TECHNOLOGY, INNOVATION AND SPECIAL EDUCATION RESEARCH

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The Bibliometric Profile of Robotic Coding Studies in Mathematics Education

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Abstract
This study aims to reveal the bibliometric profile of robotic coding studies in mathematics education and to offer insights for future research. To this end, 131 articles addressing the topic of "robotic coding in mathematics education" in the Scopus database were analyzed using the bibliometric analysis method. The study employed the Biblioshiny package, a software specifically developed for bibliometric analysis. The results indicated that the highest number of studies on this subject were conducted in 2023; the concept of *computational thinking* was the most frequently used; and the keywords reflected a variety of interdisciplinary differences. It was observed that the most commonly co-occurring concepts revolved around efforts to enhance students' computational thinking skills, improve teaching processes, and integrate these concepts into curricula. Analysis of the conceptual clusters revealed that terms such as *student*, *computational thinking*, *robotics*, and *learning algorithms* were central to the field. When examining the temporal evolution of keywords, *artificial intelligence* and *computational thinking* were initially prominent, while more recent periods introduced new terms such as *Scratch*, *programming*, and *machine learning*. The prominence of *computational thinking* in the findings suggests that it may serve as a strong candidate for future experimental research.

Keywords: *Robotic Coding*, *Mathematics Education, Bibliometric Analysis*, *Scopus*, *Biblioshiny.*

1. INTRODUCTION

Technological advancements have brought about a profound need for transformation in education systems. Individuals growing up in the digital age now have quick and easy access to information through technological tools—resources that would have taken much longer to acquire in traditional educational settings. As a result, conventional learning environments have become inadequate and even monotonous for contemporary learners (Günüç, 2017; Singh et al. 2025). In response, teachers are increasingly required to incorporate digital instructional materials in their classrooms to capture the attention of technologically savvy students and make learning more engaging and enjoyable (Alias & Razak, 2025; Lin et al. 2016). In the

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context of technology integration into mathematics education, it has been emphasized that even students who grow up with digital technologies may present instructional challenges for mathematics teachers (Yıldız & Mollaahmet, 2023).

Among various methods of integrating technology into education, coding applications hold a particularly significant place (Popat & Starkey, 2019). Coding can be defined as the ability to instruct computers and other digital devices to perform desired tasks using specific commands (Polyanskiy & Wu, 2025; Sırakaya, 2018). Integrating coding skills into education is highly valuable, as it enhances students' problem-solving and creative thinking abilities. A closely related concept, *robotic coding*, involves using robots as tools to make the learning process more tangible for students (Yumbul & Sulak, 2022). Both robotic coding and general coding education serve as essential tools for students seeking to learn the language of the digital world. A major advantage of coding instruction is its ability to transform learning into an active and enjoyable experience. When students use the code they write to move robots and complete specific tasks, the learning process becomes more interactive. This helps students better internalize knowledge by linking theoretical understanding with practical application (Eğitimia, 2018; Kidd, 2025). Moreover, robotic coding activities allow students to measure variables such as sound, temperature, light, distance, and humidity using sensors. These activities enhance their ability to analyze real-life phenomena and foster a scientific perspective (Güven, 2020). As a result, learners who engage with real-world applications in a hands-on manner acquire scientific knowledge in a more meaningful and concrete way (Soypak & Eskici, 2023).

As we progress further into the 21st century, developments in robotic coding and coding education have accelerated significantly. These innovations underline the necessity of coding skills for both individuals and societies striving to keep pace with the digital era. In addition to economic strength, nations that can meet the demands of the modern world emphasize the significance of coding by integrating it into their education systems (Rojas et al. 2025; Sayın & Seferoğlu, 2016). Research shows that many countries view coding education as a fundamental necessity for achieving developmental goals and have therefore incorporated it into their curricula (Hove & Pasipanodya, 2025; Levinson & Bers, 2025; Şahutoğlu, 2018). Coding education not only equips students with technical knowledge but also enables them to generate creative and innovative solutions to the problems they encounter. In doing so, it cultivates broader perspectives and promotes diverse approaches to problem-solving (Başaran et al. 2025; Karabak & Güneş, 2013). Additionally, coding supports the development of digital literacy, creativity, analytical and spatial reasoning, and problem-solving skills. It also strengthens students' process- and outcome-oriented thinking abilities, collaborative learning habits, and experiential learning practices (Akpınar & Altun, 2014; Demirer & Sak, 2016; Lee, Yunus & Lee, 2025; Xiang, Li & Yang, 2025). The skills students gain through robotic coding highlight the educational value of this method. In particular, students acquire competencies they previously lacked and advance their personal development through this training (Göksoy & Yılmaz, 2018; Uğraş et al. 2025). Furthermore, robotic coding contributes to the development of students' mathematical thinking skills and has proven to be an effective tool in mathematics instruction (Ekström, Pareto & Ljungblad, 2025; Soypak & Eskici, 2023).

In recent years, the integration of technology into mathematics education has gained increasing importance in making mathematics instruction more effective and comprehensible. This integration helps students perceive mathematics not merely as a subject consisting of formulas and equations, but as a field of knowledge embedded in everyday life and connected to real-world experiences (Tekin, 2020; Üstün & Kokoç, 2025). In this context, robotic coding applications emerge as powerful tools that assist students in making sense of mathematical concepts (Hangün & Türel, 2025; Soypak & Eskici, 2023). Robotic coding education also accelerates students' understanding of abstract concepts, thereby not only improving their academic performance in mathematics but also boosting their motivation toward the subject (Karahoca & Uzunboylu, 2011; Kasım & Deringöl, 2025). For instance, programming a robot's movements may require the application of mathematical concepts such as geometry and trigonometry, enabling students to gain a deeper understanding of these topics (Kim et al., 2021). Accordingly, robotic coding stands out as a functional approach that enriches learning environments in mathematics education (Karataş, 2021; Ojetunde & Ramnarain, 2025). In summary, robotic coding practices that contribute to mathematics education offer students more meaningful and lasting learning experiences (Brandsæter & Berge, 2025; Samsunlu Ersoy, 2024). As such, robotic coding education can be seen as a valuable pedagogical strategy not only in mathematics classes but also in broader educational contexts.

The purpose of this study is to reveal the bibliometric profile of research on robotic coding in mathematics education. In line with this main objective, the study seeks to answer the following sub-questions:

1. Which years have seen the highest number of studies in the field of robotic coding in mathematics education?
2. What are the most frequently used keywords, and how are these keywords related to the fields of robotic coding and mathematics education?
3. Are there any interdisciplinary differences among the most frequently used keywords?
4. What are the most commonly co-occurring keyword groups?
5. Which topics stand out in the conceptual clusters formed based on keyword co-occurrences?
6. How have keywords changed over the years, and what do these changes suggest about emerging research trends?
7. Based on the newly added or declining keywords, what inferences can be made about the development of the field?

2. LITERATURE REVIEW

In recent years, the growing body of research on robotic coding and its emergence as a trending topic has increased the importance of studies in this field. These studies provide valuable insights into evaluating the effectiveness of coding education, informing educational policies, optimizing learning processes, and enhancing students' digital competencies (Duman, 2024; Roy et al. 2025; Torres & Inga, 2025). However, the expanding scope of research makes it increasingly difficult to thoroughly explore this vast field. To overcome these challenges, bibliometric analysis has emerged as an effective tool for analyzing large datasets, identifying research trends, and visualizing topics to provide a broader perspective (Ellegard & Wallin, 2015; Kumar, 2025).

3. METHODOLOGY

3.1. Research Design

This study employed the bibliometric analysis method, a quantitative research approach. According to Bütüner (2022), bibliometrics is defined as a method that statistically analyzes publications within a specific field and time period, along with the interactions among these publications. Similarly, Köse and Kurutkan (2021) describe bibliometric analysis as a type of research method that examines, categorizes, and visualizes different types of scientific publications. Various bibliometric studies have utilized extensive databases such as Web of Science, Google Scholar, PubMed, Scopus, and Embase. In this study, the use of bibliometric analysis provides a systematic approach to understanding the potential impact and application areas of robotic coding in mathematics education. As such, the method offers data that can guide educational policies and practices while enabling a deeper understanding of the role of robotic coding in mathematics instruction.

3.2. Study Sample

This study employed purposive sampling. Purposive sampling allows for the in-depth examination of cases that are likely to provide rich information and ensures the inclusion of studies most aligned with the research objective (Patton, 2002, p. 238; Yıldırım & Şimşek, 2006, p. 112). Since the aim of this research is to investigate a specific group of studies in depth, the use of purposive sampling was deemed appropriate.

3.3. Data Collection Tools

The data included in this research were obtained from articles published in English between January 1, 1987, and November 1, 2024, in the Scopus database, focusing on the topic of "robotic coding in mathematics education." To further narrow the scope of the study, documents containing the keywords “coding,” “robotic coding,” and “mathematics education” were specifically targeted. This selection strategy helped establish a sample group most relevant to the research questions, thereby increasing the reliability and validity of the data. As a result of the search, a total of 131 articles were identified.

3.4 Data Collection Process

The data collection process was conducted using the bibliometric analysis method through the Scopus database. The data retrieved from Scopus were imported into *Biblioshiny*, a web-based interface built on the *bibliometrix* package in the R programming environment. Biblioshiny combines the analytical capabilities of bibliometrix with the Shiny package’s web application functionalities, serving as a comprehensive bibliometric analysis tool (Aria & Cuccurullo, 2022). The dataset was created based on the study’s inclusion criteria as follows: All relevant articles identified according to the defined criteria were selected using the “All” option. Subsequently, the “Export” button was clicked. For the export format, “BibTeX” was selected, and additional options such as “citation information,” “bibliographical information,” “abstract & keywords,” “funding details,” and “other information” were checked before completing the export process. Finally, the *bibliometrix* package was downloaded and executed within the R-Studio environment.

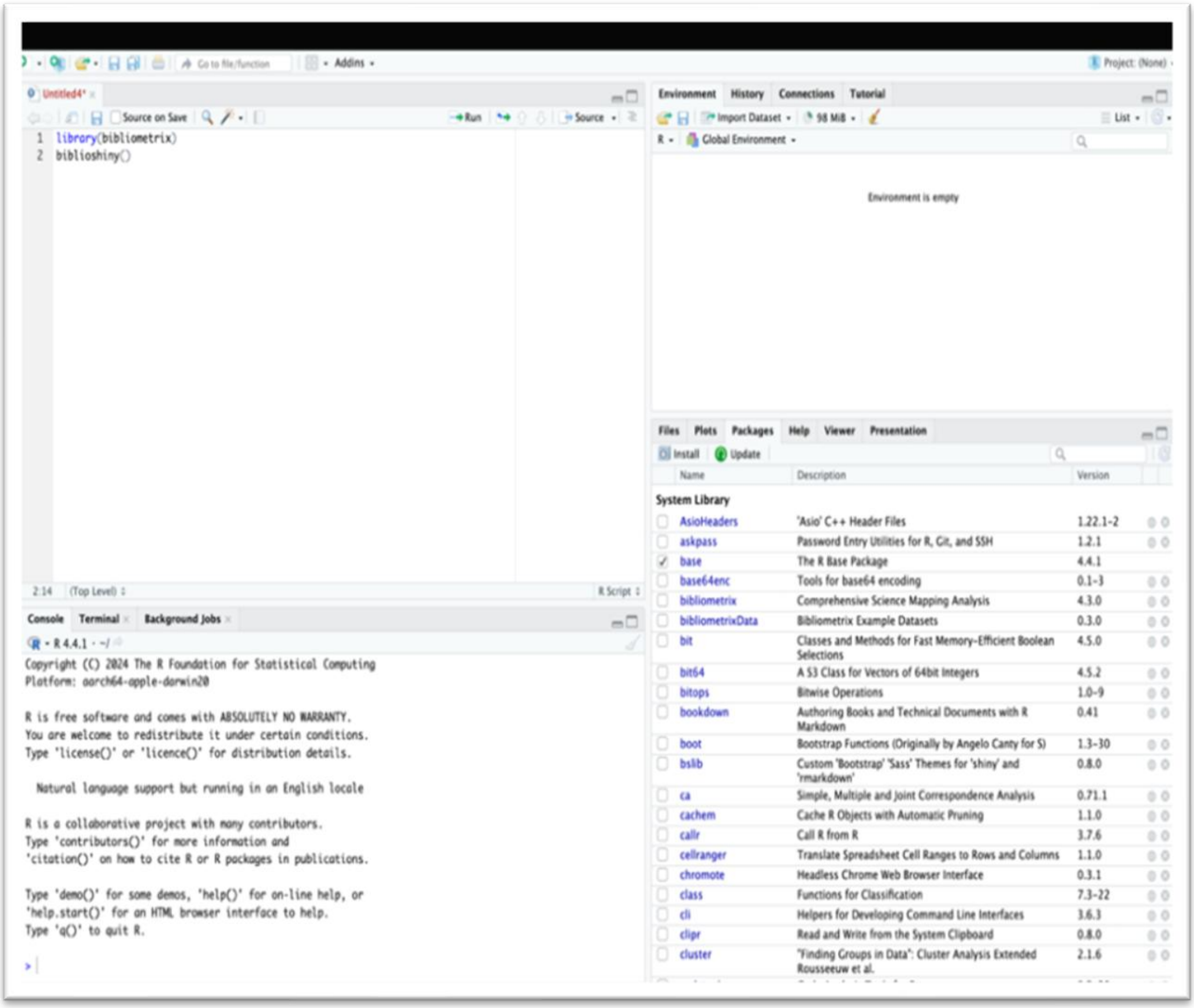

Figure 1. *Commands Required to Run the "Bibliometrix" Package in R-Studio*

The process was initiated by clicking the "Run" button, which provided access to the Biblioshiny analysis interface via R-Studio. On the interface, the previously downloaded "BibTeX" file was uploaded through the data import section, and the necessary analyses were carried out accordingly.

Initially, studies focusing specifically on the topic of "robotic coding in mathematics education" were identified. The keywords were structured to include variations such as "robotic coding in mathematics education," "robotics and mathematics education," and "educational robotics and mathematics," and were used in the querying process. To ensure the inclusion of relevant studies, publications between January 1, 1987, and November 1, 2024, were screened, and only articles published in English were considered. Each article was evaluated for its suitability for bibliometric analysis, and only original research articles were included in the final analysis. This process was conducted with great care to ensure that the data collected were aligned with the purpose of the study and met the standards of reliability. In addition, to ensure transparency and replicability of the study, the full search string used in the Scopus database was as follows: ("robotic coding" or "educational robotics" or "robot programming") and ("mathematics education" or "mathematics learning"). This search was applied to titles, abstracts, and keywords, and limited to peer-reviewed journal articles published in English. Moreover, expert opinions were sought throughout the process to assess the relevance of the studies identified through the search query to the research topic.

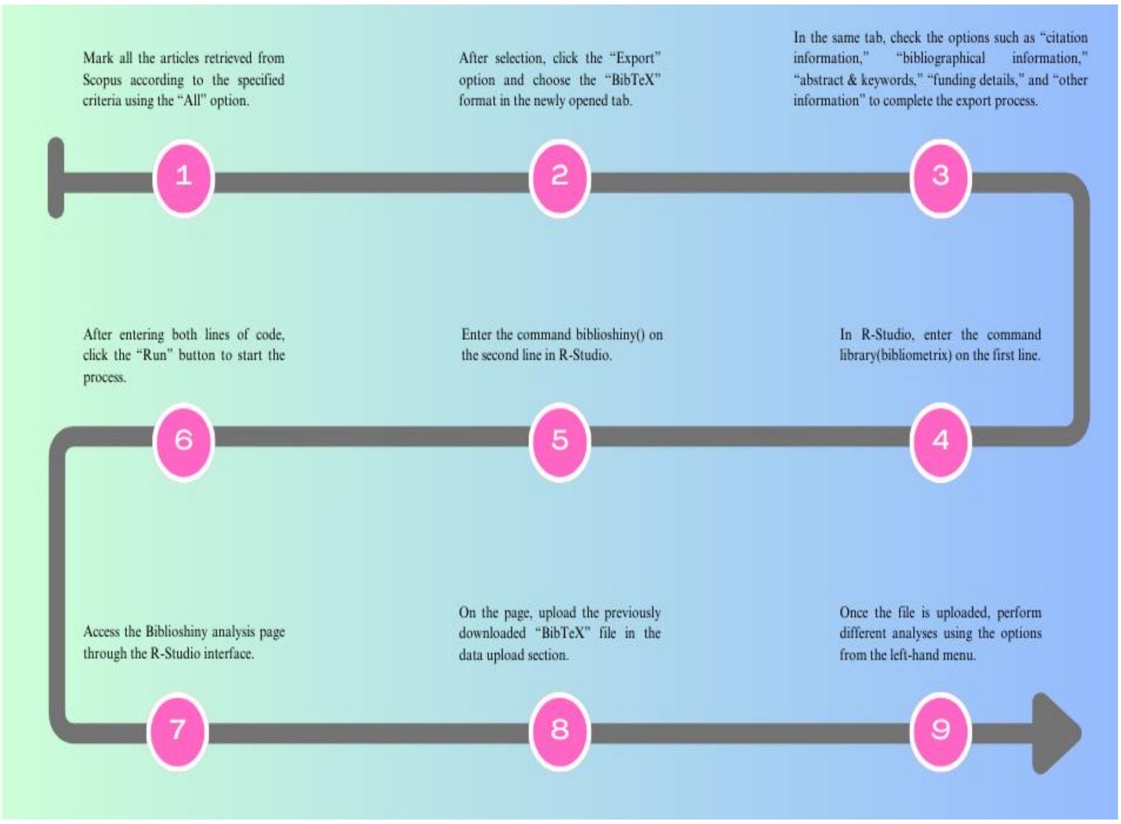

Figure 2. *The Data Transfer Process from Scopus to Biblioshiny*

3.5. Data Analysis

In this study, research on robotic coding in mathematics education was compiled from the Scopus database and analyzed using the R programming environment. The visual mapping feature of *Biblioshiny*, the graphical interface of the *bibliometrix* package, was utilized to visualize and interpret the data through various graphical outputs. The temporal distribution of the studies was examined to identify the periods with the highest research activity. Frequently used keywords were identified, and their relevance to robotic coding and mathematics education was evaluated. Additionally, the analysis explored how interdisciplinary differences were reflected in keyword usage and how the frequency of certain keywords changed over time, utilizing R's analytical capabilities. Before conducting the analysis, a comprehensive data cleaning process was performed. Keyword standardization was ensured by merging synonymous terms (e.g., "robotic coding" and "educational robotics"), correcting misspellings, and harmonizing variations in author and institution names. This step was necessary to avoid fragmentation in the data and improve the validity of the co-occurrence and clustering analyses.

Furthermore, the most frequently co-occurring keyword groups in the context of robotic coding and mathematics education were analyzed, and prominent topics within conceptual clusters based on keyword co-occurrences were identified. Changes in keywords over the years were examined to reveal emerging research trends, and the addition or decline of certain keywords was used to infer the developmental trajectory of the field. A visual representation of the study's analytical framework is presented in Figure 3.

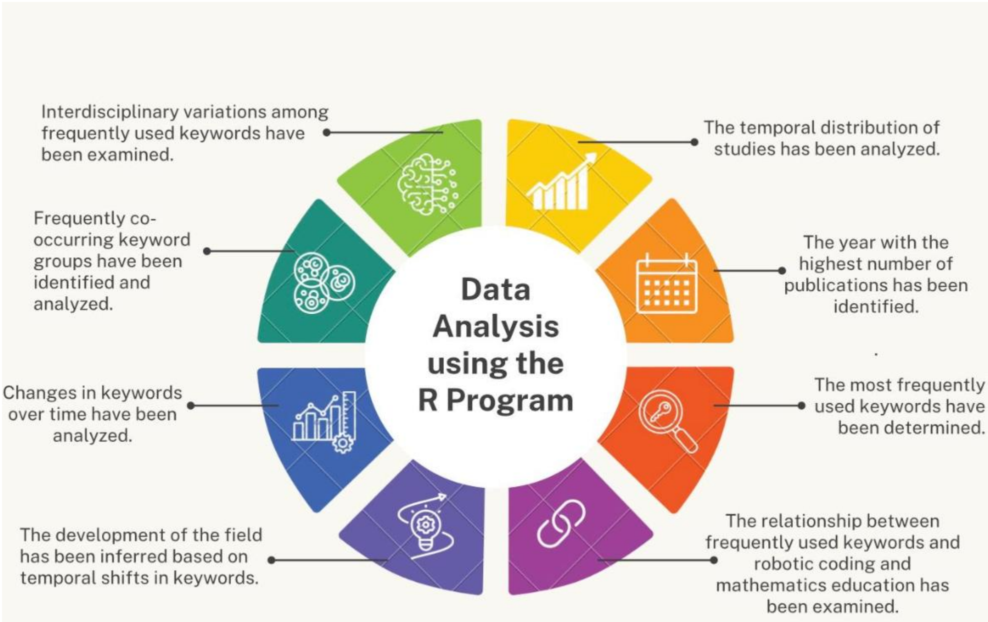

Figure 3. *Workflow Diagram of the Study*

4. FINDINGS

In this study, a total of 131 original research articles on robotic coding in mathematics education were published between 1987 and 2024. The selected articles were analyzed using the bibliometric method via the Biblioshiny interface of the R software. This section presents the findings obtained from these analyses.

4.1. Findings Regarding the Years with the Highest Research Output in the Field of Robotic Coding in Mathematics Education

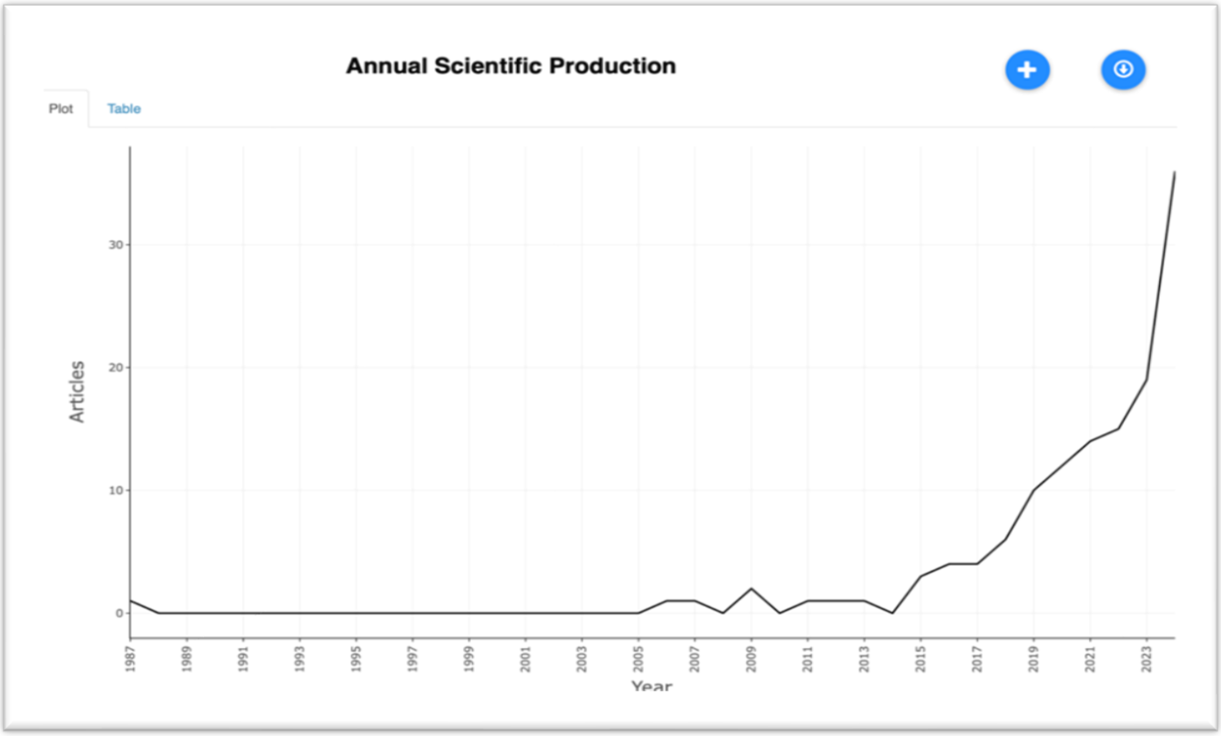

Figure 4. *Distribution of Publications by Year (Annual Scientific Output)*

As shown in Figure 4, the first study in the field was published in 1987. Between 1987 and 2005, scientific output remained relatively low and stable, with the number of articles per year staying at a minimal level. However, a noticeable increase began to emerge after 2005, with a particularly accelerated growth observed from 2015 onwards. This trend may be attributed to the broader acceptance of the interdisciplinary nature of robotic coding and mathematics education, the growing integration of technological innovations in education, and the increasing prevalence of remote and hybrid learning models. Collectively, these factors reflect the rising academic interest in the field and the impact of digitalization in education.

Following 2020, a striking surge in publication activity occurred, peaking in 2023. The intensification of research after 2020 demonstrates that robotic coding in mathematics education has attracted the attention of a growing number of researchers, leading to significant progress in the field. The overall structure of the graph clearly illustrates the evolution of the field over time and the expanding scientific interest surrounding it. The low level of publication activity during earlier periods can likely be attributed to the novelty of the field or its limited audience at the time. In contrast, the subsequent growth can be explained by both technological advancements and the increasing engagement of the academic community. As such, this graph serves as a valuable tool for understanding the dynamics of scientific output in this area and analyzing the driving forces behind its growth (Rojas et al., 2025).

4.2. Findings on the Most Frequently Used Keywords and Their Relationship to Robotic Coding and Mathematics Education

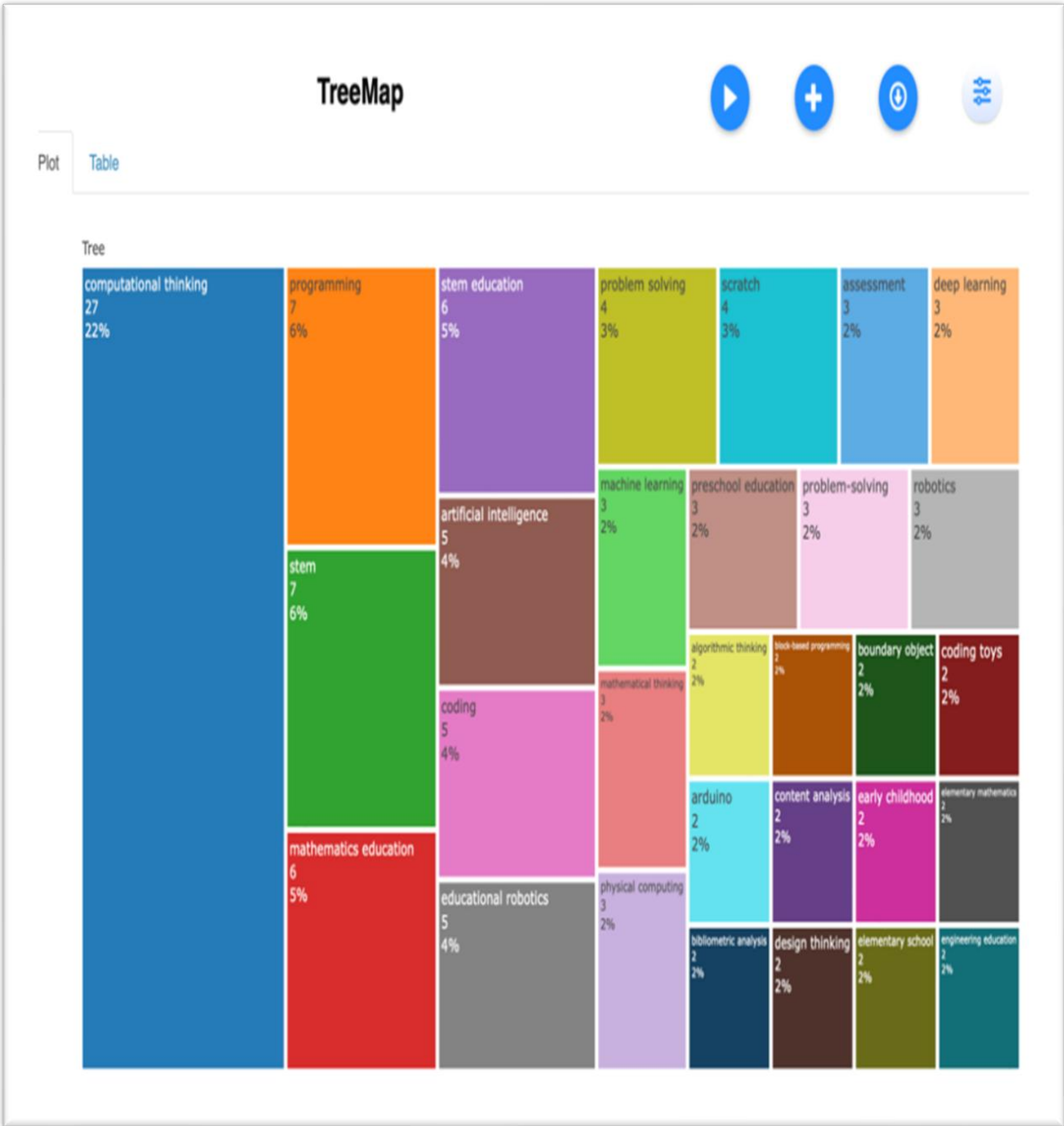

Figure 5. *Treemap of Keywords Used by Authors*

Table 1. *Keywords and Their Percentage Frequencies*

Keyword	Percentage
Computational Thinking	22%
Programming	6%
STEM	6%
STEM Education	5%
Mathematics Education	5%
Artificial Intelligence	4%
Coding	4%
Educational Robotics	4%
Problem Solving	3%
Deep Learning	2%
Machine Learning	2%

The analysis of the keywords presented in the treemap reveals the primary trends and research directions within the scientific literature on mathematics education and robotic coding. In this context, the term “computational thinking” (22%) emerges as a core concept in modern educational approaches, particularly in fostering digital skills and algorithmic thinking competencies (Wu et al., 2025). Wing (2006) defines computational thinking as a set of thought processes involved in expressing problems in a form that a human or a machine can effectively process and solve. Moreover, computational thinking enables the adoption of innovative approaches in education.

Alongside this, terms such as “programming” (6%) and “STEM” (6%) reflect the foundational elements of robotic coding and mathematics education, while also indicating a growing emphasis on interdisciplinary learning. “STEM education” (5%) and “mathematics education” (5%) highlight the increasing interest in enhancing educational processes through the integration of mathematical thinking with Science, Technology, Engineering, and Mathematics (STEM)-oriented frameworks.

Additionally, keywords like “artificial intelligence” (4%), “coding” (4%), and “educational robotics” (4%) underscore the interaction between technology and education. Other terms such as “problem solving” (3%) and “Scratch” (3%) draw attention to the importance of educational tools that promote creative thinking and active learning strategies. Finally, keywords like “deep learning” and “machine learning” (2%) signal the growing influence of these advanced concepts in the development of robotic coding and mathematics education.

In conclusion, this analysis reveals that concepts such as *computational thinking*, *STEM-oriented approaches*, and the *integration of advanced technologies* stand out as dominant research areas in studies on robotic coding and mathematics education. These themes clearly demonstrate the transformative impact of such innovations in educational contexts.

4.3. Findings on Interdisciplinary Differences among the Most Frequently Used Keywords

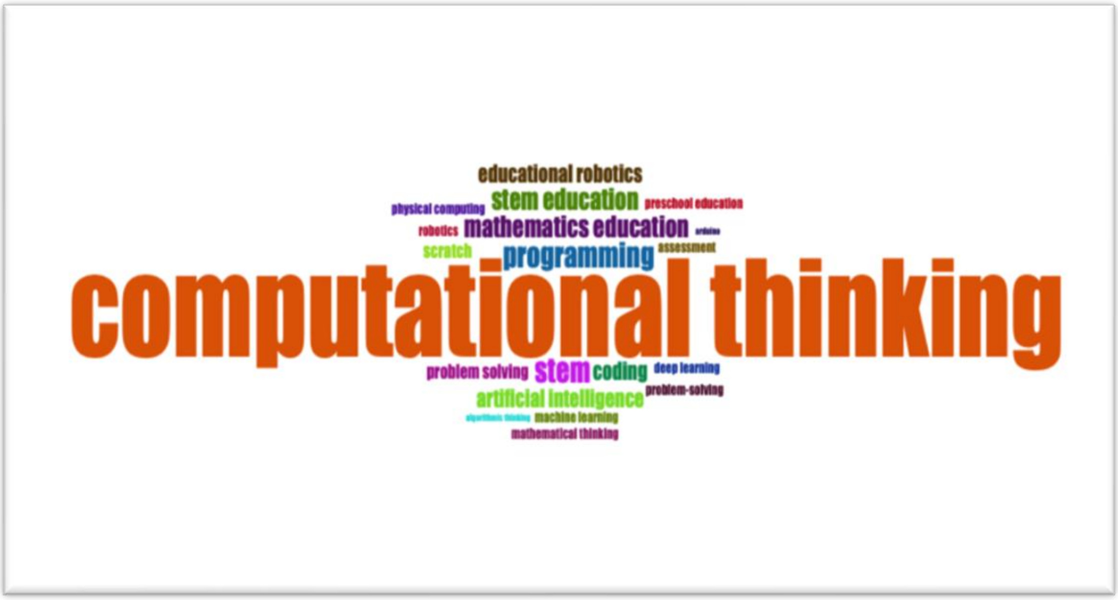

Figure 6. *Word Cloud based on Authors' Keywords*

The interdisciplinary nature of the keywords is clearly evident. The most prominent terms in the graphic represent the intersection of various academic fields such as education, engineering, and technology. These terms offer valuable insights into how interdisciplinary interaction is shaping research in robotic coding and STEM (Science, Technology, Engineering, and Mathematics) education.

The standout keyword "computational thinking" appears as a critical concept across education, computer science, and engineering, emphasizing the necessity of integrating mathematical and technical modes of thinking. Similarly, keywords such as "programming" and "STEM" indicate the dominance of engineering and technology-driven research within the field.

These findings reinforce the idea that robotic applications in education are not only promoting interdisciplinary approaches but are also enhancing learning by combining them with mathematical competencies. On the other hand, keywords like "mathematics education" and "educational robotics" point to a trend of developing innovative methods that emerge from the fusion of these two fields.

Furthermore, terms such as "artificial intelligence" and "machine learning" broaden the scope of engineering and technology research, shedding light on the potential applications of AI and engineering solutions in educational settings.

In conclusion, this interdisciplinary interaction among keywords illustrates how the boundaries between education, engineering, and technology are becoming increasingly interconnected. It also shows that research in these domains is adopting a more holistic, multi-disciplinary approach.

4.4. Findings on the Most Frequently Co-Occurring Keyword Groups in Robotic Coding and Mathematics Education

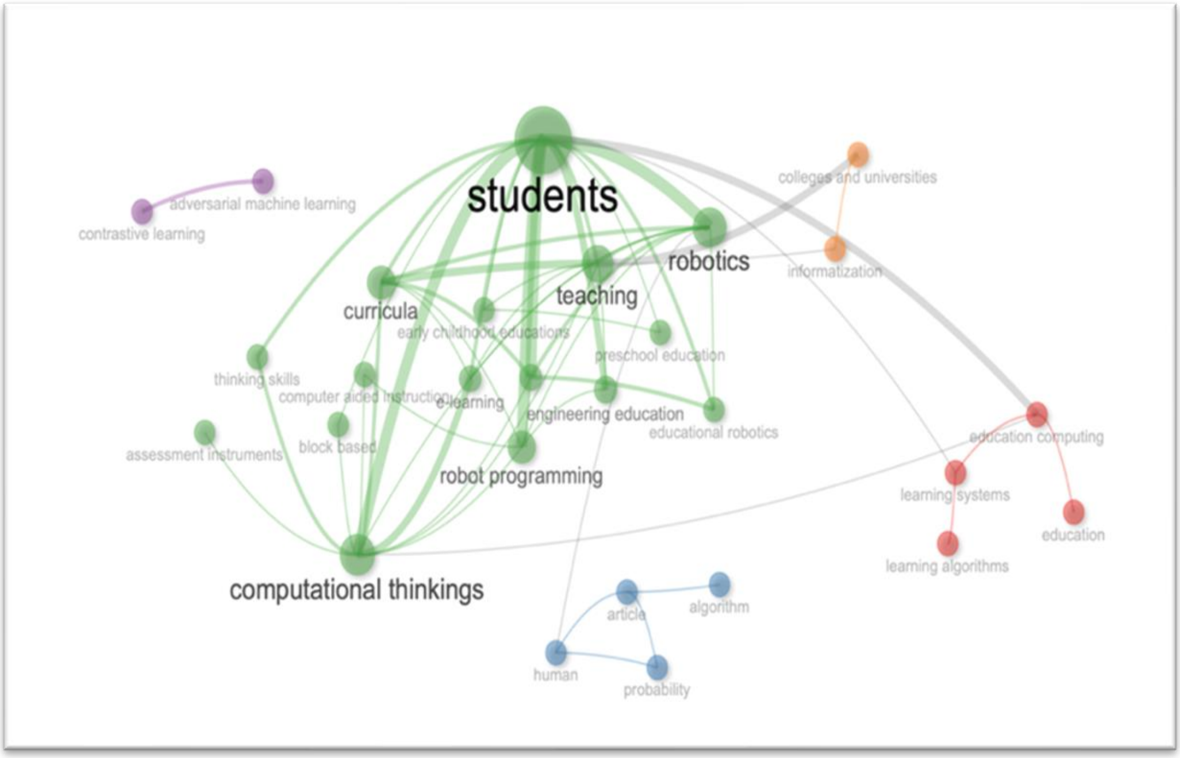

Figure 7. *Co-Occurrence Network*

An examination of the co-occurrence network reveals the most frequently used keyword groups within the context of *robotic coding* and *mathematics education*. At the center of the network lies the cluster "students", which emerges as a core concept and demonstrates strong connections with other terms. This suggests that studies in this field predominantly focus on the educational experiences of students.

The clusters "computational thinking" and "teaching" also exhibit strong ties to students, indicating that the development of computational thinking skills and the design of effective teaching strategies are central themes in robotic coding and mathematics education research.

The network also shows a close relationship between "robotics" and "curricula", highlighting the importance of integrating robotics applications into educational programs, particularly in mathematics. Additionally, the presence of terms such as "early childhood education" and "engineering education" in connection with students suggests that robotic coding is relevant across a wide range of age groups, not limited to any specific educational level.

In summary, studies in the field of robotic coding and mathematics education are largely shaped around efforts to enhance students' computational thinking skills, improve teaching processes, and integrate these concepts into curricula. The relationships among keywords emphasize the interdisciplinary nature of the field and its broad range of applications.

4.5. Findings on Prominent Topics in Conceptual Clusters Formed by Keyword Co-Occurrences

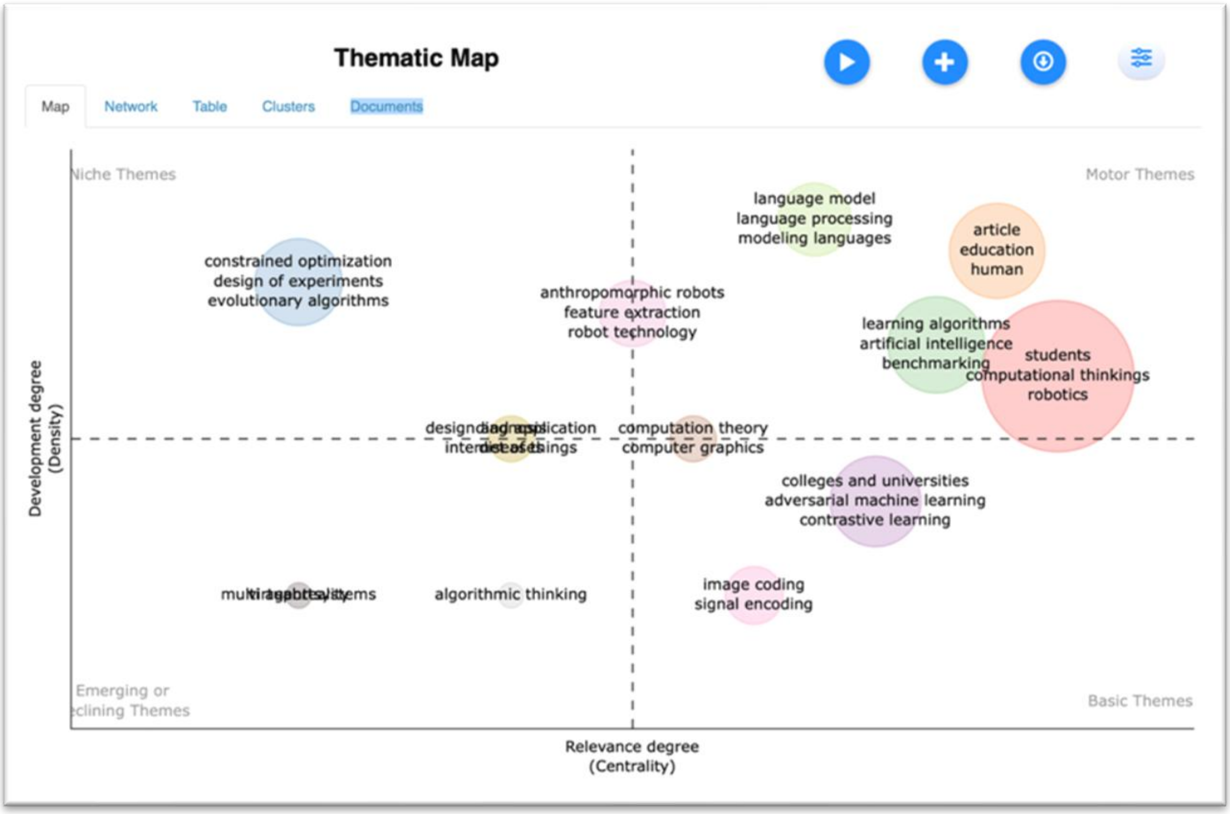

Figure 8. *Thematic Map*

The thematic map analyzes the relationships among keywords and classifies the prominent conceptual clusters in the field of robotic coding and mathematics education into four main categories:

- Motor themes represent the core and most extensively studied topics in the field. This group includes concepts such as "students," "computational thinking," "robotics," and "learning algorithms." These themes reflect the dominant trend of developing students' computational thinking skills and integrating robotic technologies into educational practices.

- Niche themes refer to more specialized topics that, while less commonly addressed, are explored in depth. Examples include "constrained optimization" and "evolutionary algorithms," which indicate a research focus on technical and theoretical aspects, particularly algorithmic solutions.

- Basic themes encompass broad but superficially explored areas. Terms such as “colleges and universities,” “adversarial machine learning,” and “contrastive learning” suggest more general research directions that may require deeper investigation in future studies.

- Emerging or declining themes include topics that are either gaining or losing scholarly attention. For instance, “algorithmic thinking” and “multi-agent systems” are not yet central to the field but may offer valuable opportunities for future research.

4.6. Findings on the Changes in Keywords Over the Years and the Emerging Research Trends Reflected by These Changes

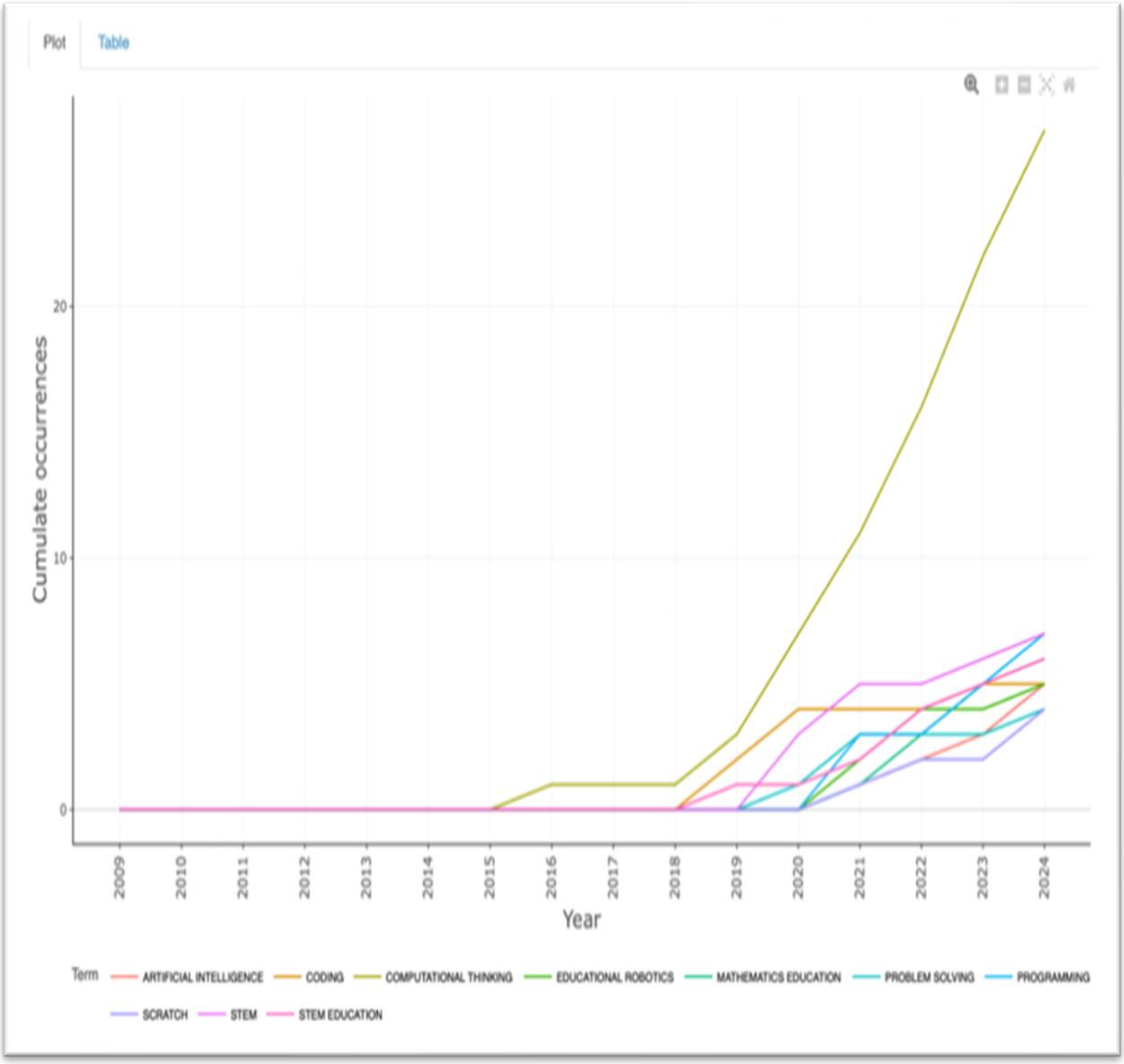

Figure 9. *Trend Graph of Keywords by Year*

An analysis of the graph in Figure 9, which illustrates changes in the most frequently used keywords over the years, reveals a clear upward trend. In particular, the concepts “STEM” and “STEM education” began to attract attention around 2018 and experienced a rapid increase after 2020. Similarly, the keyword “artificial intelligence” started to appear in the literature in

2018 and has shown a sharp rise since 2020, becoming one of the most prominent terms in the field.

In addition, keywords such as "coding," "programming," "problem solving," and "educational robotics" started appearing in publications from 2019 onwards and have shown a more gradual but steady increase over time. The term "computational thinking", which began to draw attention in 2015, exhibited a significant and accelerating increase starting in 2018.

Meanwhile, "mathematics education" and "Scratch", both of which are highly relevant to the context of mathematics education, began to rise in usage from 2020 onward; however, their growth has been more modest compared to the other keywords.

Overall, starting from 2018, there has been a notable increase in the visibility of technology- and education-oriented keywords in the literature, with this trend gaining momentum particularly after 2020. This reflects the growing importance of technological innovation and its integration into educational contexts.

4.7. Findings on the Development of the Field Based on Newly Emerging or Declining Keywords

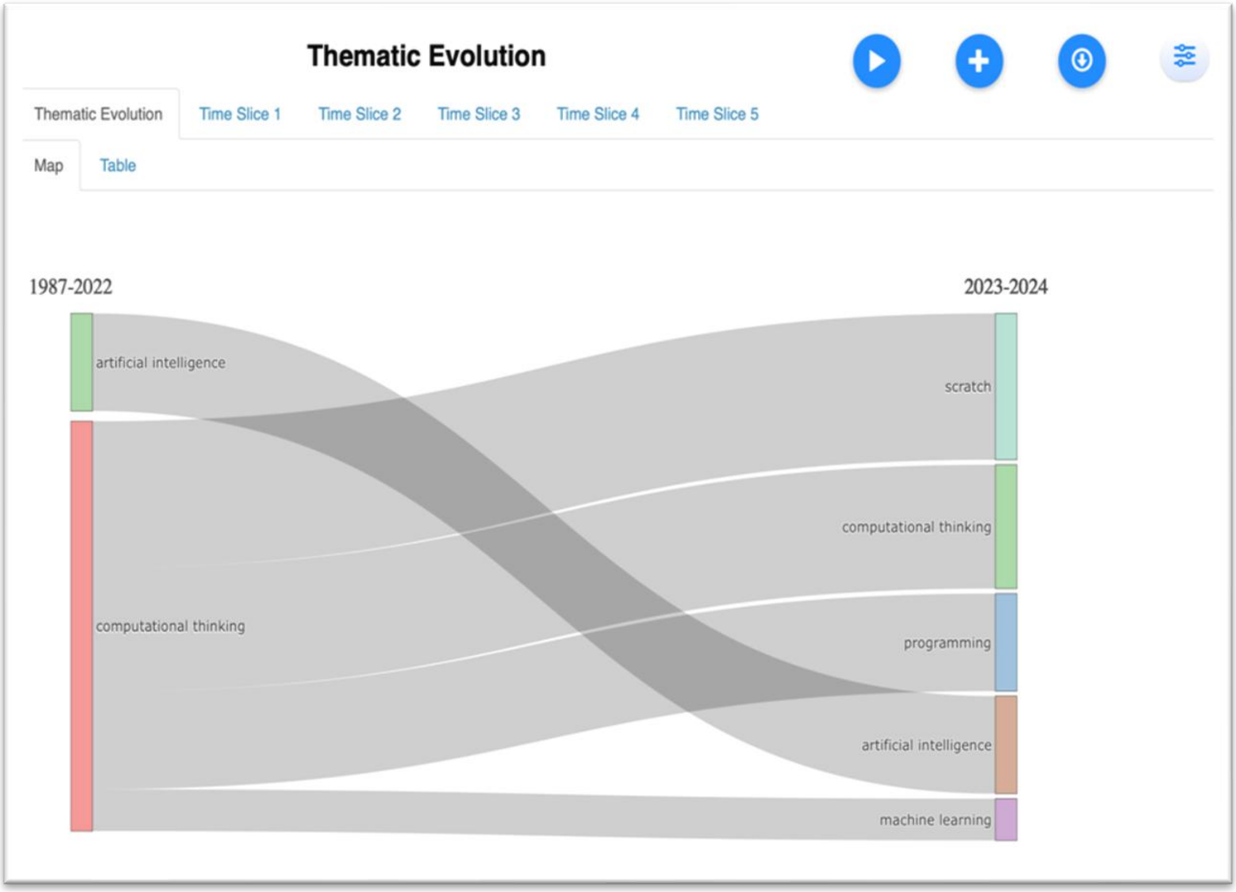

Figure 10. *Thematic Evolution Map*

The thematic evolution map offers a comprehensive visualization of the field's development and conceptual transformation over time. A comparison between the periods 1987–2022 and 2023–2024 reveals a significant shift in the core concepts of the domain. In the earlier period, keywords such as “artificial intelligence” and “computational thinking” stood out, reflecting a focus on understanding computational methods and the integration of intelligent systems.

However, in the more recent period, new keywords such as “Scratch,” “programming,” and “machine learning” have emerged alongside these earlier themes, indicating a shift in the field’s focal points.

The rise of “Scratch” highlights growing interest in educational technologies and tools that facilitate programming skills, particularly at the preschool through high school levels. Similarly, the increasing prominence of “machine learning” suggests a growing orientation toward data-driven techniques and the expansion of artificial intelligence research in educational contexts.

The continued presence of “computational thinking” demonstrates its role as a foundational concept in the field—acting as a bridge between earlier research paradigms and new areas of development. In this regard, the newly introduced keywords offer important insights into how the field is expanding across educational, technological, and theoretical dimensions. Meanwhile, the fading or replacement of older themes signifies a transition from traditional approaches to more contemporary and dynamic methods.

5. RESULTS AND DISCUSSION

The aim of this study is to reveal the bibliometric profile of studies on robotic coding in mathematics education and to provide guidance for future research. For this purpose, 131 English-language articles addressing the topic of “robotic coding in mathematics education” were analyzed using bibliometric analysis based on data obtained from the Scopus database.
When evaluating the years in which the most research was conducted in the field of robotic coding in mathematics education, it was observed that the first study was published in 1987, with no additional studies appearing between 1987 and 2005. The first study identified in 1987 examined how programmable robots, such as LOGO-based turtle robots, could be used to develop mathematical reasoning and problem-solving skills in early childhood education. The study emphasized hands-on learning and enabled students to physically manipulate the robots to explore geometric concepts and logical sequences. This approach not only facilitated the integration of technological tools into mathematics classrooms but also laid a theoretical foundation for incorporating coding and robotics into education. The research made significant contributions to the field by demonstrating that robotics applications can enhance conceptual understanding, student engagement, and creativity in mathematics education. Including this historical context provides a deeper understanding of how the field has evolved and reveals the foundations of current approaches to robotics-based learning environments (Bers et al. 2014; Papert, 1980).

A noticeable increase in publications began after 2005, with a particularly rapid rise from 2015 onwards. After 2020, a striking acceleration occurred, and by 2023, the number of articles reached its peak. Supporting this, a study noted that educational research related to coding has continued to grow and maintained its importance particularly after 2019 (Duman, 2024). These findings can be linked to the acceleration of technological advancements and the increasing integration of coding into education.

An analysis of the most frequently used keywords revealed that the concept of "computational thinking" was the most commonly used term, appearing in 22% of the studies. Similarly, another study indicated that "computational thinking" was a prominent concept particularly in the fields of computer and educational sciences (Özçınar, 2017). This analysis demonstrates that concepts such as computational thinking in education, STEM-focused approaches, and the integration of advanced technologies are dominant research areas in studies on robotic coding in mathematics education, and it clearly highlights their positive influence on educational development.

A closer look at interdisciplinary differences among keywords shows a clear diversity, indicating that the intersections of education, engineering, and technology have become increasingly distinct. This suggests that studies in these domains tend to adopt a more complementary and multidisciplinary approach. Yıldırım and Altun (2015) also emphasize the growing need for individuals who are productive, inquisitive, thoughtful, and creative, and underline the increasing significance of mathematics, science, technology, and engineering disciplines.

When analyzing frequently co-occurring keyword clusters in robotic coding and mathematics education, it is evident that the studies revolve around enhancing students' computational thinking skills, organizing and improving instructional processes, and integrating these concepts into curricula. These keyword associations underscore the interdisciplinary and broad application potential of the field. The literature supports the view that integrating robotic coding into mathematics education enhances students' problem-solving and computational thinking abilities and that effectively incorporating these processes into curricula can improve instructional quality (Tekin & Keser, 2020).

Analysis of conceptual clusters formed by keyword co-occurrence revealed that terms such as "students," "computational thinking," "robotics," and "learning algorithms" are central and most frequently used in the field. Concepts like "constrained optimization" and "evolutionary algorithms" were less frequent but involved in in-depth studies. In contrast, terms such as "colleges and universities," "adversarial machine learning," and "contrastive learning" appeared in broader yet more superficial discussions. Emerging concepts that are not yet prominent but have the potential to become important research areas in the future include "algorithmic thinking" and "multi-agent systems. Examining the changes in keywords over the years and how these reflect new research trends reveals that technology- and education-oriented keywords have become more visible in the literature since 2018, with a sharp increase especially after 2020. This underscores the growing importance of technological innovations and their integration into education. In his book, Selwyn (2016) discusses how the inclusion of technology in education enhances and transforms the learning process (Akgün-Özbek, 2016:178; Soysal & Radmard, 2017).

An analysis of the development of the field through emerging and declining keywords shows a significant shift in core concepts from the 1987–2022 period to the 2023–2024 period. While "artificial intelligence" and "computational thinking" were among the most prominent keywords in the earlier period, newer terms such as "Scratch," "programming," and "machine learning" have emerged more recently, indicating new focal points in the field.
Based on these findings, the following recommendations are offered:

- A meta-analysis study on this topic may be conducted.
- A focused analysis of studies published in Turkish can be carried out.
- The concept of "computational thinking," which emerged prominently in this study, can be investigated through experimental research.
- Given the increasing prominence of the "Scratch" concept in recent years, its bibliometric profile can be explored in detail.

6. CONFLICTS OF INTEREST

The authors declare no competing interests.

7. FUNDING

The authors did not receive any financial support.

8. ABOUT THE AUTHORS

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