Geometrical: Development of Educational Digital Game for Combined Two-Dimensional Figure Learning

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Abstract. Mathematics is one of the subjects that is often considered difficult and boring for students. This is evidenced by the poor scores obtained by the students. One of the chapters that are considered difficult is the geometry chapter, especially on the topic of combined two-dimensional figures studied by students at the Vocational High School (SMK) level. Spatial skills are needed for students to be able to solve combined two-dimensional figures questions, which to learn will be very difficult without using assisted learning media. While the learning so far is still using the conventional learning approach which is considered boring for students. This is due to the absence of learning media that is fun and can be easily accessed by students. This study tries to present a solution to this problem in the form of a mobile-based educational digital game design that can be accessed by all students. This digital educational game is called Geometry. This study uses Research & Development (R&D) combined with the Agile-Extreme Programming method to develop this educational digital game. Tests were carried out using an expert validation approach to game prototypes. This study uses a questionnaire that adapts the Computer System Usability Questionnaire (CSUQ) to assess the usability aspect of the game system built. Meanwhile, to assess this game from the point of view of educational media, this study used an evaluation questionnaire of material experts and media experts. The development process occurs in 3 iterations of development which includes the ideation, conceptualization, and prototyping stages. The results obtained from the assessment of material experts are 87.3%, while the results of the assessment obtained from media experts are 77.8%, so this game is quite feasible to be used in the field as a learning medium. Overall, this game got a good score in the pretest-posttest test in the field, where the effectiveness of the use of this game on improving student learning outcomes had a high N-Gain value of 81.43%.

Keywords: educational game, mathematics, 2-dimensional geometry, problem-solving, 2-dimensional figure, flat shapes

1. Introduction

Many studies have been conducted in the world of education to improve learning effectiveness, learning outcomes, and student skills by utilizing game-based educational media. Especially in recent years, research in this field has become increasingly crowded which proves that games can support teaching and learning...
activities compared to using conventional learning models. Games are widely used as a medium of learning in many subject disciplines, one of which is in the most popular STEM (Science, Technology, Engineering, Mathematics) fields and followed by health [1]. Therefore, it is proven that games can support math learning activities.

Several studies have stated that geometry is considered one of the most difficult fields in mathematics [2], [3], [4], [5]. It requires many skills such as spatial thinking, visualization, and imagination. Currently, students still have many problems and difficulties in learning geometry. Some of them admit that they are not confident enough about the knowledge of geometry. In many schools, teachers are trying to provide the best way to teach Geometry. They usually change the curriculum, republish textbooks, improve materials or tools, and believe that it is easy for students to understand and retain knowledge in depth [6].

There have been several studies conducted to aid the learning of geometry. One of them is Yao and Fu [7], in their research using gamification as a way to motivate first-year engineering students to take part in online workshops designed to practice their spatial visualization skills. The focus of Yao and Fu's analysis is to determine whether the player's spatial visualization skills are related to the player's behavior in the game and the number of levels completed. The results of this study conclude that players who have lower visualization abilities will make a lot of errors in the game, but the number of levels completed does not have a significant difference from players who have higher visualization abilities. From this study, it can be concluded that the Gamification approach can motivate students to improve their spatial visualization skills, this is evidenced by the number of levels completed by students with lower spatial abilities that are not significantly different even though they make a lot of errors.

There are many types of educational games that have been applied in research. From these studies, it can be concluded that learning outcomes are influenced by the type of game and certain elements in the game. Jabbar and Felicia investigated game design features that promote engagement and learning in game-based learning settings [8]. These findings illustrate the impact of key game features in GBL (Game-Based Learning) on cognitive and emotional levels. Among the factors that influence student learning outcomes are the type of game, motivational elements, interactive elements, fun elements, and multimedia elements. Toda [9] developed a geometry education media with a gamification approach that applies fun elements (levels) and motivational elements (rewards) to improve players' understanding and memorization of geometry learning materials. Xiao, Yao, and Fu [7] developed a 3D adventure simulation game that applies fun elements (levels) and motivational elements (rewards) to increase students' motivation in learning geometry. Brezovsky et al developed a puzzle game with a problem-solving learning model approach and applied fun elements (levels) and motivational elements (rewards) to improve students' basic arithmetic skills [10]. Besides Brezovsky, several other researchers develop puzzle games to improve students' skills and understanding of learning materials, such as Chen, Liao, and Chang [11], Kiili, Moeller, and Ninanus [12], and Elena, Jan, and Arnaud [13]. However, the application of puzzle games has not been found to improve students' spatial abilities related to geometry material. Meanwhile, solving geometric problems requires training to improve spatial and analytical skills.

Many studies have been carried out to support learning the geometry of 3-dimensional spaces [6], [9], [2], [4], but there are still few studies that support 2-dimensional geometry subject matter [14], [3]. But these studies tend to only focus on visualizing the geometric objects being studied, to motivate students to study geometry. Meanwhile, according to the results of interviews with mathematics teachers that have
been carried out, even in 2-dimensional geometry the students still lack understanding even though they use learning media that they make themselves from paper. So it is important to develop educational media that helps students learn the geometry chapter of 2-dimensional geometry, especially on combined plane questions as a foundation for strengthening students' understanding of the geometry chapter.

Based on the background described above, this study proposes the design of a mobile-based puzzle game that is feasible and effective as an educational medium for the basic geometry of 2-dimensional space, especially on the topic of combined flat shapes. The expected result is that, with the help of educational games, students are helped in understanding and studying the basic geometry of 2-dimensional geometry, especially on the topic of combined flat shapes. This paper focuses on discussing the proposed solutions to learning problems related to the topics that have been described in the form of educational digital game designs from the point of view of design and development using the proposed development and testing method.

2. Related Works

Many studies have been conducted in the world of education to improve learning effectiveness, learning outcomes, and student skills by utilizing game-based educational media. Especially in recent years, research in this field has become increasingly crowded which proves that games can support teaching and learning activities compared to using conventional learning models. Games are widely used as a medium of learning in many subject disciplines, one of which is in the most popular STEM (Science, Technology, Engineering, Mathematics) fields and followed by health [1]. Therefore, it is proven that games can support math learning activities.

Armando M. Toda et al. [9] apply game elements (gamification) in mathematics learning media in the Arithmetic, Combinatorics, and Geometry chapters. The concept of gamification is used to support the student's learning process in understanding and memorizing the basic concepts of mathematics. The results of this study stated that this concept succeeded in providing positive results above the average [9]. So it can be concluded that the application of game elements can help students to memorize basic mathematical concepts which will greatly help them in memorizing the basic concepts of geometry.

Several studies have been conducted to help to learn geometry. One of them is Xiao [7], in his research using gamification as a way to motivate first-year engineering students to take part in online workshops designed to practice their spatial visualization skills. The focus of Xiao's analysis is to determine whether the player's spatial visualization skills are related to the player's behavior in the game and the number of levels completed. The results of this study conclude that players who have lower visualization abilities will make a lot of errors in the game, but the number of levels completed does not have a significant difference from players who have higher visualization abilities. From this research, it can be concluded that the Gamification approach can motivate students to improve their spatial visualization skills.

Research conducted by Ziang Xiao et al. [7] applies 3D adventure simulation games as a medium for learning geometry. This study uses games to motivate first-year engineering students to practice their spatial visualization skills. The results of this study conclude that players who have lower visualization abilities will make a lot of errors in the game, but the number of levels completed does not have a significant difference from players who have higher visualization abilities. From this research, it can be concluded that the Gamification approach can motivate students to improve their spatial visualization skills. So with the help of visualization in the field of geometry in
educational media, it becomes very important to train students' spatial abilities [6] [14]. One of the goals of implementing game-based educational media for mathematics lessons is to improve students' understanding of students' skills in related materials. In many previous studies, one type of game that is widely applied to achieve this goal is puzzle-game. Brezovsky et al. [10] developed a puzzle game with a problem-solving learning model approach and applied fun elements (levels) and motivational elements (rewards) to improve students' basic arithmetic skills. Besides Brezovsky, several other researchers develop puzzle games to improve students' skills and understanding of learning materials, such as Chen et al. [11], Kiili et al. [12], and Elena et al. [13]. However, the application of puzzle games has not been found to improve students' spatial abilities related to geometry material.

Learning outcomes are influenced by certain elements in the game. Abdul Jabbar and Felicia [8] investigated game design features that promote engagement and learning in game-based learning settings. These findings illustrate the impact of key game features in GBL on cognitive and emotional levels. Among the factors that influence student learning outcomes are the type of game, motivational elements, interactive elements, fun elements, and multimedia elements. Toda [9] developed a geometry education media with a gamification approach that applies fun elements (levels) and motivational elements (rewards) to improve players' understanding and memorization of geometry learning. Xiao, Yao, and Fu [7] developed a 3D adventure simulation game that applies fun elements (levels) and motivational elements (rewards) to increase students' motivation in learning geometry. From these previous studies, it can be concluded that the level element as a fun element and the reward element as a motivational element is very important to be applied to educational games [11], [15], [16], [17], [18], [13].

Based on the previous related studies that have been mentioned above, this study proposes the development of mobile-based games as an educational medium for the basic geometry of 2-dimensional space. This game also presents interactive visualization of combined flat shapes in the form of puzzles which are expected to help students practice spatial skills.

3. Educational Digital Game

Educational games are games that are specifically designed with a specific purpose for learning related to the topic of a particular lesson or science. Educational games have 2 types which are distinguished from the type of media, namely traditional educational games in the form of non-digital games, and digital educational games, commonly called educational video games. Educational games have been widely used as media for various interests of community needs. In the field of education, games have been proven capable of being used as tools or supporting the process of learning activities. In previous studies, educational games have proven to be effective in helping to improve various abilities needed by students in learning such as problem-solving skills [9], [19], memorizing skills [9], spatial thinking skills [7], [20], thinking speed [21], material understanding [2], [22], [23], [24], and a variety of other required skills.

Overall, educational games have been proven to be able to support the learning process, but digital educational games have been proven to be able to provide higher learning motivation compared to using conventional approaches [25]. In addition, educational games have also been used as learning media at various levels of education such as the elementary school level [26], even at the high school level [7]. This proves that digital educational games are more efficient than conventional approaches because
they are easier to reach by various levels of education.

Digital educational games are digital games created with a specific purpose to support or assist the learning process [27]. Digital educational games are a solution for learning certain materials that are considered boring when using a conventional approach [28]. Digital games have become very efficient for learning because of the high public interest in digital games in recent times [29]. And it has been proven that digital games become learning media that can further improve student learning outcomes compared to using conventional learning approaches. So it can be concluded that digital educational games are one of the valid solutions to the problems found in the learning process.

4. The Combined Two-Dimensional Figure

Combined plane shapes are one of the sub-chapters in the 2-dimensional geometry chapter. This sub-chapter deals specifically with questions of flat shapes formed from two or more basic flat shapes. Working on geometry problems involves a level of visual thinking and analysis [30]. So that to be able to solve the combined flat shape problem, the spatial ability is needed to detect any flat shapes that make up certain problems in this sub-chapter. In addition, analytical skills are also needed to determine the formula and how to calculate the final answer to the questions being worked on.

As an example of a compound shape problem, based on Figure 1 students are asked to calculate the total area of the shaded flat shape. So the first step that students need to do is detect what flat shapes make up the combined flat shapes. After knowing what flat shapes form them, students are required to analyze how to calculate the area of the shaded flat shapes by determining what areas of flat shapes should be added and subtracted. The next step is to calculate the area of each flat shape that has been detected and calculate the final result.

![Fig. 1. Examples of Combined Flat Shape Problems](image)

5. Problem-Solving Approach

In NCTM [31] it is said that problem-solving is an attempt to find a way out where the solution method is not known at first. Furthermore, problem-solving is a very important part of learning mathematics, so it cannot be separated from learning mathematics.

Polya defines problem-solving as an effort to find solutions and ways out of a problem to achieve a goal that is not so easy to achieve immediately [32]. According to Polya, four steps must be taken in problem-solving as follows:
6. Proposed Method

To answer research questions, the developed games must be tested in the field to be able to assess their effects on learning performance. However, before conducting field testing, it must be ensured that the developed game is suitable for use in the field.

In the game development process, this research combines various approaches to complete each step it goes through. Because this research is product-based, broadly speaking, this research uses an R&D (Research & Development) methodological approach. R&D is used to ensure the feasibility of product designs developed before being used in the field. Of course, this method is adapted for the development of software products that are used as learning media. Several stages in this research require various methods or approaches. So these methods need to be integrated into the general research method used, namely R&D.

For software development needs, this research uses the agile-XP method. This method is in line with R&D which both apply a product development and evaluation approach regularly or iteratively to add the features needed to improve the product. In
the development process, there are 4 main steps, namely ideation, conceptualization, prototyping, and evaluation, wherein each iteration of development there is a test of the results obtained. Tests were carried out using an expert validation test approach qualitatively and quantitatively. Qualitative testing was conducted using an open interview method, while quantitative testing was conducted using a Computer Usability System (CSUQ) [33] questionnaire instrument combined with assessments related to educational aspects, and media aspects. Figure 2 visually describes the steps contained in the proposed development methodology which will be explained in detail in the following sub-chapters.

6.1 Ideation
This stage is the earliest stage of development to create an initial idea that will be the basis of the educational game that will be built in this research. As shown in figure 2, the idea that was initiated came from information that had been dug up through field observations and also literature studies related to the problems found in the field. Then the information that has been obtained is discussed with the research team to determine the main idea of the educational game which includes the purpose of the game, the main concept, the type of game, and the basic interface. This discussion also resulted in a needs analysis as a guide for the next task.

In this study, the purpose of the game was designed to help students learn mathematics in the 2nd grade of SMK, especially in the combined flat-shaped material. Specifically, the purpose of the game in this study is for students to be able to visually analyze combined flat shapes and be able to complete the calculations with the right steps. From the point of view of the development of this game, the purpose of the game designed is to create a game as an interesting interactive learning medium where students are trained to identify any flat shapes that form a combined flat figure and calculate their area with the right formula. From an educational point of view, this game aims to present interesting learning media in the form of games that can help students learn and understand the material raised with a fun experience.

As in the previous discussion, to work on combined plane problems, problem-solving is a very appropriate approach to apply. In its application to geometrical problems, this approach involves levels of visualization and analysis thinking.

Figure 3 describes the application of the four problem-solving steps to combined plane questions. The problem presented is what is the total area of the shaded flat shape. So the first step to solving this problem is to understand the problems presented in the problem, namely by detecting what flat shapes are contained in the problem. Then the second step is to plan ways to solve the problem by sorting out what areas of flat shapes are added and subtracted. After planning to solve the problem, the third step is to solve the problem according to the plan that has been made by entering the required formulas and calculating the results. After getting answers to these problems, the last step is to re-examine the correctness of the final results and the previous steps.

The main concept of the game proposed in this study is the application of a problem-solving approach in the game presented. At the beginning of the game, the player plays a puzzle to find out what basic flat shapes form a combined flat shape in a particular problem. Then the player is required to solve the problem by determining the right formulas and calculating the area of the flat figure within the time limit that has been provided. The faster you work, the higher the score you get from each question.
The basic idea in this game is to give interaction freedom to players to play a puzzle game at the beginning of the game then separate the shaded and unshaded shapes, and calculate the answers to the questions presented at each level. The puzzle game is presented with a drag and drop interaction approach, where the goal is to analyze what flat shapes make up the combined flat shapes in the questions presented. After the player has completed the puzzle, the player is required to separate the shaded and unshaded shapes, this is done to determine what areas of flat shapes are added and what areas of flat shapes are subtracted to get the answer to the area of flat shapes requested from the problem presented. Finally, players are asked to calculate the area of each existing flat shape one by one by choosing a formula that matches the calculated flat shape and entering the correct number of answers in the provided column. All game processes must be completed within the time limit.

From an educational point of view, the training process for spatial and analytical skills is strengthened by the demands of solving puzzles and the demands of sorting out groups of shaded and unshaded shapes quickly and accurately. With a puzzle game type approach, it is hoped that it will help represent the visualization of interactive educational media for students.

The basic aesthetic design of this game includes all the visual things that are presented to the user such as the interface, icons, and images. This aspect emphasizes the aesthetic and artistic nature in it so that this element will be very subjective compared to other aspects. In this study, the visual environment was built using bright
colors and presenting cute character icons to create a cheerful and fun atmosphere for students. A touch of flat design is used in the design of the interface so that the information presented is easier for players to accept and not confusing.

6.2 Conceptualization

The ideation phase creates the basis for the entire design process, while conceptualization forms the basic concept into a much more tangible and solid prototype. This phase uses task analysis from the previous phase and creates a low-fidelity prototype and then a digital mockup, then the prototype that has been made is validated by media experts. In this phase, material experts are also involved to provide input on the prototype design.

As shown in Figure 2, using the internal peer review method, the main interrelated aspects of the game in the overall game design are developed at this stage. The main aspects include game rules, aesthetic aspects, interface aspects, interaction aspects, feedback aspects, and game narrative aspects.

The rules of the game are used as the main basis for developing the design of other aspects. The basis of the game rules in this study is the demands of players to get as many game scores as possible by doing the available missions. Broadly speaking, to be able to win the game, players are required to be able to identify any flat shapes that build combined flat shapes in the problem, then calculate the area of flat shapes requested in the problem.

This game provides several missions to be able to win 1 game stage. As depicted in figure 4, the player's first mission is to solve puzzles with drag-and-drop interactions, where this mission aims to find out what flat shapes make up the combined flat shapes in the problems presented. This action can be carried out by the player through the interface of the available puzzle pieces by dragging them and placing them on the combined two-dimensional figure image.

![Fig. 4. Example of High-Fidelity Prototype Puzzle Scene](image)

The next mission is to sort between shaded and unshaded flat pieces, this mission can be done by drag and drop action. As depicted in figure 5, this mission aims to analyze the area of the plane that should be added and subtracted. The action on this mission can be done by players by sliding the puzzle-piece interface to the "plus" and "minus" tables that have been provided. Every time you put a flat shape on the table, a "formula box" will appear with the arithmetic indicator selected in the "formula" table. When placing a flat figure on the "plus" table, the "plus" arithmetic indicator will appear along with the formula box, and vice versa. Players are required to sort out correctly to go to the next scene.
After completing the sorting mission, the player will be taken to the “counting” mission as depicted in Figure 6. This mission requires players to calculate the area of the existing flat shapes one by one and continue to calculate the overall answer to the questions given. In this scene, players are given the authority to fill in numbers in each “empty box” using the numeric keyboard at the bottom of the screen. This scene begins with the appearance of “empty boxes” under each “formula box” that has been arranged in the previous scene. The “empty box” is used to fill in the calculated numbers from the formula answers in each “formula box”. To be able to calculate the answer for each “formula box”, the player must click the “empty box” below it, a float window will appear containing the calculation of the area of the selected flat shape. In this floating window, players are asked to arrange the correct formula by choosing the appropriate arithmetic operator and filling each “empty box” in it with the correct answer. After filling in all the “empty boxes” under the “formula boxes”, the player’s last task is to fill in the “answer boxes” which are right above the keyboard as the final answer to the questions given. From the point of view of education, according to material experts, the mission concept designed is in accordance with the stages of learning combined flat shapes, but the final mission will be more effective for memorizing formulas for area of flat shapes if the selection of calculation operators in the available formulas is replaced with the selection of formulas that are already available, right among the choices of formulas provided.

All actions performed by the player can be performed through an intermediary interface that is visible to the user. The player actions performed in the game through the interface are called interactions, where these interactions are limited by the authority for which they are designed. The system will provide feedback in the form of animation and audio-visual for all interactions made by the user, where all the feedback represents information.

The aesthetic aspect here includes audiovisual elements in games that are designed to make the atmosphere in the game come alive. The audio elements are designed to build a cheerful atmosphere and are appropriate for the character and age of the player. The music used is cheerful but still keeps the players focused on playing the game. In addition to music, some funny sound effects are used as feedback accompaniment in the form of animation so that the atmosphere in the game feels more alive. Visual elements are presented using a touch of flat design with bright pastel colors giving a relaxed impression but able to present information. The flat design style was chosen to be able to convey many formulas and numbers clearly but still in a relaxed manner. The color combinations used were chosen from the results of consultations with experts and discussions of the research team. Broadly speaking, the color combination chosen is a
A combination of purple and pastel beige, which looks relaxed but still focused. From an educational point of view, the aesthetic aspect helps players stay focused on working on the problems presented but with a fun and not boring feeling. From a media point of view, feedback in the form of animation is the right way to convey information visually so that it is easily accepted by players. But overall, the aesthetic design presented is considered to be still lacking in pleasure and still needs to be developed again to strengthen its appeal to the players.

The interface aspect in this project is designed in a minimalist and iconic style with little text displayed. This is done to reduce the saturation of players who have been faced with a lot of text on the formulas and calculations in the game mission. The keyboard used in the game was specially created to be placed at the bottom of the screen to make it easier for players to input answers in the existing answer column. From a media and educational point of view, the interface with a simple style can reduce player boredom in learning. However, the interface at this stage is still considered less intuitive so it can confuse players when looking for the information they need.

Interaction in the game uses a lot of drag and drop action. This was chosen to present the experience of playing in the game as natural as possible and as close as possible to the interaction of playing puzzles in the real world. From a media and educational point of view, this type of puzzle game was chosen because it can improve the visual observation skills of players, which is very useful in learning geometry.

Figure 7 illustrates the feedback that arises as a result of player interaction with educational games. After filling in the answer box, to find out the truth of the answer, the player must click the "Enter" button, if the answer is correct and the game timer has not ended, the system will provide audiovisual feedback as a sign of success as shown in Figure 4.12. If the answer or entry in the empty box is wrong, the system will provide warning feedback so that the player corrects the contents in the existing empty box. The player fails to complete this stage if the player has not completed the mission and the game timer has run out, the system will provide audiovisual feedback in the form of a "Game Over!" popup. According to experts, from the point of view of the media, the feedback presented is sufficient in accordance with the information conveyed, but there are still many player actions that need to be given feedback as a sign of appreciation or warning, which is useful information for players about what to do next.
Of course, the design of the game aspect at this stage still requires a lot of development and refinement. In this case, the presence of material experts and media experts plays an important role in the design and development phase. The design aspect of the game will continue to evolve as the validation and revision process from experts goes on.

6.3 Prototyping

The results obtained in the conceptualization phase are tested empirically to determine the achievements that have been obtained. The test was carried out using a questionnaire approach related to media aspects and usability by involving media experts. Table 1 shows the results obtained from the test. It can be seen that the results obtained are still getting a sufficient rating but tend to be lower in the assessment related to the visual communication design which this aspect is related to aesthetic and interface design. All inputs obtained in the conceptualization phase become tasks that will be carried out in the prototyping phase.

Table 1. Design Quantitative Test Results

<table>
<thead>
<tr>
<th>Expert</th>
<th>Aspect</th>
<th>Result %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Media Expert</td>
<td>Software Engineering</td>
<td>74.3 %</td>
</tr>
<tr>
<td>Media Expert</td>
<td>Visual Communication</td>
<td>72.5 %</td>
</tr>
<tr>
<td>Media Expert</td>
<td>Media Design</td>
<td>80 %</td>
</tr>
<tr>
<td>Media Expert</td>
<td>Usability Aspect (CSUQ)</td>
<td>77.1 %</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>76 %</td>
</tr>
</tbody>
</table>

This phase is the phase where the results of the conceptualization phase which have been validated by experts are implemented in the form of a high-fidelity beta version. In the previous stage, most of the implementation of the main aspects of the game in the educational game that was built was explained. Broadly speaking, this phase is a further development phase from the design phase that has been carried out in the previous phase.

Based on the reviews and input of experts in the previous phase, in this phase improvements and developments were carried out on the prototype. Along with the implementation of the concepts generated in the previous phase, every input received from experts in this phase is implemented with very high accuracy, so that the resulting prototype is as ready to be used by users as possible. However, empirical testing of the prototype produced in this phase is still needed, this process will be carried out in the evaluation phase.
The main aspects of the game that are interrelated in the overall game design are developed and refined at this stage with the aim that the prototype produced in this phase is suitable for use in the field. Broadly speaking, from an educational point of view, the improvements made are related to in-game learning strategies, the validity of the material presented, and game mechanics which are directly related to in-game learning methods. From a game point of view, improvements were made regarding the interface aspect and the feedback aspect.

The process of perfecting the learning strategy in the game carried out at this stage is related to the level division design based on the level of difficulty. There are 3 levels of difficulty, namely easy, medium, and hard, where each level has many game stages in it. The easy level contains practice questions for basic flat shapes such as triangles, squares, circles, and other flat shapes, which are made for preliminary learning towards learning compound shapes. The medium level contains simple composite shape questions in which the questions include combined flat shape questions that are easily validated by material experts. The medium level is designed for the initial learning of composite shapes. The hard level contains combined flat shape questions with the highest difficulty level. The difference between hard and medium levels is the level of complexity of the flat shapes, which in general, the level of complexity is distinguished from the number of basic flat shapes that exist in 1 combined flat shape. The hard level is designed to mature student learning on this material. Besides that, to measure student learning performance in the game, this game applies a scoring system. The scoring system in this game is designed by calculating how fast the player completes 1 stage. Each stage is designed to have a time limit (timer) to complete, in which players are required to complete the game before the time provided runs out. The amount of time on each stage is designed according to the level of difficulty and validated by material experts, the more difficult the questions, the more time provided.

At this stage, the material presented in the game needs to be validated for validity, so that the educational game is ready to be implemented in the field. Although at this stage the validity of the material presented cannot be said to be perfect, because the presentation of the material will be greatly influenced by aspects of the game design which are still in the development process, the testing phase of the validity of the material at this stage is important to do to provide a clear view as to the development limitations related to Theory. In this case, the material being tested is material that has been collected and compiled based on the needs analysis in the previous stage, where
the test is related to grouping questions based on the level of difficulty, the validity of the answer keys applied in educational games, and the amount of time given to work on each question.

In the aspect of game mechanics, this new game was designed based on input from material experts and has been validated. It can be seen in Figure 8, the multiple-choice approach applied is considered more efficient to help students memorize the formulas needed in learning flat shapes.

![Timer design revision](image)

**Fig. 9.** Timer design revision

From a media point of view, several improvements related to the interface aspect have been made, namely changing the display of the countdown timer in the game into a visual form, which previously used only text. This is done to make it easier for players to capture the remaining time information just by looking at the visuals of the timer. As depicted in Figure 9, the timer design used is to visually display the timer bar along with the number of remaining times below it. This timer bar also helps make it easier for players to see how many scores they get with the time they have spent.

![Character design](image)

**Fig. 10.** “Geo” character design

In the feedback aspect, to make it easier for players to explore educational games, it can be seen in Figure 10, a "Geo" character was created as a friend of the player in the game who guides the player to find out what missions the player must do and how to do it. The “Geo” character is also used as an information center for players when players don't know what to do. All feedback in the form of appreciation or warning of player behavior also displays Geo characters. Overall Geo characters were created to make a pleasant impression for players and make it easier to find the information players need.

In addition to Geo characters, to complete the narrative aspect in the game that is useful for teaching how to play, narration in the form of visual animation is applied at the beginning of the game stage. Narrative in the form of visual animation is applied because it is considered easier for players to understand than displaying a lot of
narration in the form of text, as well as to make the atmosphere of the game more lively and not boring.

The results obtained after carrying out various refinements and developments on the prototype will be explained in Figure 11 with a ScreenFlow approach. Figure 11 describes the flow that occurs on the screen during the game. The game begins with the presentation of a puzzle in the form of a combined flat shape that must be completed by the player. If the player has succeeded in matching any basic flat shapes that make up the combined flat shapes, the player will be taken to the scene of sorting the puzzle pieces that have been arranged previously. In this scene, to be able to move on to the next scene, the player is required to correctly sort out the area of the plane that must be added and subtracted by separating them in the plus and minus tables provided. Next, players will be taken to the final scene of the game, namely the counting scene. In this scene, players are required to answer questions by filling all the boxes with the correct numbers. To complete the calculation of the problems presented, the step that must be passed by the player is to calculate each area of the existing flat shapes one by one. To calculate the area of each flat shape, the player can calculate it in a floating window that will appear after the flat area field is pressed. In the floating window, players are asked to choose the right formula for the flat shape that is being calculated and fill in all the fields with the correct number according to the problem. After filling in all the fields and the final answer that is located right above the keyboard, the last step to finish the game is to press "Enter" to find out whether the answers that have been filled in are correct or incorrect. The system will provide feedback in the form of a warning delivered by the Geo character if the answer or input that has been entered in the field is still incorrect. The game will continue if errors are still found in filling out the box or choosing a flat shape formula. The game will end in victory for the player if there are...
no more errors found in the problem solving and the game countdown time is remaining. “Game over” will occur if the countdown time reaches 0 and the player has not finished the game.

6.4 Evaluation

This phase is the last stage in the design and development phase that occurs in this research before moving on to the implementation phase in the field. The evaluation phase is carried out by testing validation on experts to get the validity of its feasibility for use in the field. Expert validation testing at this stage is carried out using open interviews with experts accompanied by direct trials of the final prototype of the educational game that has been built. The test results are in the form of a measurable assessment obtained by using a questionnaire testing approach, in which the questionnaire used adapts the questionnaire of media experts and material experts [34], and the Computer System Usability Questionnaire (CSUQ) [33]. The entire questionnaire uses an assessment measure with a Likert scale of 1-5.

Table 2. Media Expert Validity Test Results

<table>
<thead>
<tr>
<th>Expert</th>
<th>Aspect</th>
<th>Result %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Media Expert</td>
<td>Software Engineering [34]</td>
<td>77,1</td>
</tr>
<tr>
<td>Media Expert</td>
<td>Visual Communication [34]</td>
<td>76,3</td>
</tr>
<tr>
<td>Media Expert</td>
<td>Media Design [34]</td>
<td>80</td>
</tr>
<tr>
<td>Media Expert</td>
<td>Usability Aspect (CSUQ) [33]</td>
<td>77,6</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>77,8</td>
</tr>
</tbody>
</table>

Table 2 shows the results of validation tests conducted with media experts regarding educational games from a media point of view. In this media expert test, the value obtained related to the software engineering aspect was 77.1%, the visual communication design aspect was 76.3%, the media design aspect was 80%, and the usability aspect was 77.6%. Overall, the assessment from the media's point of view gets a fairly large value, namely 77.8%, which has met the standard value in the R&D research method regarding the design value that is feasible to be applied, which is 75%.

Table 3. Subject-Matter Expert Validity Test Results

<table>
<thead>
<tr>
<th>Expert</th>
<th>Aspect</th>
<th>Result %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject-Matter Expert</td>
<td>Subject-Matter Correctness [33]</td>
<td>88,9</td>
</tr>
<tr>
<td>Subject-Matter Expert</td>
<td>Learning Evaluation [33]</td>
<td>85,7</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>87,3</td>
</tr>
</tbody>
</table>

As stated in Table 3 in the material expert validation test, the value obtained in the material suitability aspect is 88.9%, and in the learning evaluation suitability aspect the value obtained is 85.7%. Overall, from the point of view of learning materials, the final prototype design received a fairly high score of 87.3%.

Overall, the value obtained from the final validation test from the media and material point of view is quite large, namely 82.5%, and has met the standard to be able to proceed at the implementation stage in the field. From the final validation test that has been carried out, it can be concluded that the final prototype design is ready to be used for field tests.

7. Testing

After the game developed is considered feasible to use, the next step is field testing.
This chapter describes the final stage of the research, namely the game testing phase that has been built to answer the research question. Tests are carried out to see the effectiveness of the games that have been built on improving student learning performance which can be seen from the increase in the value of learning outcomes after learning to use this game.

The test study design used in this research is the Nonequivalent Control Group Design which uses 1 class of students who are divided into 2 groups with different treatments. The division of the two groups was based on the scores obtained by the students in the pretest. Both groups had an even distribution of students with pretest scores. Both groups were given both pretest and posttest but differed in their treatment. The first group is the experimental group and the second group is the control group. The experimental group was given treatment in the form of providing learning materials using educational games, while the control group was given learning materials using conventional learning methods.

Broadly speaking, Figure 12 illustrates the steps in the implementation of the experiments carried out. The technical details of the experimental implementation and data acquisition carried out in a structured manner are as follows:

1. Pretest testing for 30 minutes 2 groups at once.
2. The material is divided into 2 classes/groups of students, namely the experimental group and the control group, which is carried out for 40-45 minutes. There is an additional 10 minutes for the distribution of learning media games for the experimental group. The detailed process for providing materials is as follows:
   a. 15 minutes for material giving
   b. 25 minutes for playing learning media games with teacher guidance (experimental group)
   c. 5 minutes for backup time
3. Posttest test for 30 minutes

**Fig. 12.** Experiment Process
4. Limitations in this experiment are:
   a. Students use their respective smartphone devices for learning media needs
   b. Students continue to use counting paper in playing learning media games
   c. Students use learning media games only when given material
   d. The pretest and posttest were carried out with written exams without learning media games.

After the entire experimental process was completed, an analysis of the effectiveness of the game was carried out by looking at the values obtained from the pretest and posttest of the two groups. The values obtained in the posttest test by both groups both experienced an increase compared to the pretest values as can be seen in Tables 4 and 5.

**Table 4. Experimental Class Pretest-Posttest Results**

<table>
<thead>
<tr>
<th>Respondent</th>
<th>Pretest Score</th>
<th>Posttest Score</th>
<th>N-Gain Score Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>45</td>
<td>92.5</td>
<td>86.36 %</td>
</tr>
<tr>
<td>2</td>
<td>37.5</td>
<td>92.5</td>
<td>88.00 %</td>
</tr>
<tr>
<td>3</td>
<td>60</td>
<td>87.5</td>
<td>68.75 %</td>
</tr>
<tr>
<td>4</td>
<td>47.5</td>
<td>95</td>
<td>90.48 %</td>
</tr>
<tr>
<td>5</td>
<td>50</td>
<td>82.5</td>
<td>65.00 %</td>
</tr>
<tr>
<td>6</td>
<td>40</td>
<td>90</td>
<td>83.33 %</td>
</tr>
<tr>
<td>7</td>
<td>70</td>
<td>95</td>
<td>83.33 %</td>
</tr>
<tr>
<td><strong>Average N-Gain Score Percent</strong></td>
<td></td>
<td></td>
<td><strong>81.43 %</strong></td>
</tr>
</tbody>
</table>

**Table 5. Control Class Pretest-Posttest Results**

<table>
<thead>
<tr>
<th>Respondent</th>
<th>Pretest Score</th>
<th>Posttest Score</th>
<th>N-Gain Score Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>42.5</td>
<td>85</td>
<td>73.91 %</td>
</tr>
<tr>
<td>9</td>
<td>45</td>
<td>75</td>
<td>54.55 %</td>
</tr>
<tr>
<td>10</td>
<td>47.5</td>
<td>85</td>
<td>71.43 %</td>
</tr>
<tr>
<td>11</td>
<td>47.5</td>
<td>82.5</td>
<td>66.67 %</td>
</tr>
<tr>
<td>12</td>
<td>40</td>
<td>77.5</td>
<td>62.50 %</td>
</tr>
<tr>
<td>13</td>
<td>60</td>
<td>82.5</td>
<td>56.25 %</td>
</tr>
<tr>
<td>14</td>
<td>60</td>
<td>80</td>
<td>50.00 %</td>
</tr>
<tr>
<td><strong>Average N-Gain Score Percent</strong></td>
<td></td>
<td></td>
<td><strong>62.94 %</strong></td>
</tr>
</tbody>
</table>

To find out how effective the treatment given to the two groups was on the results of the posttest scores, the N-Gain score was taken from the pretest and posttest scores of the two groups. Gain normality test is a test method that can provide a general description of the increase in learning outcomes scores between before and after the application of a treatment. Calculation of N-Gain can be calculated as equation 1.

\[
Normalized \text{ Gain (N-Gain)} = \frac{\text{Pretest Score} - \text{Posttest Score}}{\text{Maximum Score} - \text{Pretest Score}}
\]  \hspace{1cm} (1)

Meanwhile, the N-Gain score that has been obtained can be interpreted as the level of effectiveness which refers to the interpretation of the N-Gain index [35] which is listed in table 6.

**Table 6. Category Interpretation of N-Gain Effectiveness [35]**

<table>
<thead>
<tr>
<th>N-Gain Score (g)</th>
<th>Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>( g &gt; 70% )</td>
<td>High</td>
</tr>
<tr>
<td>( 30% &lt; g \leq 70% )</td>
<td>Medium</td>
</tr>
<tr>
<td>( g \leq 30% )</td>
<td>Low</td>
</tr>
</tbody>
</table>
The average N-Gain score obtained in the experimental group was 81.43%, which is in the high category in terms of effectiveness. While the N-Gain score obtained by the control group is 62.94%, where this score is included in the moderate category in terms of effectiveness. So from the N-Gain score obtained, it can be concluded that the two groups with different treatments experienced an increase in learning outcomes, but the effectiveness of the treatment given to the experimental group was higher than the effectiveness of the treatment given to the control group, where the N-Gain score of the group the experimental group is in the "High" category, while the control group's N-Gain score is in the "Medium" category.

8. **Conclusion & Future work**

The design of a mobile-based educational game for combined flat shape learning by applying a problem-solving approach in this study managed to get a fairly good score and was suitable for use in the field. By using an R&D development methodology that uses an expert validation testing approach, this game has succeeded in getting a good assessment from the point of view of a material expert, which is 88.9% in the aspect of the validity of the material presented, and 85.7% in the evaluation aspect of in-game learning. Overall, from an educational point of view, the material expert validation test got a fairly high score of 87.3%. As for the media point of view, this digital educational game gets a pretty good score in the software engineering aspect, which is 77.1%, in the visual design aspect with a value of 76.3%, in the media design aspect with a score of 80%, and in the usability aspect, This digital educational game received a score of 77.6%. So it can be concluded that from an educational point of view, the design of digital educational games is good, but from a later point of view, the value obtained is quite good, in the sense that further refinement and development is still needed, especially in the visual design aspect which gets the lowest rating in the test. So the development of an educational game may require further development and testing methods on aspects of its visual design.

In addition, from experimental testing that has been carried out, it can be seen that learning using educational games developed in this study digitally or with conventional learning approaches are both able to improve student learning outcomes, but the value of the effectiveness of learning methods using digital educational games is higher (81.43%) of the conventional learning approach in the control class (62.94%). This proves that the combined flat shape learning using mobile-based educational games with a problem-solving thinking approach is very effective in improving learning performance.

From the digital educational games produced in this study, there are still opportunities for further research related to the details of the students' learning process in the game, such as students' problem-solving abilities, the speed of students' visual analysis abilities, and so on.

**References**


