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Analyzing the quality of game-based assessment design in basic arithmetic operations

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Abstract
The use of Serious Games in education has experienced rapid development. However, not all studies have been able to show evidence that game-based methods are superior to other methods. It is important to analyze the quality of game designs used in learning and assessment used to assess students. This study focuses on how to design a serious game called B-block used in the assessment. The researcher validates the quality of the serious game first before conducting a pilot study regarding the feasibility of the Serious Game given for assessment. The game focuses on basic arithmetic, including addition, subtraction, division, and multiplication, and involves positive and negative numbers. The study was conducted in one of the schools in Indonesia and given to 35 students with an age range of 11-12 years with different student backgrounds in their experience with game-based exams. Based on these results, 85.7% of respondents agreed that this game could be used as a substitute for paper-based exams, with the analysis of game design quality having an average value of 78% pedagogic specifications and 73% playful and 80% technical specifications. Thus, the average value of this game quality analysis is considered superior and meets almost all the specifications needed for assessment. We also argue that serious game is closely related to how game design meets specifications for use as educational tools.

1. Introduction

Mathematics is a fundamental subject in every school and has become a mandatory part of the current education system [1]. However, most students in the learning process often assume and feel that mathematics is a complicated subject that could be more interesting [2]. Many aspects influence, students in Indonesia are having difficulty understanding the basic concepts, even understanding the subject needed to memorize the formula in the given questions [3]. Another aspect is most of the problem models provided are almost similar to the textbooks, so the problem models and solutions are nearly the same, this makes students who still don't understand the concept find it difficult when given problem models with slightly different concepts. Several other aspects also affect the student learning process, but the most important is how the materials are delivered [4].

The latest research for this problem is to apply game-based methods and gamification to the education process. The serious game method can be used to clarify the presentation of educational content while at the same time attracting students' attention and increase learning motivation to influence student learning outcomes. [5], [6], [7]. Game-based can capture information from each student's achievement in their learning process and provide a more interactive learning experience. The previous research on the game PaGamo which produces a combination of gamification and traditional learning methods, can improve student learning outcomes [8]. Another research uses educational games as a medium for learning two-dimensional plane mathematics and is declared feasible to increase learning motivation [9].

The game-based method was also developed into a more specific field, namely game-based assessment. Game based-assessment is an assessment method that involves game elements in it. The assessment generally takes information about the competence of students [10]. In the game-based assessment method, we can use data from all the actions and actions of players in the game to make inferences from information such as player knowledge, skills, and other attributes that can only be obtained from player interactions in games [11]. Game-based assessment can also reduce students' anxiety when taking exams as well as increase their motivation and involvement caused by their anxiety during exams [12],[13]. However, research in the Serious Games field, including learning and assessment, is still relatively new [11], [14]. Existing research on learning and assessment methods shows that Serious Games can encourage and motivate to correct the current method and provide teachers with information that can help shape their future teaching method [15].

Another study on Formative assessment with game-based technology showed that students using game-based formative assessment feedback is more effective in helping students prepare for exams. Most participants agree that this type of exam gives students a more competitive feeling and fun and provides direct feedback [16]. Students and teachers have positive feedback towards the use of technology and integration in the classroom, and various existing technologies can be used as a means of interaction and facilitate the assessment process [17]. Serious games also prove that they can test and assess students' mathematical abilities wholly and accurately compared to traditional methods, which only measure the accuracy and knowledge of material concepts received by students [18].

The latest study on serious games shows that the application of serious games is more focused on math field education [14], This is necessary because of the importance of having flexible mathematical thinking for students from an early age and requires special skills such as problem-solving and a strong understanding of mathematical concepts [19]. To reach this stage, students need to build strong knowledge in their understanding of natural numbers so that they are able to make decisions about when and what strategies to use to solve the mathematical problems they are facing. [20] therefore, students must be provided with strong materials, learning methods, and basic arithmetic skills. because this basic ability is the fundamental ability needed to enable them to be more adaptive in solving problems that involve mathematical solving in the real-life situations [21]. However, other evidence in the learning and assessment domains for arithmetic mathematics still needs more evidence about the effectiveness of the given serious game method [18], [19]. Another analysis conducted by Joo [22] shows that using the serious game method sometimes has a positive impact and influence on students and good learning outcomes.

The effectiveness of game-based methods used in education proves to be a good solution. However, some studies also mention that this method is only sometimes successful in some research cases [23]. Some factors that influence this include: Different student backgrounds and school curricula also affect the success factors of the game-based method. Another factor that significantly affects the success of serious games is how well the game is designed to meet the objectives and can adapt to existing materials [23], [24].

Therefore, it is essential to design and analyze the influence of game design on the quality of serious games used for assessment. In this research, we are developing a serious game for arithmetic assessment, including addition, subtraction, division, and multiplication material, including negative and positive numbers. This research focuses on analyzing a serious game's quality that will use to assess students' competencies.

2. Research Method

Figure 1 shows that the stage in this research consists of four main stages: design, development, playtesting, and serious game quality. The design stage involves teachers and students to achieve excellent serious game quality. The teacher plays a special role in adding the given model material, and students give their opinions on how they think about the initial game design given. When the design had been developed, students and teachers were given the final game design to be tested. Then the last step is to analyze the results of serious game quality designed based on player feedback.

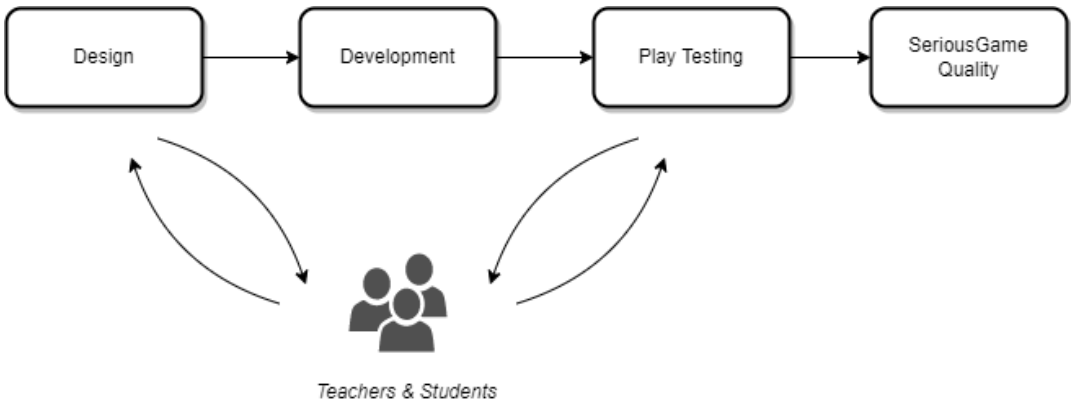

Figure 1. Serious Game Design Process

2.1 Serious Game Design

In order to translate a game design into a serious game form, this research applies the framework proposed by Silva [25] and the development of the MDA [26] and DPE [27] frameworks which also include design, prototyping, and playtesting stages. From topic selection, objective material, target audience, and genre to the determined scenario, they are combined into a game mechanic that meets the assessment outcome and the fun aspect of the game.

Table 1. Serious Game Aspect and Design Pattern

Aspect	Description
Topic	Aritmathics
Material Objective	Addition, Subtraction, Division, and Multiplication Involving negative integers
Target Audience	5-6th grade student
Genre	Puzzle
Scenarios	- UI Design for young children (6-12 years old) - Pedagogical-focused Gameplay - Result Feedback to the player - Balancing in every stage. The first stage is the easiest, and the last stage is the hardest. - Single player in a mobile phone (or tablet)

In Table 1, the aspects of the game's initial design are described. Each aspect must be closely related to the other to reach a suitable game mechanics model. From taking the topic, choosing arithmetic topics will be very closely related to Addition, Subtraction, Division, Multiplication, and Involving negative integers, then these materials will be given more to grade 5-6 elementary school students. Game genres are very influential in determining game mechanics so that the description of the game scenario can be more focused on other aspects [28], [29].

2.2 Instrument and measures

In this section, we provide a test scheme for game design. The testing scheme is divided into two stages, the first stage includes the quality of the game in the functions used in Serious Games (education), and the second stage is direct testing of users (students) regarding the evaluation of the given game.

This study uses the Quality Assessment Measure that was developed by Borji et al. [30]. These criteria are the development of previous studies on serious games [31]. Previous research [32] shows that for developing a serious game for assessment purposes, it is necessary to measure the quality of the games. The quality criteria are divided into three specifications: Pedagogical specifications include content criteria, strategies, and assessment methods; playful specifications include the attractiveness and playability aspects of the game; and technical specifications include: requirements and technical efficiency. To assess each of these criteria represented by giving a questionnaire with a Likert scale from 0 to 5, then accumulated based on Equation 1, Equation 2, and Equation 3. The total score of each specification (n) from player feedback is divided by the maximum specification score so that the three specifications have their respective values that can be used to measure where the advantages and disadvantages of the specifications of the games designed for assessment.

$$Pedagogical\ Specifications = \frac{n}{65} \quad (1)$$

$$Playful\ Specifications = \frac{n}{35} \quad (2)$$

$$Technical\ Specifications = \frac{n}{30} \quad (3)$$

The Pilot User Study aims to take valuable feedback regarding a serious game. Experiments were carried out by giving questionnaire questions, including their opinions about the game. The survey conducted will include collecting primary data on player demographics as well as questions about the game, consisting of:

1) Have you ever learned by playing video games?
2) Have you ever taken a test by playing a video game?
3) Can the games you play in this trial test your skills?
4) Is the game you play worth replacing the paper test?

2.3 Participant and Procedure

The research was conducted on 5th students during the first semester of 2021/2022 at one of the national public schools in Indonesia. Table 2 shows the demographic of the participants. With a total of 35 students consisting of 12 males and 23 females, 80% of them play games (Play time) almost every day and 51.4% of participants spend an average of 1 hour playing (Time Spent).

Table 2. Participants Details

Group		Number	Percentage (%)
Gender	Male	12	34.2%
	Female	23	65.7%
	Total	**35**	**100%**
Play Time	Once a month	1	2.85%
	Once a week	5	14.2%
	Few times within a week	1	2.85%
	Everyday	28	80.0%
	Total	**35**	**100%**
Time Spent	Around 30 minutes	17	48.5%
	An Hour or more	18	51.4%
	Total	**35**	**100%**

The game runs on a mobile platform, so every student has been provided during the exam to play games. The total length of this research is approximately 90 minutes, which is divided into three stages. In the first stage, players are accompanied and explained by a tutor while playing tutorial mode for 15 minutes, followed by free practice for 15 minutes. In the second stage, players play a test mode with a time allotted 1 hour for each session. Then the last stage, each student and teacher will be given a link to fill out an online questionnaire, including questions about the quality of the game assessment, and at each stage, will always be accompanied by a tutor.

3. Results and Discussion

3.1 Game Design, Gameplay, and Mechanics

Based on the framework analysis, the purpose of this game is to build a serious game for math assessment mainly focused on arithmetic, including positive and negative numbers. In the game, players are given levels where each level contains blocks of number, and each block has its operator value (Subtraction, Addition, Multiplication, and Division). The goal is to combine all the existing blocks until the block value meets each specified target.

There are three main types of blocks, blocks with positive numbers (blocks in blue color), blocks with negative numbers (blocks in orange color), and blocks that contain operators (circle on the block followed by operator sign). Players can combine two blocks as the first number and the second number. For example, in Figure 2 (left), the player is asked to combine all the existing blocks, where at this level, there are 3 number blocks consisting of (-1, +2, and +7) the solution to solving this level is to combine all possible exists to generate a target number (+8), so the solution for this level is: ((2 + 7) – 1). Each level can be completed in more than one way, so each level needs each player for their strategy to make decisions to find solutions. The gameplay requires in-depth calculations to achieve the target goal and is presented like a problem in arithmetic on the questions and materials given to students and learning (Figure 3).

Figure 2. Example Gameplay with one target number (Left) and example gameplay with two target numbers (Right)

Question model form in the textbook:

$a)\ ((\ldots + \cdots) \times \ldots) \div \ldots = 12$
$b)\ \ldots * \ldots = 22$

Fill in the blanks with the numbers below:
$(4.5),\quad (3),\quad (5.5),\quad (3.5),\quad (+4)$

First option solutions for the problems:
$(+3.5)\ (+4.5)\ = +8$
$(+8)\ x\ (+4.5)\ = +24$
$(+24)\ \div\ (+2) = +12$
$(+5.5)\ x\ (+4)\ = +22$

Second solution approach to the same question:
$(+3.5)\ (+4.5) = +8$
$(+8)\ \div\ (+2) = +4$
$(+4)\ x\ (+3)\ = +12$
$(+5.5)\ x\ (+4) = +22$

Figure 3. Example of Level in the Game (Left) and Examples of Questions in the Student Textbook (Right)

The game's challenge is that if every player makes a mistake in combining blocks, the player can make an undo move by pressing the "undo" button on top of the screen. However, each level has a maximum undo a move, so players must be careful in taking action. With this mechanic system, the game can also prevent players from guessing to find solutions from the level.

Figure 4 shows the core game loop. There are three main modes on the Select Game Mode menu (i.e., Tutorial, Practice, and Exam). In tutorial mode, players have explained the game's main mechanics, while in Practice mode, players are assigned to random levels with random difficulty. However, players are not given restrictions on using the undo button. While for Exam mode, players are given a different scheme for each level, The level of complexity and types of questions given vary (from only positive and negative numbers to the most complex question consisting of multiplication and division operators). The opportunity to use the undo button is limited.

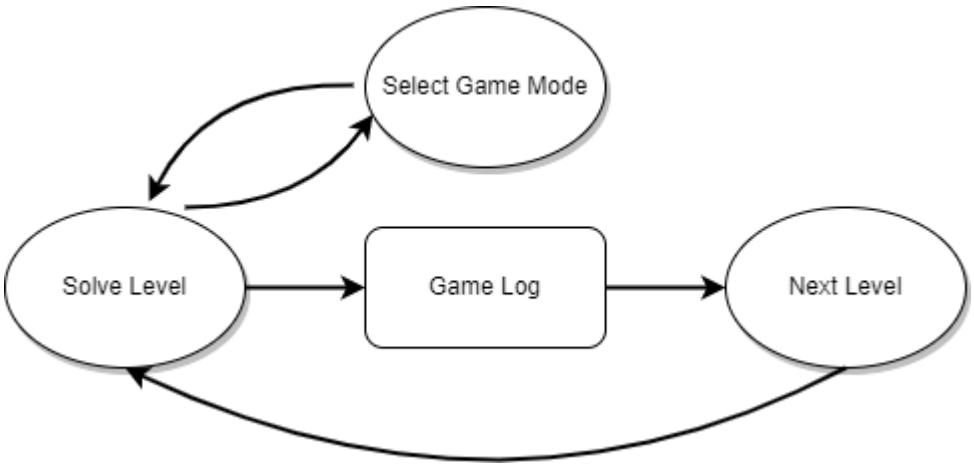

Figure 4. Core Game Loop

Each time player chooses the game mode to be played, and players will be given a puzzle to solve. Every action they take will be recorded, such as the variation of numbers and operators that are included in the puzzle, the number of undo buttons pressed, and how much time it takes to solve that puzzle will be recorded in the form of a gameplay log. If the player successfully solves the current puzzle, the game will again provide a different level and form of a puzzle.

3.2 Pilot User Study

The results of a pilot study conducted on participants regarding questions about serious games (Figure 6). In questions 1 and 2 regarding their previous experience of serious games, it can be seen that the number of students who have studied and have asked questions using games shows almost half of the number of participants. The pilot study results show that 48.5% of students have studied by playing games, while 45.7% of students have taken tests using games. While for question 3, although some have not previously studied or tested using games, all participants agree that the games played can test their academic skills in this game. For the last question, number 4, most participants (85.7%) prefer that this game can replace the paper-based test method; the rest choose paper-based exams question as the primary method.

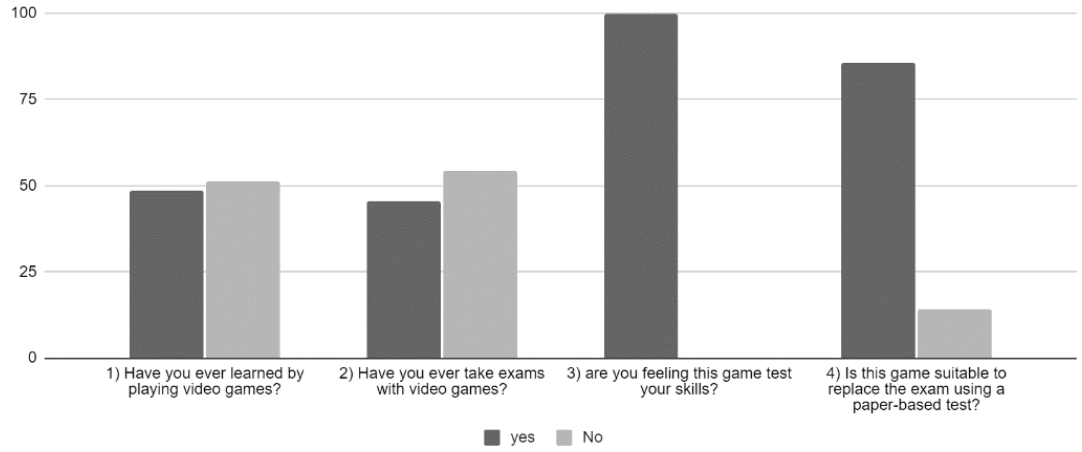

Figure 5. Students feedback questionnaire

3.3 Game Quality

Before the game testing stage began for all students, the researcher examined the B-block game to determine the level of quality of the game to be used in the educational process. The Quality Grid is divided into three categories of respondents: students, teachers, and developers. Table 3 shows the results of each criterion's evaluation and analysis, i.e., pedagogical specifications, playful specifications, and technical specifications [28]. The pedagogical specification is an aspect related to how game design can adapt in an educational context, including game content, game strategies, and assessment method are used. The playful specifications are mainly focused on how well the game can adapt to the playful dimension, including the attractiveness and the playability aspects. The technical specification is an aspect of the technical requirement, and the game's best practices mainly focus on technical efficiency and game requirements.

Table 3. The value of the quality score based on the category of respondents

	Pedagogical Specifications (%)	**Playful Specifications (%)**	**Technical Specifications (%)**
Students	72	62	71
Developers	81	77	90
Teachers	80	81	80
Average	**78**	**73**	**80**

The evaluation of game quality based on the respondents shows little significance for each category. For pedagogical specification, the highest score is on the developer respondents with 81%, and the difference is 0.8% with the category of student respondents. For Playful Specifications, the highest score is from the teacher, with 81%, with a difference of 19% compared to the data response from students. Technical Specifications the highest score is obtained from the developer of the respondents with a value of 90%; the difference is 19% from the lowest score from students' respondents.

The overall value is taken as the average value of all categories of respondents, with the Pedagogical specification getting a value of 78%. So it can be interpreted that the pedagogical value in the B-block game is categorized as superior. In other words, the game is sufficient and can be used in the educational process even though it only partially uses all the pedagogic criteria. While the Playfulness Specification gets an average score of 73%

(superior), this value shows that the game has received positive feedback regarding graphics, audio, and visuals and is quite attractive to players' attention and comfort. While for technical specifications, the average score of this game is 80% (Very Superior), indicating that the specifications of this game are complete and easy to play on the technical requirements needed during the educational process, including easy installation methods and complete information on how to play so easy to reach.

The results of the studies conducted show that the B-block puzzle game has a variety of specification values (see table 2). As previously explained, each of these aspects has its own weight in forming the final value of each specification. For the pedagogical specifications, the factor that makes the score imperfect is that it does not yet have a progress indicator and only has one type of assessment method. For playful specifications, this game lacks replayability and multiplayer value. Then, the technical specifications have shown good results in the "Very Superior" category.

However, we would like to emphasize that students should have sufficient time to familiarize themselves with how the game is played, the controls, and the mechanics of the game before carrying out the assessment. This is the most important point we mention because basically the game method is made with the aim of being able to replace traditional methods without reducing their function and usability.

Based on the results of the research that has been conducted, this research requires further evaluation considering that the sample size is relatively small, thus reducing the significance of the study. Second, this study investigates game-based assessment by involving only one arithmetic sub-material in one assessment context where in general to determine the quality of games a comparison is needed with various sub-materials, this also reduces the significance of the study. Third, it is important to conduct further studies on participants regarding their ability to play different types of games. For example, each student has different playing abilities or based on gender may have an influence on their skills in playing certain genres of games. In this study, the game is developed with a type of puzzle game that requires strong problem-solving skills. in this case, it was our goal to make the gameplay with the simplest possible mechanics so that players can quickly adapt. For this reason, we will develop a version that is simpler but can meet pedagogical needs that also support the assessment approach.

4. Conclusion

The quality of a game-based assessment can be analyzed from several specifications, including pedagogical specifications, playful specifications, and technical specifications. This study analyzes three aspects of the game-based assessment application, which was built to assess the arithmetic abilities of elementary school students. Based on the results, scores were obtained for the pedagogical specifications in the "superior" category, which showed that this game was almost perfect but sufficient to be used as an assessment tool and for educational purposes. The playfulness specifications with the "superior" criteria also show that this game can attract attention involving emotion, immersive, and interactivity which can make players feel more comfortable and enjoyable during the assessment process. Several aspects also need to be considered to improve this specification. Then for technical specifications, this game shows the "very superior" category, which shows that technical aspects, including graphics and sound, and design in this game are excellent and only require easy technical adjustments and requirements to play the game.

From all specifications, it can be concluded that this game achieves an excellent level of quality for educational use since it meets the required quality criteria and can be used as an alternative for assessment purposes. However, the quality of the pedagogic and playful specifications did not get a perfect score. Based on student feedback, this is because games' content sometimes makes students feel bored when they want to play the game repeatedly because the types of challenges given are still static. In the future, we hope the serious game assessment method can further maximize the fun aspect.

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