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Enhancing Critical Thinking in Mathematics through Android-Based Multimedia and PjBL-STEM

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Abstract

Mastery of mathematics is essential for developing critical thinking skills; however, many students still struggle in this area. This study evaluated the effectiveness of Android-based interactive multimedia, MatHub: Pattern8 Edition, in enhancing critical thinking within PjBL using a STEM approach. The research took place at SMP Negeri 4 Bandar Lampung in the 2024/2025 academic year, employing a quantitative approach with a Pretest-Posttest Control Group Design. Using cluster random sampling, class VIIIC with 32 students was assigned as the experimental group, while class VIIIF with 33 students served as the control group. Data collection techniques included questionnaires, interviews, critical thinking assessments, observation checklists, and supporting documentation. The results showed a significant improvement in critical thinking skills among students using MatHub compared to those applying discovery learning without multimedia. Overall, integrating MatHub in PjBL-STEM improved learning quality, motivation, and student participation, offering an effective alternative for enhancing mathematical thinking

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INTRODUCTION

Mathematics is recognized not just as a field dominated by abstract symbols, numbers, and formulas, but as a universal language that interlinks various scientific disciplines (Agus & Fitriani, 2019). Mastery of mathematics equips students with critical tools to navigate 21st-century challenges, enhancing cognitive abilities and fostering essential modern skills. Therefore, every student must develop critical thinking skills (CTS) (Aulia & Yuliani, 2023; Kertiyani et al., 2023; Rohmah et al., 2023). Critical thinking is a key competency developed through mathematics, enabling students to apply concepts effectively, solve problems, and approach challenges systematically (Shaw et al. 2020). Those who possess strong CTS can distinguish between relevant, irrelevant, and unnecessary information (Nur et al., 2024). Critical thinkers view mathematics not merely as a collection of facts and operations, but as a problem-solving process that demands deeper analysis (Purwati et al., 2016). This perspective not only deepens their grasp of mathematical ideas but also nurtures independence, openness to diverse viewpoints, and the ability to devise innovative solutions (Arisoy & Aybek, 2021; Pradana & Noer, 2023).

Fostering students' critical thinking in mathematics remains a challenge due to limited school initiatives. According to the 2022 PISA results by the OECD, Indonesia ranked 70th out of 81 countries in mathematics, an improvement of five places from the previous cycle, yet still below the OECD average. This suggests that the level of mathematical critical thinking skills among

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Indonesian students has not yet reached a high standard (Nurlaeli et al., 2018). Students continue to face difficulties in solving problems that require the ability to formulate (Dasaprawira & Susanti, 2019) and interpret problems mathematically (Maslihah et al., 2020), as well as to develop appropriate problem-solving strategies (Korkmaz & Alkan, 2023).

This issue is evident in research at SMP Negeri 4 Bandar Lampung, where 95.24% of students were found to have low or very low critical thinking skills. The preliminary study revealed that most students struggle to identify key problems and explore alternative solutions in essay questions, indicating that learning quality remains suboptimal. While students are highly interested in mathematics and educational media, there is still a lack of innovation in using technology, particularly multimedia tools to enhance learning. Many students also underutilize their Android devices for supporting mathematics learning, despite widespread access. To address this challenge, the development of effective learning media is crucial to support the success of mathematics education (Amelia et al., 2022). Learning media can serve as an efficient tool to present information visually and interactively, enhancing students' understanding and engagement. Specifically, learning media can present material more visually and interactively; Stimulate students' thinking, emotions, attention, and interest (Fitrianti et al., 2020); and provide simulations, demonstrations, or interactive exercises that help develop specific physical or cognitive skills required for problem-solving.

The implementation of learning media in mathematics is widely recognized as an effective means of enhancing mathematical thinking. Numerous efforts have been made to design and develop a variety of learning media, including e-books (Al-Astal & Zaydah, 2015; Pramasdyahsari et al., 2023; Shatat et al., 2017), e-modules (Hadiyanti et al., 2021; Purwoko et al., 2023), worksheets (Astuti et al., 2017; Prayitno et al., 2021), interactive comics (Risti, 2021; Tay et al., 2024), and videos (Schoenfeld, 2017; Ulusoy & Çakıroğlu, 2018). These resources are carefully designed to encourage students to develop critical thinking skills by understanding and applying mathematical concepts. Consequently, such media provide a strong foundation for cultivating the critical thinking abilities essential for mathematics learning. The integration of technology in learning media involves multimedia, which combines multiple media elements (Supardi et al., 2018; Muhammad & Angraini, 2023). Multimedia enables active participation from both teachers and students, enriching mathematics instruction through visual and practical approaches. This dynamic method helps link mathematical concepts to real-life contexts, thereby enhancing students' critical thinking skills.

In addition to the advantages offered by multimedia in promoting critical thinking, the use of appropriate instructional models is equally crucial for enhancing students' cognitive development. One effective model is Project-Based Learning (PjBL). As highlighted by Barrows and Tamblyn, Wiratman et al. (2023), PjBL encourages critical thinking by actively involving students throughout the learning experience. Grant (2002) PjBL is an effective instructional model for fostering students' critical thinking abilities. Also emphasizes that PjBL is a powerful approach for developing students' critical thinking skills. In this model, teachers serve as facilitators, guiding students, offering constructive feedback, monitoring engagement levels, and ensuring that project tasks are both relevant and meaningful (Pratiwi et al., 2020). The PjBL model typically begins with a central question and culminates in the creation of a product (Fadilah et al., 2023). The outcomes of these projects, achieved collaboratively, often result in tangible products and memorable experiences for students (Kokotsaki et al., 2016).

As Prabawati & Agustika (2020) stated, the integration of the PjBL model with the STEM (Science, Technology, Engineering, and Mathematics) approach can significantly increase its effectiveness. Both PjBL and STEM share common goals and features, as they encourage students to address real-world problems by producing tangible solutions or technological innovations (Herlita et al., 2023). The STEM integrates these four disciplines into a cohesive framework aimed at developing students' knowledge and skills (Chamidah, 2023). Prior studies have demonstrated that engaging students in challenging STEM-based projects naturally fosters critical thinking (Wiratman et al., 2023). The integration of PjBL-STEM emphasizes a systematic design process for solving problems with well-defined outcomes. This approach trains and enhances students' critical thinking abilities by leveraging the interconnectedness of the four STEM disciplines. Previous studies Priatna et al. (2020) and Allanta & Puspita (2021) have primarily explored PjBL-STEM as a broad educational strategy but have not specifically examined its implementation in mathematics education alongside multimedia learning tools and its impact on critical thinking skills.

This research seeks to fill a gap in existing studies by combining the PjBL model with a STEM approach and Android-based interactive multimedia. Its novelty lies in the focused implementation of the PjBL-STEM framework within mathematics education, highlighting the development of critical thinking through real-world problem-solving tasks. Additionally, this study introduces an innovative instructional framework that combines the PjBL-STEM approach with interactive features of Android-based interactive multimedia applications, such as simulations, real-time feedback, and multimedia content, offering a unique contribution to the existing body of research. By addressing these unexplored aspects, this research provides state-of-the-art insights into the practical implementation of PjBL-STEM in enhancing critical thinking in mathematics. Accordingly, the primary objective of this research is to examine the effectiveness of Android-based interactive multimedia in improving students' critical thinking skills within PjBL-STEM.

METHOD

This research was carried out using a descriptive method within a quantitative design. A quantitative-descriptive method involves processing data in the form of numerical values or percentages to derive comprehensive conclusions (Suardani et al., 2023). The research design adopted an experimental framework, specifically the Pretest-Posttest Control Group Design. This design was selected to assess the effectiveness of the implemented learning media, as presented in Table 1.

Table 1. Pretest-Posttest Control Group Design

Class	Pre-test	Treatment	Post-test
Experimental	O_1	X_1	O_2
Control	O_1	X_2	O_2

The treatment for the Experimental group (X_1) involved a PjBL-STEM approach, utilizing Android-based interactive multimedia. The researcher applied the STEM Embedded approach in this treatment, as it focuses on enhancing learning by integrating the core subject (mathematics) with other interconnected or less emphasized subjects. Conversely, the second treatment (X_2) involved conventional teaching methods without the use of Android-based interactive multimedia. The sequence of the research process, from preparation to data analysis, is illustrated in Figure 1, providing a visual overview of the procedural steps in this study.

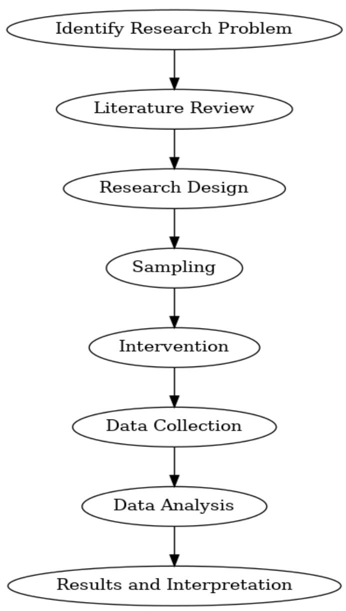

Figure 1. Research Flowchart

The study took place at SMP Negeri 4 Bandar Lampung, targeting all eighth-grade students enrolled during the Odd Semester of the 2024/2025 academic year as the research population. The sample was selected through a cluster random sampling method, where entire classes were chosen at random rather than individual students. As a result, class VIIIC (n = 32) was assigned as the experimental group, and class VIIIF (n = 33) as the control group. The main focus of the study was on students' critical thinking abilities, with additional attention given to the implementation quality of PjBL in mathematics.

Research instruments included a critical thinking skills test and an observation sheet designed to assess the implementation of the learning process, the latter employing a Guttman scale. The critical thinking test consisted of four essay-type questions on the topic of number patterns. Before the implementation, the test items were validated by experts and subjected to item analysis, which included validity, reliability, difficulty level, and discrimination power tests. The observation sheet, aligned with the lesson plan in the teaching module, was designed to evaluate the learning process. An independent observer (a mathematics teacher with experience in observation and assessment) completed this sheet to assess the researcher's teaching competence during the learning sessions.

Data analysis commenced once all student responses had been gathered. To test the research hypothesis, an Independent Samples T-Test was employed, followed by the calculation of Cohen’s d to evaluate the effect size and determine the practical relevance of the results. Furthermore, a proportion test was carried out to provide additional insights into the data.

RESULTS AND DISCUSSION

The Android-based interactive multimedia, implemented in PjBL with a STEM approach, is the 'MatHub: Pattern8' software. Developed by the researcher, this application has been validated for its validity, based on content and media feasibility, and its practicality, assessed through ease of use and user engagement. The results of these tests demonstrate that the “MatHub: Pattern8” is both feasible and practical for use as a mathematics learning medium. The Application can be accessed and downloaded through the following link: https://bit.ly/mathubpattern8. Figure 2 shows a screenshot of the application.

Figure 2. MatHub App Home View

In the initial phase, the teacher instructs students to install and launch the Android-based interactive multimedia “MatHub: Pattern8” which will serve as the primary teaching material throughout the lesson. The teacher also presents a problem designed to form the basis for students to address the guiding questions that will be provided. Subsequently, students are organized into groups to engage in the PjBL process with a STEM approach. During this phase, students are introduced to the functionalities of the Android-based interactive multimedia, including navigating menus, selecting learning modules, and accessing materials relevant to the topic under study. The Android-based interactive multimedia serves as a complementary tool, enhancing the appeal of learning materials and supporting the PjBL process effectively. The following figure 3 shows students using the application.

Figure 3. Students are opening MatHub

Students open the "Activity Guide" menu in MatHub and collaborate in their groups to work on Task 1, using the answer sheet provided by the teacher. The teacher provides guidance to students in carrying out project activities. At one point, students engage in discussions to identify problems and design solutions to address them. Consistent with Hacıoğlu & Gülhan (2021)this, students continuously seek the truth to find the best solutions during the project-based learning process. In doing so, they consistently consider the perspectives of their group members. This activity is seen in Figure 4.

Figure 4. Students Carry Out Project Activities

In Figure 4, students carry out project activities that integrate elements from the fields of science, technology, engineering, and mathematics according to a predetermined schedule, with guidance from the teacher, following the steps provided in the MatHub application. This activity is designed to develop students' critical and collaborative thinking skills by utilizing the interactive features available in the application. Students are encouraged to identify patterns, solve problems independently, and discuss their findings with their group members. The teacher's role during this phase focuses on providing clear instructions, answering student questions, and ensuring active participation from all students throughout the learning process.

During the learning activities, the implementation of MatHub within the PjBL-STEM approach was monitored using an observation sheet. This sheet was completed by a mathematics teacher who served as the observer, documenting the process from the beginning to the end of the instructional session by the prepared teaching module. The observer assessed each component of the learning implementation by marking the relevant rows and columns on the sheet. A Guttman scale was employed for the evaluation, offering binary response options: 'Yes' or 'No.' The data collected through this instrument were then used to determine the extent to which the PjBL-STEM was implemented during instruction, as summarized in Table 2.

Table 2. Implementation of the PjBL-STEM Approach

Learning Implementation Score					**Average**
I	**II**	**III**	**IV**	**V**	
Pre-test	94%	74%	98%	Post-test	88%

As shown in Table 2, the overall implementation of the learning process reached 88%, which falls within the 'good' category. This suggests that the majority of instructional stages were executed effectively under the planned teaching design. Nevertheless, despite this favorable implementation level, certain aspects still require refinement to achieve optimal instructional delivery. Specifically, improvements are needed in encouraging students to respond confidently and directly during discussions, as well as in ensuring that all ideas and contributions from group members are systematically documented. Following the analysis of the learning implementation, the subsequent section presents the results of students' critical thinking assessments, both pre-test and post-test for the experimental and control groups, as shown in Table 3.

Table 3. Descriptive Statistical Test Results

Class		**Description**				
		N	**Minimum**	**Maximum**	**Mean**	**Std. Deviation**
Experimental	Pre-Test	32	9,375	56,250	28,27	9,0184
	Post-Test	32	46,875	100	80,61	15,0177
Control	Pre-Test	33	3,125	40,625	18,89	9,3535
	Post-Test	33	31,250	100	50,91	16,8876

As presented in Table 3, the post-test results of the Experimental group surpass those of the Control group in terms of average, maximum, and minimum scores. The higher maximum score achieved by the Experimental group suggests that some students attained a deeper level of understanding. To further validate this finding, an N-Gain analysis was performed. This involved examining the pre-test and post-test results related to students' mathematical critical thinking skills to determine the degree of improvement between the group exposed to interactive multimedia integrated with the PjBL-STEM approach and the group taught through conventional methods. The resulting g-values derived from both groups' test scores are displayed in Table 4.

Table 4. Interpretation of N-Gain on Students' Critical Thinking Skills

Class	**N-Gain Average**	**Interpret**	**Std. Deviation**
Experimental	0,75	High	0,18174
Control	0,45	Medium	0,19966

As presented in Table 4, the results of the N-Gain analysis for critical thinking skills reveal that the experimental group attained an average score of 0.75, falling within the high category. In contrast, the control group achieved an average N-Gain score of 0.45, which is classified as moderate. Despite these averages, individual differences were evident in both groups. Some students in the experimental group experienced substantial improvements, while others demonstrated more modest progress. Likewise, the control group displayed a range of outcomes, suggesting that the instructional impact varied among students. The higher N-Gain in the experimental group indicates that the applied instructional strategy effectively enhanced students' critical thinking and had a meaningful educational impact. These findings align with previous studies underscoring the value of active learning in promoting critical thinking. Specifically, this result supports the findings of Amin & Sholihah (2024), who noted improvements in students' critical thinking following the implementation of PjBL-STEM in the experimental group, alongside conventional instruction in the control group.

Before performing hypothesis testing, it is crucial to verify that the critical thinking data fulfill the statistical assumptions required for such analysis. These preliminary tests include the normality test, which determines whether the data are normally distributed, and the homogeneity test, which assesses whether the variances between groups are equal. In this study, the Shapiro–Wilk test was used to evaluate normality, and the results are shown in Table 5.

Table 5. Normality Test Results

		Sig.	Significance Level	Description
Students' Critical Thinking Ability	Experimental Pre-Test	0,242	0,05	Normal Data
	Experimental Post-Test	0,057	0,05	Normal Data
	Experimental N-Gain	0,087	0,05	Normal Data
	Control Pre-Test	0,244	0,05	Normal Data
	Control Post-Test	0,103	0,05	Normal Data
	Control N-Gain	0,358	0,05	Normal Data

Table 5 presents the significance (Sig.) values for the Pre-test, Post-test, and N-Gain scores in both the experimental and control groups, all of which exceed the 0.05 threshold. These results indicate that the data for each variable follow a normal distribution, fulfilling the assumption of normality. With this requirement satisfied, the next step involves conducting a homogeneity test to determine whether the variances between the two groups are statistically similar. The outcomes of this test are detailed in Table 6.

Table 6. Homogeneity Test Results

		Levene Statistic	*df1*	*df2*	Sig.
Students' Critical Thinking Ability	Based on Mean	0,032	1	63	0,860
	Based on Median	0,009	1	63	0,924
	Based on Median and with adjusted df	0,009	1	56,631	0,924
	Based on trimmed mean	0,009	1	63	0,923

Table 6 shows a significance (Sig.) value of 0.860, which is above the 0.05 threshold, indicating that the variances in students' critical thinking scores are homogeneous. This result confirms that the pre-test and post-test data from both the experimental and control groups meet the required assumptions of normality and homogeneity. With these conditions satisfied, the analysis moves forward to hypothesis testing using the Independent Samples T-Test, with the outcomes detailed in Table 7.

Table 7. Independent Sample T Test Results

	t	df	Sig. (2-tailed)
Equal Variances Assumed	5.713	63	.000

Referring to Table 7, the Sig. (2-tailed) value of 0.000 falls below the 0.05 significance level, indicating a statistically significant difference in outcomes. The integration of interactive multimedia within the PjBL-STEM approach proved more effective than the discovery learning model in enhancing students' critical thinking abilities on number pattern material. This finding is relevant to eighth-grade students at SMP Negeri 4 Bandar Lampung during the 2024/2025 academic year.

Next, the effect size, as measured by Cohen's d, is 0.018586, indicating a weak effect. This finding implies that the practical effectiveness of the applied learning method remains limited, meaning its impact on students' critical thinking development is not substantial. Thus, although the study results indicate a significant difference, adjustments are necessary to ensure that this approach delivers more meaningful benefits in improving students' critical thinking skills. The last is the analysis of the proportion test on critical thinking ability data in the experimental class. The following are the results of the proportion test for the critical thinking ability data in Table 8.

Table 8. Critical Thinking Ability Data Proportion Test Results

	Category	N	Observed Prop.	Test Prop.	Exact Sig. (1-tailed)
Group 1	≤ 74,99	10	0,3	0,4	0,205[a]
Group 2	> 74.99	22	0,7		
Total		**32**	**1.0**		

Table 8 illustrates that the overall mastery of student learning outcomes at SMP Negeri 4 Bandar Lampung exceeded the 60% benchmark after applying the PjBL-STEM. This outcome demonstrates the model's effectiveness in promoting essential 21st-century skills, particularly in enhancing students' critical thinking, creativity, and collaboration.

In this research, the use of Android-based interactive multimedia offers a dynamic and engaging platform that complements the PjBL-STEM by providing students with access to simulations (De Freitas, 2018; Jagodzinski et al., 2014), visualizations (Fan et al., 2023), and interactive activities (Soares et al., 2020) that are not easily achievable with traditional teaching methods.. The interactive nature of the multimedia promotes student initiative (XiangXu et al., 2024), allowing them to explore STEM concepts independently while receiving immediate feedback on their progress. For instance, in the context of project-based tasks, Android-based tools can provide interactive tutorials, problem-solving simulations, and virtual experiments that enhance students' understanding and critical thinking. Additionally, the portability and accessibility of Android devices ensure that students can collaborate effectively during group discussions.

When integrated within the PjBL-STEM, Android-based interactive multimedia enhances the effectiveness of instruction by providing students with more personalized and engaging learning experiences. The findings of this study are consistent with Bulu & Tanggur (2021)those who reported that the implementation of PjBL-STEM is effective in fostering critical thinking skills. Through the integration of science, technology, engineering, and mathematics within a project-oriented structure, students are afforded opportunities to apply theoretical concepts to real-world challenges. Giang (2021), further supports this approach, noting that PjBL promotes student initiative, critical thinking, and collaborative group discussions. Similarly, Chistyakov et al. (2023) highlight that this instructional model empowers learners to translate their ideas into practice, thereby encouraging deeper and more meaningful learning. Unlike traditional didactic methods, PjBL-STEM positions students as active participants in the learning process, which in turn enhances their cognitive development by requiring them to analyze, evaluate, and synthesize information while completing authentic projects.

PjBL-STEM, through the use of MatHub, is more effective in enhancing students' critical thinking skills, particularly in the context of number pattern material. These findings align with those of Khoiriyah (2018) who reported that the STEM approach is more effective in developing critical thinking abilities compared to the discovery learning approach. The PjBL-STEM, which focuses on real-life problems, can enhance students' sense of responsibility (Connors-Kellgren et al., 2016). By engaging with authentic, context-based tasks, students are able to connect what they learn in the classroom to the world around them. This sense of relevance, combined with the opportunity to approach problems from the perspective of scientists or engineers (Baran et al., 2021), motivates students to take ownership of their learning. The model's emphasis on active engagement not only improves critical thinking skills but also cultivates a sense of purpose and responsibility, preparing students to tackle future challenges with confidence and competence.

There are several factors in the field that make the "MatHub" application different from other digital learning tools. First, MatHub provides interactive exercise simulations that allow students to test their understanding of number pattern material easily and frequently (Roesler & Dreaver-Charles, 2018) , and allow students to solve interactive problems on their mobile devices (Deb et al., 2014). Second, MatHub allows students to work on project-based tasks, such as a group project where they determine number patterns based on objects from everyday life, which are presented within the MatHub application. Students are also tasked with creating their number patterns using magnetic tools, arranging them to form specific numerical sequences. The project-based learning activities implemented through the PjBL-STEM challenge students to think critically, make predictions, and draw conclusions based on the data they gather and analyze. Such activities offer significant benefits by enabling students to grasp mathematical concepts through meaningful and contextualized learning experiences (Andriani et al., 2023; Rahmania, 2021). Furthermore, the incorporation of MatHub into this framework aligns with the STEM approach, which blends science, technology, engineering, and mathematics. This integration not only supports a more comprehensive understanding of number patterns through interdisciplinary perspectives but also motivates students to explore supplementary information that strengthens their conceptual grasp (Pamungkas et al., 2019).

LIMITATIONS

This study acknowledges several limitations that may have influenced the findings. First, the scope of this research was restricted to a specific set of number patterns, which may limit its applicability to broader mathematical concepts. Additionally, some students encountered difficulties in accessing MatHub on older devices, potentially affecting their engagement with the platform's interactive features. The study also involved a relatively small sample size from a single school, which may restrict the generalizability of the results to other educational contexts. Moreover, this study does not account for potential biases that may have influenced the findings. For example, instructor effects could have played a role, as variations in teachers' familiarity with MatHub may have impacted how students interacted with the platform. Additionally, differences in students' prior mathematical knowledge were not explicitly controlled, meaning that variations in their foundational understanding may have influenced their ability to engage with and benefit from the interactive tasks. Lastly, the complexity of the project tasks may have imposed a high cognitive load, making it challenging for some students to complete assignments with full comprehension within the given timeframe. These limitations should be carefully considered when interpreting the study's findings and suggest areas for further research to mitigate potential biases and enhance generalizability.

CONCLUSION

The results of this study reveal that the use of Android-based interactive multimedia, particularly MatHub within a PjBL-STEM, has a substantial positive impact on students' critical thinking abilities. Students who engaged with MatHub outperformed their peers in the control group with respect to critical thinking abilities. Furthermore, this instructional approach contributed positively to overall student learning outcomes, indicating its potential as an effective tool for fostering higher-order thinking and academic achievement in mathematics education. However, the observed classical completion rate of over 60% suggests that a substantial proportion of students still face challenges in mastering the material, indicating a need for further refinement in instructional strategies. Additionally, the small effect size (Cohen's d = 0.018586) suggests that while the intervention has potential, its impact may be influenced by contextual factors. From a practical perspective, mathematics teachers should consider incorporating MatHub as a supplementary tool to facilitate the teaching of number patterns. To maximize its effectiveness, teachers need to integrate it with well-structured PjBL activities, ensure alignment with curriculum goals, and provide adequate scaffolding to support diverse student needs. Schools should also evaluate the availability of technological resources to ensure seamless implementation. Future research should focus on long-term studies to assess the sustained impact of MatHub on students' cognitive development. Comparative studies with other digital learning tools could provide deeper insights into its relative effectiveness. Additionally, investigating adaptive learning strategies or personalized multimedia interventions could help optimize student engagement and achievement. By addressing these areas, future research can contribute to the development of more effective technology-enhanced learning frameworks in mathematics education.

AUTHOR CONTRIBUTIONS

KCP was involved in performing the literature review, designing the intervention, collecting data, conducting statistical analysis, interpreting the results, and drafting portions of the manuscript. SHN played a key role in conceptualizing the study, offering expertise in project-based learning, overseeing the research process, and leading the writing and revision of the manuscript. SS provided critical feedback during manuscript preparation, developed the theoretical framework, and managed references. All authors collaborated on the preparation of the final manuscript, approved its content, and accepted responsibility for the accuracy and integrity of the work.

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REFERENCES

Agus, I., & Fitriani, F. (2019). The effectiveness of the guided discovery learning (GDL) method using a contextual approach reviewed from mathematical critical thinking ability of senior high school in Muna District. *Matematika Dan Pembelajaran*, *7*(1), 22–34. https://doi.org/10.33477/mp.v7i1.1043

Al-Astal, I. H., & Zaydah, A. A. A. (2015). The effectiveness of an e-book on developing mathematical thinking skills and acquisition of mathematical concepts among 5th graders in Gaza. *International Journal of Computer Applications*, *116*(21). https://doi.org/10.5120/20461-2824

Allanta, T. R., & Puspita, L. (2021). Analisis keterampilan berpikir kritis dan self efficacy peserta didik: Dampak PjBL-STEM pada materi ekosistem. *Jurnal Inovasi Pendidikan IPA*, *7*(2), 158–170. https://doi.org/10.21831/jipi.v7i2.42441

Amelia, W., Marini, A., & Nafiah, M. (2022). Pengelolaan pendidikan karakter melalui pembelajaran matematika di sekolah dasar. *Jurnal Cakrawala Pendas*, *8*(2), 520–531.

Amin, S., & Sholihah, M. (2024). PjBL terintegrasi STEM meningkatkan kemampuan berpikir kritis dan kreatif siswa kelas XII SMA. *Jurnal Yudistira: Publikasi Riset Ilmu Pendidikan Dan Bahasa*, *2*(2), 357–362. https://doi.org/10.61132/yudistira.v2i2.761

Andriani, D., Setyarini, M., Lengkana, D., & Herlina, K. (2023). Utilization of PjBL-STEM based interactive e-modules to improve visual literacy: Teacher and student perspectives. *Jurnal Penelitian Pendidikan IPA (JPPIPA)*, *9*(12), 12166–12174. https://doi.org/10.29303/jppipa.v9i12.6357

Arisoy, B., & Aybek, B. (2021). The effects of subject-based critical thinking education in mathematics on students' critical thinking skills and virtues. *Eurasian Journal of Educational Research*, *92*, 99–119. https://doi.org/10.14689/ejer.2021.92.6

Astuti, P., Purwoko, P., & Indaryanti, I. (2017). Pengembangan LKS untuk melatih kemampuan berpikir kritis dalam mata pelajaran matematika di kelas VII SMP. *Jurnal Gantang*, *2*(2), 145–155. https://doi.org/10.31629/jg.v2i2.244

Aulia, M., & Yuliani, H. (2023). POE-based e-module (Predict, Observe, and Explain): Improving students' critical thinking skills on kinetic theory of gases. *Online Learning In Educational Research (OLER), 2*(2), 57–66. https://doi.org/10.58524/oler.v2i2.128

Baran, M., Baran, M., Karakoyun, F., & Maskan, A. (2021). The influence of project-based STEM (PjbL-STEM) applications on the development of 21st century skills. *Journal of Turkish Science Education*, *18*(4), 798–815. https://doi.org/10.36681/tused.2021.104

Bulu, V. R., & Tanggur, F. (2021). The effectiveness of STEM-based PjBL on student's critical thinking skills and collaborative attitude. *Al-Jabar: Jurnal Pendidikan Matematika*, *12*(1), 219–228. https://doi.org/10.24042/ajpm.v12i1.8831

Chamidah, A. (2023). The influence of the implementation of problem-based learning and STEM on the HOTS ability of high school's students in Surabaya. *Matematika Dan Pembelajaran*, *11*(1), 1–19. https://doi.org/10.33477/mp.v11i1.3342

Chistyakov, A. A., Zhdanov, S. P., Avdeeva, E. L., Dyadichenko, E. A., Kunitsyna, M. L., & Yagudina, R. I. (2023). Exploring the characteristics and effectiveness of project-based learning for science and STEAM education. *Eurasia Journal of Mathematics, Science and Technology Education*, *19*(5), em2256. https://doi.org/10.29333/ejmste/13128

Connors-Kellgren, A., Parker, C. E., Blustein, D. L., & Barnett, M. (2016). Innovations and challenges in project-based STEM education: Lessons from ITEST. *Journal of Science Education and Technology*, *25*, 825–832. https://doi.org/10.1007/s10956-016-9658-9

Dasaprawira, M. N., & Susanti, E. (2019). Developing mathematics questions of PISA type using Bangka context. *Journal on Mathematics Education*, *10*(2), 303–314. https://doi.org/10.22342/jme.10.2.5366.303-314

De Freitas, S. (2018). Are games effective learning tools? A review of educational games. *Journal of Educational Technology & Society*, *21*(2), 74–84.

Deb, D., Fuad, M. M., & Farag, W. (2014). Developing interactive classroom exercises for use with mobile devices to enhance class engagement and problem-solving skills. *2014 IEEE Frontiers in Education Conference (FIE) Proceedings*, 1–4. https://doi.org/10.1109/FIE.2014.7044043

Fadilah, S., Yuberti, Y., & Hidayah, N. (2023). PjBL learning model assisted by YouTube: The effect on students critical thinking skills and self-confidence in physics learning. *Online Learning In Educational Research*, *3*(1), 23–32. https://doi.org/10.58524/oler.v3i1.198

Fan, D., Fay Siu, A., Rao, H., Kim, G. S.-H., Vazquez, X., Greco, L., O'Modhrain, S., & Follmer, S. (2023). The accessibility of data visualizations on the web for screen reader users: Practices and experiences during covid-19. *ACM Transactions on Accessible Computing*, *16*(1), 1–29. https://doi.org/10.1145/3557899

Fitrianti, I., Handayani, D. E., & Suyitno, Y. P. (2020). Keefektifan media magic box terhadap hasil belajar matematika materi jaring-jaring bangun ruang sederhana. *Mimbar PGSD Undiksha*, *8*(2), 323–329.

Giang, N. N. (2021). Project-Based learning on the topic of aromatic wax production. *Journal of Education and E-Learning Research*, *8*(4), 395–407. https://doi.org/10.20448/journal.509.2021.84.395.407

Grant, M. M. (2002). Getting a grip on project-based learning: Theory, cases and recommendations. *Meridian: A Middle School Computer Technologies Journal*, *5*(1), 83.

Hacıoğlu, Y., & Gülhan, F. (2021). The effects of STEM education on the students' critical thinking skills and STEM perceptions. *Journal of Education in Science Environment and Health*, *7*(2), 139–155. https://doi.org/10.21891/jeseh.771331

Hadiyanti, N. F. D., Prihandoko, A. C., Murtikusuma, R. P., Khasanah, N., & Maharani, P. (2021). Development of mathematics e-module with STEM-collaborative project based learning to improve mathematical literacy ability of vocational high school students. *Journal of Physics: Conference Series*, *1839*(1), 12031. https://doi.org/10.1088/1742-6596/1839/1/012031

Herlita, F., Yamtinah, S., & Wati, I. K. (2023). The Effect of the PjBL-STEM model on students' critical thinking ability in science learning. *Jurnal Inovasi Pendidikan IPA*, *9*(2), 192–202. https://doi.org/10.21831/jipi.v9i2.57963

Jagodzinski, P., Phillips, M., Rogers, T., & Smith, C. (2014). Models of knowledge, learning and representation for multimedia learning environments. In *Aspects of Educational and Training Technology* (pp. 211–218). Routledge.

Kertiyani, N. M. I., Sarjana, K., & Lu'luilmaknun, U. (2023). The critical thinking ability of student with low prior knowledge who learn using problem based learning. *Matematika Dan Pembelajaran*, *11*(1), 10–19. https://doi.org/10.33477/mp.v11i1.4582

Khoiriyah, N., Abdurrahman, A., & Wahyudi, I. (2018). Implementasi pendekatan pembelajaran stem untuk meningkatkan kemampuan berpikir kritis siswa sma pada materi gelombang bunyi. *Jurnal Riset dan Kajian Pendidikan Fisika*, *5*(2), 53–62. https://doi.org/10.12928/jrkpf.v5i2.9977

Kokotsaki, D., Menzies, V., & Wiggins, A. (2016). Project-based learning: A review of the literature. *Improving Schools*, *19*(3), 267–277. https://doi.org/10.1177/1365480216659733

Korkmaz, E., & Alkan, S. (2023). The preservice teachers' approaches toward incorrect probability problems. *SAGE Open*, *13*(4), 21582440231206604.

https://doi.org/10.1177/21582440231206605
Maslihah, S., Waluya, S. B., & Suyitno, A. (2020). The role of mathematical literacy to improve high order thinking skills. *Journal of Physics: Conference Series*, *1539*(1), 12085. https://doi.org/10.1088/1742-6596/1539/1/012085
Muhammad, I., & Angraini, L. M. (2023). Student learning interest in the use of augmented reality media on triangles and quadrilaterals. *Matematika Dan Pembelajaran*, *11*(1), 32–49. https://doi.org/10.33477/mp.v11i1.4299
Nur, F., Asdar, F., & Majid, A. F. (2024). Meta analysis: The effect of cooperative learning models on students' critical thinking abilities. *Matematika Dan Pembelajaran*, *12*(1), 1–16. https://doi.org/10.33477/mp.v12i1.6479
Nurlaeli, N., Noornia, A., & Wiraningsih, E. D. (2018). Pengaruh model pembelajaran problem based learning terhadap kemampuan berpikir kritis matematis siswa ditinjau dari adversity quotient. *FIBONACCI: Jurnal Pendidikan Matematika Dan Matematika*, *4*(2), 145–154. https://doi.org/10.24853/fbc.4.2.145-154
Pamungkas, I., Zubaidah, Z., & Ijuddin, R. (2019). Penerapan model project based learning pada materi barisan dan deret aritmatika di SMK. *Jurnal Pendidikan Dan Pembelajaran Khatulistiwa (JPPK)*, *8*(3).
Prabawati, P. L. S., & Agustika, G. N. S. (2020). Project-based learning based on STEM (Science, Technology, Engineering, And Mathematics) enhancing students science knowledge competence. *Jurnal Ilmiah Sekolah Dasar*, *4*(4), 621–629.
Pradana, K. C., & Noer, S. H. (2023). Critical thinking and mathematical problem solving skills of students through schoology-assisted blended learning models. *Mathline: Jurnal Matematika Dan Pendidikan Matematika*, *8*(3), 827–844. https://doi.org/10.31943/mathline.v8i3.455
Pramasdyahsari, A. S., Setyawati, R. D., Aini, S. N., Nusuki, U., Arum, J. P., Astutik, I. D., Widodo, W., Zuliah, N., & Salmah, U. (2023). Fostering students' mathematical critical thinking skills on number patterns through digital book STEM PjBL. *Eurasia Journal of Mathematics, Science and Technology Education*, *19*(7), em2297. https://doi.org/10.29333/ejmste/13342
Pratiwi, G., Sova, F., Putra, F. G., Putra, R. W. Y., Kusuma, A. P., & Rahmawati, N. K. (2020). The influence of project-based learning (PjBL) and learning style om mathematics communication skills of junior high school students. *Journal of Physics: Conference Series*, *1467*(1), 12064. https://doi.org/10.1088/1742-6596/1467/1/012064
Prayitno, H. J., Narimo, S., Ishartono, N., & Sari, D. P. (2021). The development of student worksheets based on higher order thinking skill for mathematics learning in junior high school. *Journal of Physics: Conference Series*, *1776*(1), 12032. https://doi.org/10.1088/1742-6596/1776/1/012032
Priatna, N., Lorenzia, S. A., & Muchlis, E. E. (2020). Pengembangan model project-based learning terintegrasi STEM untuk meningkatkan kemampuan berpikir kritis matematis siswa SMP. *Jurnal Penelitian Pendidikan*, *20*(3), 347–359. https://doi.org/10.17509/jpp.v20i3.29636
Purwati, R., Hobri, H., & Fatahillah, A. (2016). Analisis kemampuan berpikir kritis siswa dalam menyelesaikan masalah persamaan kuadrat pada pembelajaran model creative problem solving. *KadikmA*, *7*(1), 84–93.
Purwoko, R. Y., Kusumaningrum, B., Laila, A. N., & Astuti, E. P. (2023). Development of open ended based mathematics e-modules to enhance students' critical thinking ability. *Mathline: Jurnal Matematika Dan Pendidikan Matematika*, *8*(1), 194–206. https://doi.org/10.31943/mathline.v8i1.337
Rahmania, I. (2021). Project based learning (PjBL) learning model with STEM approach in natural science learning for the 21st century. *Budapest International Research and Critics Institute (BIRCI-Journal): Humanities and Social Sciences*, *4*(1), 1161–1167. https://doi.org/10.33258/birci.v4i1.1727
Risti, D. (2021). Pengembangan komik interaktif soal cerita matematika berbasis TPACK untuk meningkatkan keterampilan berpikir kritis siswa kelas IV SD. *Symmetry: Pasundan Journal of Research in Mathematics Learning and Education*, *6*(2), 204–220. https://doi.org/10.23969/symmetry.v6i2.4788
Rohmah, L. A., Anggoro, B. S., & Gunawan, W. (2023). PDEODE strategy assisted by GeoGebra: Improving students' critical thinking and mathematical analysis. *Online Learning In*

Educational Research (OLER), 3(1), 15–22. https://doi.org/10.58524/oler.v3i1.203

Roesler, W. J., & Dreaver-Charles, K. (2018). Responsive eLearning exercises to enhance student interaction with metabolic pathways. *Biochemistry and Molecular Biology Education*, *46*(3), 223–229. https://doi.org/10.1002/bmb.21112

Schoenfeld, A. H. (2017). Uses of video in understanding and improving mathematical thinking and teaching. *Journal of Mathematics Teacher Education*, *20*, 415–432. https://doi.org/10.1007/s10857-017-9381-3

Shatat, F. H., Aldalalah, O. M. A., & Ababneh, Z. W. (2017). The impact of the e-book on levels of bloom's pyramid at ECT students in light of the internal and external motivation to learn mathematics and statistics. *Asian Social Science*, *13*(2), 49. https://doi.org/10.5539/ass.v13n2p49

Shaw, A., Liu, O. L., Gu, L., Kardonova, E., Chirikov, I., Li, G., Hu, S., Yu, N., Ma, L., & Guo, F. (2020). Thinking critically about critical thinking: Validating the Russian HEIghten® critical thinking assessment. *Studies in Higher Education*, *45*(9), 1933–1948. https://doi.org/10.1080/03075079.2019.1672640

Soares, F., Lopes, A. P., Cellmer, A., Uukkivi, A., Rebollar, C., Varela, C., Feniser, C., Bravo, E., Safiulina, E., & Kelly, G. (2020). Developing interactive e-contents for a mathematic erasmus+ project–challenges and experiences. *INTED2020 Proceedings*, 477–485. https://doi.org/10.21125/inted.2020.0203

Suardani, N. P., Ariyana, I. K. S., Subrata, G. H., Mastiningsih, N. N., & Windayani, N. L. I. (2023). Development of CORE model-based mathematics learning videos for grade VI students at SDN 1 Kaba-Kaba. *Metta: Jurnal Ilmu Multidisiplin*, *3*(1), 97–106. https://doi.org/10.37329/metta.v3i1.1784

Supardi, N., Rakhmawati, R., & Rinaldi, A. (2018). Lembar kerja peserta didik berbasis kegiatan transaksi kewirausahaan materi sistem persamaan linier dua variabel. *Desimal: Jurnal Matematika*, *1*(1), 49–55. https://doi.org/10.24042/djm.v1i1.2012

Tay, X. W., Toh, T. L., & Cheng, L. P. (2024). Primary school students' perceptions of using comics as a mode of instruction in the mathematics classroom. *International Journal of Mathematical Education in Science and Technology*, *55*(4), 997–1023. https://doi.org/10.1080/0020739X.2023.2170287

Ulusoy, F., & Çakıroğlu, E. (2018). Using video cases and small-scale research projects to explore prospective mathematics teachers' noticing of student thinking. *EURASIA Journal of Mathematics, Science and Technology Education*, *14*(11), em1571. https://doi.org/10.29333/ejmste/92020

Wiratman, A., Bungawati, B., & Rahmadani, E. (2023). Project-based learning integrated with science, technology, engineering, and mathematics (STEM) to the critical thinking skills of students in elementary school. *SITTAH: Journal of Primary Education*, *4*(2), 167–180. https://doi.org/10.30762/sittah.v4i2.1828

XiangXu, W., Panicker, C. M. V., & Islam, A. (2024). A study that compares traditional classroom teaching with online learning and using traditional textbooks with online learning in middle schools. *International Academic Journal of Education & Literature*, *5*(2), 1–8. https://doi.org/10.38124//ijisrt/IJISRT24MAY2486