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# Recent One-Decade Trends in Mathematical Representation Research: Systematic Mapping Study

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**Abstract**

Research can change over time and can be influenced by technological developments, educational trends, and current social issues. Developments on trends in mathematical representation research over the past ten years are discussed in this systematic mapping study (SMS). The review research question with the systematic mapping study method is about the trend of mathematical representation research over the last decade and what new topics can be researched by future researchers related to the themes of mathematical representation. The method used in this review is the PRISMA method, which includes five stages carried out: 1) defining eligibility criteria, 2) determining information sources, 3) data selection, 4) data collection, and 5) data collection. This systematic mapping study starts from searching for articles on the topic of mathematical representation during the last decade, namely the range of 2013-2023, articles obtained from the scopus database in July 2023 with the keywords "representations" AND Mathematics" initial data obtained 1907 articles after the exclusion process obtained 120 articles which were then analyzed using R-Studio and Vos-Viewer tools. The results of SMS obtained the relationship of representation topics in the last ten years of research with the issues of visual, computer software, computer aid instruction, data mining, open source software, network architecture, natural language processing systems, intelligent systems, and information analysis. In addition, research over the past decade on representation has led to more data mining, data security, and STEM. Artificial Intelligence or artificial intelligence is the latest topic that has grown over the past three years in various articles that deal with the theme of mathematical representation and is accompanied by the theme of multi-representation. The evolution of research topics related to mathematical representations that used to be only associated with visual representations and image representations now leads to computer programs, programming algorithms, and artificial intelligence. Research has evolved over the past decade in implementing technology representations.

**Keywords:** Mathematics, Representation, Systematic Mapping Study

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## INTRODUCTION

Mathematical representations are crucial in problem-solving. Mathematics is a universal language used to describe and analyze phenomena in the real world (Ceccherini-Silberstein et al., 2022; Peng et al., 2015; Tomita, 2018). In the context of problem-solving, mathematical representations help in the following ways: 1) Better understanding: Mathematical representations allow us to understand problems in greater depth. By representing the problem in mathematical form, we can identify the patterns, relationships, and underlying structures of the problem. It helps gain a richer understanding of the problem and reveals the essence of what we want to solve; 2) Simplification of complexity: Some complex problems can be simplified through mathematical representations. In mathematics, abstract concepts can be used to represent complex real-world phenomena. By translating problems into mathematical language, we can reduce their complexity into a more orderly and solvable form. 3) Analysis and modeling: Mathematical representation allows us to analyze and model problems systematically.(Arakawa et al., 2022; Gao & Chen, 2020; Gülkılıka et al., 2015; Shestakova, 2018; Tan et al., 2022; Taxipulati & Lu, 2021). Through mathematics, we can develop equations, functions, and models that describe problems mathematically. It helps us analyze problems' properties, find optimal solutions, and predict outcomes using existing mathematical methods. 4) Clear communication: Mathematics provides a clear and consistent language to communicate about problem-solving. Mathematical representations allow us to share understanding and solutions with others who use the same mathematical language. 5) Practical application: Mathematics is the basis for many disciplines and practical applications. By representing problems in mathematical form, we can apply various existing mathematical techniques and methods to solve the problem. Mathematical representations allow us to benefit from mathematical knowledge and tools developed over the centuries (Bouissou, 2020; Brazhnikova, 2016; Kohlhase et al., 2017; Mazo & Baudrier, 2017).

The urgency of mathematical representation in problem-solving lies in its ability to help us understand problems better, simplify complexity, analyze and model problems, communicate clearly, and apply existing mathematical techniques to achieve desired solutions. Mathematical representations provide a solid foundation for effective and efficient problem-solving (Bakar et al., 2020; Castro-Alonso et al., 2021; Ikeda & Stephens, 2015). Over the past ten years, there has been a rapid increase in research on mathematical representations related to machine learning and artificial intelligence. (Bai et al., 2015; Bille et al., 2015; Greiner-Petter et al., 2023; Padalkar & Hegarty, 2015). Machine learning methods such as neural networks, graph-based representations, and natural language processing algorithms are essential in shaping this development. Graph representation – graph-based mathematical representation – has been a significant research focus. (Bomanson et al., 2016; Búrigo & Da Rosa, 2021; Dorrek, 2017; Nitsch et al., 2015; Parta et al., 2021; Shestakova, 2018; Waisman et al., 2014, 2023; Yu et al., 2022). Methods such as graph network representation, learning-based graphing, and application of graph representation in complex data modeling have become popular. (Cao et al., 2019; Sandie et al., 2019; Tugtekin & Odabasi, 2022; Uysal, 2016). Research on mathematical representations in natural language processing is proliferating. Mathematical representation plays a vital role in data understanding, statistical analysis, and predictive model creation in data science. Research on data representation methods and applications of big data and multidimensional data continues to grow. Research on mathematical representation has also developed in the field of education. The study of effective mathematics teaching and learning strategies, including visual, semantic, and symbolic representations, has become essential in finding ways to improve students' understanding of mathematics.

However, no exact data related to many publications and topic mapping has been researched, even though this data is critical for academics to map the development of studies on this topic from year to year. Therefore, the research questions presented in this study are: How has mathematical representation research trended over the last decade, and what new topics related to mathematical representation themes can future researchers research?

## METHODS

This research uses the Systematic Literature Review (SLR) method to identify trends in translational topics between forms of representation in problem-solving and identify new development opportunities for further research. The Elsevier scopus database was identified as a source of literature search related to this research topic. Only the Scopus database was used for this study because it has far more data choices than other databases. The search for electronic databases of scopus uses the terms "representations" AND "mathematics". The initial articles obtained were 1907 documents, after inclusion with the following criteria: 1) journal articles written in English, 2) papers in the field of social sciences, and 3) articles published between 2013-2023 so that 207 documents were obtained. The priority on dynamic structure in this systematic mapping study review looks at how the characteristics of the representation theme are related to the field of mathematics. In particular, we wanted to understand whether significant aspects of mathematics teaching theory have used the concept of representation. Finally, we try to understand how it relates to other significant topics in the representation and teaching of open mathematics. Figure 1 presents the bibliometric and the recommended science mapping workflow.

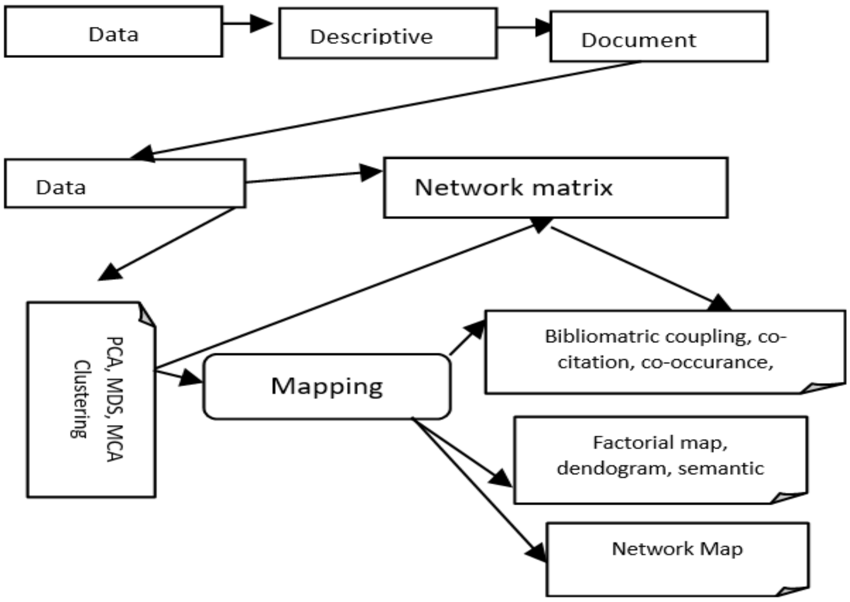


Figure 1. Bibliometric and the recommended science mapping workflow

In general, the PRISMA diagram in the systematic mapping study is presented in Figure 2. The PRISMA flowchart in Figure 2 describes the process of exclusion and inclusion of representation-related articles. One thousand nine hundred seven articles were obtained initially through the Scopus database with the search keywords "representations" AND "mathematics." After going through the exclusion process by selecting articles from reputable journals with Quartile Q4-Q1 on Scimagojr and selected articles related to mathematical representation in learning, 120 articles were analyzed.

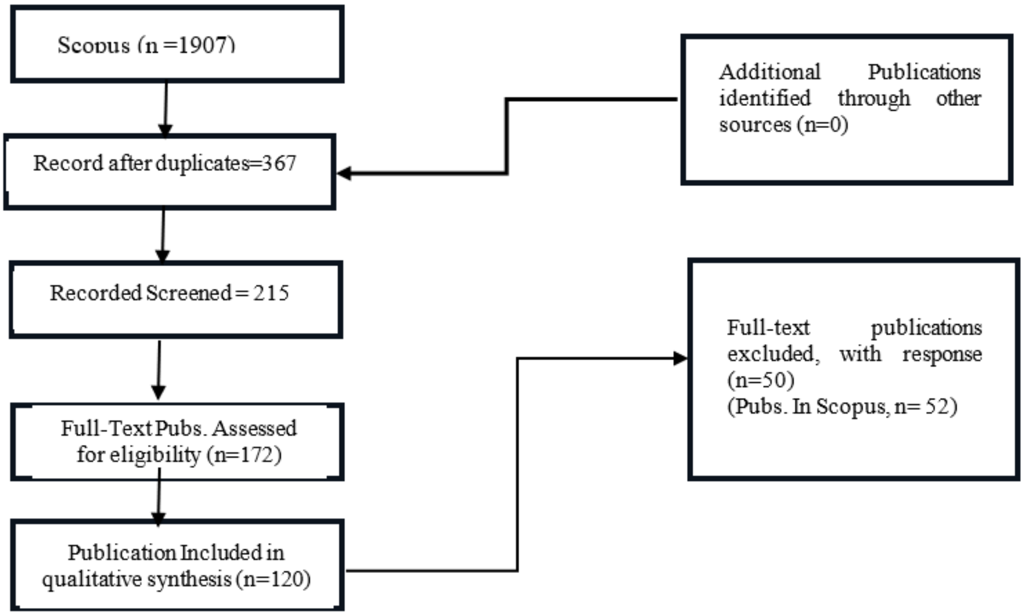


Figure 2. PRISMA Flowchart for Systematic Mapping Study

## RESULTS & DISCUSSION

A deep systematic mapping study uses R-Studio's tools on bibliometrix and Vos-Viewer menus (Aria et al., 2020). Articles obtained in the scopus database, as many as 1907 documents from 2013-2023 (data taken in July 2023), were then analyzed using Biblioshiny, and primary data was generated as follows.

Figure 3. Keywords “Representations” and “Mathematics”

Figure 3 shows that articles obtained from databases of scopus (problem-solving), visual representations, mathematics imaging (image representation), and visualization geometry (visual geometry) are essential topics that are often related to representation. The topic of science, technology, engineering, and mathematics (STEM) and knowledge representations is a topic that will develop in the future in research related to representation; this is in line with the recommendations of the research conducted (Guo et al., 2021; Iancu et al., 2013; Munthe-Kaas, 2016; Sandie et al., 2019; Taxipulati &; Lu, 2021). Learning systems, syntactics, and abstract syntax are also trends in research topics related to mathematical representation. The development of these themes is relevant to the results of research that provides research recommendations for the keywords "representations" and "mathematics" over the past ten years from 871 sources, 4851 authors, 229 single authors, 16.89% international co-authors (Ceccherini-Silberstein et al., 2022; Selkälä et al., 2020). The article growth percentage decreased by 9.57% per year, but the number of citations increased with a coefficient of 7.417. The decrease in the number of articles and the increase in citations are exciting findings on why this is so. One of the initial analyses is the document's average age at a coefficient of 4.74; this illustrates that articles in the scopus database are still growing with that ratio over 1 decade. To see one of the factors decreasing the number of articles in more detail, then exclude data, which was initially 1907 articles with various specific considerations and specific keywords on research variables related to mathematical representation in depth excluded.

After going through the scopus document extraction process, 120 articles were left from 102 sources with 367 authors, 20 single authors, and 21—67% co-authors. Citations per document are 10.46, with the number of references reaching 4070. However, the annual article growth is still at -3.97%, originally before the extraction process reached -9.47%. The extraction and excluded data process is more clearly seen in Figure 4.


Figure 4. Data After Going Through The Extraction Process

Figure 5 clearly shows the relationship between topic networks and the topic of mathematics and knowledge information. In the last ten years, articles published in the Scopus database illustrate the topics of visualization, computer software, computer aid instruction, data mining, open source software, network architecture, natural language processing systems, intelligent systems, and information analysis. Looking at this network of topics, the latest themes or topics in research related to mathematical representation are more directed towards visual representations that lead to data mining and computer systems. According to (Aria Cuccurullo, 2017)This topic's networking function can map interrelated themes in a study.

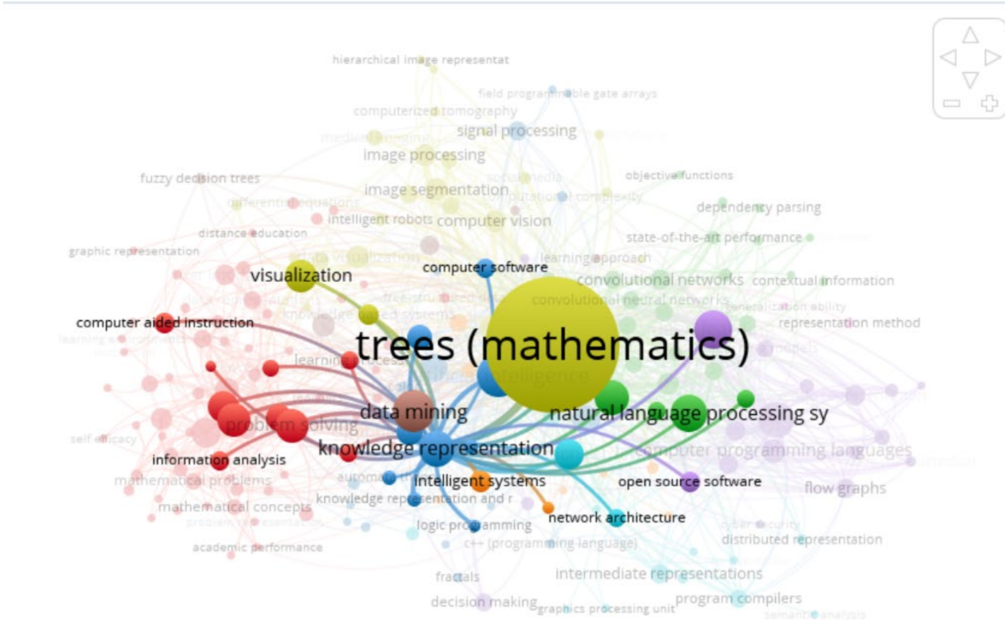

Figure 5. Network Visualization 2013-2023

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Exciting findings from a collection of articles in the Scopus database over the last decade on the topic of research on mathematical representations related to data mining are decision-making and data security. This shows that the increasingly rapid development of technology, especially in data security, is strongly influenced by studies related to mathematical representation. Decision-making skills are also a close part of the topic of data mining and data security. If it is associated with learning, the topic of data mining is related to e-learning and STEM. Specifically, in the topic network in Figure 3, mathematics representations are related to codes, learning approaches, and learning representations. Figure 6 confirms that this mathematical representation over the past ten years has had much research on learning approaches and symbols.

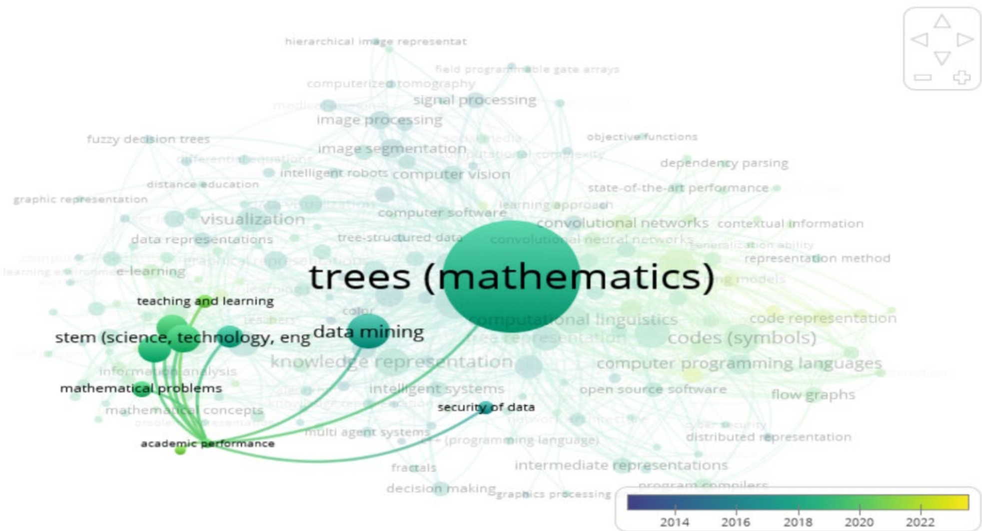

Figure 6. Networking Data Mining Topics

Figure 7 shows that the topic of artificial intelligence is related to the topic of mathematical representation in various studies of the last decade. Artificial intelligence is related to data mining, computer programming, learning approaches, representation learning, C++ programming, intermediate representations, flow graphs, and symbols. Flow graphs and symbols have much to do with mathematical representation research. This shows the role of graphic and symbol representation in various research contexts that raise the theme of data mining. The opportunity to research these themes is very open for future researchers.

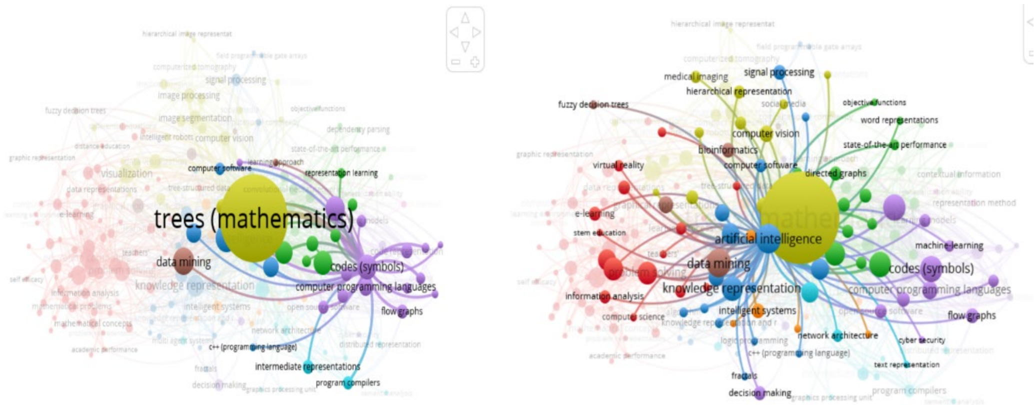


Figure 7. Network of Artificial Intelligence and Mathematical Representation Topics

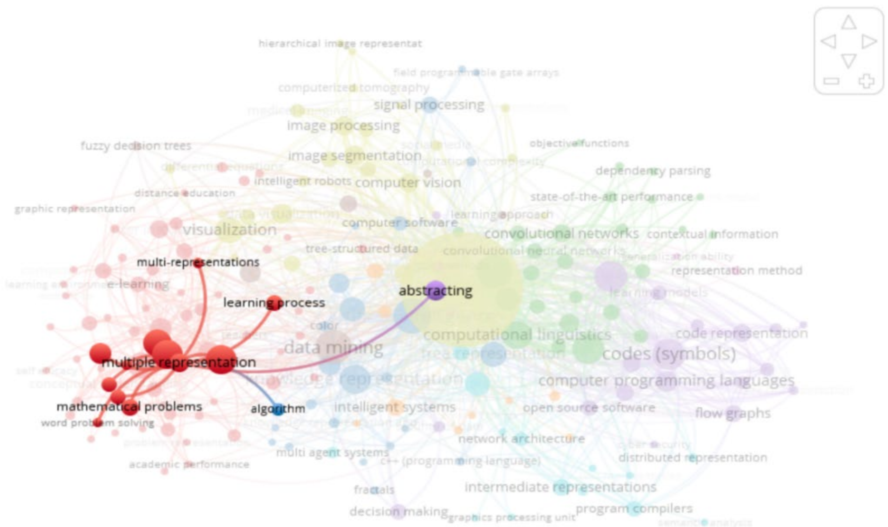


Figure 8. Multi-Representations Topics Related To Mathematical Problems

In addition to the topic of representation related to data mining and computer programming, it turns out that multi-representation has many links. Figure 8 shows that one of the links between multi-representation topics is the learning process, abstracting, mathematical problems, word problem solving, and algorithms. The topic of multi-representation networking is also in line with research conducted by (Helingo et al., 2019 Lemus et al., 2015 Sandie et al., 2019; Waite & Byrne, 2015), which states that in mathematics learning, there is mostly more than one representation used by students, closely related to the concept of multi-representation. Multi-representation is also closely related to problem-solving and word problems (Greiner-Petter et al., 2023; Mainali, 2021; Tan et al., 2022).

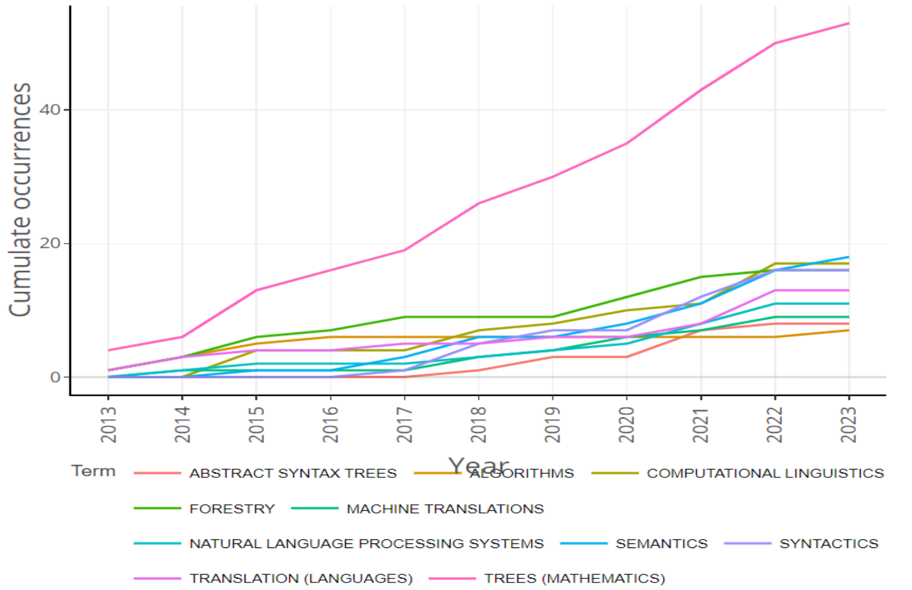


Figure 9. Development Topics Related to Mathematical Representation

The significant improvement in mathematical topics is seen drastically in Figure 9. Over the past 10 years, mathematics topics have increased from year to year, followed by forestry, semantics, and algorithms. The development picture of this topic is related to the relationship that topics always appear in every article on the topic of representation, meaning every journal article over the last 1 decade that discusses definite representations related to mathematics, algorithms, computing, semantics, and syntax. Research results from (Taxipulati &Lu, 2021 Van Den Eynde et al., 2019) It is stated that the relationship and development of research topics related to mathematical representation impact the growth of research on representation, especially on semantics and algorithms.

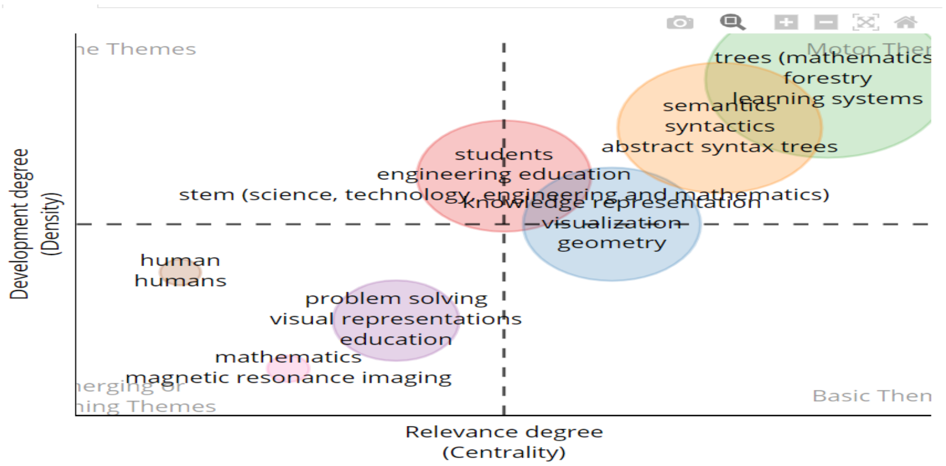


Figure 10. Development of Research Trends Related to Mathematical Representation

Research trends related to representation are shown in Figure 10. Problem-solving, visual representations, mathematics imaging, visualization geometry, and other essential topics are often associated with representation. STEM (science, technology, engineering, and mathematics) topics and knowledge representations are topics that will develop in the future in research related to representation; this is in line with the recommendations of the research conducted (Guo et al., 2021; Iancu et al., 2013; Munthe-Kaas, 2016; Sandie et al., 2019; Taxipulati & Lu, 2021). Learning systems, syntactics, and abstract syntax are also trends in research topics related to mathematical representation. The development of these themes is relevant to the results of research conducted by (Ceccherini-Silberstein et al., 2022; Selkälä et al., 2020), which provide research recommendations on learning systems and syntax related to representation.

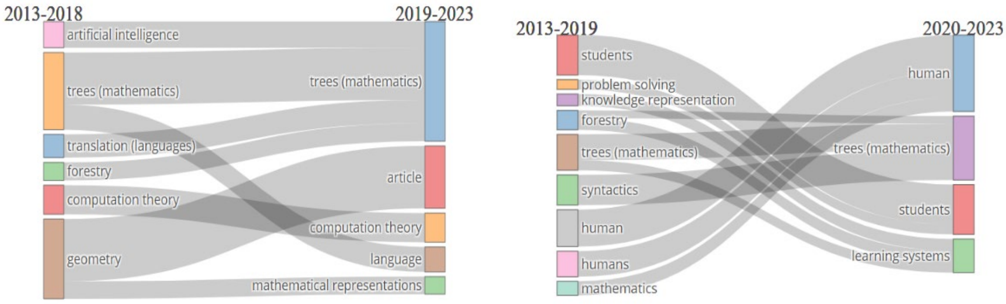


Figure 11. The Evolution of the Topic of Mathematical Representations

It is also clearly shown in Figure 11 that the evolution of the topic is divided into 2 phases: the first phase in 2013-2018 or 2013-2019, and the second phase in 2019-2023 or 2020-2023. In the first phase, the topics discussed were students, problem-solving with representation, and trees (mathematical content). In contrast, in the second phase, they evolved into discussions about learning systems, artificial intelligence, and computational theory. Looking at the evolutionary trend, research topics related to mathematical representation have led to computer theory and artificial intelligence. This aligns with the research (Istadi et al., 2017; Mainali, 2021; Mbusi & Luneta, 2021; Parta et al., 2021).

## CONCLUSION

During 2013-2023, research related to mathematical representations evolved from visual and verbal representations in the presentation of mathematical ideas in classroom learning towards representations related to technology. The topic of representation in the last 10 years of research is connected to computer software, computer aid instruction, data mining, open source software, network architecture, natural language processing systems, intelligent systems, and information analysis. In addition, the topic of representation also leads to data mining, security of data, and STEM. Artificial Intelligence or artificial intelligence is the latest topic that has grown over the past 3 years in various articles, raising the theme of mathematical representation accompanied by the theme of multi-representation. Multi-representation is the main topic of discussion in various articles that relate the topic of representation to STEM, programming algorithms, and various computer technologies designed based on the concept of representation.

## CONFLICT OF INTEREST

There is no Conflict of Interest in this research.

**REFERENCES**

Arakawa, T., Creutzig, T., & Feigin, B. (2022). Urod algebras and Translation of w-algebras. *Forum of Mathematics, Sigma*, *10*. https://doi.org/10.1017/fms.2022.15

Aria, M., & Cuccurullo, C. (2017). bibliometrix: An R-tool for comprehensive science mapping analysis. *Journal of Informetrics*, *11*(4), 959–975. https://doi.org/10.1016/j.joi.2017.08.007

Aria, M., Misuraca, M., & Spano, M. (2020). Mapping the evolution of social research and data science on 30 years of social indicators research. *Social Indicators Research*, *149*(3), 803–831. https://doi.org/10.1007/s11205-020-02281-3

Bai, C., Zhao, T., Wang, W., & Wu, M. (2015). *An efficient indexing scheme based on K-Plet representation for fingerprint database* (B. V., H. D.-S., & P. P. (eds.); Vol. 9225, pp. 247–257). Springer Verlag. https://doi.org/10.1007/978-3-319-22180-9_25

Bakar, K. A., Mohamed, S., Yunus, F., & Karim, A. A. (2020). Use of multiple representations in understanding addiction: The case of preschool children. *International Journal of Learning, Teaching and Educational Research*, *19*(2), 292–304. https://doi.org/10.26803/IJLTER.19.2.18

Bille, P., Li Gørtz, I., & Vind, S. (2015). *Compressed data structures for range searching* (D. A.-H., M.-V. C., F. E., & T. B. (eds.); Vol. 8977, pp. 577–586). Springer Verlag. https://doi.org/10.1007/978-3-319-15579-1_45

Bomanson, J., Gebser, M., Janhunen, T., Kaufmann, B., & Schaub, T. (2016). Answer set programming modulo acyclicity. *Fundamenta Informaticae*, *147*(1), 63–91. https://doi.org/10.3233/FI-2016-1398

Bouissou, M. (2020). *Automatic translation from dynamic models to boolean representation suitable for i&ab quantification* (B. P., D. M. F., & Z. E. (eds.); pp. 1868–1875). Research Publishing, Singapore. https://doi.org/10.3850/978-981-14-8593-0_4865-cd

Brazhnikova, Y. A. (2016). Innovative technique of working with music text by symmetry operations. *Integration of Education*, *20*(4), 507–521. https://doi.org/10.15507/1991-9468.085.020.201604.507-521

Búrigo, E. Z., & Da Rosa, N. G. (2021). Machines and numbers: Translations of Nicole Picard's texts in Porto Alegre during the 1970s. *Educacao and Realidade*, *46*(2). https://doi.org/10.1590/2175-6236112151

Cao, J.-X., Yang, R.-H., & He, L.-M. (2019). *Effect of subtitle presentation types on students' learning outcome and cognitive load*. 144–147. https://doi.org/10.1145/3369255.3369268

Castro-Alonso, J. C., Wong, R. M., Adesope, O. O., & Paas, F. (2021). Effectiveness of multimedia pedagogical agents predicted by diverse theories: a meta-analysis. *Educational Psychology Review*, *33*(3), 989–1015. https://doi.org/10.1007/s10648-020-09587-1

Ceccherini-Silberstein, T., Scarabotti, F., & Tolli, F. (2022). Representations of Finite group extensions via projective representations. In *Springer Monographs in Mathematics* (pp. 189–228). Springer Science and Business Media Deutschland GmbH. https://doi.org/10.1007/978-3-031-13873-7_7

Dorrek, F. (2017). Minkowski Endomorphisms. *Geometric and Functional Analysis*, *27*(3), 466–488. https://doi.org/10.1007/s00039-017-0405-z

Gao, W., & Chen, Y. (2020). Approximation analysis of ontology learning algorithm in linear combination setting. *Journal of Cloud Computing*, *9*(1). https://doi.org/10.1186/s13677-020-00173-y

Greiner-Petter, A., Schubotz, M., Breitinger, C., Scharpf, P., Aizawa, A., & Gipp, B. (2023). Do the math: Making mathematics in wikipedia computable. *IEEE Transactions on Pattern Analysis and Machine Intelligence*, *45*(4), 4384–4395.

Gülkılıka, H., Uğurlub, H. H., & Yürükc, N. (2015). Examining students' mathematical understanding of geometric transformations using the Pirie-Kieren model. *Kuram ve Uygulamada Egitim Bilimleri*, *15*(6), 1531–1548.

Guo, D., Ren, S., Lu, S., Feng, Z., Tang, D., Liu, S., Zhou, L., Duan, N., Svyatkovskiy, A., Fu, S., Tufano, M., Deng, S. K., Clement, C., Drain, D., Sundaresan, N., Yin, J., Jiang, D., & Zhou, M. (2021). *Graphcodebert: pre-training code representations with data flow*. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85139426637&partnerID=40&md5=887d147a2eac53b296f7973e2bb16380

Helingo, D. D. Z., Amin, S. M., & Masriyah, M. (2019). *Translation process of mathematics representation: From graphics to symbols and vice versa* (P. P.W. (ed.); Vol. 1188, Issue 1). Institute of Physics Publishing. https://doi.org/10.1088/1742-6596/1188/1/012055

Iancu, M., Kohlhase, M., Rabe, F., & Urban, J. (2013). The mizar mathematical library in omdoc: translation and applications. *Journal of Automated Reasoning*, *50*(2), 191–202. https://doi.org/10.1007/s10817-012-9271-4

Ikeda, T., & Stephens, M. (2015). Reconsidering the roles and characteristics of models in mathematics education. In *International Perspectives on the Teaching and Learning of Mathematical Modelling* (pp. 351–361). Springer Science and Business Media B.V. https://doi.org/10.1007/978-3-319-18272-8_29

Istadi, Kusmayadi, T. A., & Sujadi, I. (2017). *Students' mathematical representations on secondary school in solving trigonometric problems*. *855*(1). https://doi.org/10.1088/1742-6596/855/1/012021

Kohlhase, M., Müller, D., Owre, S., & Rabe, F. (2017). *Making PVS accessible to generic services by interpretation in a universal format: Vol. 10499 LNCS* (M. C.A. & A.-R. M. (eds.); pp. 319–335). Springer Verlag.

Lemus, E., Bribiesca, E., & Garduño, E. (2015). Surface trees - representation of boundary surfaces using a tree descriptor. *Journal of Visual Communication and Image Representation*, *31*, 101–111. https://doi.org/10.1016/j.jvcir.2015.06.004

Mainali, B. (2021). Representation in teaching and learning mathematics. *International* Journal *of Education in Mathematics, Science and Technology*, *9*(1), 1–21. https://doi.org/10.46328/ijemst.1111

Mazo, L., & Baudrier, É. (2017). *Study on the digitization dual combinatorics and convex case: Vol. 10502 LNCS* (K. W.G., A. N.M., & J. I. (eds.); pp. 363–374). Springer Verlag. https://doi.org/10.1007/978-3-319-66272-5_29

Mbusi, N. P., & Luneta, K. (2021). Mapping pre-service teachers' faulty reasoning in geometric translations to the design of Van Hiele phase-based instruction. *South African Journal of Childhood Education*, *11*(1). https://doi.org/10.4102/sajce.v11i1.871

Munthe-Kaas, H. Z. (2016). Groups and symmetries in numerical linear algebra. In *Lecture Notes in Mathematics* (Vol. 2173, pp. 319–406). Springer Verlag. https://doi.org/10.1007/978-3-319-49887-4_5

Nitsch, R., Fredebohm, A., Bruder, R., Kelava, A., Naccarella, D., Leuders, T., & Wirtz, M. (2015). Students' competencies in working with functions in secondary mathematics education—empirical examination of a competence structure model. *International Journal of Science and Mathematics Education*, *13*(3), 657–682. https://doi.org/10.1007/s10763-013-9496-7

Padalkar, S., & Hegarty, M. (2015). Models as feedback: Developing representational competence in chemistry. *Journal of Educational Psychology*, *107*(2), 451–466. https://doi.org/10.1037/a0037516

Parta, I. N., Sa'dijah, C., Sirajuddin, & Sukoriyanto. (2021). *How do prospective teachers solve the algebra problem as a broad measure* (S. H., H. H., & R. D. (eds.); Vol. 2330). American Institute of Physics Inc. https://doi.org/10.1063/5.0043738

Peng, F., Li, J., & Long, M. (2015). A lossless watermarking algorithm for STL model using entity rearrangement based on average coding tree. *Journal of Computational Information Systems*, *11*(8), 2895–2904. https://doi.org/10.12733/jcis14064

Sandie, Purwanto, Subanji, & Hidayanto, E. (2019). Process thinking of students in translating representation of covariational dynamic events problems. *International Journal of Scientific and Technology Research*, *8*(10), 1405–1408. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85074175739&partnerID=40&md5=3ca4072de2b037887fd5e46b1b299bf1

Selkälä, A., Callegaro, M., & Couper, M. P. (2020). *Automatic versus manual forwarding in web surveys - a cognitive load perspective on satisficing responding: Vol. 12194 LNCS* (M. G. (ed.); pp. 130–155). Springer.

Shestakova, M. (2018). Visualization of the philosophical and conceptual foundations of modern natural sciences in Renaissance painting. *Praxema*, *186*(4), 263–272. https://doi.org/10.23951/2312-7899-2018-4-263-272

Tan, S., Clivaz, S., & Sakamoto, M. (2022). Presenting multiple representations at the chalkboard: bansho analysis of a Japanese mathematics classroom. *Journal of Education for Teaching*. https://doi.org/10.1080/02607476.2022.2150538

Taxipulati, S., & Lu, H.-D. (2021). The influence of feedback content and feedback time on multimedia learning achievement of college students and its mechanism. *Frontiers in Psychology*, *12*. https://doi.org/10.3389/fpsyg.2021.706821

Tomita, K. (2018). Does the visual appeal of instructional media affect learners' motivation toward learning? *TechTrends*, *62*(1), 103–112.

Tugtekin, U., & Odabasi, H. F. (2022). Do interactive learning environments have an effect on learning outcomes, cognitive load, and metacognitive judgments? *Education and Information Technologies*, *27*(5), 7019–7058. https://doi.org/10.1007/s10639-022-10912-0

Uysal, M. P. (2016). Evaluation of learning environments for object-oriented programming: measuring cognitive load with a novel measurement technique. *Interactive Learning Environments*, *24*(7), 1590–1609.

Van Den Eynde, S., Van Kampen, P., Van Dooren, W., & De Cock, M. (2019). Translating between graphs and equations: The influence of context, direction of translation, and function type. *Physical Review Physics Education Research*, *15*(2). https://doi.org/10.1103/PhysRevPhysEducRes.15.020113

Waisman, I., Brunner, C., Grabner, R. H., Leikin, M., & Leikin, R. (2023). (Lack of) neural efficiency related to general giftedness and mathematical excellence: An EEG study. *Neuropsychologia*, *179*.

Waisman, I., Leikin, M., Shaul, S., & Leikin, R. (2014). Brain activity associated with translation between graphical and symbolic representations of functions in generally gifted and excelling in mathematics adolescents. *International Journal of Science and Mathematics Education*, *12*(3), 669–696.

Waite, A., & Byrne, W. (2015). *The geometry of statistical machine translation*. 376–386. https://doi.org/10.3115/v1/n15-1041

Yu, M., Bai, C., Yu, J., Zhao, M., Xu, T., Liu, H., Li, X., & Yu, R. (2022). Translation-based embeddings with octonion for knowledge graph completion. *Applied Sciences (Switzerland)*, *12*(8). https://doi.org/10.3390/app12083935