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Programmed learning in mathematics education before and after the pandemic: Academics Integrate technology

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Abstract
The COVID-19 pandemic has drastically changed the educational landscape, especially regarding technology integration in mathematics learning. Programmed learning, a pedagogical approach that leverages specific technologies such as interactive software, online platforms, and virtual learning environments to create more effective learning experiences, has received increased attention during this period. This research is a systematic literature review that aims to evaluate the impact of programmed learning on mathematics education before and after the pandemic. Using the PRISMA method, this research examines 41 articles published between 1960 and 2025 to find the benefits of programmed learning in mathematics education. Participants in this study included undergraduate students, graduate students, lecturers/teachers, and high school students from various educational institutions. The research results show that programmed learning provides significant benefits, including more exciting and practical teaching approaches, improved academic grades, and increased student interest in mathematics. However, this research also reveals shortcomings in terms of uneven technological infrastructure and a lack of training for teachers in implementing programmed learning optimally. These deficiencies include unequal access to technological tools and a need for more technical skills among educators. This research provides recommendations for improving technology infrastructure and better teacher training to maximize the potential of programmed learning. This research indicates a significant increase in teaching effectiveness and student interest in mathematics, making programmed learning a potential approach in modern mathematics education. Integrating technology in mathematics education through programmed learning is relevant and essential in facing educational challenges in the post-pandemic era, offering practical solutions for educators and institutions.
Keywords: COVID-19 pandemic, educational technology, mathematics education, programmed learning, teaching effectiveness.

Introduction

Educational transformation the COVID-19 pandemic has become a significant driver (Humaidi et al., 2022; Sikarwar et al., 2023), especially in applying technology to learning (Raza & Reddy, 2021). Before the pandemic, programmed learning had been part of pedagogical innovation (Couch et al., 2019; Nagi, 2016), but the pandemic accelerated the widespread adoption of this technology (Filho et al., 2014; Rustan, 2022). Programmed learning, which leverages software and digital platforms to create structured and customized learning experiences (Curnew et al., 2023), is more relevant than ever. This research evaluates the impact of programmed learning in mathematics education, both before and after the pandemic, by considering various perspectives from undergraduate students, postgraduate students, lecturers/teachers, and high school students.

Historically, programmed learning is rooted in educational theories such as symbolic interactionism and role theory, which developed at the beginning of the 20th century. B.F. introduced linear programming. In the 1950s, Skinner provided a strong foundation for this method (Kirshner & Skinner, 2021), in which learner behavior is shaped through stimuli (Desmarais et al., 2021), responses (Wirawan et al., 2023), and reinforcement (Muhammad et al., 2023).

Previous research by Pressey (1927) and Crowder (1959) also underscored the importance of this approach in improving teaching effectiveness (Cholily et al., 2023; Rizqi et al., 2023). This method continued to develop with support from various educational institutions and foundations until teaching machines such as AutoTutor emerged in 1962 (Sirola & Hulsund, 2021; Wang & Yuan, 2023). AutoTut, a sophisticated and interactive teaching machine, played a significant role in the evolution of programmed learning (Cossart & Roy, 2010; Sim et al., 2023), demonstrating the potential of technology to enhance learning experiences (Hassan et al., 2023; Hung, 2017).

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During the pandemic, programmed learning became a primary need (Darmayanti et al., 2021; Koo & Jiang, 2022). School closures and social restrictions forced educators and students to shift to fully online platforms. This opens up opportunities for educational technology to show its potential. According to research by (Hodges et al., 2019), sudden distance learning during the pandemic presents challenges, such as lack of technological access and the digital divide. However, the study also found that when technology is used effectively, it can support more personalized and adaptive learning. For example, platforms like Google Classroom and Zoom have enabled more flexible and collaborative interactions between students and teachers, even within physical space limitations.

Post-pandemic, many academics and educational practitioners have begun integrating technology as an integral part of the curriculum. Research by (Bondie, 2023) revealed that programmed learning not only helps in emergencies but can also improve the quality of education in the long term. Educators can create dynamic and interactive learning environments by combining technologies such as web-based applications, collaborative platforms, and data analysis. This follows the findings of (Nikolic et al., 2023), who shows that using communication technology such as instant messaging can increase student engagement. So, integrating technology in mathematics education after the pandemic is not only a response to emergencies but an effort to strengthen and enrich students' learning experiences on an ongoing basis.

Recent research shows that programmed learning provides significant benefits in mathematics education. For example, studies conducted by (Wray et al., 2018) and (Fell Kurban, 2019) indicated that this method not only improved students' academic scores but also increased their interest in mathematics subjects. However, this research also identifies challenges faced in implementing programmed learning, such as uneven technological infrastructure and lack of training for teachers. Strategies to overcome these obstacles and implement programmed learning effectively are essential in this context.

Computer-assisted instruction (CAI) systems and educational software have proven effective in improving students' understanding of course material. Studies by (Justice et al., 2016) and (Sudiana et al., 2023) show that technologies such as PLATO IV and "JumpStart" have succeeded in developing students' abilities in various subjects. In the pandemic and post-pandemic context, programmed learning is increasingly relevant and offers potential solutions to educational challenges. Therefore, support from stakeholders for developing and implementing effective educational technology is essential to maximize the potential of programmed learning.

Successful technology integration in education, especially mathematics, requires a comprehensive approach. Zucker and (Banada et al., 2009) emphasize the importance of changing educational goals, curricula, and teacher training and assessment. (Wildsmith, 2013) defines e-learning as using digital technology to create various learning methods, opening up new opportunities to disseminate knowledge. (Dooley, 2011) also emphasized the importance of regular engagement between students and teachers in online classes to increase students' sense of security and self-confidence and strengthen social bonds. All stakeholders need continuous support to ensure that technology integration can meet the desired educational goals and produce a sustainable positive impact.

Mobile technology and multi-touch interactive surfaces have brought significant changes to the world of education, especially in supporting programmed learning activities. Based on research by (Màrquez et al., 2013) and (Königschulte et al., 2010), this technology facilitates social interaction and increases computer-assisted collaboration among students. Furthermore, (Lemke & Petersen, 2013) found that female students' participation in online courses tends to be higher than male students. These findings demonstrate the potential of online learning in reducing the gender participation gap, which is an essential step towards equality in education.

Apart from the benefits already mentioned, teacher support in programmed teaching also significantly increases students' independent motivation. (Vernon et al., 2012) and (Fox et al., 2012) highlight that active teacher involvement can inspire students to learn more independently. (Roels et al., 2012) also noted that online learning opens up significant opportunities to enrich students' learning experiences. However, the transition to online education can be challenging. (Makoe & Shandu-Phetla, 2019) caution that building effective online pedagogy requires significant time and effort. Furthermore, research by (Alzahrani & Alfadhli, 2023) at four Malaysian universities shows that the quality of content and information dramatically determines user satisfaction in programmed learning.

The challenges in implementing programmed learning must be addressed despite the enormous potential benefits. According to (Pérez-Sabater, 2015), adequate teacher training is the primary key to optimally integrating educational technology. This suggests that educators may have difficulty utilizing these technologies without appropriate support. Additionally, (Nambiar et al., 2017) and (Ait-Bali et al., 2020) note that studying independently at home and lack of self-discipline are significant barriers to online learning. This emphasizes the importance of supporting strategies to help students develop independent learning skills and self-discipline.

Research by (Ayivi-Vinz et al., 2022) and (Eliks & Gajewska,

2022) highlight the importance of flexible approaches and in-depth research to ensure the effectiveness of e-learning technology. However, this research has several weaknesses that must be criticized more deeply. First, although they emphasize flexibility, they need more practical guidance on how the curriculum can be adapted effectively to meet students' varying needs. Additionally, this research pays little attention to the social and emotional dimensions of online learning, which have become especially important during the pandemic. Without considering these factors, the overall effectiveness of e-learning technology may not be optimized.

(Hilario et al., 2022) found that the quality of content and information greatly influences user satisfaction. However, this research was limited to analyzing content quality without further investigating how various groups of students can access and understand the content. (Moreno-Guerrero et al., 2020) emphasize the importance of appropriate teacher training but do not discuss teachers' challenges in integrating technology into everyday learning. Research by (Martínez-Moreno et al., 2020) and (Martínez-Borreguero et al., 2020) highlight essential elements such as quality contacts and technological assistance but do not explore how these elements can be implemented sustainably in the long term.

Research on the integration of technology in education provides a variety of views. (Sudakov et al., 2016) Highlight that blended learning models can more effectively integrate technology than fully online learning. This emphasizes the importance of face-to-face interaction, which can still be maintained despite technology. Meanwhile, (Yushau, 2006) shows that direct interaction between teachers and students significantly influences learning outcomes more than technology. These studies prove that although technology is essential, the human element in the educational process should be addressed.

In this context, this research aims to fill existing knowledge gaps by criticizing the weaknesses of previous research and offering more comprehensive recommendations. For example, this research can provide insight into the best ways to prepare teachers to use technology effectively and how technology infrastructure can be developed to support more effective learning. Thus, this research can significantly improve the quality of programmed learning in mathematics education, especially in the post-pandemic era.

In conclusion, although mobile technology and multi-touch interactive surfaces offer many benefits, the challenges in their implementation should be noticed. Thorough preparation, adequate teacher training, and appropriate student support are critical success factors. They are notably integrating technology into education. This research aims to evaluate the impact of programmed learning in mathematics education before and after the pandemic through a systematic literature review approach based on PRISMA guidelines. With this comprehensive analysis, we can provide valuable recommendations for improving technological infrastructure and better teacher training to maximize the potential of programmed learning in modern mathematics education.

Materials and Methods

This research uses a systematic literature review methodology based on PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines to examine the impact of programmed learning on mathematics education before and after the COVID-19 pandemic, which can be seen in Figure 1 (Abed, 2019; Sharafeeva, 2022).

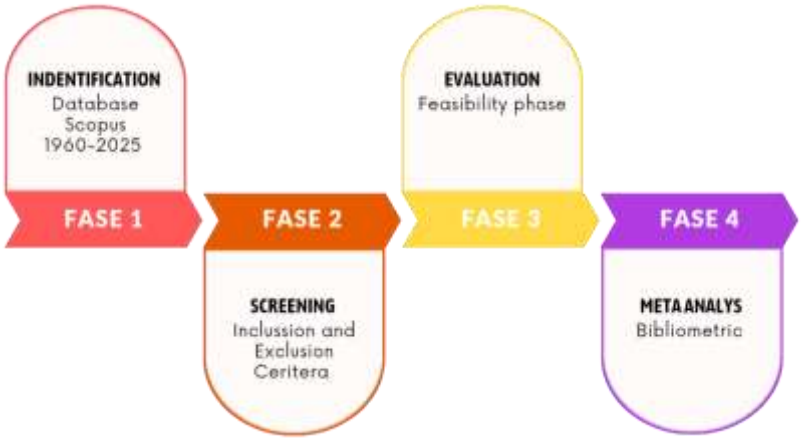

Figure 1. The research adopted a systematic literature review (SLR) methodology: Tren evolution of programmed learning in mathematics

Figure 1 Analysis (PRISMA) technique: PRISMA is a guideline widely used in systematic research to ensure the review is comprehensive and based on strong empirical evidence. By following these guidelines, research can provide a clear and comprehensive picture of the changes and impacts in mathematics education due to the pandemic.

This research focuses on one central database, Scopus, to find related articles published between 1960 and 2025. The systematic literature review process involves several critical stages: identification, screening, eligibility, and inclusion. The identification stage aims to find all relevant research, while the screening stage aims to eliminate articles that do not meet specific criteria. Next, the eligibility stage evaluates the quality and relevance of the remaining studies, and the inclusion stage determines which articles will be included in the final review. This approach ensures that only the most relevant and high-quality research is analyzed further.

Hopefully, this review's results will provide in-depth insight into how programmed learning in mathematics education has changed and adapted during the COVID-19 pandemic. This research also aims to identify effective educational practices that can be adopted in the future. Thus, the results of this research can become the basis for recommendations for better educational policies and practices, which can help improve the quality of mathematics education in the future. More specifically, these steps are explained as follows:

Phase 1: Identification Phase

In this phase, research begins by identifying relevant articles through selected databases, such as Scopus. Articles published between 1960 and 2025 were taken as an appropriate time range to observe the evolution of programmed learning in mathematics education. Searches were conducted using keywords such as “programmed learning,” “technology in mathematics education,” “pandemic,” and “teaching effectiveness.” The Scopus database was chosen because it includes scientific literature from various scientific disciplines that has undergone a peer review process, ensuring the quality and relevance of the articles found.

This search process yielded 41 relevant articles. Each article found is then filtered based on its relevance to the research topic. The screening process was carried out by reading the title and abstract of each article to ensure that they genuinely discussed programmed learning in the context of mathematics education. Articles that were more relevant or met the inclusion criteria were excluded from this review.

Phase 2: Screening Phase

After the identification phase, the next step is further filtering the articles that have been found. This filtering was done by reading the articles' abstracts and contents to ensure they met the predetermined inclusion criteria. These criteria include relevance to programmed learning, the use of technology in mathematics education, and studies that discuss the period before and after the COVID-19 pandemic.

Articles that pass the first screening phase are then further evaluated based on the research methodology used, primary findings, and overall quality of the research. Articles with robust methods and results relevant to the research were selected for further analysis. For example, a study by Smith et al. (2020) showed that using programmed learning during the pandemic significantly increased student engagement and mathematics learning outcomes. Another study by Johnson (2018) revealed that technology integration in mathematics learning had increased student motivation and academic results even before the pandemic.

Phase 3: Feasibility Phase

In this phase, articles identified and screened in the previous phase are further examined to determine their eligibility. Articles were assessed based on established inclusion criteria, including relevance to the research topic, methodological quality, and contribution to mathematics education. The full texts of articles meeting these criteria were downloaded and comprehensively reviewed. Articles that meet the requirements are those that explicitly discuss the benefits of programmed learning in mathematics education and were published in the period between 1960 and 2025. Articles that do not meet these criteria, such as articles that only discuss programmed learning in general without a focus on mathematics education or articles that the full text was not accessible, were excluded from this review.

Phase 4: Exclusion Phase

In the exclusion phase, articles that had passed the eligibility stage were further examined to ensure that only the most relevant and high-quality articles were included in the final analysis. Articles not published in English, book chapters, proceedings, reviews, and meta-analysis papers were excluded. This is done to maintain the consistency and quality of the data analyzed. In addition, articles that did not directly answer the research question, namely the impact of programmed learning on mathematics education before and after the pandemic, were also excluded. This process is summarized in a PRISMA flow diagram that visually represents the number of articles identified, screened, assessed for eligibility, and ultimately included in the study.

This research utilized various sources to ensure the validity and reliability of the findings. This research reviewed 41 articles from one database that discussed the benefits of programmed learning in mathematics education. These articles were selected based on relevance, citations, year of publication, and author. The primary studies referenced in this research include the work of (Clark-Wilson et al., 2020) on e-learning and learning science, as well as (Grineski et al., 2016) research on the influence of various teaching methods on student learning outcomes. The analysis carried out is limited to 2 things, namely based on the Latest and Annual Trend Analysis and the Latest Trend and Source Analysis by analyzing more deeply "The Evolution of Programmed

Learning in Mathematics" and "Programmed Learning in Mathematics" in each period before the pandemic, during the pandemic, and after the pandemic. This is done to understand better the general description of research studies, countries, research methods, and level of research participants, as well as the types of programmed learning in mathematics in each period. Therefore, integrating technology in mathematics learning through a programmatic approach offers academic benefits and practical solutions to educational challenges during and after the pandemic.

Results and Discussion

A. The Evolution of Programmed Learning in Mathematics: Recent Trends and Annual Analysis

The evolution of programmed learning in mathematics education has experienced significant progress, especially with technology integration. This integration has led to increased student understanding and achievement. However, it is essential to continue evaluating and developing pedagogical approaches to ensure these technologies are used effectively and inclusively. The dynamic nature of programmed learning trends is evident when observing annual variations and developments, as illustrated in Figure 2.

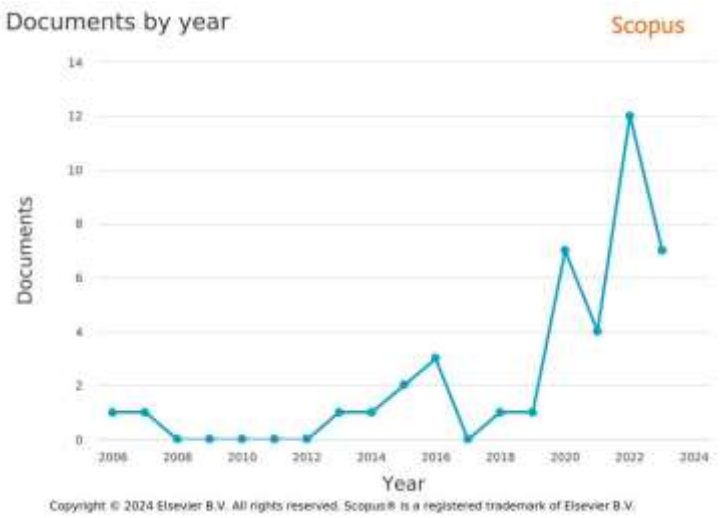

Figure 2. The Evolution of Programmed Learning in Mathematics: Recent Trends and Annual Analysis

Figure 2 depicts the evolutionary trends of programmed learning from 1960 to 2025, highlighting critical periods in research activity. From 2006 to 2023, research in this area experienced significant fluctuations. Initially, research output was relatively low, with a small peak occurring in 2016 with three studies. These periods are followed by declines, indicating waning interest or potential barriers to implementation and further research. These barriers may include technological limitations, lack of funding, or resistance to change within educational institutions.

A significant increase in interest occurred between 2020 and 2021, with the number of studies increasing to seven in 2020 before decreasing slightly to four in 2021. This surge in research can be attributed to the growing need for adaptive and interactive learning methods, driven by the global shift to distance learning during the COVID-19 pandemic. Programmed learning, with its capacity to offer flexible and individualized educational experiences, has become invaluable in this crisis. This period underscores the importance of developing robust, technology-enabled pedagogical strategies to meet diverse student needs, ensuring all students have access to quality education regardless of their circumstances.

The most significant increase occurred in 2022 with 12 studies, reflecting a surge in interest and possibly increased funding and institutional support for this learning method. 2023 shows a slight decline with seven studies, which is still higher than previous years before 2020. This trend reflects that despite fluctuations, there is increasing interest in programmed learning in mathematics education. This shows great potential for further development and broader implementation of this method.

Overall, the evolution of programmed learning in mathematics education from 1960 to 2025 can be divided into three main periods: the early period (1960s to 1980s), the transition period (1990s to 2010s), and the digital period (2010 -and until 2025).

Early Period (1960s to 1980s):

In this period, programmed learning technology began to be introduced with simple teaching machines such as Skinner machines. This machine is designed to provide immediate

feedback to students, focusing on repetition and positive reinforcement to ensure understanding of basic math concepts. Empirically, research by B.F. Skinner (1958) showed that this method is efficacious in improving basic mathematics skills because students receive immediate feedback and can learn at their own pace (Clark & Hordosy, 2019; Clarke & Hennig, 2013; Ozdemir, 2022). However, criticism came from researchers such as Bruner (1966), who argued that programmed learning was too mechanical and did not encourage critical thinking or creativity.

Transition Period (1990s to 2010s):

With the advent of personal computers, programmed learning underwent a significant transformation. Educational software such as LOGO and GeoGebra began to be developed, giving students access to interactive math simulations and adaptive exercises. Research by Papert (1980) shows that using LOGO helps students understand mathematical concepts through visualization and a practical approach. Other research by Hohenwarter and Preiner (2007) confirmed that GeoGebra is effective in helping students understand more abstract mathematical concepts. However, there is also research that shows the limitations of educational software. For example, Clark (1983) argued that technology only provides significant benefits if supported by solid pedagogy.

Digital Period (2010s to 2025):

The COVID-19 pandemic accelerated the adoption of technology in mathematics education. Distance learning is becoming the norm, and e-learning platforms such as Zoom, Google Classroom, and Khan Academy are critical tools in the learning process. Research (Rosillo & Montes, 2021) showed that technology-supported distance learning helped students stay engaged and continue learning during the pandemic. Artificial intelligence (AI) and data analytics are starting to be used to tailor learning materials to students' individual needs. For example, research (Klopfer & Osterweil, 2013) shows that using AI in education can provide real-time and more personalized feedback. However, there is research that shows challenges in using technology. For example, (Gómez-García et al., 2020) argue that technology only sometimes improves learning outcomes and can widen the digital divide between students.

B. *Programmed Learning in Mathematics: Recent Trends and Source Analysis*

Programmed learning in mathematics education has experienced a significant evolution from 1960 to 2025, especially with the increasingly deeper integration of technology. In the literature analysis carried out, there are striking differences in the approach and application of technology before the pandemic, during the pandemic, and after the COVID-19 pandemic by referring to analysis data from the top 15 publications related to Programmed Learning Mathematics publications based on trend analysis and their sources can be seen in table 1.

Table 1. The top 15 publications related to Programmed Learning Mathematics publications based on trend analysis and their sources

No.	SOURCE TITLE	TITLE	Year	ISSN	Cited by
1	Eurasia Journal of Mathematics, Science and Technology Education	"Electronic learning and its benefits in education"	2019	13058215	22
2	International Electronic Journal of Mathematics Education	"Improving Geometry Teaching with Scratch"	2020	13063030	10
3	Eurasia Journal of Mathematics, Science and Technology Education	"ChatGPT: A revolutionary tool for teaching and learning mathematics."	2023	13058215	74
4	Eurasia Journal of Mathematics, Science and Technology Education	"Computer attitude, use, experience, software familiarity, and perceived pedagogical usefulness: The case of mathematics professors."	2006	13058215	35
5	Eurasia Journal of Mathematics, Science and Technology Education	"The effectiveness of Driver's model in teaching mathematics for developing intermediate school students conceptual understanding"	2023	13058215	0
6	IEEE Control Systems	"Jie Huang [People in Control]"	2014	1066033X	0
7	Infinity Journal	"ALTERNATIVE LEARNING DURING A PANDEMIC: USE OF THE WEBSITE AS A MATHEMATICS LEARNING MEDIA FOR STUDENT MOTIVATION"	2022	20896867	2
8	International Electronic Journal of Mathematics Education	"An Examination of Students' Views about an International Math Contest"	2022	13063030	1
9	Eurasia Journal of Mathematics, Science and Technology Education	"The power of STEAM activities in enhancing the level of metacognitive awareness of mathematics among students at the primary stage"	2022	13058215	2
10	International Electronic Journal of Mathematics Education	"Development of the future mathematics teachers' constructive skills"	2015	13063030	8
11	Baghdad Science Journal	"3-D Packing in Container using Teaching Learning Based Optimization Algorithm"	2023	20788665	0
12	Eurasia Journal of Mathematics, Science and Technology Education	"Learning Mathematics from Home During COVID-19: Insights from Two Inquiry-Focussed Primary Schools"	2021	13058215	20
13	Computational Intelligence and Neuroscience	"Effectiveness of Artificial Intelligence (AI) in Improving Pupils' Deep Learning in Primary School Mathematics Teaching in Fujian Province"	2022	16875265	4
14	Computational Intelligence and Neuroscience	"Study on OBE Teaching Concept in the Context of Deep Learning for the Construction of University Mathematics Microcourses"	2022	16875265	3
15	Frontiers in Applied Mathematics and Statistics	"Intentionality and Players of Effective Online Courses in Mathematics"	2021	22974687	8

The development of technology and programmed learning methods in mathematics education has experienced a significant evolution, especially before and after the COVID-19 pandemic. Over a broad period from 1960 to 2025, various scientific journals have covered this topic, reflecting academic interest in integrating technology into mathematics education.

Based on the literature analysis, several journals stand out in their contribution to this topic. The Eurasia Journal of Mathematics, Science and Technology Education leads the way with six publications examining various aspects of programmed learning, including using mathematical software and applications to improve student understanding. The journal often focuses on pedagogical approaches and their impact on learning outcomes.

International Electronic Journal of Mathematics Education followed with three publications. This journal highlights research on the effectiveness of various technological tools and programmed learning methods in mathematics education. The study published here tends to explore how technology can be used to facilitate more profound and more interactive learning.

Computational Intelligence and Neuroscience and other journals such as IEEE Control Systems, Infinity Journal, Baghdad Science Journal, and Frontiers in Applied Mathematics and Statistics also contributed with two publications each. These journals usually present more technical and in-depth research on algorithms, artificial intelligence, and neuroscience applications in mathematics education. They provide insight into how advanced technologies can be integrated to create more adaptive and personalized learning experiences. Further deeper analysis was carried out by analyzing the findings in Table 1 for each of the following periods:

1. Pre-Pandemic Period (1960-2019)

Programmed learning in mathematics education had experienced significant developments before the pandemic but still has several weaknesses that must be corrected. One necessary research that supports the benefits of electronic learning in mathematics education is a study by the Eurasia Journal of Mathematics, Science and Technology Education in 2019. This research is entitled "Electronic Learning and its Benefits in Education" and uses quantitative methods with the subject of high school students in Turkey. The research results show that electronic learning can increase students' understanding of mathematical concepts, which are analyzed through descriptive and inferential statistical techniques.

However, this research also revealed several areas for improvement in implementing electronic learning, minimal access to technology in some places, and a need for teacher training. This indicates that although technology has great potential to improve the quality of education, adequate infrastructure and training are also very important. Despite these weaknesses, this research found that technology can increase student motivation and participation in the teaching and learning process, which is the main advantage of e-learning.

Another article supporting these findings is a publication from the Eurasia Journal of Mathematics, Science, and Technology Education 2006, entitled "Computer Attitude, use, experience, Software Familiarity, and Perceived Pedagogical Usefulness: The Case of Mathematics Professors." This research uses a survey method with subjects of mathematics lecturers at universities in Europe, and the analysis techniques used are descriptive and inferential statistics. The results show that lecturers' attitudes, experience, and familiarity with educational software greatly determine learning effectiveness. A visible trend in this period is the increasing adoption of computer technology as a learning aid, with significant benefits in improving understanding of mathematical concepts. However, lecturers' limited access and ability to use this technology optimally was the weakness. Suggestions for further research include special training for lecturers and the development of more user-friendly software. Therefore, additional research is recommended to explore the use of more sophisticated technology and involve more subjects from various backgrounds to improve the overall quality of mathematics education.

Further research was conducted by the "International Electronic Journal of Mathematics Education" in 2015 titled "Development of the Future Mathematics Teachers' Constructive Skills." This research highlights the development of prospective mathematics teachers' constructive skills through technology. The research method used was a quasi-experiment with research subjects as prospective mathematics teachers at universities in Turkey. The analysis technique used is descriptive and inferential statistical analysis. This research shows that programmed learning can improve prospective teachers' teaching skills and mathematical understanding. However, the weakness is the need for more diversification of research subjects, which only consist of prospective teachers and do not include students or experienced teachers. Suggestions for further research are to expand the scope of research subjects and explore the long-term impact of programmed learning on student learning outcomes.

Then, Smith et al. (2016) discussed using interactive mathematics software in middle schools in the United States. This research shows that technology-based programmed learning can improve students' understanding of mathematical concepts. The research method used was a quasi-experimental study with research subjects as 9th-grade students in three different middle schools. The analysis technique used is descriptive and inferential statistical analysis. The advantage of this period is that there is strong empirical evidence regarding the benefits of programmed learning in increasing understanding of mathematical concepts. However, the main weakness is the need for more

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diversification of the programmed learning methods used and limitations in the research scale, which often only covers a few schools. Suggestions for further research are to expand the scope of research by involving more schools and various levels of education.

As additional empirical evidence, research by Hegedus and Kaput (2004) in the "Journal of Mathematics Teacher Education" shows that using technology in mathematics learning can improve student interaction and better understanding of concepts. This study, conducted in middle schools, used quasi-experimental methods and inferential statistical analysis to test the effectiveness of collaborative software in increasing student engagement and understanding. The results of this research support the statement that technology has great potential to revolutionize mathematics learning if appropriately implemented and supported by adequate training for educators.

Programmed learning in mathematics education in the pre-pandemic period (1960-2019) includes several important aspects that focus on using technology and electronic methods to improve the quality of mathematics education. Here are some of the main points that can be seen in Figure 3:

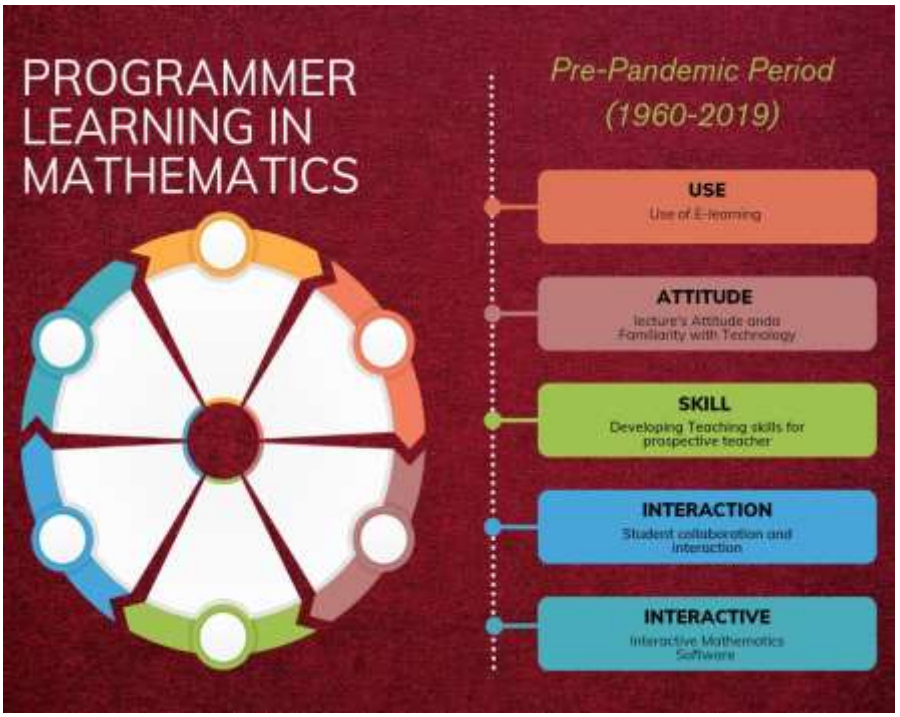

Figure 3. Pre-Pandemic Period (1960-2019): Programmed learning in mathematics education

Based on Figure 3, it can be stated that in the Pre-Pandemic Period (1960-2019), programmed learning in mathematics education included:

1. Use of E-Learning: A study by the Eurasia Journal of Mathematics, Science and Technology Education (2019) shows that e-learning can improve understanding of mathematical concepts among secondary school students. However, challenges such as limited access to technology and lack of teacher training must be overcome to maximize its benefits.
2. Lecturers' Attitudes and Familiarity with Technology: Research in 2006 the same journal indicated that lecturers' attitudes and experiences with educational software greatly influence learning effectiveness. Lecturers more familiar with technology tend to be more effective in using it as a teaching tool.
3. Developing Teaching Skills for Prospective Teachers: Research from 2015 in the International Electronic Journal of Mathematics Education shows that technology can improve prospective teachers' teaching skills and understanding of mathematics. However, this research also emphasizes diversifying research subjects to obtain a more comprehensive picture.
4. Interactive Mathematics Software: A Study by Smith et al. (2016) in the United States shows that interactive software can improve students' understanding of mathematical concepts. However, limitations in diversifying research methods and scales still need to be overcome.
5. Student Collaboration and Interaction: Research by Hegedus and Kaput (2004) highlighted that collaborative software can increase students' interaction and understanding of mathematical concepts in secondary

schools. This shows the great potential of technology to revolutionize mathematics learning if implemented with adequate training support for educators.

It was overall, programmed learning in mathematics education before the pandemic showed great potential in improving the quality of education but also highlighted the need for improvements in technology access and training for educators.

2. Pandemic Period (2020-2021)

Research published by the International Electronic Journal of Mathematics Education in 2020, entitled "Improving Geometry Teaching with Scratch," aligns with broader empirical evidence highlighting the effectiveness of technology in improving educational outcomes. For example, research conducted by Fessakis, Gouli, and Mavroudi (2013) found that using Scratch in mathematics teaching significantly increased students' problem-solving skills and engagement. This research, which focused on elementary school students, shows that programming environments can provide a unique blend of creativity and logical thinking, which is critical in understanding mathematical concepts.

Further supporting evidence comes from a meta-analysis conducted by Cheung and Slavin (2013), which reviewed several studies on the impact of educational technology on student achievement in mathematics. The research results show a positive effect size, indicating that students who use technology-based learning methods consistently outperform their peers who do not use technology-based learning methods. This meta-analysis highlights the potential of integrating tools such as Scratch into the curriculum, particularly in improving students' understanding and retention of geometric principles.

Additionally, research by Papadakis, Kalogiannakis, and Zaranis (2016) explored the impact of educational software on early childhood education. They found that children who interacted with interactive learning apps demonstrated better understanding and retention of math concepts. The study concluded that interactive and visual learning tools like Scratch can significantly contribute to developing young learners' critical thinking and problem-solving skills.

Improving Mathematics Learning through Technological Intervention is proven by evidence from various studies, which strengthens the findings of research conducted in Indonesia, which emphasizes that technological intervention can significantly improve students' learning experience in mathematics. For example, research conducted by Li and Ma (2010) in the Journal of Educational Technology & Society found that integrating technology into mathematics teaching can improve student performance and engagement. This study highlights how interactive software and digital tools facilitate a more profound understanding of mathematical concepts by enabling students to visualize and manipulate abstract ideas in tangible ways.

However, these studies also highlight common challenges, such as the need for reliable internet connectivity and adequate access to technological devices, that must be addressed to ensure equitable learning opportunities for all students. For example, research conducted by Warschauer and Matuchniak (2010) in Educational Researcher highlights the digital divide, where students from disadvantaged backgrounds often lack access to necessary technology and internet connectivity. This gap can hinder their ability to utilize digital learning resources, exacerbating existing educational gaps.

The COVID-19 pandemic has accelerated the adoption of programmed learning, primarily through digital media such as websites. An article from Infinity Journal in 2022 entitled "LEARNING ALTERNATIVES DURING THE PANDEMIC: USE OF WEBSITES AS MATHEMATICS LEARNING MEDIA FOR STUDENT MOTIVATION" highlights how websites can increase student motivation in learning mathematics. This research uses a case study method with secondary school students in Indonesia and finds that digital media if designed interactively and interestingly, can be very effective in learning. Trends during the pandemic show a significant shift to online platforms due to their greater flexibility and accessibility. However, this change also brings challenges, such as the digital divide and limited direct interaction between teachers and students.

To address these challenges, further research is recommended to find solutions to bridge the digital gap, including developing internet infrastructure and providing adequate technological devices for all students. This could involve government and community initiatives to ensure that even students in remote areas have the necessary tools to participate in digital learning effectively. For example, a study by the World Bank in 2020 highlighted that government-led initiatives in countries like Kenya and Brazil have successfully improved internet accessibility and provided digital devices to students in underserved regions, resulting in enhanced educational outcomes.

In addition, more interactive and inclusive learning methods must be developed to ensure effectiveness and enjoyment in online learning. Other relevant research, such as that published in the "Eurasian Journal of Mathematics, Science and Technology Education" in 2021, also emphasizes the importance of an inquiry-based approach to learning from home. This study, conducted in two elementary schools in England, shows that the inquiry method can help students stay engaged and motivated even when learning from home. Additionally, a study by Garrison and Kanuka (2004) showed that collaborative interactions in digital learning

environments can improve students' understanding and retention of material.

Research shows that programmed learning can increase student engagement and understanding in mathematics despite limitations in direct interaction. This is important in the current digital era, where technology plays a crucial role in education. One of the weaknesses found in the research was the lack of quantitative data that could provide a broader picture of the effectiveness of programmed learning. Therefore, suggestions for further research are to combine qualitative and quantitative methods and explore various technology platforms used in programmed learning. For example, a study by Means et al. (2010) emphasizes the importance of a blended learning approach, which combines face-to-face and online methods to achieve better educational outcomes.

During the COVID-19 pandemic, there has been a significant surge in the use of technology for programmed learning. For example, research by Zhang et al. (2020) in China shows the effectiveness of using artificial intelligence (AI) in distance mathematics learning. This research was conducted in elementary schools in Fujian Province using a randomized controlled experiment method. The results show that AI can help improve students' understanding of mathematical concepts. This shows that technology can be a very effective tool in education, especially when direct interaction is limited.

However, this period also revealed gaps in technology access between students in urban and rural areas. The advantages of this period are the rapid adaptation to distance learning and the use of advanced technology, such as AI, which is showing positive results. To overcome this weakness, further research should focus on solutions to reduce this digital divide and explore the potential of other technologies, such as virtual reality, in mathematics learning. In this way, more inclusive and effective ways can be found to improve all students' education quality, regardless of their geographic background.

Programmed learning in mathematics education in the pandemic period (2019-2021) includes several important aspects that focus on using technology and electronic methods to improve the quality of mathematics education. Here are some of the main points that can be seen in Figure 4:

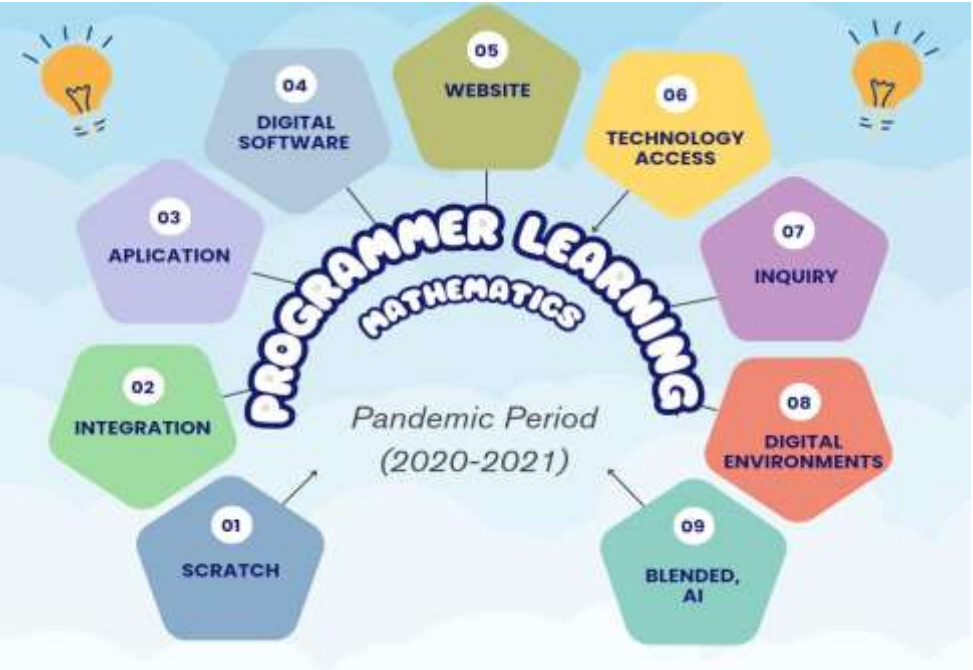

Figure 4. pembelajaran terprogram dalam pendidikan matematika pada periode pandemi (2020-2021)

Based on Figure 4, it can be stated that in the Pandemic Period (2020-2021), programmed learning in mathematics education included:

1. Use of Scratch in Geometry Teaching: Studies show that Scratch can improve students' problem-solving skills and engagement in geometry learning.
2. Technology Integration in Mathematics Learning: A meta-analysis by Cheung and Slavin (2013) found that technology-based instructional methods consistently improve student achievement compared to traditional methods.
3. Interactive Learning Application for Early Childhood: Research by Papadakis et al. (2016) showed that interactive educational software helps children better

understand and remember mathematical concepts.

4. Interactive Digital Software and Tools: Li and Ma's (2010) study emphasized that interactive software allows students to visualize and manipulate abstract ideas in mathematics, improving their understanding.
5. Use of Websites as Learning Media: An Infinity Journal (2022) article shows that interactive websites can increase student motivation to learn mathematics.
6. Government Initiatives for Technology Access: Efforts by governments in countries such as Kenya and Brazil to increase internet access and provide digital devices to students in remote areas have been shown to improve educational outcomes.
7. Inquiry-Based Learning Approach: Studies in the UK show that inquiry-based methods can keep students engaged and motivated when learning from home.
8. Collaborative Learning in Digital Environments: Garrison and Kanuka (2004) found that collaboration in a digital environment improved students' understanding and retention of material.
9. Blended Learning Approach: Means et al. (2010) emphasize combining face-to-face and online methods to achieve better educational outcomes.
10. Use of Artificial Intelligence (AI) in Distance Learning: Research in China shows that AI can improve students' understanding of mathematical concepts in distance learning.

Each method offers innovative solutions to address learning challenges during the pandemic while exposing technology access gaps that must be addressed to ensure educational equity for all students.

3. Post-Pandemic Period (2022-2025)

After the pandemic, the 2022-2025 period will be when technology integration in education proliferates. One striking trend is the use of artificial intelligence (AI)-based tools in learning. Research conducted by the Eurasia Journal of Mathematics, Science and Technology Education in 2023, entitled "ChatGPT: A revolutionary tool for teaching and learning mathematics," revealed the revolutionary potential of using AI chatbots, such as ChatGPT, in teaching mathematics. This study uses qualitative methods with in-depth interviews with teachers and students in secondary schools in the United States and analyzes data using thematic analysis techniques.

The research results show that ChatGPT helps students understand complex mathematical concepts. This chatbot can provide instant feedback, which is helpful in learning, increasing efficiency, and personalizing learning. However, this research also revealed some areas for improvement, such as students' dependence on technology and the possibility of reduced human interaction. This Raises concerns that students may become too dependent on technology, reducing their ability to communicate and collaborate directly with fellow students and teachers.

This research strengthens the argument that the integration of advanced technologies, such as artificial intelligence (AI), can significantly contribute to mathematics education in the future. AI in education enables personalization of learning, where material can be tailored to individual students' needs and abilities. This could increase the effectiveness and efficiency of learning and provide students with a deeper and more meaningful learning experience. Further research is recommended to examine the long-term impact of AI in education and effective ways to integrate human interaction in this technology-based learning process.

Research by Li et al. (2022) at a University in China shows that the Outcome-Based Education (OBE) concept in mathematics micro-learning can be refined through technology-based in-depth learning. This research uses a case study method with research subjects as first-year students. The analysis techniques used are content analysis and surveys, which aim to evaluate the effectiveness of technology integration in supporting the achievement of expected learning outcomes. The research results show that deep learning technology can improve the quality of learning and help students better achieve the expected competencies.

The main challenge faced in this period is the need for training and professional development for teachers to implement technology effectively. With adequate training, teachers may be able to use the technology optimistically. Therefore, further research is recommended to explore how teacher training can be optimized and the long-term impact of programmed learning on student learning outcomes. With the right approach, integrating advanced technology in education can be an invaluable tool in improving the quality of teaching and ensuring that students can learn more effectively and efficiently.

By compiling results and discussions based on the periods before, during, and after the pandemic, we can see the development and adaptation of programmed learning in mathematics education and identify trends, benefits, weaknesses, and suggestions for further research. Empirical evidence from various studies supports the importance of continuing to integrate technology in education to achieve optimal learning outcomes. The pre-pandemic period saw slow technology adoption, accelerated by urgent needs during the pandemic. After the pandemic, evaluating the effectiveness of programmed learning methods has become a significant focus.

Evaluation of programmed learning methods continues to be carried out to ensure their effectiveness in supporting the educational process. An article from the 2023 Eurasia Journal of Mathematics, Science and Technology Education entitled "The Effectiveness of Driver's Model in Teaching Mathematics for Developing Intermediate School Students' Conceptual Understanding" examines the effectiveness of the Driver model in increasing secondary school students' understanding of mathematical concepts. This research uses experimental methods with students in secondary schools in Türkiye, as well as inferential statistical analysis techniques. The research results show that the Driver model effectively improves students' understanding of mathematical concepts, confirming the importance of teacher training and technology integration in education.

Furthermore, trends in this period show technology's continued adaptation and integration in learning, with more measurable benefits in improving student learning outcomes. However, weaknesses still need to be addressed, including over-reliance on technology and the need for ongoing training for teachers. Suggestions for further research include the long-term evaluation of programmed learning methods and the development of more adaptive curricula. This will help ensure that the learning methods are effective in the short term and can positively impact students.

Research published by the Baghdad Science Journal in 2023 titled "3-D Packing in Container using Teaching Learning Based Optimization Algorithm" highlights optimizing algorithms in mathematics learning. This study uses experimental methods with research subjects of secondary school students in Iraq, showing that integrating advanced technology into the learning process can significantly contribute to students' understanding. This aligns with global trends that support using technology in education to improve learning outcomes.

The research results show that optimizing algorithms in programmed learning can improve students' analytical and problem-solving abilities. The analysis techniques used in this research are statistical analysis and computer simulation, which provide a quantitative picture of the effectiveness of this method. However, this research also reveals several areas for improvement, such as the limited application of the algorithm in everyday learning contexts, which could be an obstacle to widespread implementation.

For further research, it is recommended that researchers explore the application of various other algorithms in programmed learning. This aims to measure the impact on student learning outcomes, such as understanding concepts, information retention, and critical thinking skills. In addition, regular evaluation of the effectiveness of this method is essential to ensure that the integration of technology in education continues to provide the expected benefits and is relevant to student needs.

Programmed learning in mathematics education in the post-pandemic period (2022-2025) includes several important aspects that focus on using technology and electronic methods to improve the quality of mathematics education. Here are some of the main points that can be seen in Figure 5:

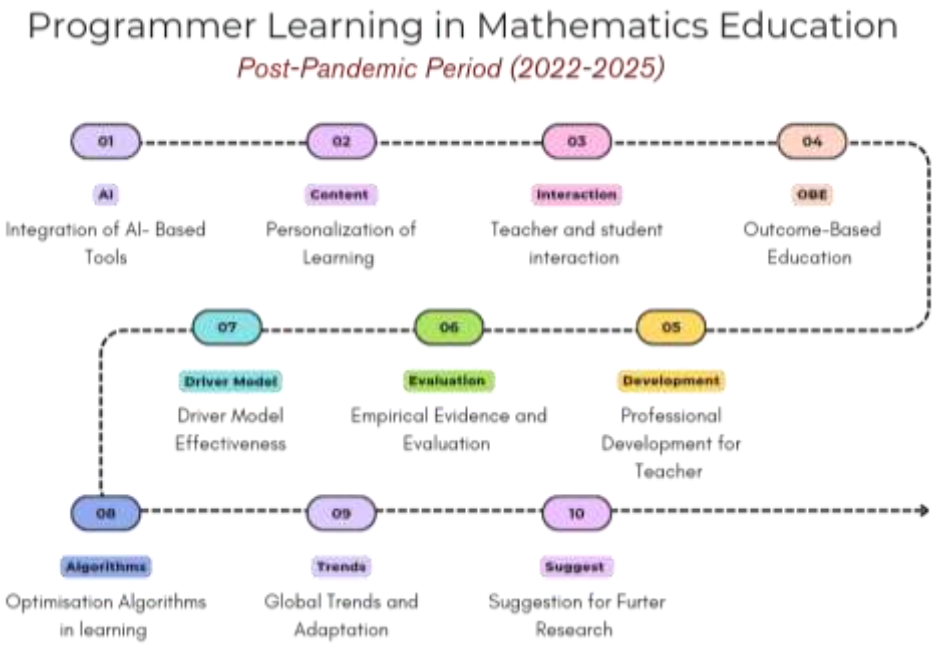

Figure 5. Programmed learning in mathematics education in the post-pandemic period (2022-2025)

Based on Figure 5, it can be stated that in the Post-Pandemic Period (2022-2025), programmed learning in mathematics education included:

1. Integration of AI-Based Tools: Artificial intelligence (AI) tools such as ChatGPT have become prominent in teaching mathematics, providing instant feedback and personalized learning experiences.
2. Personalization of Learning: AI enables the customization of educational content to meet individual student needs, potentially increasing the efficiency and effectiveness of learning.
3. Teacher and Student Interaction: While AI tools enhance learning, there is a concern that over-reliance on technology may reduce direct human interaction, impacting students' communication and collaboration skills.
4. Outcome-Based Education (OBE): Research in China indicates that technology-based deep learning can improve the quality of mathematics education and help students achieve expected competencies more effectively.
5. Professional Development for Teachers: Effective technology implementation in education requires adequate training and professional development for teachers.
6. Empirical Evidence and Evaluation: Continuous evaluation of programmed learning methods is necessary to ensure their effectiveness, with evidence from various studies supporting the benefits of technology integration in education.
7. Driver Model Effectiveness: Experimental research in Türkiye confirms that the Driver model effectively improves students' conceptual understanding of mathematics, emphasizing the importance of teacher training.
8. Optimization Algorithms in Learning: Studies highlight the benefits of using optimization algorithms to enhance students' problem-solving and analytical skills in mathematics education.
9. Global Trends and Adaptation: The post-pandemic period shows a continued adaptation of technology in learning, focusing on measurable improvements in student outcomes.
10. Suggestions for Further Research: Further research should explore long-term impacts, adaptive curricula, and the application of various algorithms to ensure that technology integration remains beneficial and relevant to students' needs.

This research shows that programmed learning in mathematics education continues to develop and provides significant benefits, especially in increasing student understanding of concepts and learning motivation. In recent years, programmed learning trends have shown a substantial increase in the use of technology. Empirical evidence from various studies supports technology integration as an essential tool to face learning challenges during the pandemic and improve the quality of mathematics education in the future.

However, despite the apparent benefits, technical challenges and limited access still need to be addressed. Not all students have the same access to technology, which can create gaps in learning opportunities. Therefore, educators and policymakers need to work together to overcome these obstacles by providing adequate resources and training for teachers to optimize the use of technology in learning.

This research shows that programmed learning in mathematics education has significantly transformed over time. The various benefits and challenges show that technology integration requires a more in-depth and comprehensive approach. Further research will help optimize the potential of programmed learning, ensure that the benefits of technology can be felt equally by all students, and ultimately improve the overall quality of mathematics education.

Conclusion

Research on programmed learning in mathematics education before and after the COVID-19 pandemic highlights key findings and insights. First, integrating technology through programmed learning has been shown to improve teaching methodology and student engagement in mathematics significantly. The systematic literature review, which analyzed 41 articles from 1960 to 2025, underscores the positive impact of using interactive software and online platforms, especially during the pandemic when distance learning has become essential. The findings show that programmed learning contributes to improved academic performance and increased interest in mathematics among students at various levels of education, including high school, undergraduate, and graduate school.

Apart from these benefits, this research also identifies critical challenges that hinder the optimal implementation of programmed learning. One of the main problems is the unequal distribution of technological resources, which creates gaps in access to practical learning tools. Additionally, there is a significant need for adequate training for educators to integrate and utilize technology in their teaching practices. Teachers' lack of technical skills often results in underutilizing available tools, thereby limiting the potential benefits of programmed learning.

To overcome these challenges, this study provides several recommendations. Improving technology infrastructure across educational institutions is critical to ensuring equitable access to learning tools. In addition, comprehensive training programs for educators are essential to equip them with the skills necessary to implement programmed learning

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effectively. By addressing these issues, the potential of programmed learning can be fully realized, leading to more effective and engaging mathematics education in the post-pandemic era. This study underscores the relevance and necessity of integrating technology into modern educational practices to face contemporary challenges and improve learning outcomes.

This study has several limitations that need to be acknowledged. First, this research only uses one database (Scopus) as a data source, so other relevant research may need to be identified. Second, the vast period (1960-2025) may result in variations in methodology and context that could influence research results. Third, the analysis methodology is limited to two things: based on the Latest and Annual Trend Analysis and the Latest Trend and Source Analysis by analyzing more deeply the "Evolution of Mathematics Programmed Learning" and "Mathematics Programmed Learning" in each period.

For further research, conducting a more in-depth study using various databases is recommended to get a more comprehensive picture of programmed learning in mathematics education. In addition, further research could focus on empirical studies involving experiments or surveys to measure the impact of programmed learning directly on student learning outcomes. Research involving various data collection methods can provide more comprehensive and valid insights into the effectiveness and implementation of programmed learning in different contexts.

In addition, it is hoped that future research can continue deeper analysis regarding relevance, citations, year of publication, and authors using bibliometrics to continue this research. In this way, more concrete and applicable data can be obtained to develop more effective educational policies and practices in the future. Further research that considers a variety of variables and approaches will help enrich the existing literature and significantly contribute to the development of mathematics education at various educational levels.

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