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Mathventure SPLDV: Developing an Educational Math Game to Improve Students' Critical Thinking Skills

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ABSTRACT

This study aims to develop and evaluate Mathventure SPLDV, an Android-based educational game to enhance eighth-grade students' critical thinking on Systems of Linear Equations in Two Variables. The study used the ADDIE model in a Research and Development (R&D) approach. Data were collected using questionnaires and essay tests, and analyzed using a paired samples t-test after meeting normality and homogeneity assumptions. Validation from media and material experts showed high validity (87.78% and 93.63%), while student and teacher responses showed high practicality (89.26% and 96%). A significant improvement in critical thinking was found ($t = 2.638 > 1.6698$), indicating H_0 rejection. Based on the results, Mathventure SPLDV is recommended for classroom use as an effective tool to support students' critical thinking.

1. Introduction

In the 21st century, critical thinking is an essential skill that every individual must possess due to its important role in learning (Özelçi, 2023). This ability enables someone to effectively solve problems that arise in daily life as well as in the field of education (Setiana et al., 2021). Someone with critical thinking skills can quickly identify and formulate problems, analyze them from various perspectives, and deeply evaluate each step taken in the problem-solving process (Maričić et al., 2016). When faced with complicated issues, critical thinking abilities help students make more thoughtful and logical judgments by enabling them to properly examine, evaluate, and synthesize information. (Ennis, 2011; Laar et al., 2019). Students trained in critical thinking can apply their knowledge in real-world

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contexts and develop the ability to solve more complex problems with more innovative and effective solutions (Halpern & Dunn, 2021). With these skills, students will be able to identify relevant information and make appropriate decisions in various situations. Hence, it is essential for educators to consistently enhance instructional practices that emphasize critical thinking, as such skills are foundational competencies that students need in order to navigate real-life challenges effectively. (Efendi, 2022).

However, the reality is that students' critical thinking skills in Indonesia are still relatively low. Based on the PISA 2022 results released by the OECD, the average mathematics proficiency score of Indonesian students was recorded at 366, while the global average score was 472 (OECD, 2023). This result remains consistent with the PISA 2018 findings, which indicate that Indonesia continues to demonstrate low academic performance while maintaining a high level of equity. Additionally, the average performance of Indonesian students in mathematics, reading, and science remains below the OECD standards. Only 18% of Indonesian students achieve the minimum level 2 competency in mathematics, while the OECD average is 69%. Most Indonesian students are at level 1a, which means they can solve simple math problems with clear information but struggle to use critical and creative thinking to solve more complex problems (Trisnani et al., 2024). These findings are in line with national studies reporting that students' critical thinking skills are still far below the expected level (Agustiani & Jailani, 2023; Martyanti, 2018).

The limited critical thinking skills of students in Indonesia are reflected in their difficulties in solving problems effectively (Firdaus & Kailani, 2015). Mathematics is a discipline that contributes to the development of critical thinking skills because of its well-defined structure and the interconnectedness of its concepts (Aizikovitsh & Amit, 2010). In mathematics education, critical thinking becomes an important aspect that is honed through the ability to reason and analyze deeply, so that students can apply this understanding in problem-solving and everyday life (Munawaroh et al., 2018). Furthermore, critical thinking skills are essential for achieving success in mathematics learning. (Popova et al., 2024). Skills are essential in mathematical activities, especially in the problem-solving process (Khusna et al., 2024), as well as for solving problems rationally and making accurate decisions (Verschaffel et al., 2020). Therefore, critical thinking and problem-solving skills are interconnected (Susandi et al., 2019). A subject that demands critical thinking abilities is the Systems of Linear Equations in Two Variables (SLETV), because solving it requires the ability to analyze, understand the relationships between variables, and interpret solutions in various problem contexts.

Findings from observations and interviews with eighth-grade teachers at SMP Negeri 2 Jaten indicate that students' critical thinking abilities in the topic of SLETV are still encountering significant challenges. Daily test results on this topic showed that most students scored below the Minimum Completeness Criteria. In addition, a pretest designed to assess students' critical thinking on SLETV yielded an average score of 56.84, which falls into the low category. These findings are consisten with the study by (Maghfiroh & Dasari, 2023), which stated that classroom learning still face various obstacles that hinder the achievement of learning objectives. These obstacles include the use of less appropriate learning models, strategies, or approaches, as well as a lack of practice questions specifically designed to develop students' mathematical critical thinking skills. Similarly,

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(Pramasdyasari et al., 2024) revealed that the critical thinking skills of eighth-grade students still require significant improvement.

The students' low critical thinking skills are reflected in their tendency to memorize solution patterns for contextual problems without fully understanding the fundamental concepts. This is caused by a non-student-centered learning approach, making them more passive and only learning through rote memorization. Additionally, the lack of critical thinking training, the dominance of low-cognitive-level questions, and the habit of teachers providing example questions before tests cause students to struggle with different variations of questions (Astuti et al., 2019; Efendi, 2022). When encountering difficulties in solving math problems, students are often given direct answers instead of being encouraged to find solutions on their own. This obstructs the growth of their critical thinking skills in solving problems. (Fadhilah et al., 2021). The still conventional teaching methods also contribute to the low critical thinking skills of students. Students are not encouraged to think more deeply when learning materials are used insufficiently and passively. On the other hand, creating a more fun and exciting learning environment requires the use of interactive and engaging learning materials (Qureshi et al., 2023). Therefore, innovation in learning media and more effective use of technology are needed to enhance students' critical thinking skills.

In modern education, technology as a learning medium plays an important role in enhancing the effectiveness of the teaching and learning process. One of the most popular learning media among students is game-based learning, as it provides entertainment that makes students feel happier and more motivated while studying. Through games, students can more easily understand the material and undergo the learning process in a more enjoyable atmosphere. (Ebner & Holzinger, 2007; Fatimah & Santiana, 2017). In mathematics education, game-based learning has the potential to improve students' academic performance simultaneously (Ersen & Ergul, 2022).

Research has shown that the use of educational games is effective in supporting mathematics learning (Tristanti et al., 2021). Android-based games have been widely studied implemented in mathematics education. (Lestari et al., 2019; Qohar et al., 2021; Sarifah et al., 2022). The study by Qohar et al. (2021) indicates that the Android-based educational game they developed demonstrates a high degree of practicality, positioning it as an effective tool for mathematics instruction. Game-based learning models are considered an effective approach to fostering critical thinking skills (Yang & Chang, 2013; Cicchino, 2015). Furthermore, (Vos et al., 2011) argue that digital game-based learning fosters an environment that encourages students to engage in active critical thinking.

Based on the explanation above, the researcher is interested in developing a valid and practical educational mathematics game for eighth-grade students to be used as a learning medium. It is also expected to be effective in training and enhancing students' critical thinking skills in mathematics learning, particularly in the topic of SLETV.

2. Method

2.1. Participants

The research and development of the educational game media Mathventure

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SPLDV involved eighth-grade students from SMP Negeri 2 Jaten as participants. The study population comprised all eighth-grade students at the school. Two classes were selected as the sample through a simple random sampling method. Class VIII-G, consisting of 32 students, served as the experimental group, while Class VIII-F,also with 32 students, functioned as the control group.

2.2. Research Design and Procedures

This research uses a Research and Development (R&D) approach by developing Android-based educational game media. It utilizes the ADDIE development model(Frydenberg, 2011) which includes five stages: analysis, design, development, implementation, and evaluation. In the analysis phase, problem and needs identification are conducted to determine the type of product to be developed. The design stage aims to design various aspects necessary for product development, including creating the storyline and game flowchart, while the development stage encompasses the realization of the product design, including validation by subject matter experts and media experts, with the goal of producing a product prototype. In the implementation stage, the validated product is tested in schools through a math educational game to evaluate its practicality, with limited trials and large-scale trials. Following the trial, the evaluation stage is conducted to ascertain whether the product can enhance students' critical thinking abilities by evaluating its effectiveness in both the experimental and control groups.

2.3. Instruments

This study utilized data collection instruments in the form of tests and non-tests. The test instrument developed by the researcher was a critical thinking ability test, arranged as essay-based pretest and posttest items, referring to critical thinking indicators within the topic of Systems of Linear Equations in Two Variables (SLETV). The critical thinking indicators used in this study included understanding the problem, generating ideas relevant to the problem, determining appropriate problem-solving strategies, and rechecking the solution by providing reasons or conclusions. The topic focused on solving contextual problems related to SLETV accurately through various methods. In addition, the researcher prepared a validation questionnaire to evaluate the educational game's content, covering aspects such as content feasibility, presentation, and language. The media expert validation questionnaire included assessments of appearance, programming aspects, and ease of product use. A student response questionnaire was also used for data collection, providing a series of questions to the respondents. Additionally, a teacher response questionnaire was used to gather feedback from educators. The collected data were analyzed through processes of organization, classification, description, and conclusion drawing. A descriptive approach was employed to interpret participants' responses from tests, questionnaires, interviews, and observations.

2.4. Data Analysis

The data analysis techniques in this study consist of validity analysis, practicality analysis, and effectiveness analysis of the educational math game media. Data validation is conducted using a questionnaire that assesses the feasibility of the educational game in terms of content and media. The assessment of media

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feasibility is conducted by media expert validators, who evaluate aspects of appearance, programming, and product usage. Meanwhile, the validation of material feasibility is carried out by subject matter expert validators by assessing the aspects of content, presentation, and language. In addition to the game products, the test instruments are also validated. The mean score obtained from the validators' evaluations is subsequently transformed into a percentage to assess the feasibility and appropriateness of the learning media and test instruments for practical implementation. The next step is the practicality test of the media, which is conducted by distributing questionnaires to gather responses from students and teachers. This questionnaire assesses how easy it is to use and operate the educational game, as well as the section that provides recommendations for improvement. The data obtained is analyzed to understand user responses, including the weaknesses and shortcomings of the media. The results of the trial can be used as a basis for modifying the media to make it better for learning. The survey results are calculated using the following percentage formula,

$$P = \frac{TSe}{TSm} \; x \; 100 \; \% \tag{1}$$

Notation *TSe* refers to the total empirical score obtained, while *TSm* represents the maximum possible score. The collected data is then converted into percentages and analyzed according to validity and practicality criteria developed based on the characteristics of the assessment instrument. These characteristics are categorized into four groups. A percentage score ranging from 85.01% to 100% indicates that the product is very valid or very practical. Scores between 70.01% and 85.00% are classified as valid or practical. If the score falls between 50.01% and 70.00%, the product is considered less valid or less practical. Meanwhile, a percentage score between 1.00% and 50.00% indicates that the product is not valid or not practical.(Akbar, 2013)

An effectiveness test was conducted to show that the educational games used in this study are capable of enhancing students' critical thinking skills. Before starting the effectiveness test, it is important to ensure that the distribution of the dependent variable values is normal and homogeneous. This study involves two groups, the experimental class and the control class, each given a pretest to ensure that there are no significant differences between them. Effectiveness is assessed by comparing the scores after the critical thinking skills test between the experimental class, which received treatment with educational game media during teaching, and the control class, which did not use such media. A product is deemed effective if the average critical thinking score of the experimental class is higher than that of the control class. Based on these findings, it can be concluded that the product meets the criteria of validity, practicality, and effectiveness.

3. Results and Discussion

3.1. Analysis Stage

At the analysis stage, the identification of the needs and problems of eighth-grade students was carried out through interviews with teachers and the administration of questionnaires. According to the findings of the interview with the math teacher for the eighth grade, the teaching still only makes use of the school's textbooks, and there is still very little media utilized. The learning media used is still

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conventional, relying only on the blackboard to deliver the material. The teacher doesn't have time to create other learning media because it takes time and money, as well as the limited facilities of the school. During the learning activities, students tend to be less active and often encounter difficulties in solving mathematical problems. The teacher noted that the students' critical thinking skills require further development. This is reflected in the low assignment results, especially in solving math problems, including the topic of SLETV. Students' knowledge, particularly on this topic, is still limited. This is evident from the average score of the last daily test results, which is still below the minimum completeness criteria. In fact, 87.5% of students scored below the minimum mastery criterion of 70, indicating that most students have not yet mastered the topic of SLETV.

Students are only able to memorize concepts without truly understanding them. Students tend to rely on memorization and example solutions to answer questions and are not yet able to handle problems that require analysis or evaluation, depending on example solutions first before exams, making it difficult for them when given questions in a different format. Moreover, students' motivation to learn mathematics is very low, as evidenced by the presence of students chatting during lessons. Some students often do not focus on the lessons because the media used is less engaging for them. As a result, some students still struggle to understand the concept of SLETV.

According to the results from a questionnaire given to the students at SMP Negeri 2 Jaten, the instructors frequently employ the lecture format and have not yet incorporated a variety of instructional media. These findings are reinforced by observations during the learning process where the math teacher used group discussion methods followed by presentations, after which the teacher explained the material. The frequency that is too often acknowledged makes students feel bored and less enthusiastic. All students desire the presence of varied and innovative learning media as a medium for learning mathematics.

At this stage of the analysis, it is also stated that the initial research was undertaken by administering a test to students to establish their baseline ability in critical thinking skills. The critical thinking test was administered to 32 eighth-grade students at SMP Negeri 2 Jaten, focusing on the prerequisite material for SLETV, namely the one-variable linear equation topic. It was found that 15.63% of the students met the indicator for understanding the problem. Students still face difficulties in writing down what they know and identifying what the question is asking, based on this indicator. Regarding the indicator of generating ideas relevant to the problem, only 21.88% of students were able to meet this criterion. In this aspect, many of their abilities are still not optimal in creating mathematical models according to the context of the problem, such as writing equations that describe the relationships between variables in the question. Meanwhile, for the aspect of determining problem-solving, there are 15.63% of students. Only a portion completed all stages of the math problem-solving process in a sequential and systematic manner. For the indicator of rechecking by providing reasons/conclusions, it was found that 12.50% of students met this indicator. In this aspect, on average, students do not write the conclusion of the solution correctly.

3.2. Design Stage

Following the completion of the analysis stage, the researcher proceeded to the

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second phase of the ADDIE development model, namely the design stage. The product developed is an Android-based educational game intended to support eighth-grade mathematics learning, specifically focusing on the topic of SLETV. This game, titled *Mathventure SPLDV*, is designed as an adventure game. The design stage involved preparing the content material, creating the storyline, and developing the game flowchart, all aligned with the learning objectives and expected competencies related to SLETV.

On the initial screen, players are introduced to a character known as the material gatekeeper. The game consists of three levels, each starting with players interacting with in-game characters to unlock chests containing contextual problems. Players then explore the environment with the mission of solving these problems and collecting keys obtained from character checkpoints. The visual display was created using Canva, while audio features such as cheerful background music and sound effects were added to enhance the gameplay experience. Unity was selected as the development platform for building the application. At this stage, the researchers also developed various instruments for evaluating the educational game, including validation, practicality, and effectiveness assessment sheets in the form of questionnaires and test instruments.

3.3. Development Stage

At the stage of game product development using the Unity application, the initial game screen displays an adventurer character who will explore a village. Instructions are provided to control the character's movement using the left, right, and up directional buttons. The left button moves the character to the left, the right button moves it to the right, and the up button allows the character to jump. This screen also includes an info menu that contains the profile of the educational game developer. The material menu display, in which part of Image 2, presents the learning content available in this educational game. The content includes a summary of the SLETV material, encompassing learning objectives, essential concepts, sample problems, and solution strategies, such as the substitution, elimination, and combination methods.

On the game adventure page, in this section, the character explores a village after encountering a problem or challenge from the previous chest. Players must complete all stages by interacting with characters at each checkpoint. There are four posts, namely post 1 to post 4. Each character at each post presents a challenge to the player, which involves solving problems related to SLETV sequentially at each stage. Each character post represents one stage, from "Fact Exploration" to "Critical Conclusion." If the player's answer is correct, the character will give a key. Players must collect all the keys from each checkpoint to advance to the next level.

During the exploration, players will encounter several obstacles. On this page, there are also three heart symbols in the top left corner, indicating the player's three chances. If the player answers incorrectly or hits an obstacle, then the opportunity will be reduced by one. If the player's chances run out, the game will end (game over). Additionally, there is a map menu that keeps a record of previous character paths, such as cases to be solved and every answer given at previous checkpoints. This helps players track their progress and gain further insights into their journey in completing the game. The display of the educational game "Mathventure SPLDV" is shown in Figure 1.

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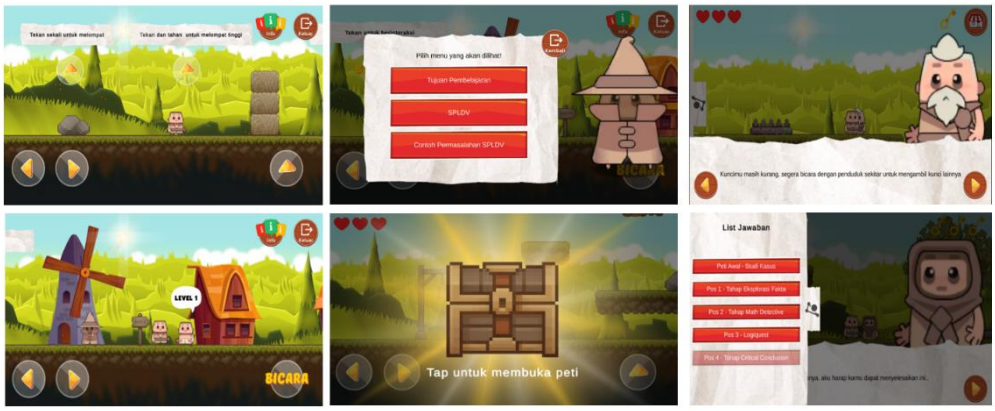

Figure 1. Display of the Educational Game "Mathventure SPLDV"

After the game media was developed, the researchers then conducted validation. Validation is part of the implementation phase in the ADDIE development model, aimed at obtaining feedback from experts regarding the validity of the learning media, both in terms of content and media. This validation is conducted through the distribution of questionnaires to media experts and content experts.

The evaluation conducted by media experts using a questionnaire addressing appearance, programming, and usability aspects resulted in an average validation score of 87.78%, categorizing the media as "very valid." Meanwhile, the assessment results from content experts through a questionnaire evaluating the aspects of content feasibility, presentation, and language show an average validation percentage of 93.63%, also categorized as "very valid."

3.4. Implementation Stage

In the implementation stage, the validated product was tested in the school on eighth-grade students to evaluate its practicality. The trial phase in this development included a limited-scale trial (group trial) and a field trial. The group trial was conducted with 32 students from class VIII-G at SMP Negeri 2 Jaten. The practicality assessment of the educational game product was obtained through response questionnaires from teachers and students. Following the implementation of the learning process using the game-based media, students were asked to complete response questionnaires to evaluate their perceptions and experiences. Meanwhile, the mathematics teacher at SMP Negeri 2 Jaten completed the teacher response questionnaire.

Based on the results of the student response questionnaires, a practicality score of 89.26% was obtained, while the teacher's response score was 96%. Thus, it was concluded that the educational game product met the criteria of being very practical. Therefore, the practicality indicators of the game were fulfilled, as evidenced by the student and teacher response questionnaires. In the field trial, after obtaining valid and practical results, a large-scale trial was conducted. The field trial was conducted with class VIII-G as the experimental group, comprising 32 students, and class VIII-F as the control group, also with 32 students. The experimental group utilized the educational game media during learning, whereas the control group did not use the educational game media.

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3.5. Evaluation Stage

For the purpose of determining how effectively the product has improved students' critical thinking abilities, evaluation is the final stage in the development process. An effectiveness test was conducted on the developed educational game media following the completion of the trial phase. Prerequisite tests, such as homogeneity and normality tests, were performed beforehand. According to the normality test results, data from both the experimental class (L-count = 0.118 < L-table = 0.159) and the control class (L-count = 0.136 < L-table = 0.159) were normally distributed. The homogeneity test, conducted using Excel's F-test, yielded an F-calculated value of 1.380, which is less than the F-table value of 1.822, indicating that the data were homogeneous. Next, an equivalence test was conducted to ensure that the initial scores (pretest) between the experimental and control classes were comparable. The results indicated no significant difference at the beginning of the learning process. After confirming that all prerequisites were met, learning activities proceeded with the experimental class using the educational game media, while the control class employed conventional methods. Following the learning sessions, normality and homogeneity tests were performed again on the posttest data, confirming that the data remained normally distributed and homogeneous.

To evaluate the effectiveness of the educational game, a one-tailed t-test was performed. The analysis yielded a t-observed value of 2.638, which lies within the critical region (DK= {t | t > 1.6698}), leading to the acceptance of H_1. Therefore, a significant difference exists between the experimental and control groups, demonstrating that the Mathventure SPLDV educational game media effectively improves students' critical thinking skills.

The enhancement in these skills is closely related to the design and characteristics of Mathventure SPLDV, which is specifically designed as an adventure-based educational game to encourage students to actively solve contextual problems related SLETV. This game integrates four critical thinking indicators: understanding the problem, considering ideas according to the problem, determining problem-solving and rechecking by providing reasons/conclusions. The four indicators are integrated into the game flow through four thematic stations: *Fact Exploration*, *Math Detective*, *LogiQuest*, and *Critical Conclusion*.

Each station challenges students to solve problems step by step with an approach aligned with critical thinking stages. In playing, students become accustomed to evaluating information, making decisions, and drawing conclusions based on relevant arguments. Thus, the learning process becomes not only meaningful but also gradually fosters critical thinking skills. This is in line with the findings of Ismail et al. (2022) ,who assert that critical thinking skills are more effectively developed through contextual problem-based mathematics learning relevant to real life, as it helps students connect concepts with their experiences. This is also supported by the explanation of (Ailiyyah et al., 2024), who noted that contextual mathematical problems can encourage students to engage in critical thinking during learning. Furthermore problem-solving in mathematics also trains logical, analytical, and critical thinking skills(Trisnani et al., 2024).

This research developed an educational game called Mathventure SPLDV, aimed at improving the critical thinking skills of eighth-grade students at SMP

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Negeri 2 Jaten, particularly on the topic of SLETV. The game was evaluated for its validity, practicality, and effectiveness, with results showing that it met all three criteria, indicating its feasibility for classroom implementation. These findings are consistent with various previous studies. Research by Lestari et al. (2019) shows that Android-based educational games can enhance students' critical thinking skills. According to Angelelli et al. (2023), the integration of game elements into instructional practices can significantly enhance students' abilities in critical thinking, reasoning, and problem-solving. Similarly, Game-Based Learning (GBL) provides simulated real-world environments within a safe setting, allowing learners to explore various strategies, receive immediate feedback, reflect on their decisions, and further strengthen their critical thinking skills) (Mao et al., 2022). Moreover, educational games with an adventure concept have been proven effective in developing creativity and decision-making abilities in the context of problem-solving (Efendi, 2022).

Mathventure SPLDV is a well-designed adventure-based educational game that systematically integrates critical thinking indicators into contextual problem-solving activities. Its structured stages, real-world relevance, and engaging gameplay format make it a powerful tool to foster students' critical thinking skills in mathematics. However, the scope of the game is limited to a single mathematical topic. Therefore, further research is recommended to expand the game content to other mathematical concepts in order to maximize its applicability and impact in broader educational settings.

4. Conclusions

This development resulted in an educational mathematics game designed to enhance students' critical thinking skills. The final product, titled Mathventure SPLDV, was found to be valid, practical, and effective. The validity of the game was established based on evaluations by media and subject matter experts, with average scores categorized as very valid. The practicality of the media was assessed through questionnaires administered to both students and teachers, which indicated that the game was considered very practical. The effectiveness of the product was evaluated using a hypothesis test that compared the mean scores of effectiveness data between the experimental class and the control class. The results revealed a significant difference between the two groups, indicating that the implementation of Mathventure SPLDV had a positive impact on improving students' critical thinking skills. Therefore, it can be concluded that Mathventure SPLDV is an effective learning media and is suitable for use as a supplementary tool in the mathematics learning process.

Author Contributions

The first author was responsible for collecting, processing, and analyzing the data; designing and developing the product; and preparing the initial draft of the scientific article. The second and third authors provided input and suggestions in refining the research, data analysis, and manuscript writing.

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Declaration of Competing Interest

There are no conflicts of interest to declare.

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