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Research Trends in the Use of Technology in Fostering Mathematical Critical Thinking Skills: A Review

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Abstract*— Critical thinking skills are among the key objectives of 21st-century education. This study conducted a content analysis of several articles published between 2016 and 2023, emphasizing the role of technology in improving mathematical critical thinking abilities. The findings reveal that from 2021 to 2022, the number of publications addressing mathematical critical thinking skills through technology increased. Among these publications, quantitative research with quasi-experimental designs was the most prevalent. Additionally, the 8th grade of junior high school and the topics of 'geometry and algebra' were the most frequently targeted subject and material. Similarly, Geogebra and discovery learning were the most widely used technologies and methods. The most commonly used instrument was tests, with t-tests being the primary data analysis method. Several recommendations are proposed for future research focusing on the development of mathematical critical thinking skills through technology.

***Keywords:** Technology, Mathematics, Critical Thinking Skills, Content Analysis, Systematic Literature Review.*

I. INTRODUCTION

Mathematics is systematic knowledge obtained through reasoning and logic [1]. Mathematics is seen by education as something essential and cannot be replaced. Mathematics will provide sustainable benefits for life. Mathematics is taught from elementary to secondary levels, even up to the university level. Apart from being a calculation facility, mathematics is essential in training logical, consistent, and systematic thinking skills. However, students still need help to learn mathematics. This aligns with the opinion of Weng and Yang [2], who state that most students consider mathematics a complex subject. One reason is the need for more motivation to learn from the students themselves.

The 21st century presents increasingly complex challenges for humans, ranging from survival to education. Education is currently regarded as crucial for shaping a competent society in the 21st century [3]. The 21st century demands the mastery of various skills, especially in education. Education is required to prepare students to master various skills used in everyday life. It is underlined that students in the twenty-first century require not just conceptual mastery but also competences that allow them to cultivate higher-order thinking abilities [4]. Crucial abilities including creativity, communication, teamwork, critical thinking, and problem-solving are highly valued in the twenty-first centur [5].

Critical thinking, or the capacity to think critically and assess information, is one of the primary competencies that are prioritized in the twenty-first century. Paul and Elder [6] define that critical thinking skills are the art of enhancing one's ability to analyze and evaluate problems in order to find effective solutions. In addition, according to Glazer [7], mathematical critical thinking is the capacity to apply past information, mathematical reasoning, and cognitive methods to generalize, prove, or assess obscure mathematical problems successfully. Critical thinking skills include reasoning, inference, analysis, and assessment in order to make informed and rational decisions [8]. Thus, critical thinking skills involve the ability to evaluate the strengths and weaknesses of an argument by determining whether the evidence supports the conclusion [9]. A person who has good critical thinking skills can: 1) collect and assess relevant information using abstract ideas to find solutions effectively; 2) formulate critical questions and problems and be able to formulate problems precisely and clearly; 3) communicate effectively with other people to find solutions to problems; 4) produce logical conclusions and be able to test them using specific criteria and standards [10].

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Every student has the potential to think critically in mathematics; the challenge lies in how teachers can effectively foster and enhance these critical thinking skills through their teaching methods in math education. The field's findings, however, indicate that pupils' critical thinking skills still require development. The findings of other earlier studies that looked at pupils' critical thinking skills lend weight to this. The research results from Basri et al. [11] indicated that students' critical thinking abilities remain relatively underdeveloped. This happens because students need help to acquire evaluation, analysis, and self-regulation skills. Research by Kharisma [12] also shows that students' critical thinking abilities are still relatively low in almost all critical thinking indicators due to students' lack of habit in solving critical thinking ability questions.

Due to students' low critical thinking skills, there needs to be follow-up action from teachers regarding this problem. One of the most important roles in guaranteeing learning success is that of the teacher. Teachers have a key role in creating a more efficient learning environment and fostering students' competence and critical thinking abilities [13]. The strategy employed by teachers to enhance students' critical thinking skills involves creating an engaging learning environment and simplifying the material to help students grasp it more easily. One thing that can be used is applying technology in learning. Technology utilization in education is crucial [14]. Apart from that, using technology in learning influences the development of students' abilities, especially in mathematics [15], [16].

Based on the outline above, this study seeks to explore the patterns related to the integration of technology in improving students' mathematical critical thinking skills. The goal is for the findings to serve as a valuable resource for educators interested in utilizing technology to foster the development of 4C skills, especially increasing mathematical critical thinking skills. Thus, content analysis is needed to support the novelty of research related to the use of technology that can improve students' mathematical critical thinking abilities. Aacharya [17] asserts that content analysis is highly beneficial for researchers. Its word richness and the qualitative and quantitative analyses it contains provide academics unique study opportunities for their investigations. Thus, by conducting a content analysis of several scholarly journals indexed in SINTA or Scopus from 2016 to 2023, the aim of this study is to collect data on various studies that explore the relationship between mathematical critical thinking skills and the integration of technology.

In detail, the following questions were the focus of our investigation.

RQ1: What was the annual trend in the quantity of research on technologically aided mathematical critical thinking skills??

RQ2: How were various research designs employed to investigate mathematical critical thinking skills with technology?

RQ3: What was the most frequently chosen research subject when studying the use of technology in fostering mathematical critical thinking skills?

RQ4: What was the most popular topic for studying how well students used technology to think critically about mathematics??

RQ5: What strategies did the researchers use to help students become more adept at using technology to think critically about mathematics??

RQ6: What technology was most often used by researchers to examine students' mathematical critical thinking abilities?

RQ7: What instruments did the researchers utilize to assess technology-assisted mathematics critical thinking abilities??

RQ8: What methods of data analysis did the researchers employ to examine technologically aided mathematical critical thinking abilities?

II. METHODS

(a) Research Design

This study employs the concepts of content analysis, concentrating on the results of several investigations into the application of technology to improve mathematical critical thinking abilities that have been published in academic publications that are indexed by SINTA or Scopus. The content analysis applied by researchers is quantitative content analysis. Additionally, the research methodology is comparable to that of Fauzi and Pradipta [18].

(b) Data Source

The data used in this study are obtained from the articles published in the indexed scientific journal, either sinta (http://sinta2.ristekdikti.go.id/) or scopus (https://www.scopus.com/home.url), which have been published online before October 2023. Henceforth, all articles that review the use of technology in fostering mathematical critical thinking skills are collected from each of these journals. Based on the collected article data, 30 articles from 24 journals review the impact of technology in improving mathematical critical thinking skills, and all these articles were analyzed in this study.

(c) Research Instrument

Research instruments play a crucial role in the research process. They are an integral component of the research methodology, as they serve as tools for gathering, examining, and analyzing data related to the problem being studied [19]. The research instrument used in this study referred to research by Fauzi and Pradipta [18] and was modified by the researcher according to research needs (Table 1).

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Table 1. The research instruments used in content analysis study

Aspects	Categories	
Types of research (2a)	A.1 Quantitative Research A.2 Qualitative Research A.3 R&D	A.4 CRA A.5 Mixed-Methods Research A.6 Others
Types of quantitative research (2b)	B.1 Observation Studies B.2 Correlational Research B.3 Survey Research B.4 Pre-Experimental Designs	B.5 True-Experimental Designs B.6 Quasi-Experimental Designs B.7 Ex Post Facto Designs
Types of R&D (2c)	C.1 ADDIE C. 2 4D	C.3 Plomp C.4 Others
Research subjects	D.1 VII Grade JHS students D.2 VIII Grade JHS students D.3 IX Grade JHS students D.4 X Grade SHS students D.5 XI Grade SHS students D.6 XII Grade SHS students	D.7 Undergraduate students D.8 Postgraduate students D.9 JHS teacher D.10 SHS teacher D.11 Lecturer
Data collection instruments	E.1 Questionnaire E.2 Observation E.3 Test	E.4 Interview E.5 Documents E.5 Others
Data analysis methods	F.1 Mean/SD F.2 Percentage F.3 N-gain F.4 T-test F.5 ANOVA F.6 ANCOVA	F.7 MANOVA F.8 MANCOVA F.9 Correlation F.10 Non-parametric tests F.11 Others F.12 Unidentified

(Source: adapted from Fauzi and Pradipta [18] and modified by researchers)

In this study, eight key areas are examined based on Table 1. The aforementioned factors encompass the following: (1) quantity of publications annually; (2) type of the study; (3) participants in the research; (4) the mathematics topic selected for the study; (5) treatment; (6) technology employed; (7) tools for gathering data; and (8) techniques for analyzing data. Nevertheless, there are some exceptions to this research, specifically the categories in aspects (1), (4), (5), and (6) that were not established initially because no prior study existed that could serve as a guide for establishing what should be established in categories, and it is possible that overgeneralization of categories will occur when content analysis of several articles is carried out. Furthermore, prior to data collection, categories in aspects (2), (3), (7), and (8) were determined. Moreover, aspect (2) is further broken down into three sub-aspects: general types of research (2a), quantitative research design (2b), and R&D research design (2c).

(d) Data Analysis

Each article that meets a predetermined category is grouped into a specific category based on certain aspects. The author's explanations of the information in the abstract, methodology, results, and discussion sections of the article served as the foundation for these clauses. After then, the gathered data is analyzed and shown as tables and diagrams.

III. RESULTS

(a) Number of Publications

From 2016 to October 2023, 30 published studies on using technology to foster mathematical critical thinking skills were published. The distribution of the studies by year of publication is displayed in Figure 1. The more studies that look into how technology affects students' capacity for mathematical critical thinking, the more beneficial the effects will be for Indonesia's educational system. In addition, the outcomes of earlier studies can also have an impact on educational practice for a number of reasons, including: (1) the ability for educators to use research findings as reliable information and put them into practice; (2) the capacity of research results to form the basis of local, state, and federal educational policy decisions; and (3) the ability for research findings to have an impact on educators' perspectives.

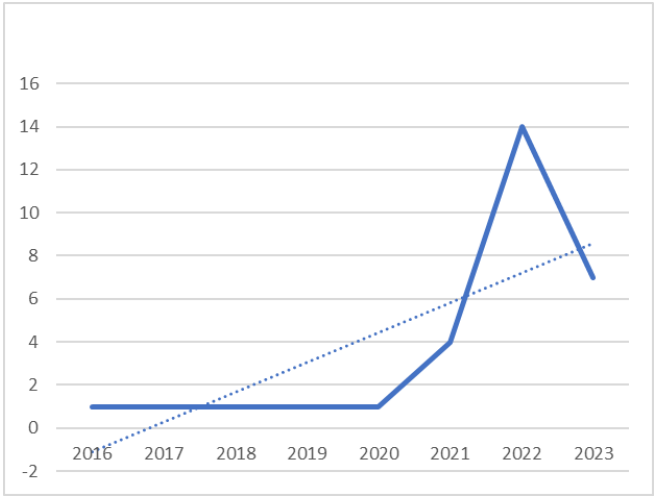

Figure 1. Studies based on publication year.

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Based on Figure 1, from 2016 to 2020, there was consistently one research per year. Meanwhile, in 2021, there began to be an increase. Four studies were published that year and 14 were published in 2022. It indicates that technology is increasingly used to foster mathematical critical thinking skills. Meanwhile, from 2023 until October, seven studies have been on using technology to foster mathematical critical thinking skills. This number can still increase because there are still several months until 2023 ends. The number of scholars interested in investigating the use of technology to improve students' critical mathematical thinking skills has significantly increased as a result of the growing number of publications pertaining to this topic. The quantity of published publications demonstrates the frequency of research throughout a given time frame.

Additionally, the rise in research publications in 2021 on using technology to promote mathematical critical thinking skills can be attributed, in part, to the impact of COVID-19. It encourages teachers to integrate technology into mathematics instruction, especially since face-to-face learning activities are restricted and students are required to stay at home. As a result, learning is primarily conducted using various technological tools and platforms. This finding aligns with research by Alabdulaziz [20], which states that COVID-19 provides enormous potential in using digital technology in mathematics learning. A similar pattern of using live streams to teach mathematics during the epidemic was also seen in Brazil, according to research by Borba [21].

(b) Types of Research

Research on using technology to foster mathematical critical thinking skills is carried out in various types. A suitable research design is essential for the successful completion of any research project. It is the strategy selected by the researcher prior to data collection, aimed at effectively achieving the research objectives. The primary purpose of a research design is to transform a research problem into data that can be analyzed to provide insightful answers to the research questions. Furthermore, the choice of research design is influenced by a comprehensive review of the problem statement, research questions, conceptual and theoretical frameworks, and relevant literature [22], [23]. As for the distribution of research based on its type is presented in Figure 2.

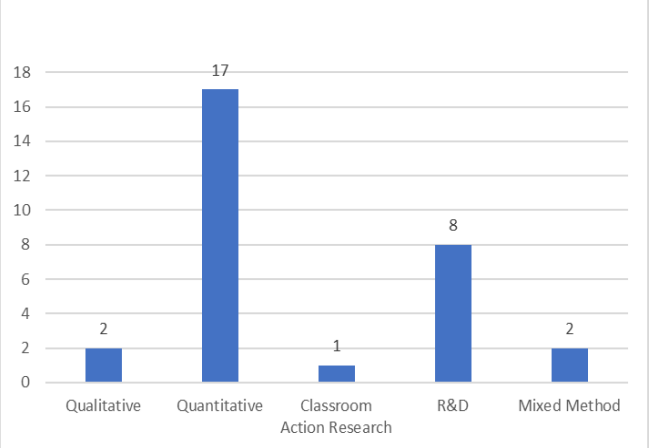

Figure 2. Studies based on types of research.

As shown in Figure 2, the most popular techniques for examining patterns in the use of technology to enhance mathematical critical thinking abilities are quantitative research methodologies; 17 studies use quantitative research methods. Eight studies used R&D methods, two used qualitative research methods, two used mixed methods, and one used classroom action research methods. Critical thinking ability is one of the thinking skills, so teaching it can be done in two ways, namely: (1) by providing specific classes or activities that support this thinking skill or (2) by integrating it into existing subjects [24].

Therefore, quantitative research methods are widely used in technology research to foster mathematical critical thinking skills because, through quantitative research, researchers can develop and produce models and theories that explain student behavior [25]. Additionally, this study outlines the quantitative research designs employed by researchers, with the quasi-experimental design being the most frequently used to investigate the role of technology in enhancing mathematical critical thinking skills in mathematics education, as much as 14 articles. In addition, there are also quantitative studies that use pre-experimental designs, as much as three articles.

A research method that is also often used to research the use of technology to foster mathematical critical thinking skills is R&D. Of the eight articles that used the R&D method, seven were identified using the ADDIE model, and others used the 4-D method. Furthermore, in classroom action research, there is 1 article that used descriptive statistics, and two mixed-method articles used sequential and concurrent embedded explanations. Additionally, two articles were identified using qualitative methods, both using a descriptive approach. This aims to reveal an overview of mathematical critical thinking skills. The lack of studies using qualitative research methods can undoubtedly open opportunities for other researchers to conduct qualitative research related to technology to foster mathematical critical thinking skills.

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(c) Research Subject

Technology has been extensively integrated into mathematics education at all levels, ranging from elementary school to university, to foster mathematical critical thinking skills. Figure 3 illustrates the distribution of research on the use of technology to promote mathematical critical thinking skills.

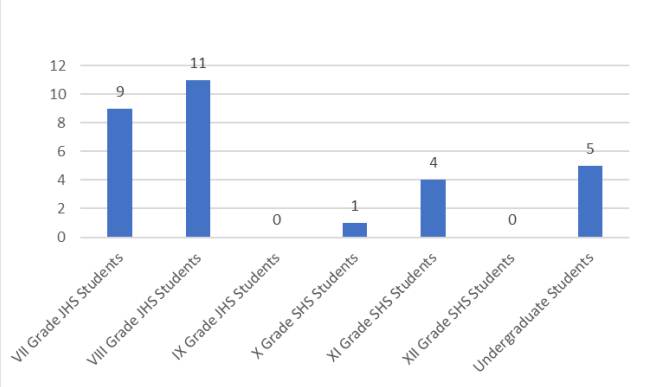

Figure 3. Studies based on research subject.

Figure 3 shows that, with a total of 11 studies, grade 8 students are the ones who use technology in mathematics instruction the most, followed by grade 7 students (n=9), university students (n=5), grade 11 students (n=4), and grade 10 students (n=1). Meanwhile, in grades 9 and 12, researchers have not found research on using technology to foster mathematical critical thinking skills in either class. This is because mathematics learning in grades 9 and 12 in Indonesia has been focused on preparing for the final exam for graduation, so there needs to be research involving these two classes. Furthermore, because these programs are the last ones offered at the junior high and high school levels, teachers are unable to make adjustments for future instruction, which limits the impact on teaching practices.

(d) Mathematics Topic Selected When Conducting Studies

Based on the results of these studies, some studies examine specific topics with the consideration that these topics have yet to be mastered or are difficult for students to understand. For example, Alghadari et al. [26] used geometry (three-dimensions) in their research because students needed help connecting basic geometric concepts with those they had just learned. Jaelani [27] chose the topic of geometry (distance and angles) because students still needed help understanding the concept, so students' geometric thinking abilities were still low. Similarly, Pramesti and Retnawati [28] stated that students' mastery of algebra topics still needs to be improved. This is proven by the TIMSS results in 2007 and 2011 and data on student learning outcomes in the algebra domain in Bantul Regency from 2014 to 2018. Other researchers choose topics according to the technology that will be used in the research, such as Hikmah [29] and Andriani et al. [30], who chose the topic of algebra (equations of straight line) with the help of geogebra because this application makes it easy to draw objects and has features for drawing equation of straight line.

The topics often chosen by researchers to improve mathematical critical thinking skills with the help of technology can be seen in Table 2.

Table 2. The most frequently chosen topics in research are improving mathematical critical thinking skills assisted by technology.

Topics	Number of articles
Numbers and operations	4
Measurements	-
Algebra	9
Geometry	9
Data analysis and probability	1
Calculus	1
Unidentified	6

Table 2 leads to the conclusion that the mathematics topics most frequently selected in research on using technology to enhance mathematical critical thinking skills are geometry and algebra. Nine articles select geometry and algebra topics. This topic of geometry can be found in research at the middle school, high school, and university levels. Meanwhile, algebra topics are only found in junior high school and university research. Furthermore, six articles should have mentioned the mathematical topic being studied.

(e) Treatments

In student learning development, teachers can provide specific treatments to influence students. These treatments result from what students have done in their learning process. Treatment in learning can be carried out in three ways: through learning approaches, learning models, and learning methods. The learning approach is closely linked to how learning materials are structured and presented for delivery, for example, the scientific approach, contextual approach, and so on. The learning model relates to how a teacher organizes students to be actively involved in the learning process, for example, problem-based learning models, discovery learning, and so on. Meanwhile, learning methods relate to how the learning material will be taught, such as discussion methods, question and answer, and so on.

Negash et al. [31] stated that the learning approach is a fundamental strategy to apply in learning because it influences student learning outcomes and is also helpful for learning throughout the student's life. Likewise, with learning methods and learning models, several studies show that learning methods and learning models also influence student learning outcomes [32], [33]. Therefore, it can be concluded that high-quality student learning outcomes are the direct result of an effective and well-structured learning process

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[34]. However, to ensure a high-quality learning process, teachers must have the ability to implement teaching strategies that meet the specific needs of the classroom. Inadequate or mismatched approaches can undermine the quality of the learning experience. Therefore, teachers should utilize effective teaching methods that enhance student learning outcomes in schools.

The results of the research reveal various treatments used in research, such as project-based learning, problem-based learning, realistic mathematics education, REACT, discovery learning, flipped learning, blended learning, CORE learning, problem-solving, and contextual teaching and learning. Based on these several treatments, discovery learning and realistic mathematics education emerged as the treatments most frequently used by researchers, each with three articles, and then project-based learning and problem-based learning, each with two articles.

(f) Technology Used in Fostering Mathematical Critical Thinking Skills

Technology has become an integral part of human life that cannot be separated in the current digital era and has made breakthroughs in education, specifically in mathematics [35]. In the current globalized period, the field of education is unavoidably impacted by the quick development of information technology. Demands from around the world force the education industry to continuously adjust to technological advancements in order to improve the quality of education, especially by incorporating ICT into the educational process. Haleem et al. [36] state that the use of technology in the classroom increases student engagement, which has a significant impact on the educational system. Additionally, studies by Tawafak et al. [37] shows that various research related to technology from 2011-2017 has positively influenced the education sector. This shows that technology positively impacts learning in the classroom, considering that innovation in learning is needed to support students' skills in the 21st century.

According to a review of thirty studies on the topic of using digital tools to improve mathematical critical thinking abilities, Geogebra is one of the most widely utilized tools in math classes. Ten articles review the use of geogebra in improving mathematical critical thinking skills. This finding aligns with research by Susanto et al. [38], who stated that geogebra is a digital technology often used by researchers in research in mathematics education. This shows there are limitations to exploring digital technology in developing mathematical critical thinking skills. This means that future research needs to review the use of other technologies, such as live worksheets, augmented reality, virtual reality, scratch, desmos, and so on.

(g) Data collection instrument

In research, instruments play an essential role. The choice of research instrument is crucial in determining the quality and reliability of the research outcomes. This is because the accuracy in selecting research instruments primarily determines the validity of the data obtained in research. In a research study, a data instrument is a tool used to collect data or information [39]. This data is essential for testing the hypotheses proposed in the research. The data collection instruments used in the research are shown in Figure 4.

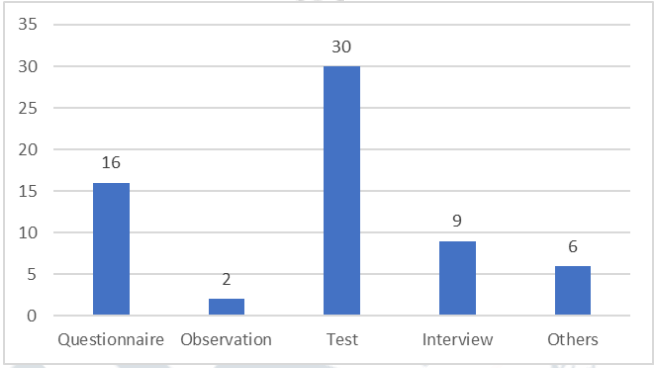

Figure 4. Data collection instrument.

Based on Figure 4, there are 16 studies using questionnaires, two studies using observation, 30 studies using tests, nine studies using interviews, and six studies using other than these instruments. Six other studies used validation questionnaires in their research. Most researchers use test instruments to measure students' critical thinking abilities. The use of tests for data collection is considered a more objective method compared to the use of questionnaires and observations. After all, the research sample answers are measured consistently. Then, this test instrument provides quantitative data that allows researchers to carry out statistical analysis in more detail and provide more decisive conclusions. Furthermore, Gurel et al. [40] stated that Students are given the chance to openly express their thoughts and show their understanding through test instrument. Through the use of test instruments, teachers can identify the level of knowledge and misconceptions that students may have when working on questions.

Assuring the validity and reliability of the instruments used in research is essential, however many researchers frequently ignore this. It is important to note whether instruments such as tests, questionnaires, or interviews used in research have gone through a validation and reliability process before being tested further. This is in line with Capinding [41] emphasized that quality research instruments must go through these stages to ensure the validity and reliability of the data obtained. Therefore, including information regarding the validation process and instrument reliability is essential to strengthen the credibility of the research results conducted.

(h) Data analysis method

Data analysis methods are a crucial aspect of research. Choosing the correct data analysis method will affect the quality of research results. Choosing the proper data analysis

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method is difficult for most researchers [42]. Adapting data analysis methods to the type of research being conducted is essential. Each research type has its unique characteristics, and the chosen analysis methods must effectively contribute to a thorough understanding of the phenomenon being studied. As a result, this choice significantly affects the reliability and validity of the study findings. As for the data analysis method used in the research are shown in Figure 5.

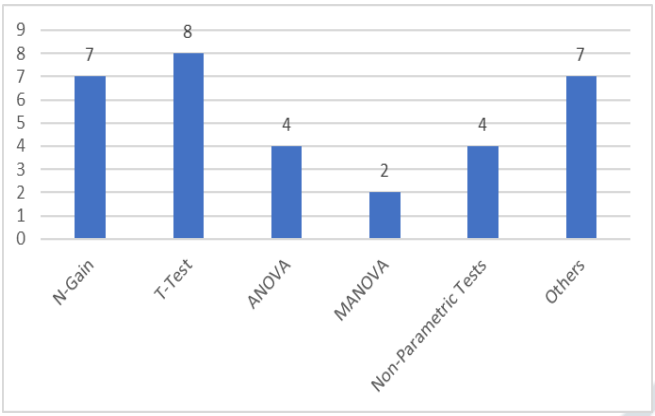

Figure 5. Data analysis method.

Based on Figure 5, the majority of data analysis used by researchers is the t-test in 8 studies and the N-Gain test in 7 studies. Then, other data analyses used by researchers were the ANOVA (n=4), MANOVA (n=2), non-parametric tests (n=4), and other studies used other analyses according to the instruments created by researchers in Table 1. The t-test used in the research includes the independent t-test and paired sample t-test. The independent t-test test assesses the difference in averages of two separate groups, and the paired sample t-test compares the averages of two paired samples [43]. According to Tan [44], researchers often use the t-test because it is more appropriate for using sample data. Meanwhile, the N-Gain test is used in one data group by comparing pretest and posttest scores. The N-Gain test is often used in quantitative research and R&D because the test is used to determine differences and improvements in the treatment given.

Furthermore, several studies used ANOVA and MANOVA, which were used in quantitative analysis. ANOVA makes it possible to determine differences between more than two groups tested [45]. Meanwhile, MANOVA analyzes differences in multiple dependent variables [46]. Moreover, several studies use non-parametric statistical tests, namely the Mann-Whitney test. This test is the same as the t-test; the difference between the Mann-Whitney test and the t-test is that the Mann-Whitney test is used when the prerequisite tests do not meet homogeneity or normality. Other data analyzed used in the research are structural equation modeling, descriptive qualitative, and descriptive statistics tests.

IV. CONCLUSION

Based on the findings in the results and discussion section, there is a limited amount of research that explores the use of technology in enhancing students' mathematical critical thinking skills. Additionally, the lack of diversity in the choice of technology, learning models, and topics studied are also key findings that warrant further investigation in future research. As a result, several recommendations have been proposed for upcoming studies focused on developing mathematical critical thinking skills through the use of technology.

Researchers should take into account the relationship between technology, learning topics, and the instructional methods used, as well as ensure that the data collection and analysis instruments align with the type of research being conducted. These considerations serve as recommendations from this study to support the development of students' mathematical critical thinking skills through technology. Moreover, it is hoped that this research will contribute to advancing studies on how technology can be effectively integrated into education to enhance students' 21st-century skills.

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Conflict of Interest:

The authors declared that there is **no potential conflict of interest** concerning this article's research, authorship, and/or publication**.**

REFERENCES

[1] C. Cresswell and C. P. Speelman, “Does mathematics training lead to better logical thinking and reasoning? A cross-sectional assessment from students toprofessors,” *PLoS One*, vol. 15, no. 7,pp. 1–21, 2020, doi: 10.1371/journal.pone. 0236153.

[2] T. S. Weng and D. C. Yang, “Research on mathematical animation using pascal animation as an example,” *Eurasia J. Math. Sci. Technol. Educ.*, vol. 13, no. 6, pp. 1687–1699, 2017, doi: 10.12973/eurasia.2017.00692a.

[3] R. S. Malik, “Educational challenges in 21st century and sustainable development,” *J. Sustain. Dev. Educ. Res.*, vol. 2, no. 1, pp. 9–20, 2018, doi: 10.17509/jsder.v2i1.12266.

[4] M.Miterianifa, A. Ashadi, S. Saputro, and S. Suciati, “Higher order thinking skills in the 21st century: Critical thinking,” in *Proceedings of the 1st International Conference on Social Science, Humanities, Education and Society Development*, 2020. doi: 10.4108/eai.30-11-2020.2303766.

[5] H. A. Alismail, “Teachers’ perspectives of utilizing distance learning to support 21st century skill attainment for K-3 elementary students during the COVID-19 pandemic era,” *Heliyon*, vol. 9, no. 9, pp. 1–13, 2023, doi: 10.1016/j.heliyon.

2023.e19275.
[6] R. Paul and L. Elder, *The miniature guide to critical thinking concepts and tools*. London: Rowman & Littlefield, 2019.
[7] E. Glazer, *Using internet primary sources to teach critical thinking skills in mathematics*. United States of America: Bloomsbury Publishing, 2001.
[8] P. A. Facione, *Critical thinking: A statement of expert consensus for purposes of educational assessment and instruction*. The California Academic Press, 1990.
[9] C. O'Reilly, A. Devitt, and N. Hayes, "Critical thinking in the preschool classroom - A systematic literature review," *Think. Ski. Creat.*, vol. 46, pp. 1–20, 2022, doi: 10.1016/j.tsc.2022.101110.
[10] I. W. Widana, I. W. Y. Parwata, N. N. Parmithi, I. G. A. T. Jayantika, K. Sukendra, and I. W. Sumandya, "Higher order thinking skills assessment towards critical thinking on mathematics lesson," *Int. J. Soc. Sci. Humanit.*, vol. 2, no. 1, pp. 24–32, 2018, doi: 10.29332/ijssh.v2n1.74.
[11] H. Basri, Purwanto, A. R. As'ari, and Sisworo, "Investigating critical thinking skill of junior high school in solving mathematical problem," *Int. J. Instr.*, vol. 12, no. 3, pp. 745–758, 2019, doi: 10.29333/iji.2019.12345a.
[12] E. N. Kharisma, "Analisis kemampuan berpikir kritis matematis siswa SMK pada materi barisan dan deret," *J. Rev. Pembelajaran Mat.*, vol. 3, no. 1, pp. 62–75, 2018, doi: 10.15642/jrpm.2018.3.1.62-75.
[13] A. Widiyatmoko, S. Utaminingsih, and Santoso, "Android-based math learning to improve critical thinking," *J. Phys. Conf. Ser.*, vol. 1823, no. 1, 2021, doi: 10.1088/1742-6596/1823/1/012091.
[14] P. Kaur, H. Kumar, and S. Kaushal, "Technology-assisted language learning adaptive systems: A comprehensive review," *Int. J. Cogn. Comput. Eng.*, vol. 4, pp. 301–313, 2023, doi: 10.1016/j.ijcce.2023.09.002.
[15] D. R. Joshi, "Influence of ICT in mathematics teaching," *Int. J. Innov. Res. Multidiscip. F.*, vol. 3, no. 1, pp. 7–11, 2017.
[16] R. Novita and T. Herman, "Digital technology in learning mathematical literacy, can it helpful?," *J. Phys. Conf. Ser.*, vol. 1776, pp. 1–9, 2021, doi: 10.1088/1742-6596/1776/1/012027.
[17] H. Aacharya, "Content analysis," *Int. J. Res. Dev.*, vol. 7, no. 4, pp. 177–180, 2022, doi: https://doi.org/10.36713/epra2016.
[18] A. Fauzi and I. W. Pradipta, "Research methods and data analysis techniques in education articles published by Indonesian biology educational journals," *JPBI (Jurnal Pendidik. Biol. Indones.*, vol. 4, no. 2, pp. 123–134, 2018, doi: 10.22219/jpbi.v4i2.5889.
[19] H. F. Nasution, "Instrumen penelitian dan urgensinya dalam penelitian kuantitatif," *Al-Masharif J. Ilmu Ekon. Dan Keislam.*, vol. 4, no. 1, pp. 59–75, 2016.
[20] M. S. Alabdulaziz, "COVID-19 and the use of digital technology in mathematics education," *Educ. Inf. Technol.*, vol. 26, no. 6, pp. 7609–7633, 2021, doi: 10.1007/s10639-021-10602-3.
[21] M. C. Borba, "The future of mathematics education since COVID-19: Humans-with-media or humans-with-non-living-things," *Educ. Stud. Math.*, vol. 108, no. 1–2, pp. 385–400, 2021, doi: 10.1007/s10649-021-10043-2.
[22] B. M. Asenahabi, "Basics of research design: A guide to selecting appropriate research design," *Int. J. Contemp. Appl. Res.*, vol. 6, no. 5, pp. 76–89, 2019.
[23] K. J. Sileyew, "Research design and methodology," in *IntechOpen*, 2019. doi: 10.5772/intechopen.85731.
[24] M. Z. Zahid, "Telaah kerangka kerja PISA 2021: Era integrasi computational thinking dalam bidang matematika," *Prism. Pros. Semin. Nas. Mat.*, vol. 3, pp. 706–713, 2020.
[25] W. K. Hoy and C. M. Adams, *Quantitative research in education: A primer*. Sage Publications, 2015.
[26] F. Alghadari, T. Herman, and S. Prabawanto, "Factors affecting senior high school students to solve three-dimensional geometry problems," *Int. Electron. J. Math. Educ.*, vol. 15, no. 3, pp. 1–11, 2020, doi: 10.29333/iejme/8234.
[27] A. Jaelani, "Geometric thinking in learning distance and angle," *J. Phys. Conf. Ser.*, vol. 1778, pp. 1–7, 2021, doi: 10.1088/1742-6596/1778/1/012022.
[28] T. I. Pramesti and H. Retnawati, "Difficulties in learning algebra: An analysis of students' errors," *J. Phys. Conf. Ser.*, vol. 1320, pp. 1–7, 2019, doi: 10.1088/1742-6596/1320/1/012061.
[29] R. Hikmah, "Pengaruh aplikasi geogebra dalam meningkatkan kemampuan berpikir kritis siswa di SMPN Cibinong," *SAP (Susunan Artik. Pendidikan)*, vol. 5, no. 2, pp. 152–161, 2020, doi: 10.30998/sap.v5i2.6908.
[30] T. Andriani, N. H. A. Ulya, T. P. Alfiana, S. Solicha, S. B. A. Hafsari, and N. Ishartono, "Improving student's critical thinking skill in mathematics through geogebra-based flipped learning during pandemi COVID-19: An experimental study," *J. Medives J. Math. Educ. IKIP Veteran Semarang*, vol. 6, no. 1, pp. 49–66, 2022, doi: 10.31331/medivesveteran.v6i1.1901.
[31] T. T. Negash, M. T. Eshete, and G. A. Hanago, "Students' learning approaches as a factor of academic achievement at selected public universities: A cross-sectional study," *Front. Educ.*, vol. 7:965573, pp. 1–9, 2022, doi: 10.3389/feduc.2022.965573.
[32] R. Koskinen and H. Pitkäniemi, "Meaningful learning in mathematics: A research synthesis of teaching approaches," *Int. Electron. J. Math. Educ.*, vol. 17, no. 2, pp. 1–15, 2022, doi: 10.29333/iejme/11715.
[33] L. Zhang and Y. Ma, "A study of the impact of project-based learning on student learning effects: A meta-analysis study," *Front. Psychol.*, vol. 14, pp. 1–14, 2023, doi: 10.3389/fpsyg.2023.1202728.
[34] H. Humairah, T. Solfitri, Armis, and D. Permana, "Improving mathematic students' learning process and achievement through discovery learning model at MAN 2 Model Pekanbaru," *J. Phys. Conf. Ser.*, vol. 1351, pp. 1–5, 2019, doi: 10.1088/1742-6596/1351/1/012084.
[35] M. N. Singh, "Inroad of digital technology in education: Age of digital classroom," *High. Educ. Futur.*, vol. 8, no. 1, pp. 20–30, 2021, doi: 10.1177/2347631120980272.
[36] A. Haleem, M. Javaid, M. A. Qadri, and R. Suman, "Understanding the role of digital technologies in education: A review," *Sustain. Oper. Comput.*, vol. 3, no. May, pp. 275–285, 2022, doi: 10.1016/j.susoc.2022.05.004.
[37] R. M. Tawafak, A. B. T. Romli, R. bin A. Arshah, and R. A. S. Almaroof, "Assessing the impact of technology learning and assessment method on academic performance: Review paper," *Eurasia J. Math. Sci. Technol. Educ.*, vol. 14, no. 6, pp. 2241–2254, 2018, doi: 10.29333/ejmste/87117.
[38] A. Susanto, W. Setyaningrum, F. Camellia, and N. W. Asriani, "Tren pemanfaatan teknologi dalam meningkatkan

kemampuan pemecahan masalah matematis siswa," *AKSIOMA J. Progr. Stud. Pendidik. Mat.*, vol. 12, no. 3, pp. 3088–3100, 2023, doi: https://doi.org/10.24127/ajpm.v12i3.7545.

[39] E. Elfrianto and G. Lesmana, *Metodologi penelitian pendidikan*. UMSU Press, 2022.

[40] D. K. Gurel, A. Eryilmaz, and L. C. McDermott, "A review and comparison of diagnostic instruments to identify students' misconceptions in science," *Eurasia J. Math. Sci. Technol. Educ.*, vol. 11, no. 5, pp. 989–1008, 2015, doi: 10.12973/eurasia.2015.1369a.

[41] A. T. Capinding, "Construction and validation of mathematical satisfaction questionnaire: An exploratory and confirmatory factor analysis," *Probl. Educ. 21st Century*, vol. 81, no. 3, pp. 327–339, 2023, doi: 10.33225/pec/23.81.327.

[42] H. Taherdoost, "Data collection methods and tools for research: A step-by-step guide to choose data collection technique for academic and business research projects," *Int. J. Acad. Res. Manag.*, vol. 10, no. 1, pp. 10–38, 2021, [Online]. Available: https://hal.science/hal-03741847

[43] P. Mishra, C. Pandey, U. Singh, A. Keshri, and M. Sabaretnam, "Selection of appropriate statistical methods for data analysis," *Ann. Card. Anaesth.*, vol. 22, no. 3, pp. 297–301, 2019, doi: 10.4103/aca.ACA_248_18.

[44] T. K. Tan, "Practical t-test power analysis with R," *Pract. Assessment, Res. Eval.*, vol. 27, no. 18, pp. 1–27, 2022, doi: 10.7275/mmna-sh25.

[45] M. A. Martinez, "Computer discourse and use as determinants of student math outcomes: Performativity and action at work in the lower school grades," *Heliyon*, vol. 8, pp. 1–9, 2022, doi: 10.1016/j.heliyon.2022.e08888.

[46] J. E. John, P. A. Nelson, B. Klenczar, and R. D. Robnett, "Memories of math: Narrative predictors of math affect, math motivation, and future math plans," *Contemp. Educ. Psychol.*, vol. 60, pp. 1–11, 2020, doi: 10.1016/j.cedpsych.2020.101838.