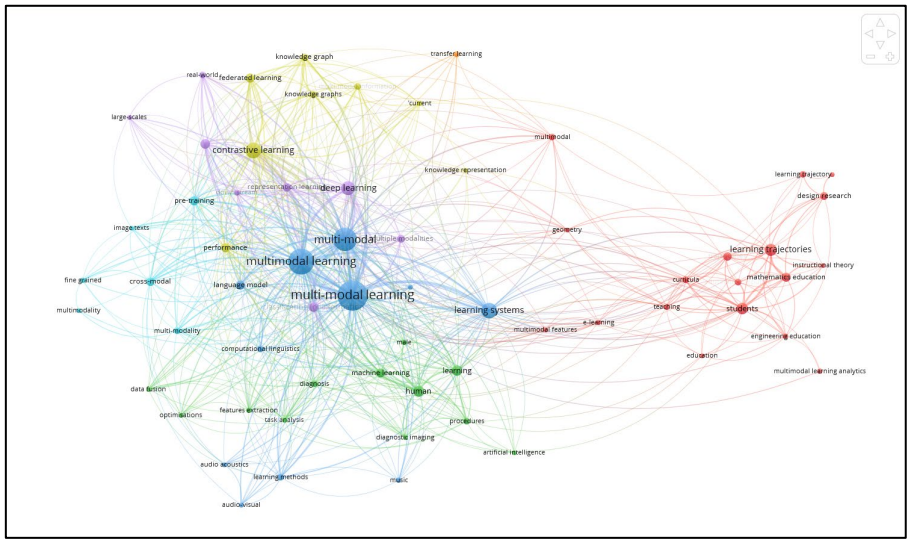

Figure 6. VOSViewer results with the keywords learning trajectory, multimodality and mathematical transfer.

Based on the results of the co-occurrence of keywords mapping, the bibliometric results link keywords that frequently appear in scientific publications. The circle means a cluster of related research topics. The most dominant cluster is the keyword multimodal learning and multi-modal learning. This shows that learning involving modality elements (verbal and visual) has extensive research studies. Other keywords directly related to multimodal learning and multi-modal learning include "deep learning", "machine learning", "learning systems", and "computational linguistics", indicating that most multimodal learning developments and applications utilize artificial intelligence techniques, especially deep learning, to process and understand data from various sources. The relationship with the closest concepts, namely "representations", "language models", and "feature extraction" also appears in this cluster, showing a focus on how information from different modalities is represented and integrated so that it can be understood by the learning system.

The second dominant cluster is red, which has the most frequently discussed keywords in Scopus publications, namely learning trajectories. This cluster is related to other adjacent keywords, including "mathematics education", "design research", "instructional theory", "geometry", "students", and "education" which are very prominent here. This shows that research on learning trajectories is very relevant in the context of education, especially in mathematics and geometry learning, and often involves "design research" methodologies to develop learning interventions.

The interconnected clusters represent the interdisciplinary nature of the field of study, including: 1) The connection between the blue cluster (multimodal learning) and the red cluster (learning trajectory) is significant. This implies that multimodal learning approaches and deep learning techniques may be explored or applied to understand, analyze, or even design more effective "learning trajectories" in educational contexts, especially for concepts such as geometry, 2) "Multimodal features"

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and "multimodal" serve as a bridge between the blue and red clusters, showing how features from different modalities can be utilized in educational contexts and the development of learning paths, 3) The connection between the blue and purple/yellow clusters, where "deep learning" and "contrastive learning" techniques can be used in multimodal learning contexts to improve "knowledge representation" or "transfer learning". Thus, this map shows that strong research is centered on the development and application of multimodal learning supported by deep learning, with a significant focus on how these techniques can be used to understand and facilitate effective learning pathways in educational contexts, especially mathematics and geometry, as well as exploration of advanced techniques such as "contrastive learning" for knowledge representation.

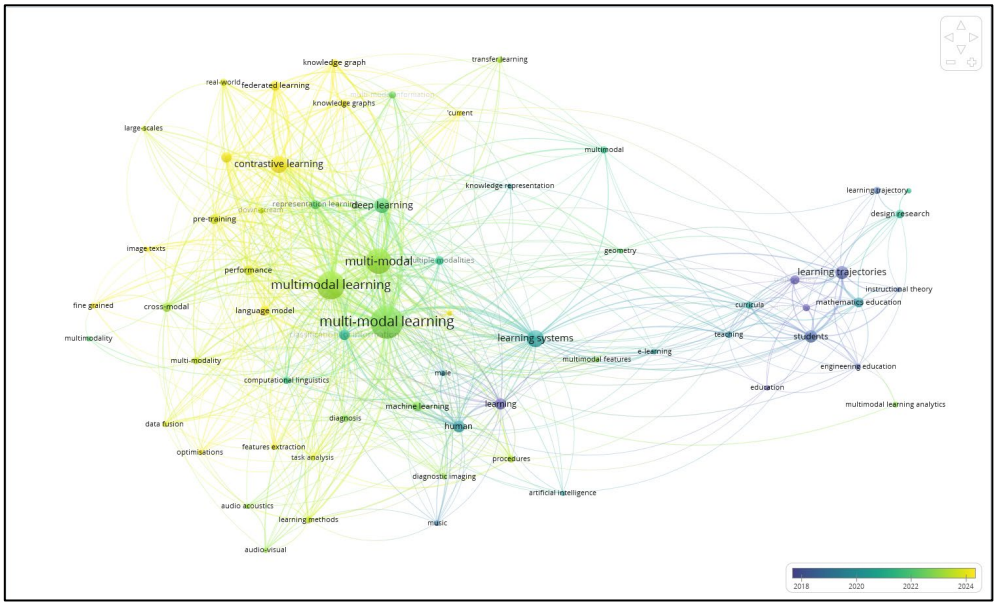

Figure 2. Overlay Visualization Results

Figure 2 shows the trend of keyword development over time, with the reference withdrawal period of 2018 - 2024. The color of the node indicates the average year of publication related to the keyword, where dark blue represents older publications (around 2018-2019) and light yellow represents newer publications (around 2023-2024).

The keywords that appear to dominate as new research trends are deep learning and multimodal learning. This cluster includes the keywords "multi-modal learning", "multimodal learning", and "deep learning" in light yellow and light green. This means that the topics have continued to grow rapidly as research topics in recent years (around 2022-2024). Related keywords such as "language model", "representations", and "contrastive learning" are also mostly colored yellow, meaning that advanced methods in AI and machine learning are the focus of current research.

Some clusters, such as the keywords “learning systems” and “machine learning,” show a mix of colors, from light green to yellow. This may indicate that while these core concepts are still relevant, they are being updated with new applications or methodologies. The clusters in the upper right centered

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around "learning trajectories," "mathematics education," "design research," "instructional theory," and "students" show more blue and purple colors. This means that research in these areas of education and pedagogy developed earlier (around 2018-2020), and have recently begun to intersect with newer multimodal/deep learning trends. The keyword "multimodal learning analytics," which is more yellow, indicates more recent integration efforts. Keywords like "artificial intelligence" and "diagnostic imaging" are more blue/purple, meaning that these areas have been around for a long time and can be used as the basis for more specific applications today.

The most influential country and journals, and the research trend in this field

Next, an analysis was conducted using the Bibliometrix application with the imported A1 documents. After the initial initiation stage, there are 221 reference sources from the combination of the three keywords and 514 Scopus documents (A2).

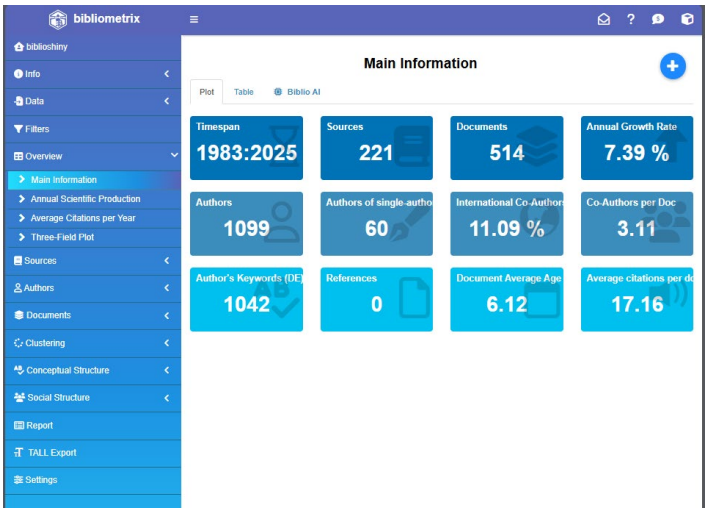

Figure 3. Main Information Display on Bibliometrix

Figure 3 shows that the number of Scopus document authors is 1099 with 60 documents divided into single authors and the rest are collaborating authors. Next, we will look at the Annual Scientific Production which is the number of publications each year. Based on Figure 3, it is obtained that the publication of Scopus documents on Learning Trajectory, multimodality and transfer in mathematics has increased in 2024, namely more than 60 documents. The trend on this topic has experienced a decrease in the number of publications, namely in the period 2020 - 2022. Next, we will look at the research trends on this topic and the number of citations from the 10 countries with the most publications. The goal is to identify countries that produce the most Scopus documents and build collaboration in the field of learning trajectories for mathematics learning.

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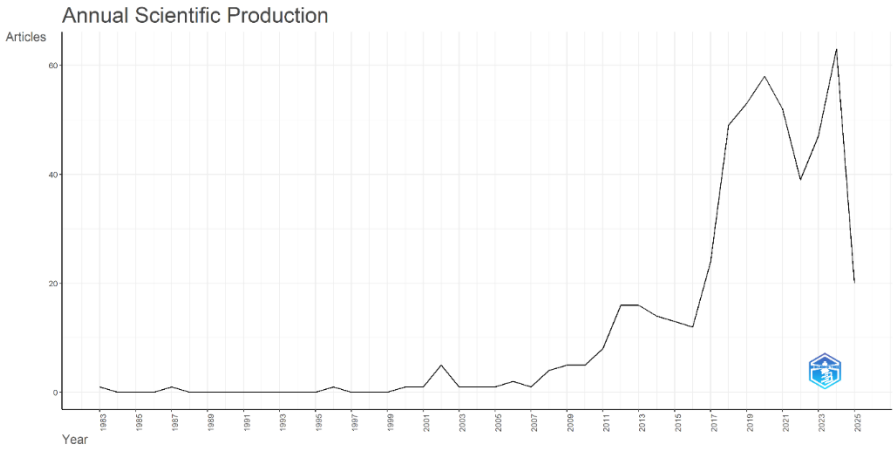

Figure 3 Results of Annual Publication Mapping

Table 1 shows that the USA has the largest number of publications on Scopus, namely 341 documents with the largest number of document citations, namely 3385 citations. Meanwhile, Indonesia has the second largest number of Scopus documents, namely 280 documents with a total of citations of 306. Countries that are close to each other have the potential to collaborate on research in the fields of learning trajectory, multimodality and mathematical transfer, including the USA and Canada. Furthermore, on the same continent and close to each other, namely Indonesia, China, Japan, the Philippines, Singapore, and Malaysia. For the European Continent, countries that are close to each other and have the potential to collaborate on research on similar topics include Turkey, Germany, the Netherlands, Spain, the UK and Sweden.

Table 1. Number of Publications from the 10 Largest Countries

Rank	Country	Publication Frequency	Number of Citation
1	USA	341	3385
2	INDONESIA	280	306
3	TURKEY	34	175
4	CHINA	33	153
5	GERMANY	31	210
6	AUSTRALIA	27	178
7	NETHERLANDS	27	41
8	SPAIN	22	78
9	UK	17	67
10	CANADA	10	67

Identification of journal indexing based on Impact by H Index obtained results as shown in Figure 4.

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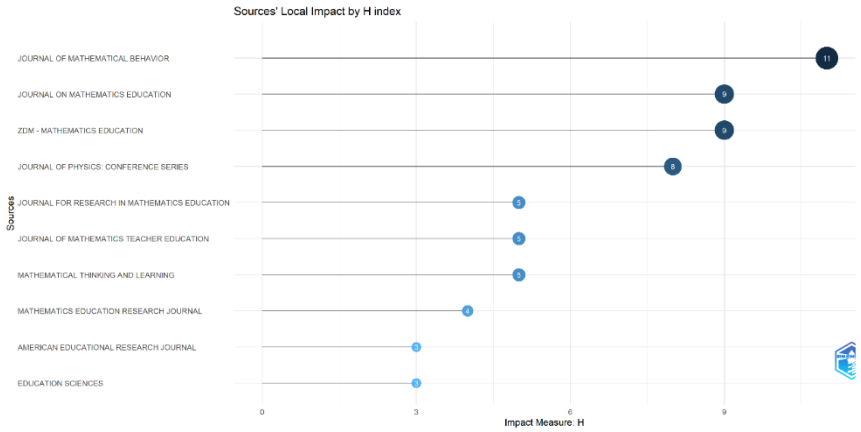

Figure 4 Journal Sources and Indexes

Based on Figure 4, it can be seen that the Journal of Mathematical Behavior has an H-Index of 11. This journal ranks first in the indexation of journals that are sources for writing topics on learning trajectory, multimodality and mathematical transfer. The second rank is the Journal on Mathematics Education which is affiliated in Indonesia and has an H-Index of 9. Identification of journals that publish Scopus documents on the topics of learning trajectory, multimodality and mathematical transfer, the largest source of Scopus document publications is the Journal of Physics: Conference Series with a total of 75 documents in 2022-2025, while in 2021 there were 74 documents and in 2020 there were 58 documents. For the second rank, namely AIP Conference Proceedings, the number of documents in 2024-2025 was 34 documents, while in 2023 there were 17 documents.

In Indonesia, the journal that actively publishes Scopus documents with the topics of learning trajectory, multimodality and mathematical transfer is the Journal on Mathematics Education where in 2025 there were 25 documents and in 2024 there were 23 documents. Further analysis related to keywords that often appear in Scopus documents with the topics of learning trajectory, multimodality and mathematical transfer. Based on tree mapping, the results obtained are as in Figure 5.

Based on Figure 5, the results show that the term "learning trajectory" appears 156 times or 12% of all terms. Furthermore, there is the term "students" in 99 documents, which means that learning trajectory is studied by involving students as research subjects. The term related to the next topic, namely "mathematics education", appears in 81 documents, which means that mathematics learning is used as the focus of the research.

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Figure 5 TreeMap Topic learning trajectory, multimodality and mathematical transfer

For research methods, there are 56 documents on design research. Furthermore, data on research trends related to the topics of learning trajectory, multimodality and mathematics transfer are analyzed. The results of the Scopus document search can be seen in Figure 6.

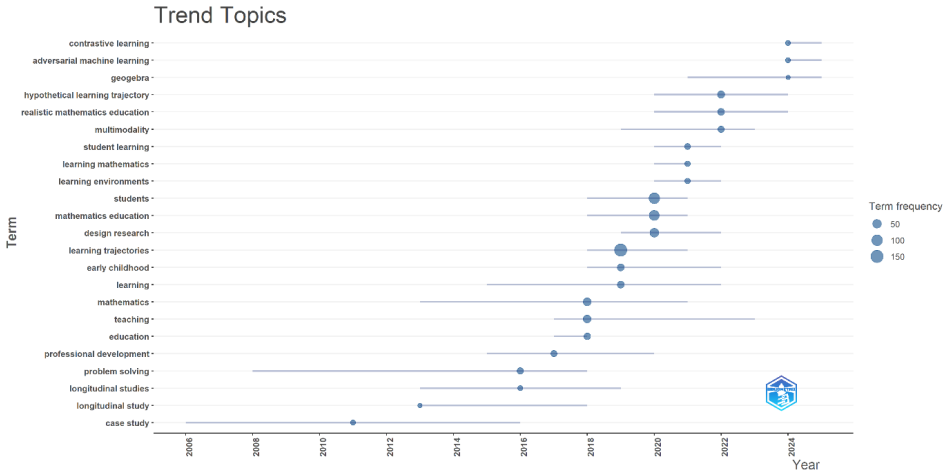

Figure 6 Research Trends Topics of learning trajectory, multimodality and mathematical transfer

Based on Figure 6. the research trend in the last year is related to constrastive learning where the frequency of appearance is still 6 Scopus documents. The technology-based application that has become a research trend since 2020 in Scopus is Geogebra. The research topic that is trending related to learning trajectory is hypothetical learning trajectory (HLT) which has become a trend since 2019 with the most Scopus documents in 2024 as many as 27 documents. The term learning trajectories itself has become a trend since 2018 and in 2019 reached 156 documents published in Scopus. The term that has been trending for quite a long time is learning which appeared in 2014 to 2022. In addition, there is

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the term problem-solving which was also a trend in 2008 to 2018 with the most documents in 2016, namely 26 documents. In contrast to the term multimodality which has been trending since 2018 to 2022 with the most published documents in 2022 as many as 16.

DISCUSSION

Based on the VOSviewer visualization and the results from Biblioshiny, several major research trends can be identified. The co-occurrence map of keywords shows the dominance of the closely related topics of "multi-modal learning" and "deep learning", forming a current research cluster. This trend is reinforced by the overlay visualization analysis which displays a bright yellow color on the keywords, indicating that this is the cluster with the most publications in recent years (around 2022-2024). This reflects a significant shift in artificial intelligence and machine learning research that now focuses on the integration of various data modalities for more sophisticated learning models (Leahy & Sweller, 2011; Sedaghatjou, 2018). In addition, there are research clusters centered on "learning trajectories", "mathematics education", and "design research". Although the overlay visualization analysis shows that these topics have older publication roots (dominated in blue and purple, around 2018-2020), the “Trend Topics” graph also confirms their continued relevance, with “hypothetical learning trajectories” and “realistic mathematics education” emerging as relevant topics until 2024 (Revina & Leung, 2021; Umasugi et al., 2022). The keyword tree map also confirms that “learning trajectories” and “mathematics education” are very large and important topics in the overall document corpus, indicating a strong foundation in the field of education.

The most influential country which has research on the topics of learning trajectory, multimodality and mathematical transfer is the USA. The research mostly used multimodal practices (Morales et al., 2024), learning trajectory as scaffold (Ivars et al., 2020) and research subject of learning trajectory for university student (Cuevas-Vallejo et al., 2023). The Journal of Mathematical Behavior, with an H-Index of 11, is ranked first as a leading source of publications on the topics of learning trajectories, multimodality, and mathematical transfer. The research title "Local Learning Trajectory with Interactive Multimodal Approach to Construct Understanding of Geometry Concepts Through Literal and Figural Mathematics Transfer" strategically combines these two trends, utilizing an interactive multimodal approach (which is part of the multi-modal learning/deep learning trend (Firmansyah et al., 2022; Manzoor et al., 2023; Suzuki & Matsuo, 2022) to understand and construct understanding of geometry concepts within the framework of "local learning trajectory" (the core of the mathematics education trend).

CONCLUSION AND SUGGESTION

The bibliography analysis shows that publication trends in this field have increased significantly since 2015, with a particular spike in 2020-2022, indicating growing interest. The United States and Indonesia were found to be the most influential countries in contributing publications, while the Journal

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of Mathematical Behavior and Educational Studies in Mathematics were the main journals hosting related research. Thematically, research tends to focus on the development of adaptive learning trajectory models and the use of technology to support multimodal learning. These findings provide an important basis for researchers to identify research gaps and develop more effective pedagogical interventions in the future.

Based on the conclusions above, here are some suggestions for further research and development. Research could be continued by explicitly integrates multi-modal and deep learning technologies with pedagogical concepts such as learning trajectories.

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