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The Development of Scratch Based Interactive Mathematics Learning Media "Zuma Function" to Enhance Understanding in Relations and Functions

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Abstract: Objective: This study aims to describe the process of developing educational multimedia, specifically the "Zuma Function" game, using Scratch programming for mathematics learning on the topic of relations and functions. Methods: The research employed a Research and Development (R&D) approach, following the ADDIE model (Analysis, Design, Development, Implementation, and Evaluation). The study involved 35 mathematics education students from a university in West Java and 6 eighth-grade students from a junior high school in Bandung, Indonesia. Data were collected using various instruments, including questionnaires, tests, interviews, and documentation. Findings: The developed learning media was evaluated by experts, receiving a material expert test score of 81%, and a learning media expert test score of 83%, both categorized as feasible. The functionality test, measured through User Acceptance Testing, yielded an average score of 85.1%, indicating a very feasible category, while the effectiveness test showed a 30.5% improvement in students' conceptual understanding, with scores rising from 64.83 to 95.33. Conclusion: Based on the study's findings, the Scratch-based multimedia for teaching relations and functions in mathematics was successfully developed using the ADDIE model. Positive user feedback and significant improvements in student test scores suggest that this multimedia is effective in enhancing students' understanding of the concept, though there are areas that could be further refined.

Keywords: learning media, mathematics game, function, Scratch, ADDIE.

▪ INTRODUCTION

The development of science and technology (IPTEK) continues to advance along with the passage of time. This progress has significantly influenced various fields, including education, particularly in mathematics learning. Mathematics is a discipline that plays a crucial role in the advancement of knowledge and technology. It is not only essential for everyday life but also contributes significantly to the development of students' cognitive and analytical abilities at all levels of education (Schoenfeld, 2016). Through mathematics, students learn how to think critically, reason logically, and engage in mental processes that foster a continuous flow of thought, culminating in a deeper understanding of the material being taught.

Understanding, as emphasized by Mayer (2001), is a fundamental element of the learning process, and effective learning models must focus on fostering this understanding. Key components of understanding include comprehending the object itself, recognizing its relationship with similar objects, and understanding its interaction with objects of different types. Hewson & Thorley (1989) define understanding as a conception that can be grasped by students, enabling them to express the concept clearly and explore its various possibilities. Thus, achieving such understanding, particularly in mathematics, is challenging. According to Hiebert, J. & Carpenter (1992), understanding in mathematics can be observed through behaviors such as recognizing concepts, laws, principles, and mathematical generalizations; converting mathematical forms; and

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following explanations effectively. In mathematics learning, mathematics understanding becomes crucial, and it highlights the importance of ensuring that students not only memorize mathematical material but also deeply understand it. Such depth of understanding allows students to grasp the underlying concepts and essence of the subject matter presented. However, mathematics is often perceived as difficult and abstract by students, making it a challexnging process for them.

This complexity and abstraction pose significant obstacles to comprehension, and inhibit students from digesting concepts effectively (Davis and Sumara 2014). Moreover, several factors also contribute to students' low levels of understanding, including limited conceptual grasp (Hiebert and Lefevre 2013), low interest and motivation in learning mathematics (Pe Dangle, 2021). and the lack of engaging learning approaches (Freeman et al. 2014; Hattie 2008). To address these challenges, there is a pressing need for innovative and engaging learning approaches that can enhance students' understanding of mathematical concepts, particularly relations and functions. One promising strategy involves the use of effective learning media.

The use of learning media plays a critical role in supporting students' understanding of mathematical concepts and achieving the desired learning objectives. According to Mayer (2001), learning media function to create effective learning environments, accelerate the teaching-learning process, and facilitate students' comprehension of classroom material. Research has consistently demonstrated that learning media can enhance students' cognitive abilities, engagement, interest, motivation, and creativity when faced with learning challenges (Higgins, Xiao, and Katsipataki 2012; Kozma 1991; Zhang et al. 2006) further concluded that the appropriate use of learning media not only enriches students' learning experiences but also actively engages them in discovering and understanding mathematical concepts.

In recent years, technology-based learning media have become a central focus of modern educational studies. These media have proven effective in addressing students' difficulties in understanding abstract material, such as relations and functions. The evolution of learning media has kept pace with technological advancements, offering diverse resources to meet students' needs and preferences. Modern technology has revolutionized education by providing easy access to a wide range of learning resources that greatly support teaching and learning in today's era. Modern tools, such as apps, softwares, and other interactive tools, enable teachers to design engaging and interactive mathematics lessons, specifically through an interactive multimedia.

Interactive multimedia is a digital learning media that integrates various formats, including text, images, audio, video, and interactive elements, to create a richer learning experience. This approach fosters active student participation, enhances critical thinking, and inspires creativity. One notable application is the Scratch platform. Scratch can be utilized to develop interactive learning media that offer an innovative approach, particularly in the context of teaching mathematics. However, to better measure the effectiveness of this approach, research using Scratch as an interactive learning medium should be compared with other technology-based approaches, such as Android-based applications or web-based educational games. This comparison could provide broader insights into the advantages and limitations of various types of technology in supporting mathematics learning.

In this context, the Zuma Function multimedia tool has been designed using Scratch to facilitate student interaction with relation and function materials. This tool allows students to visualize the outcomes of relations and functions. It aligns with the learning objectives outlined in the Independent Curriculum for phase D, which requires students to understand relations and functions (including domain, codomain, and range) and present them in arrow diagrams, tables, paired sets, and graphs. Furthermore, students are expected to present, analyze and solve problems involving relations, functions, and linear equations. The Zuma Function multimedia tool supports these objectives by facilitating students to explore relations and functions through visual and interactive media, thereby enhancing comprehension

Research by Mayer (2005) further highlights the advantages of interactive multimedia compared to other learning media, as interactive multimedia promotes active student engagement by involving them directly in its operation. For example, in the Zuma Function multimedia tool, students can observe how function equations are formed by analyzing input and output values. Dede (2009) also emphasized that interactive multimedia increases students' enthusiasm for learning. This is supported by Hwang & Chang (2011), whose findings indicate that technology-based multimedia improves learning outcomes through collaborative and interactive activities. However, despite its numerous advantages, Scratch-based multimedia still has limitations, as indicated in prior research.

One of the identified shortcomings in existing research is the lack of studies examining the use of Scratch-based interactive multimedia for teaching relations and functions. Therefore, this study aims to develop a Scratch-based interactive multimedia tool, Zuma Function. The goal is to assist students struggling with this material, in order to enhance their conceptual understanding of relations and functions and ultimately improve overall learning outcomes.

▪ METHOD

Participants

The participants in this study were eighth-grade students from Bandung Regency who had previously studied relations and functions. Using purposive sampling, six students were selected based on specific research criteria, particularly their prior understanding of the concept of relations and functions. The study was conducted in May 2024 to evaluate improvements in students' comprehension of relations and functions.

Research Design and Procedure

The research method employed in this study is Research and Development (R&D), which involves developing new products or improving existing ones (Okpatrioka 2023). The study focused on the development of learning media using ADDIE model, which consists of five stages: Analysis, Design, Development, Implementation, and Evaluation. 1) The Analysis stage involved understanding students' needs and learning conditions to identify problems that would form the foundation for developing the interactive multimedia tool. The aim was to ensure that the product addressed the identified challenges effectively. 2) The Design stage involved creating a storyboard for the interactive learning media. The design team included five individuals, comprising three students and two lecturers. The process was conducted at a state university in West Java over five months. 3) In the Development stage, the interactive learning media was created using Scratch, integrating engaging features. Validation tests were also conducted by material and multimedia experts to ensure the product's validity and readiness for implementation. 4) The Implementation stage consists of product trials, starting with functionality testing through User Acceptance Testing (UAT) on mathematics education students at a university in West Java. The results of User Acceptance Testing were in the form of questionnaires to provide detailed feedback, and three participants were chosen for in-depth follow-up interviews. Following this, the product's effectiveness was tested on eighth-grade students at a junior high school in Bandung. A pre-test was administered to evaluate the students' initial understanding before using Zuma Function, and a post-test was conducted afterward to measure their understanding after using the media. 5) The Evaluation stage involved assessing the product's functionality based on the results of the User Acceptance Testing and making necessary improvements to ensure optimal performance.

Instruments

To collect the data, the instruments used in this study included both test and non-test instruments to achieve the research objectives. The test instrument was designed to measure students' conceptual understanding of relations and functions. It was developed by the researchers and validated by a mathematics education expert to ensure its validity and relevance on examining students' understanding of relations and functions. There are five questions in the test, which assess students' comprehension of key indicators, including 1) determining relations and functions from two sets, 2) distinguishing functions from non-functions, 3) identifying domains, codomains, and ranges for relations or functions, 4) presenting functions in various forms, and 5) solving contextual problems related to functions. Each question aligned with a specific indicator. To ensure that the results reflected students' independent thinking, they were prohibited from referring to books, using calculation tools, or seeking assistance from peers during the test.

Non-test instruments, on the other hand, included various types of questionnaires, namely 1) the material expert test questionnaire, 2) the media test questionnaire, and 3) the User Acceptance Test (UAT). Each questionnaire is carefully designed to evaluate specific aspects of the media or learning materials with indicators that align with the focus of each questionnaire. The material expert test questionnaire ensures the material's alignment with curriculum standards, the accuracy of its content, and its usefulness in achieving learning objectives. This questionnaire evaluates material aspects, language aspects, and presentation aspects. The material aspect includes indicators such as 1) the suitability of the material with basic competencies, 2) the alignment of the material with the indicators, 3) the accuracy of the material, 4) the clarity of the material, examples, questions, discussions, and games, 5) the alignment of the material with the games, 6) the availability of interactive materials, 7) the availability of contextual materials, and 8) the material's relevance and timeliness. The language aspect assesses 1) the use of correct and appropriate language as well as 2) terms consistent with the relevant scientific field. The presentation aspect evaluates the systematic, logical, coherent, and clear presentation of material.

The media expert test focuses on assessing the quality of the learning media in terms of design, language, and user-friendliness, ensuring it effectively supports the learning process. Within the design aspect of the Scratch learning media, the indicators include 1) the background design and multimedia animation, 2) Scratch learning, 3) the clarity of the text, 4) the presentation of supportive images, 5) the appropriateness of image layout, 6) the size and quality of images, 8) the use of visuals and audio that enhance understanding without disturbing students' focus on learning the material, 9) the integration of contextual animations, and 10) the inclusion of interactive and engaging animations. The language aspect is evaluated based on the quality of language use. In the ease-of-use aspect, the indicator assesses the overall user-friendliness of the Scratch learning media. The material expert and media expert testing process involves a mathematics education expert with specific competencies in learning materials and media to validate and assess the designed learning media for its relevance and reliability.

User trials aim to evaluate the user experience with the learning media. The user trial questionnaire is developed based on several indicators to ensure that the media is academically relevant, user-friendly, and effective in enhancing the learning experience. The indicators in the User Acceptance Test (UAT) include: 1) Appearance, which evaluates the visual quality of the media such as graphic design, layout, and color schemes; 2) Material content, which assesses the accuracy and quality of the presented material; 3) and Program functionality, which examines technical and functionality aspects, ensuring the program runs smoothly with fully operational features based on its design and no technical issues such as errors or slow loading. Furthermore, 4) the Interest indicator measures the extent to which the media captures and maintains the user's attention, particularly that of students. 5) The Sound indicator evaluates the quality of the audio components in the learning media, while 6) the Usefulness indicator measures the practical benefits the media provides to users. Each indicator is represented through a combination of open-ended and closed questions, ensuring a comprehensive assessment of the learning media's performance and impact.

Data Analysis

Data analysis techniques for test and non-test instruments were conducted differently to align with the characteristics of the data collected. The test instrument was employed to measure the improvement in students' conceptual understanding of relation and function material. The results of the test were analyzed using the N-Gain formula, which evaluates the effectiveness of the learning approach based on the increase in students' conceptual understanding. The N-Gain formula calculates the difference between the initial score (pre-test) and the final score (post-test), normalizing this difference against the maximum possible score. The degree of improvement is categorized as low, medium, or high, depending on the N-Gain value achieved.

Non-test instruments, such as questionnaires used in the material expert test, media expert test, and User Acceptance Test, were analyzed using a Likert scale by calculating the average score for each indicator. For the User Acceptance Test, responses to open-ended questions were analyzed qualitatively by identifying recurring patterns, themes, and user perspectives on the learning media. To ensure the accuracy and validity of the findings, this study integrated multiple data sources, including results from the User Acceptance Test questionnaire and responses from semi-structured interviews. Initially, user responses were examined to identify consistent patterns or themes related to their interaction with the Zuma Function learning media. These findings were then cross-referenced with insights derived from interviews, which provided additional context and elaboration on user experiences. By comparing and contrasting data from diverse sources, researchers were able to identify the strengths and weaknesses of the learning media, as well as opportunities for further development. This process was further enhanced through the triangulation method, ensuring the validity and reliability of the research findings. The triangulation approach offered a more comprehensive and nuanced understanding of user interactions with the product, thereby contributing to a deeper evaluation of its overall effectiveness.

▪ RESULT AND DISSCUSSION

Analysis

In the analysis stage, a needs assessment was conducted to identify the challenges and requirements students face in understanding the material on relations and functions. This analysis involved observation and interviews with mathematics teachers at a State Junior High School (SMP) in Bandung. The selected learning topic, "Relations and Functions," is a critical component of the curriculum. At the end of Phase D, students are expected to achieve specific learning outcomes, including the ability to understand relations and functions (domain, codomain, range) and represent them using arrow diagrams, tables, paired sets, and graphs. Furthermore, students should be able to present, analyze, and solve problems involving relations, functions, and linear equations.

Findings from observations and interviews with a mathematics teacher revealed that material delivery predominantly relies on the lecture method or direct approach using basic learning media, such as PowerPoint presentations created by the teacher. Despite these efforts, students often struggle to focus and grasp mathematical concepts effectively eventhough the topic has been explained before. This highlights the need for alternative media that can enhance students' interest, motivation, and conceptual understanding in mathematics. Teachers expressed limited awareness of more engaging multimedia alternatives, such as interactive learning games, that integrate dynamic content and allow for independent student use. These challenges further emphasized the necessity for developing interactive multimedia tools like the Zuma Function game to address these gaps.

The Zuma Function game is designed to integrate relation and function materials through an engaging, contextual approach. Its development focuses on several key indicators: (1) understanding the concept of relations, (2) understanding the concept of functions, (3) determining the notation, domain, codomain, and range of a relation or function, and (4) solving problems related to relations and functions. The game stages are progressively structured to strengthen students' conceptual understanding. For example, activities include matching data pairs to identify relations, solving puzzles that involve function representations, and deriving function equations based on input and output values. This gamified approach is expected to enhance student understanding of relations and functions while fostering greater engagement in learning.

Design

In this stage, the design of the multimedia was created by determining the main concept, which was based on the Zuma game and focused on relations and functions. Thus, the multimedia was named "Zuma Function". A team of five people developed a storyboard that outlined each scene and game flow. The materials were aligned with the basic competencies on the topic of relations and functions. The game Zuma Function starts with a visually attractive frame, featuring a background resolution of 1024x768 pixels. The title "Zuma Function" is displayed with a dynamic animated effect, immediately capturing the player's attention. After clicking the Start button, players are introduced to the main menu. The main menu displays several sections, including the profile menu (containing the identity of the multimedia developer), the indicator menu (outlining the expected learning objectives), the material menu (which includes interactive materials and questions), and two games. Game 1 focuses on determining output values, and Game 2 focuses on identifying functions based on input and output values. The materials for the topic of functions were taken from textbooks and additional references from online sources, and the visual design was created using Canva.

Audio elements play a significant role in enhancing the gaming experience. The background music is cheerful, creating an engaging atmosphere. As players progress through the levels, they hear audio cues that match the material being presented, such as specific sounds related to the Zuma game and other in-game actions. The inclusion of audio material further complements the educational aspect of the game, keeping students engaged while reinforcing the learning of relations and functions.

Development

At this stage, the development of the game-based learning media took place using the Scratch application, following the plan from the previous stage. Below are some of the displays of the game designed with Scratch for the topic of relations and functions.

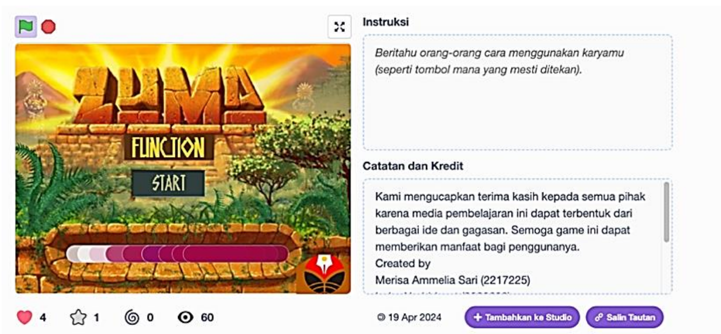

Figure 1. Initial display of the game program

This game can be accessed conveniently through https://scratch.mit.edu/projects/993304019 and provides a user-friendly interface for new players. The initial display of the game is shown in Figure 3. To begin, users press the green flag button, after which the screen displays the game title, Zuma Function, along with a start button. By clicking the start button, the game transitions to the initial input screen, where users are prompted to enter their name. After confirming by clicking the "OK" button, the interface navigates to the main menu, as illustrated in Figure 2.

The game menu display, as shown in Figure 2, presents buttons that guide the learning flow for the topic of relations and functions. The game consists of five main menus that players must navigate to complete the game: the profile menu, indicator menu, material menu, game menu 1, and game menu 2. Each menu serves a distinct purpose. The profile menu provides information about the identity of the game designer. The

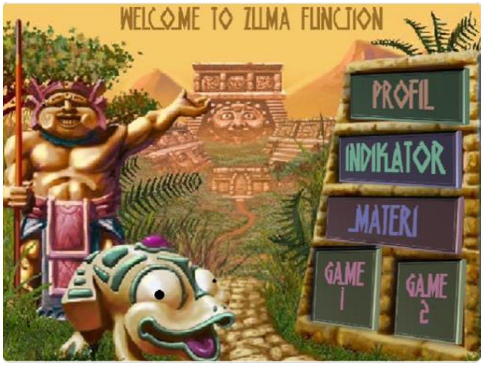

Figure 2. Game menu display

indicator menu outlines the learning objectives to be achieved through the game. The material menu delivers an in-depth explanation of the concepts of relations and functions, including interactive illustrations designed to enhance student understanding. Game menu 1 and game menu 2 consist of challenges and interactive activities aligned with the themes of relations and functions, requiring players to overcome specific tasks at each level. If the player selects the material button, the subsequent display introduces an array of explanations and questions to reinforce learning as shown below.

Figure 3. Question material display

Figure 3 displays the question material with an animated frog named Adventure Frog. The frog provides guidance for navigating the game and explains the rules at each level. The material is divided into five levels, each covering a different aspect of relations and functions: Level 1: Relations, Level 2: Domain, codomain, and range, Level 3: Functions, Level 4: Forms of function presentation, and Level 5: Problem-solving with functions. The material for this level include several matching questions, multiple-choice, and true or false questions. Players can enter each level by clicking on the corresponding stone-shaped buttons (levels 1 to 5).

Figure 4 shows the content for level 1, which covers relation material. It includes a discussion of open-ended sentences and matching questions. Players must match the statements correctly and can click the “next” arrow to continue. Upon completing a level, players are rewarded and can proceed to the next one until they complete all five levels. After finishing the material, Figure 5 appears. Once all questions from level 5 are completed, Figure 5 provides instructions to proceed to either Game 1 or Game 2. If players choose Game 1, the following display will appear

Figure 4. Level 1 relation material display

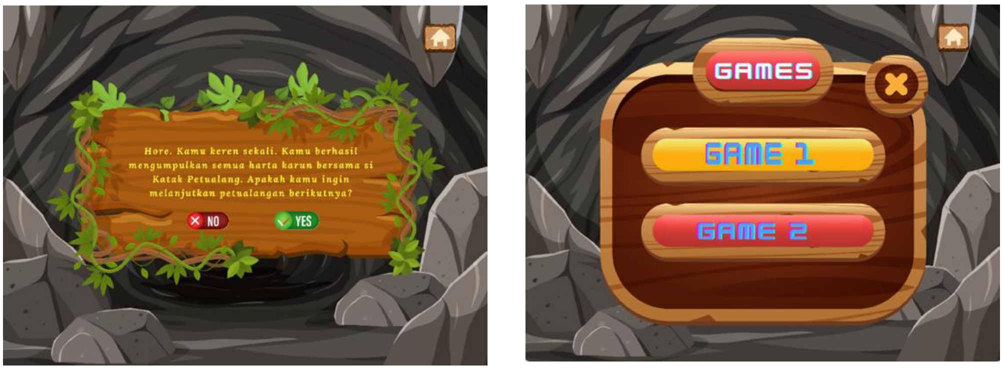

Figure 5. Final Material Display

Figure 6. Game 1 display, zuma function

Figure 6 displays the Zuma Function game, designed to teach the concept of functions. The game starts with a background labeled “Zuma Function,” and players can initiate the gameplay by pressing the start button, which leads to the selection of game levels. There are five levels in total, each with increasing difficulty. Players must click on one of the level buttons to progress to the next page. The game features a frog character that shoots a ball containing an input value towards another ball representing the output value (range), as indicated by the function equation displayed above the frog's head. Points are awarded when the ball shot by the frog successfully collides with the correct output value ball according to the function equation. Upon completing this game, a victory screen appears, confirming that the player has achieved the maximum score. After finishing the first game, players can proceed the second game, as illustrated in Figure 7.

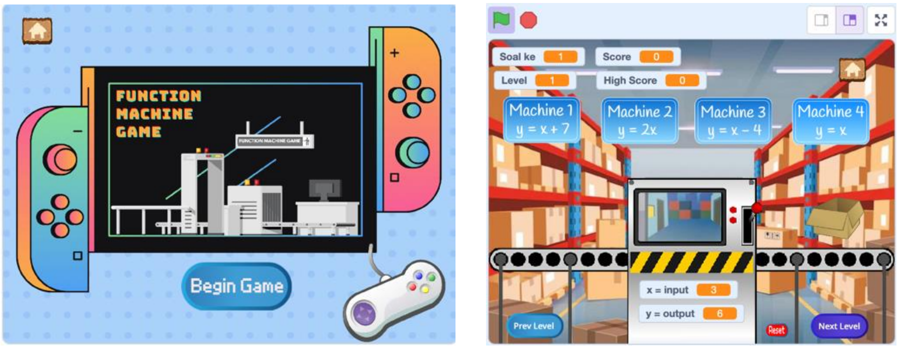

Figure 7. Game 2 display, function machine

Figure 7 shows the "Function Machine Game", where players interact with a machine that processes input values and generates output values. The game begins with a package box containing input values that pass through the machine, producing corresponding output values. Afterward, a set of buttons appears, each containing a different function equation. To start, players press a red handle, which activates the machine, moving the package box with the input values through it to generate output values. Players are then prompted to select the correct function equation from the buttons. If the chosen function matches the input and output values displayed, players score points. If incorrect, the game provides feedback, instructing the player to select the right function equation.The game features three levels, each progressively more challenging, and each level presents 11 questions. Players must correctly match functions at each level to advance.

After the development of Zuma Function, repeated testing was conducted by the creators and developers with some revisions prior to the implementation testing. To ensure the accuracy and feasibility of the multimedia, the researchers conducted validity testing consisting of material and media validations. Two lecturers from the Mathematics Education field at a university in Bandung, West Java were involved in validating both the content and media design. Based on their feedback, the multimedia tool was deemed feasible, with minor revisions before the implementation testing was performed. A functionality test was then employed on undergraduate students in Mathematics Education in a university in Bandung, West Java, followed by a limited effectiveness testing with junior high school students. The feasibility validation of the multimedia game was conducted by two experts: a material expert and a learning media expert. The material expert awarded a validity score of 81%, while the learning media expert assigned a score of 83%. Both scores fall within the "valid" category, These results confirm that the developed multimedia meets the criteria for use in educational settings, both in terms of material content and media quality.

Implementation

At this stage, the multimedia application was tested to gather user responses. The development of the Scratch-based learning media was successfully completed, and functionality and effectiveness tests were subsequently conducted. The functional testing aimed to ensure that all features of the application operated according to the predetermined specifications. This testing was carried out using User Acceptance Testing (UAT) to assess user responses to the learning media. A total of 35 Mathematics Education students at a university in West Java participated by filling out open-ended and closed questionnaires distributed via Google Form.

The closed statements and open-ended questions were coded to facilitate the analysis of the responses. The closed statements included: The visuals and text in this game are clear and well-presented (Q1); The features or buttons in this game are easy to use, making it enjoyable to play (Q2); After using this game, I have a better understanding of the topic of functions (Q3); The material in this game is complete and aligns with the learning indicators (Q4); I had no difficulty accessing this game (Q5); The game runs smoothly without any errors (Q6); I enjoyed using this game (Q7); Using this game motivates me to learn mathematics (Q8); The background sound in this game is pleasant (Q9); The background sound in this game is distracting (Q10); This game helps me better understand mathematics, particularly the topic of functions (Q11); I can experience interactive learning through this game (Q12).

The open-ended questions included: How do you rate the overall appearance of this game? (Q13); Are there any conceptual errors in this game? If so, explain (Q14); How easy is it to operate this game? Please explain (Q15); Does this game motivate you to learn? Please explain (Q16); Does the background sound in this game make you feel more engaged? Please explain (Q17); How useful is this game for learning mathematics? Please explain (Q18). The results from the user acceptance testing are summarized in Table 1.

Table 1. Results of the user acceptance testing

No	Indicators	Percentage	Category
1	Interface	84%	Very Good
2	Content	94%	Very Good
3	Program	75%	Good
4	Interest	90	Very Good
5	Sound	87%	Very Good
6	Usefulness	93%	Very Good

Based on the data in Table 1, prospective mathematics teachers showed a very positive attitude toward the developed online games, with an average score reaching 80% across all indicators. This finding aligns with previous studies indicating that educational games generally receive positive feedback. The responses from the participants regarding various aspects of the game reveal both positive feedback and areas for improvement. For question 13, concerning the game's display, respondent P23 finds the game display interesting and nostalgic, with attractive visuals. P31 agrees that the image display is good and that the features and buttons are user-friendly, though they note that some text is too small, and the resolution appears broken at times. P33 echoes these sentiments, commenting that the game design evokes childhood memories and that the overall appearance is appealing.

In response to question 14, which addresses the material's content, P23 mentions that the material presented is complete and aligns with achievement indicators. P31 confirms that there are no material errors, as the content matches the intended learning concepts. P33 adds that the question material is accurate and conforms to educational standards, making it clear and easy for students to understand.

Regarding gameplay and functionality issues in question 15, P23 highlights a bug where pressing the home icon during level 4 causes sprites to remain visible and reappear on the home screen. P31 points out that matching elements during the material chapter is challenging because they need to be precisely placed within a circle. P33 mentions a similar issue at level 4, where a sprite remains visible when switching slides.

In response to question 16, which evaluates the game's motivational impact, P23 states that the game is interesting and can motivate students to learn mathematics, offering an engaging alternative to reading from books. P31 agrees, noting that the game motivates students by combining learning with fun challenges, thus enhancing the learning experience through gamification. P33 simply agrees, affirming that the game motivates students to learn mathematics.

For question 17, regarding the sound quality, P23 appreciates the sound quality, specifically noting that the correct-answer sound provides a sense of satisfaction. P31 mentions that the game feels empty during gameplay, especially when answering questions, and suggests adding soft, calming background music to improve the atmosphere and reduce stress. P33 notes that the sound aligns with the game’s theme.

Finally, in response to question 18, which assesses the game's usefulness in learning mathematics, P23 finds the game useful for learning mathematics, particularly through the use of Scratch, which helps students understand functions more easily. P31 agrees that the game presents the material clearly, making it an effective tool for interactive learning. P33 states that the game provides an interactive and enjoyable learning experience, which increases motivation and engagement.

Based on Table 1 and the interview results, it can be concluded that the “Zuma Function” learning media received highly positive feedback, with an average user rating of 85.1% across all evaluated aspects. This indicates that users rated the media in the “very good” category.

Following the results of the functionality test performed through a user acceptance test, the next phase involved testing the effectiveness of the media. This was done by comparing students’ conceptual understanding before and after using the “Zuma Function” multimedia. Initially, a pre-test was conducted to gauge students’ understanding before exposure to the media. Afterward, students engaged with the multimedia during their learning process, and a post-test was administered to assess their understanding after using the media. In terms of learning outcomes, the average pre-test score prior to using the Zuma Function multimedia game was 64.83. After utilizing the multimedia, the average post-test score increased significantly to 95.33. This reflects a score improvement of 30.5 points. The results, analyzed using the N-Gain formula, produced an N-Gain score of 0.87, further proving that there is a substantial increase in students’ conceptual understanding after using the multimedia. The increase in scores is shown in the graph below.

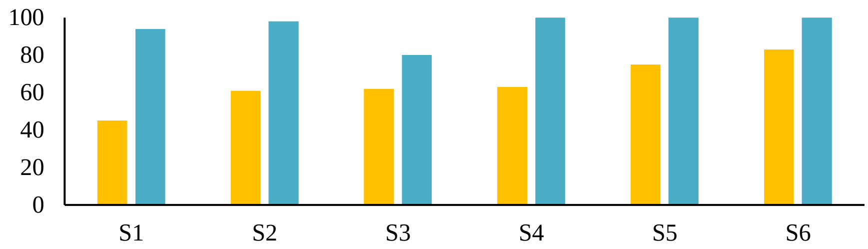

Figure 11. Graph of increase in students' conceptual understanding ability

The graph depicted in Figure 11 illustrates the significant improvement in students' conceptual understanding as a result of integrating the Zuma Function multimedia into the learning process. Each student exhibited notable progress in their conceptual understanding, as confirmed by the N-Gain score of 0.87, which categorizes the improvement as "high". To provide a more comprehensive understanding, the pre-test and post-test data were further analyzed and supplemented with insights from interview transcripts.

The first test question aimed to evaluate students' ability to represent the relationship between two sets using arrow diagrams, paired sets, and graphs. Initial analysis of the pre-test responses revealed a learning obstacle in converting relationships between two sets from a table format into arrow diagrams, paired sets, and graphs. Specifically, five out of six students successfully represented the relationship in arrow diagram form. However, only one student managed to present the relationship using a Cartesian diagram, and none could accurately represent it as paired sets. For instance, when presented with the question, all six students gave the response: {(Aditya, chess, volleyball, swimming), (Bondan, volleyball), (Cindy, running, swimming)}. This highlights a common misconception; students struggled to grasp that paired sets must represent one-to-one relationships. One student's (S1) response is provided in the accompanying figure, showcasing this misunderstanding and underscoring the need for focused instruction in this area.

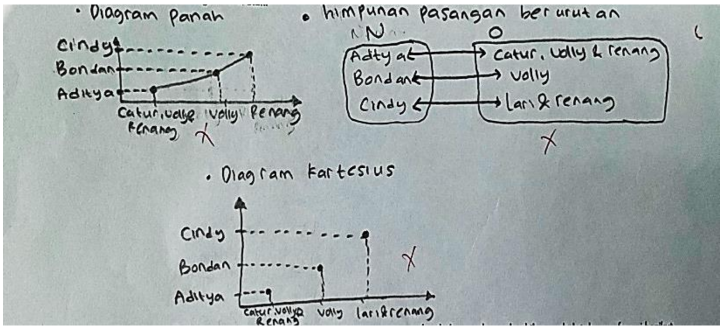

Figure 12. S1 Student answers on pre-test

In Figure 12, the challenges faced by students in presenting the relationship between two sets in various forms arrow diagrams, paired sets, and graphs are evident. For the arrow diagram, students made errors by incorrectly formatting their responses as graph diagrams. In the ordered pair set, students mistakenly represented it as an arrow diagram and further erred by improperly identifying the domain. Similarly, in the Cartesian diagram, the domain was not represented element by element, revealing a misunderstanding. During an interview, one student remarked, “I don’t know if all elements should be connected or just some. I’m also not sure about how to answer it.” This statement highlights a significant gap in the student’s conceptual understanding of relations and their representations in different forms.

Following the integration of the Zuma Function learning media, there was a marked improvement in students’ conceptual understanding. All students successfully demonstrated the ability to represent relations using arrow diagrams, paired sets, and graphs. An example of the improved understanding is shown in the figure below,

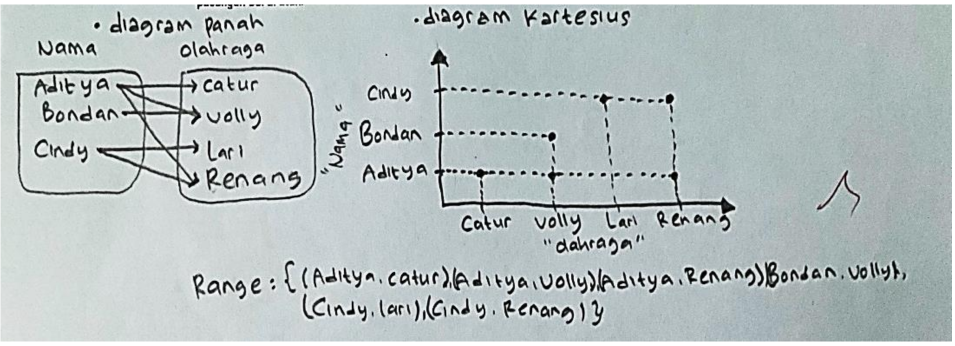

Figure 13. S1 Student’s answer in the post-test

In Figure 13, the student correctly represented the relationship, drawing arrows that accurately depicted the relationships specified in the question. The arrow diagram was structured correctly, without any errors in determining the arrow directions. S1, who previously made errors in paired set representation, now adhered to the requirements, with the response {(Aditya, Chess), (Aditya, Volleyball), (Aditya, Swimming), (Bondan, Volleyball), (Cindy, Running), (Cindy, Swimming)} fully aligned with the instructions. In the Cartesian diagram, the same set of ordered pairs was accurately visualized, as S1 student is able to visualize the pair {(Aditya, Chess), (Aditya, Volly), (Aditya, Swimming), (Bondan, Volly), (Cindy, Running), (Cindy, Swimming)} with points clearly plotted and the axes correctly labeled. During a follow-up interview, the S1 student reflected, “After playing the Zuma Function game and listening to the teacher’s explanation, I understand better how to determine the direction of relationships in the arrow diagram, place sequential pairs, and describe them in a Cartesian diagram.” This illustrates how the integration of interactive multimedia can significantly enhance learning outcomes by clarifying complex concepts. The observed improvements align with existing research, which demonstrates that interactive media fosters better learning outcomes (Johnson 1994), enhance student engagement in understanding concepts (Cairncross 2001; Zhang et al. 2006), and boost student learning motivation (Poçan, Altay, and Yaşaroğlu 2023).

Evaluation

The evaluation stage involves a comprehensive assessment of the effectiveness and quality of the developed learning media. This process is aimed at measuring how well the multimedia learning tool achieves the desired learning objectives. Mathematics education students, serving as respondents, evaluated the “Zuma Function” multimedia using a questionnaire. A total of 36 students participated in the survey, which included 18 questions covering aspects such as appearance, content, functionality, engagement, sound, and usefulness. The questionnaire results revealed that: 84% of students liked the "Zuma Function" learning media and its visual design, 94% agreed that the material was comprehensive and aligned with learning indicators, 89% stated that the media's color, animation, audio, and text were appropriate and easy to understand, especially for recognizing the concept of relations and functions.

Overall, the findings suggest that the "Zuma Function" multimedia offers an appealing design, with visually engaging characters, colors, and animations. The material on relations and functions is easy to understand, and the media is highly interactive, making it an effective tool for students. In addition to the questionnaire, interviews were conducted to gain deeper insights into user experiences with the multimedia. Participants shared various views about the educational game's strengths and areas for improvement. While respondents praised the nostalgic and attractive visuals, they also pointed out a few issues. For instance, some mentioned that the text size was too small and the image resolution appeared distorted, which could affect user comfort. Clear, readable visuals are essential for enhancing student engagement and understanding in digital learning (Mayer 2001).

Regarding the content, all respondents agreed that the material was complete and in line with learning objectives and educational standards, without any conceptual errors. This aligns with previous research highlighting the importance of accurate content for effective (Brusilovsky and Millán 2007). However, a few technical issues were noted, such as sprites not disappearing when switching screens and difficulty in matching elements during the game, suggesting the need for technical improvements.

The game was highly regarded for its ability to increase students' learning motivation by combining learning with play. This approach makes the learning process more engaging and challenging, consistent with previous studies that emphasize the role of educational games in boosting student motivation and engagement (Higgins et al. 2012; Kozma 1991; Li, Chen, and Deng 2024). However, opinions on the background music were mixed. While P23 and P33 found the music appropriate for the theme, P31 felt the game lacked sufficient sound and suggested adding soft, calming background music along with an on/off option for user customization.

The results of this study indicate that the developed educational game received a positive response from users, highlighting its potential for effective use with Scratch software. Previous research supports this finding, showing that learning media created with Scratch often garner favorable feedback from students (Bender et al. 2023; Çakiroğlu et al. 2018). Moreover, the ADDIE model has been proven effective in producing quality, practical, and functional learning media, as demonstrated in various studies (Richey and Klein 2014; Zhang, Hurst, and McLean 2016).

Game-based learning media have been shown to facilitate content delivery, making it easier for educators to teach complex concepts (Coleman and Money 2020; Crocco, Offenholley, and Hernandez 2016; Hartt, Hosseini, and Mostafapour 2020; Hwa 2018). This approach not only enhances learning but also supports students' independent understanding of material, contributing to a more enjoyable and engaging educational experience (Hattie 2008; Mayer 2001). The integration of interactive game elements further encourages student participation and boosts motivation, which in turn fosters deeper understanding of key concepts. The high level of student interest in this game is likely to result in improved learning outcomes and a stronger grasp of the material. Therefore, game-based learning media have significant potential to address various challenges in mathematics education and enhance students' academic performance.

▪ CONCLUSION

Based on the results of the study, it can be concluded that the development of mathematics learning media for relation and function material using the Scratch application was successfully completed following the ADDIE stages, although there are areas that still require improvement. The ADDIE process—analysis, design, development, implementation, and evaluation—was executed effectively. User responses to the media were overwhelmingly positive, with the media receiving a "very good" rating, achieving an average score of 85.1% across all assessed aspects. Furthermore, the significant improvement in students' pretest and posttest results demonstrates the effectiveness of the multimedia in enhancing students' conceptual understanding of relations and functions. For future development, it is recommended to seek a copyright certificate for the game from the Ministry of Law and Human Rights. Further research on Scratch-based learning media is also encouraged, particularly in exploring different topics to expand the scope and impact of this educational tool.

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