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Implementation of the Sugeno Fuzzy Algorithm for a Dynamic Scoring System in an Educational Game on Fraction and Decimal Operations

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Abstract

Technology in education provides opportunities for independent learning through diverse media, and educational games have emerged as powerful tools to enhance motivation and comprehension. However, traditional assessment in mathematics often relies on binary *right-or-wrong* evaluation, limiting fairness and overlooking students' learning processes. This study introduces an Android-based educational game on fraction and decimal operations that integrates the Sugeno Fuzzy Algorithm for dynamic scoring. Unlike previous applications that primarily used fuzzy logic for reward allocation, this approach incorporates three input variables correct answers, time, and remaining lives to generate a more holistic evaluation of student performance. The game was developed using the Game Development Life Cycle (GDLC) framework and tested with 24 sixth-grade students at SDN 17 Kuningan. Results show that the fuzzy-based scoring system was perceived as fairer by students and contributed to improved understanding of fraction and decimal operations. The broader contribution of this research lies in demonstrating how fuzzy logic can be embedded into educational games to support adaptive and equitable assessment. Limitations include the small sample size and the context-specific design of fuzzy rules, which call for further research with larger populations and more diverse subjects.

Keywords: Dynamic scoring, educational games, Sugeno Fuzzy Algorithm, fractions and decimals, adaptive assessment.

1 INTRODUCTION

The utilization of technology as a learning medium provides opportunities for students to engage in independent learning and access more diverse learning resources, thereby enhancing both their motivation and academic performance. Technological advancements have given rise to innovative and creative learning models within the educational process (Effendi & Wahidy, 2019). Among these, educational games are considered one of the most engaging tools, as they combine technological features with enjoyable learning methods. Educational games have been reported to improve students' motivation and learning outcomes by providing interactive and enjoyable learning experiences (Oktiviani et al., 2017) Furthermore, learning media allow students to participate more actively and independently, leading to better comprehension of subject matter (Nuraini , I., Sutama, & Narimo, 2019). The integration of technology into educational games allows students to learn while playing, making the learning process more engaging and effective.

However, based on interviews with the homeroom teacher of class 6B at SDN 17 Kuningan, mathematics lessons are still predominantly delivered through lecture-based instruction, with textbooks serving as the primary learning media. Such limitations restrict both the delivery and comprehension of material, resulting in passive student engagement and reduced motivation to learn. This condition directly impacts students' understanding of mathematics and leads to suboptimal achievement, as reflected in the finding that only 37.5% of students achieved scores above the minimum competency standard (Adrillian et al., 2024). Moreover, assessments in mathematics are often limited to binary right-or-wrong evaluations, without considering other aspects of students' learning processes. These challenges contribute to students' perception of mathematics as a difficult and less appealing subject.

Dynamic assessment has been suggested as an alternative that can enhance critical thinking and more fairly reflect students' learning progress (Situngkir et al., 2023). In this context, several prior studies have utilized the Sugeno Fuzzy Algorithm within educational and serious games. For instance, Astriningrum, et al., (2017) developed the *Marine Ecosystem Hero* game using Sugeno Fuzzy to calculate scores based on time and points. While their approach demonstrated the algorithm's applicability, it was limited to a narrow set of input variables and did not capture broader learning performance. Similarly, Oktavia dan Maulidi (2019) applied Sugeno Fuzzy in the *Aku Bisa* game for early childhood sexual education, where rewards were determined using three inputs (score, lives, time). Although the design provided adaptive rewards, the scoring system remained reward-oriented rather than supporting cognitive assessment. More recently, Sanjaya et al,.(2022) implemented Sugeno Fuzzy in a mobile platformer game to assign bonuses from inputs such as points and lives. Their focus was primarily on maintaining engagement, but the scoring mechanism did not integrate deeper educational objectives.

From these studies, it is evident that while Sugeno Fuzzy has been applied in educational and gamified contexts, most implementations remain limited to reward allocation and rely on a restricted set of variables. Few have explored its use in supporting dynamic scoring systems that comprehensively reflect students' performance across multiple dimensions of learning. Recent works in game-based learning emphasize the importance of adaptive assessment mechanisms that consider time, accuracy, and consistency to better support personalized learning. For instance, adaptive scaffolding in game-based learning has been shown to influence accuracy, completion time, and systematicity, illustrating how multiple performance metrics can be integrated into adaptive systems (Bolsinova et al., 2022) . Similarly, adaptive gamified assessments adjust task difficulty based on knowledge rating derived from both accuracy and response time, enabling continuous personalization of learning scenarios (Papadimitriou et al., 2019). Moreover, systematic reviews of adaptive game-based learning demonstrate that personalized educational games those adjusting in real time to learner behavior can significantly enhance student motivation, engagement, and performance (S. Zhu et al., 2023). Yet, integration of such approaches in mathematics education, and particularly in topics such as fractions and decimals, remains under-explored.

Therefore, the present study addresses this gap by applying the Sugeno Fuzzy Algorithm for *dynamic scoring* in an Android-based educational game focused on fraction and decimal operations. Unlike prior works, this research integrates three input variables correct answers, time, and lives (hearts)—to generate a more holistic score that reflects both accuracy and learning process. The game is specifically designed for grade 6B students at SDN 17 Kuningan and aims to provide an alternative interactive medium that enhances students' motivation and comprehension of mathematical concepts. Beyond entertainment, the integration of dynamic scoring is expected to foster fairer assessment, improve learning engagement, and serve as a practical teaching aid for educators.

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Volume 7 No. 2 August 2025

2 Literature Review

2.1 Educational Games

A game is generally defined as a structured form of play governed by specific rules that allow players to win or lose Gunawan et al., (2021). In educational contexts, games are designed not merely for entertainment but to integrate learning objectives with gameplay, creating interactive and enjoyable experiences. Prior research highlights that educational games can foster engagement and improve comprehension due to the integration of challenge, feedback, and active participation (Dony Novaliendry, 2013). However, many early implementations of educational games emphasized entertainment value more than adaptive learning features, leading to limited impact on deeper cognitive outcomes (Hamari et al., 2016);(Friel et al., 2009). More recent studies stress the importance of adaptive mechanisms, such as dynamic feedback and personalized scoring, to enhance the educational effectiveness of game-based learning (S. Zhu et al., 2023). This study builds upon such findings by embedding a dynamic scoring system using the Sugeno Fuzzy Algorithm, aiming to move beyond static right-or-wrong evaluations and foster fairer, multidimensional assessment.

2.2 Sugeno Fuzzy Algorithm

The Sugeno Fuzzy Method was introduced by Takagi, Sugeno, and Kang in 1985 (Chast, 2002). *Sugeno Fuzzy is a fuzzy logic method that employs IF–THEN rules for decision-making. There are two main models of the Sugeno method, described as follows*:

a. Zero-order Sugeno Fuzzy Model
   In general, the Zero-order Sugeno Fuzzy model is expressed as:
   $$IF\ (x_1\ is\ A_1)\ AND\ (x_2\ is\ A_2)\ \ldots\ (x_n\ is\ A_n)\ THEN\ z = k \quad (1)$$
   where x_i is the i-th fuzzy set as the antecedent, and k is a constant representing the consequent.
b. First-Order Sugeno Fuzzy Model
   In general, the First-Order Sugeno Fuzzy model is expressed as:
   $$IF\ (x_1\ is\ A_1)\ AND\ (x_2\ is\ A_2)\ \ldots\ (x_n\ is\ A_n)\ THEN\ z = p_1x_1 + p_2x_2 + \cdots + p_nx_n + q \quad (2)$$
   where A_i is the i-th fuzzy set as the antecedent, p_i is the i-th constant, and q is also a constant in the consequent.

2.3 Mathematics

Mathematics is one of the core subjects taught at all levels of education, from elementary school to higher education. It is a compulsory field of study. As stated by Farhana et al. (Farhana et al., 2022). "Mathematics is a deductive, axiomatic, formal, and abstract science that uses symbolic language. Therefore, it is crucial to introduce mathematics to children as early as elementary school. " This importance stems from the fact that mathematics functions not only as a scientific discipline but also as a foundational tool for understanding various other fields of study.

2.4 Game Development Life Cycle (GDLC)

The Game Development Life Cycle (GDLC) is a game development process that follows an iterative approach consisting of six phases: concept initiation, pre-production, production, testing, beta, and release (Krisdiawan, 2018).

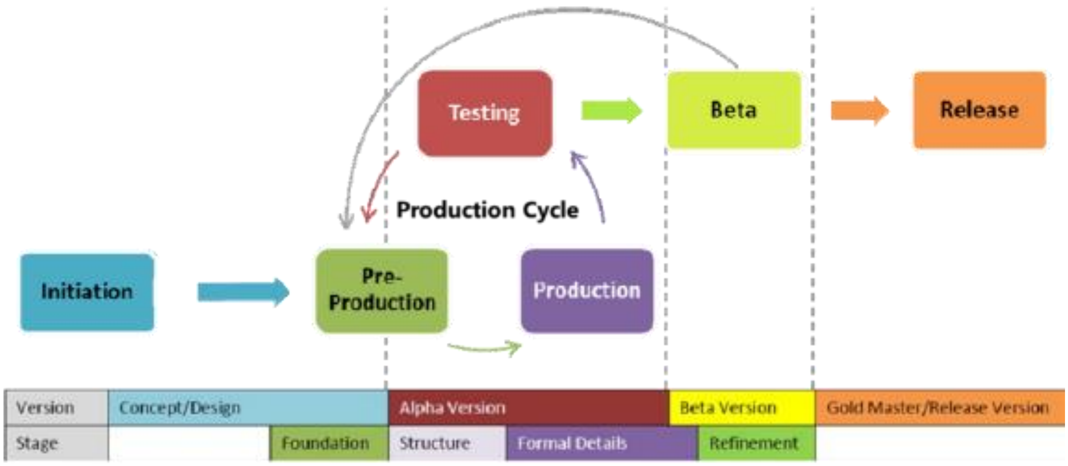

Figure 1. GDLC Stages

3 Research Methodology

The research method employed in this study for developing the mathematics educational game is based on the Game Development Life Cycle (GDLC) model. The problem-solving approach utilizes the Sugeno Fuzzy Algorithm, while the system design is carried out using the Unified Modeling Language (UML). The research object is class 6B of SDN 17 Kuningan, located at Jl. Siliwangi, Purwawinangun, Kuningan, Kabupaten Kuningan.

3.1 Data Collection Methods

a. Observation
The observation process was conducted by directly monitoring the teaching and learning activities in class 6B of SDN 17 Kuningan. In addition, the researchers administered a pre-test consisting of 10 questions and distributed questionnaires to 24 students in class 6B to identify learning difficulties faced by the students.
b. Interview
The interview process was conducted directly with the informant, Mr. Nunu Nugraha, S.Pd., the homeroom teacher of class 6B as well as the mathematics teacher for the class. This interview provided information regarding the learning process, the teaching media used, and the challenges encountered during lessons.
c. Literature Study
A literature review was conducted by reading and analyzing various references relevant to the research topic from different types of scientific publications, textbooks, journal articles, and other credible sources related to the study, such as those discussing the Sugeno Fuzzy Algorithm, GDLC, and game development.

3.2 Problem-Solving Method

The Sugeno Fuzzy Algorithm was implemented to enable dynamic scoring within the game. The Sugeno Fuzzy Method was first introduced by Takagi, Sugeno, and Kang in 1985 (Chast, 2002). It is a fuzzy logic method that uses IF–THEN rules for decision-making. In this study, the Sugeno Fuzzy Algorithm is applied to dynamic assessment within the game by considering multiple performance indicators in the scoring process.

e-ISSN: 2655-867X
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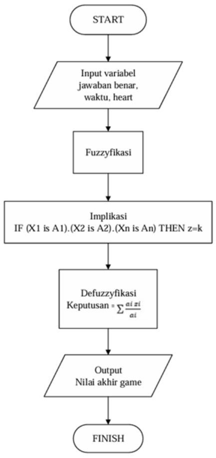

Figure 2. Flowchart of the Sugeno Fuzzy Algorithm used in this study

1. Input Variable : In this study, three determining input variables are used: correct answers, time, and heart. Additionally, one output variable is used, namely the score.
2. Linguistic Values
    a. Linguistic values for the *correct answers* variable: **low**, **medium**, **high**.
    b. Linguistic values for the *time* variable: **slow**, **moderate**, **fast**.
    c. Linguistic values for the *heart* variable: **few**, **moderate**, **many**.
    d. Linguistic values for the *score* output variable: **A**, **B**, **C**.
3. **Fuzzy Rules and Membership Functions**
    The rules were constructed in collaboration with the mathematics teacher to reflect realistic evaluation criteria. For example:
    - IF correct answers are *high* AND time is *fast* AND heart is *many* THEN score = *A*.
    - IF correct answers are *medium* AND time is *moderate* AND heart is *few* THEN score = *B*.
    - IF correct answers are *low* AND time is *slow* AND heart is *few* THEN score = *C*.

    Membership functions for each variable (correct answers, time, heart) were designed using **trapezoidal and triangular functions** due to their simplicity and suitability for representing linguistic values.
4. Fuzzification
    Fuzzification is the initial stage in the fuzzy logic process, in which crisp sets are transformed into fuzzy sets with continuous membership values [4].
    a. Fuzzy set for correct answers
    Figure 3 illustrates the membership function for the correct answers variable:

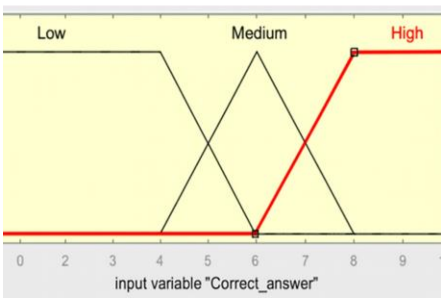

Figure 3. Membership function of correct answer

e-ISSN: 2655-867X
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Volume 7 No. 2 August 2025

$$Less : Trapezoid: \mu(x) = \begin{cases} 1; \ \leq 4 \\ \dfrac{6-x}{6-4}; 4 < x \leq 6 \\ 0; \ x \geq 6 \end{cases} \quad (3)$$

$$Medium : Triangle : \mu(x) = \begin{cases} 0; x \leq 4 \ atau \ x > 8 \\ \dfrac{x-4}{6-4}; 4 < x \leq 6 \\ \dfrac{8-x}{8-6}; 6 < x \leq 8 \\ 1; x = 6 \end{cases} \quad (4)$$

$$Many : Trapeziums : \mu(x) = \begin{cases} 0; x \leq 6 \\ \dfrac{x-6}{8-6}; 6 < x \leq 8 \\ 1; x \geq 8 \end{cases} \quad (5)$$

b. Time Fuzzy Set
Figure 4 below is the membership function of the Time variable:

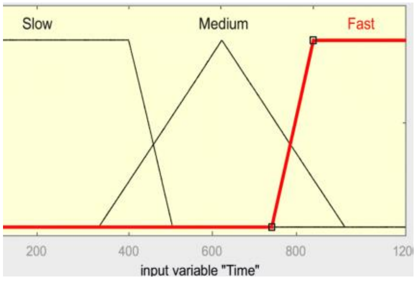

Figure 4 Time membership function

$$Slow : Trapezoid : \mu(x) = \begin{cases} 1; \ x \leq 400 \\ \dfrac{500-x}{500-400}; 400 < x \leq 500 \\ 0; \ x \geq 500 \end{cases} \quad (6)$$

$$Medium : Triangle : \mu(x) = \begin{cases} 0; x \leq 400 \ atau \ x \geq 1000 \\ \dfrac{x-400}{700-400}; 400 < x \leq 700 \\ \dfrac{1000-x}{1000-700}; 700 < x \leq 1000 \\ 1; \ x = 700 \end{cases} \quad (7)$$

$$Fast : Trapezoid : \mu(x) = \begin{cases} 0; x \leq 900 \\ \dfrac{x-900}{1000-90}; 900 \ \leq x \leq 1000 \\ 1; x \geq 1000 \end{cases} \quad (8)$$

c. Fuzzy Heart Set
Figure 5 below is the membership function of the Heart variable:

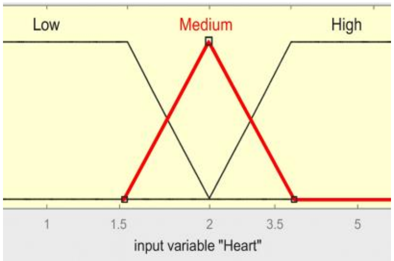

Figure 5 Heart membership function

$$Little : Trapezoid: \mu(x) = \begin{cases} 1; \ \leq 2 \\ \dfrac{3-x}{3-2} ; \ 2 < x \leq 3 \\ 0; \ x \geq 3 \end{cases} \quad (9)$$

$$Medium : Triangle: \mu(x) = \begin{cases} 0; x \leq 2 \ atau \ x \geq 4 \\ \dfrac{x-2}{3-2} ; 2 < x \leq 3 \\ \dfrac{4-x}{4-3} ; 3 < x \leq 4 \\ 1; \ x = 3 \end{cases} \quad (10)$$

$$Many : Trapeziums : \mu(x) = \begin{cases} 0; x \leq 3 \\ \dfrac{x-3}{4-3} ; 3 \ \leq x \leq 4 \\ 1; x \geq 4 \end{cases} \quad (11)$$

5. Defuzzification
   In the Sugeno method, the defuzzification process is carried out using the Average method with the following formula.:

$$Z^* = \frac{\sum ai \ zi}{\sum ai} \quad (12)$$

3.3 System Development Methods

The system development method used in this research is the Game Development Life Cycle (GDLC) method. GDLC consists of 6 stages, namely:(Krisdiawan, 2018)

a. Initialization
   At this stage, the researcher collected data through observations, interviews, questionnaires, and pretests with students. Afterward, the researcher determined the game concept to suit user needs.
b. Pre-Production
   At this stage, the researcher revised the game design and created a game prototype. Pre-production ended when the revisions or changes to the game design were approved and documented in the GDD.
c. Production
   At the production stage, the researcher created assets using Adobe Illustrator, wrote program code using C# and PHP, and developed the game using Unity.
d. Testing
   At this stage, the researcher tested the game's functions. The researcher conducted black-box and white-box testing of the game. The results would determine whether it was time to advance to the next phase (Beta) or repeat the production cycle.

e-ISSN: 2655-867X
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Volume 7 No. 2 August 2025

e. Beta
Beta is the phase for conducting third-party or external testing, known as beta testing. The author conducted testing using User Acceptance Tests (UAT) with students and homeroom teachers of Grade 6B SDN 17 Kuningan.

f. Release
At this stage, the game has been successfully developed and has completed alpha and beta testing. At this stage, the game is ready for use by students.

4 RESULT AND DISCUSSION

4.1 Game Design Document (GDD)

1. Game Layout Chart
The image shows the flow structure of the game in a game layout chart that depicts the overall navigation from the beginning to the end of the game. Figure 6 below is the game layout chart for this game.

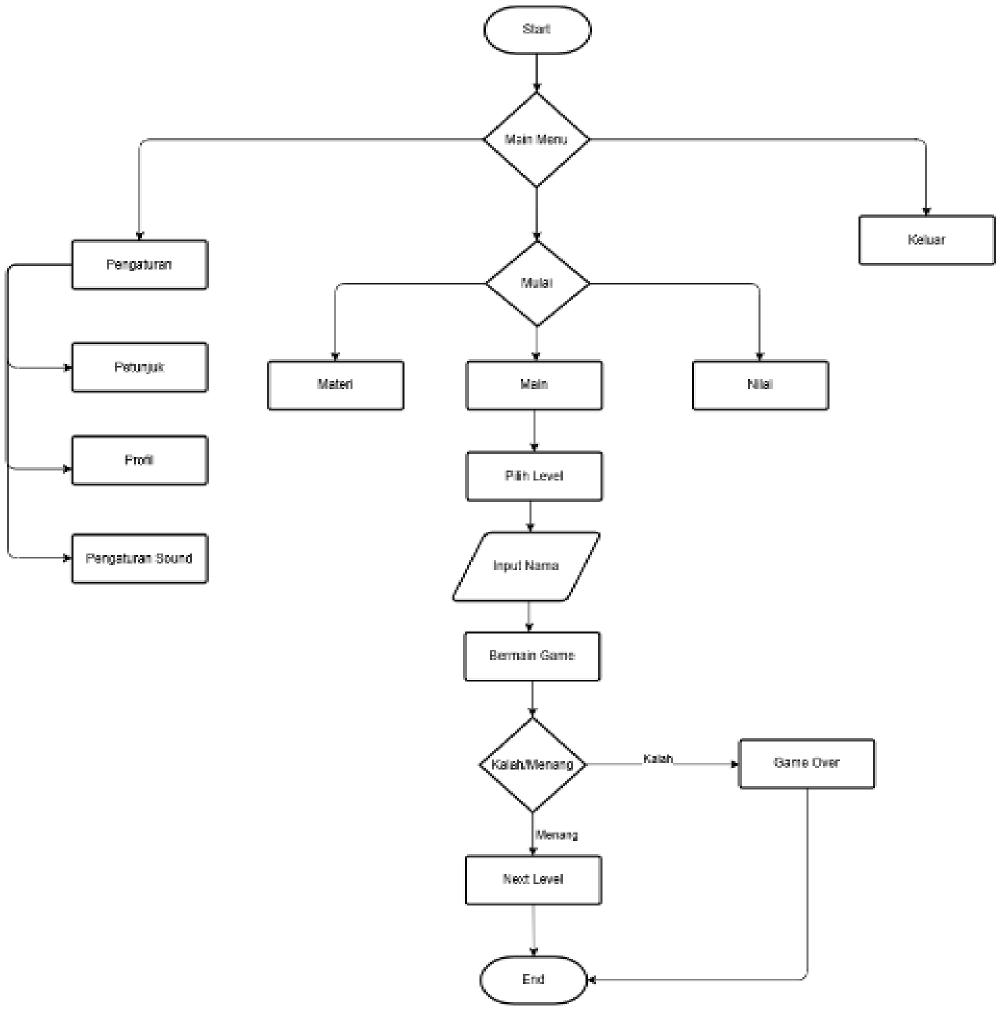
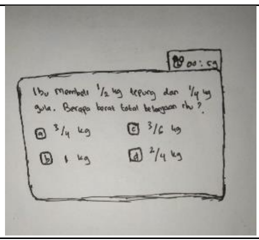


Figure 6. *Game* layout chart

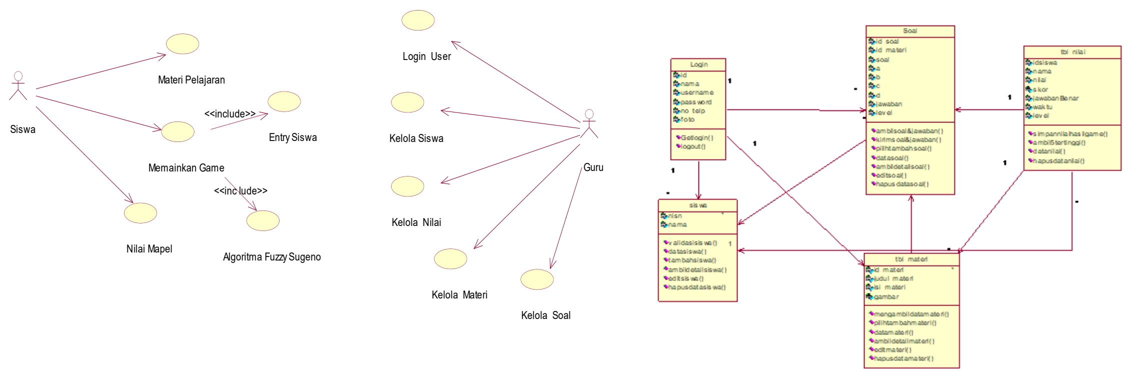
2. Storyboard

Table 1. Storyboard

No	Scene game	Information
1.		Level 1 is set in summer. The interface features controls for moving left and right, jumping, and sliding. Players must avoid enemies and cliffs to avoid losing lives. Additionally, 10 paper scrolls appear throughout the adventure, displaying random fraction operation problems, which players must answer correctly to avoid losing lives. At the end, a finish board indicates successful completion and displays a panel containing the game's results.
2.		The question panel will appear when the player touches the rolled paper object. The questions displayed are random. The question panel consists of the question text, buttons a, b, c, d, and a timer.

4.2 Unified Modelling Language (UML)

Figure 7.(a) below is a use case of the educational game that was created, which involves 2 actors, namely students and teachers, while Figure 7.(b) is a class diagram of the educational game that was created.



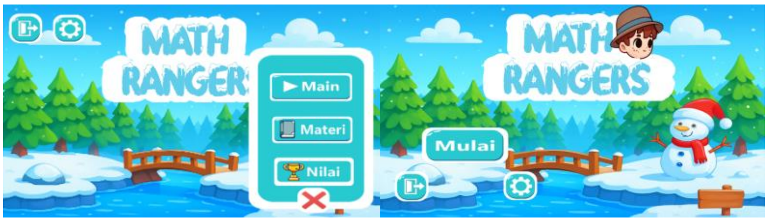
(a) (b)

Figure 7. (a) Use case diagram; (b) Class diagram

Figure 8.(a) below illustrates the flow of activities carried out by the actor (student) when playing the game depicted in the activity diagram. Figure 8.(b) below is a sequence diagram of playing the game that illustrates the flow of communication between the main objects in the system during the actor's interaction process with the game.

4.3 Interface Game

1. Main Menu and Menu Interface
   Figure 9.(a) is the initial page that will appear when the player enters the application. Meanwhile, Figure 9.(b) is the page that appears when the player selects the start menu on the main menu page.



(a) (b)

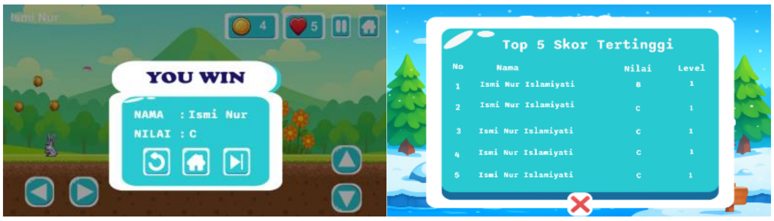
Figure 9. (a) Menu interface; Menu interface (b)

2. Game Play Interface & Question Display
   Figure 10.(a) is the game play page, this page appears when the player selects the main menu and selects a level and then enters a name. Then Figure 10.(b) is the question display page, this page appears when the player touches the game question object while playing the game.

(a) (b)

Figure 10. (a) Main game interface; (b) Question display interface

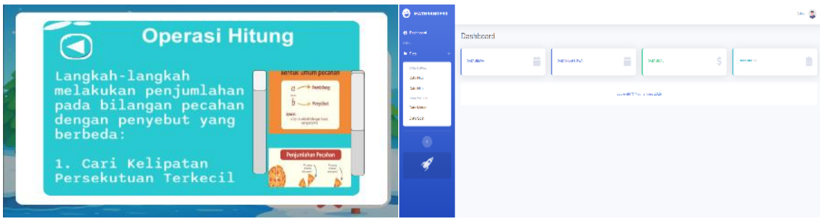
3. Score and Value Results Interface
   Figure 11.(a) is the score results page that appears when a player successfully completes the game and reaches the finish line. Figure 11.(b) is the score page, which displays the five highest scores from all students. This page appears when a player selects the score menu on the menu page.



(a) (b)

Figure 11. (a) Score result interface; (b) Value interface

4. Material Interface & Teacher Dashboard
   Figure 12.a is the page that appears when a player selects the material menu on the menu page. Figure 12.b, on the other hand, shows the teacher dashboard; this page is not in-game and can only be accessed by teachers.



(a) (b)

Figure 12. Material interface and teacher dashboard interface

4.4 Blackbox Testing

The results of blackbox testing (Table 2) confirm that all core features of the game functioned as designed. This indicates that the system architecture developed using GDLC and UML diagrams was successfully implemented without major technical errors. Likewise, whitebox testing confirmed that the internal logic of the fuzzy membership functions operated according to specification. These findings provide assurance that the algorithmic implementation of the Sugeno Fuzzy method was technically sound, allowing us to focus the analysis on its pedagogical impact.

Table 2. Blackbox testing

Button Function	Testing Scenarios	Expected Results	Result
Begin	Player presses the Start button	The system displays the game menu page	Valid
Material	Player presses Material button	The system displays the material list page	Valid
Main	Player presses Play button	The system displays the select level page	Valid
Finish	Players touch the finish	The system calculates the value and displays the score results page	Valid
Value	Player presses the value button	The system displays the highest 5 rated pages	Valid
Setting	Player presses the settings button	The system displays the game settings page	Valid

From the tests that have been carried out, it was found that all the functionality of the features in the game are running according to the initial design.

4.5 Whitebox *Testing*

White box testing is a test that is carried out by looking into the modules and codes in the application. (Krisdiawan, 2018). *Whitebox testing is performed to ensure that the program's logic flows according to the structure and conditions specified in the code. The following is an example of source code used in whitebox testing*:

```
public float[] GetjawabanBenar(float jawabanbenar){
if (jawabanbenar <= 4) {
jawabanBenarkurang = 1;}
else if (jawabanbenar > 4 && jawabanbenar <= 6){
jawabanBenarkurang = (6 - jawabanbenar) / (6 - 4); }
else if (jawabanbenar >= 6){
```

```
jawabanBenarkurang = 0;}
if (jawabanbenar > 4 && jawabanbenar <= 6){
jawabanBenarsedang = (jawabanbenar - 4) / (6 - 4)}
else if (jawabanbenar > 6 && jawabanbenar <= 8){
jawabanBenarsedang = (8 - jawabanbenar) / (8 - 6);}
else if (jawabanbenar == 6){
jawabanBenarsedang = 1; }
else{
jawabanBenarsedang = 0;}
if (jawabanbenar > 6 && jawabanbenar <= 8){
jawabanBenarbanyak = (jawabanbenar - 6) / (8 - 6);}
else if (jawabanbenar > 8){
jawabanBenarbanyak = 1;}
else{
jawabanBenarbanyak = 0;}
return new float[] { jawabanBenarkurang, jawabanBenarsedang, jawabanBenarbanyak };
```

Based on the code example above, the following calculations are obtained:

$$V(G) = cyclomatic\ complexity$$
$$E = Total\ number\ of\ edges$$
$$N = Total\ number\ of\ nodes$$
$$V(G) = E - N + 2$$
$$V(G)\ 33 - 25 + 2 = 10$$

4.6 User Acceptance Test (UAT)

To find out the respondents' responses to the mathematics educational game that had been made, a test was carried out on 24 students. The assessment uses the Likert scale which consists of five answer choices, namely Strongly Agree is given a weight of 5, Agree is given a weight of 4, Neutral is given a weight of 3, Disagree is given a weight of 2, and Strongly Disagree is given a weight of 1.

Table 4. UAT Results

No	Question	Answer					Result
		Strongly agree x_5	Agree x_4	Neutral x_3	Disagree x_2	Strongly Disagree x_1	
1.	This educational game is easy to use	70	28	9	0	0	107
2.	The menus and buttons in this game are clear and easy to use	55	40	9	0	0	104
3.	This educational game is interesting and makes you more motivated to learn	85	8	15	0	0	108
4.	The questions and materials in this game are the same as the teachers teach in class	70	32	6	0	0	108

No	Question	Answer					Result
		Strongly agree x_5	Agree x_4	Neutral x_3	Disagree x_2	Strongly Disagree x_1	
5.	This educational game can help you understand the basic operation of fractions and decimals	85	4	3	0	0	92
6.	This educational game can be used as an alternative learning medium in schools	95	16	3	0	0	114
7.	The final game score is in accordance with how you play and answer questions	110	4	3	0	0	117
Total							750

From 3 teacher respondents and 24 student respondents, the total weight was obtained: 750. The expected score or maximum score is as follows: Students: 24 × 7 × 5 = 840, Then the percentage value is as follows :

Percentage of Eligibility (%) = $\frac{\text{(Corps of test results)}}{\text{(Expected score)}} \times 100\%$

Percentage of Eligibility (%) = $\frac{750}{840} \times 100\%$

Percentage of Eligibility (%) = $89{,}28\%$

The User Acceptance Test yielded an average feasibility score of **89.28%**, suggesting that students and teachers perceived the game as both engaging and suitable as a learning tool. As shown in Table 4, the highest agreement (117 total score) was on the item *"The final game score is in accordance with how you play and answer questions."* This result is particularly significant, as it demonstrates that students perceived the **fuzzy-based scoring system** as fair and reflective of their performance. Unlike traditional binary scoring, the fuzzy system incorporated accuracy, response time, and remaining lives, allowing for a more nuanced evaluation.

This multidimensional approach reduced frustration among students who answered correctly but took slightly longer or lost lives. For instance, students who showed persistence despite mistakes could still achieve an intermediate score (B), rather than being penalized with a low score (C). Such fairness is aligned with the principles of **dynamic assessment** (Situngkir et al., 2023), which emphasizes evaluating learning processes rather than just outcomes.

4.7 Pre-Test and Post-Test Testing

This Pre-test and Post-Test test is carried out to measure the level of students' understanding of fractional and decimal operation materials before and after using this educational game. This pre-test and post-test were carried out to 24 students in grade 6b of SDN 17 Kuningan which consisted of 10 essay questions which were done within 20 minutes using the same questions, the results of this test can be seen in Figure 13.

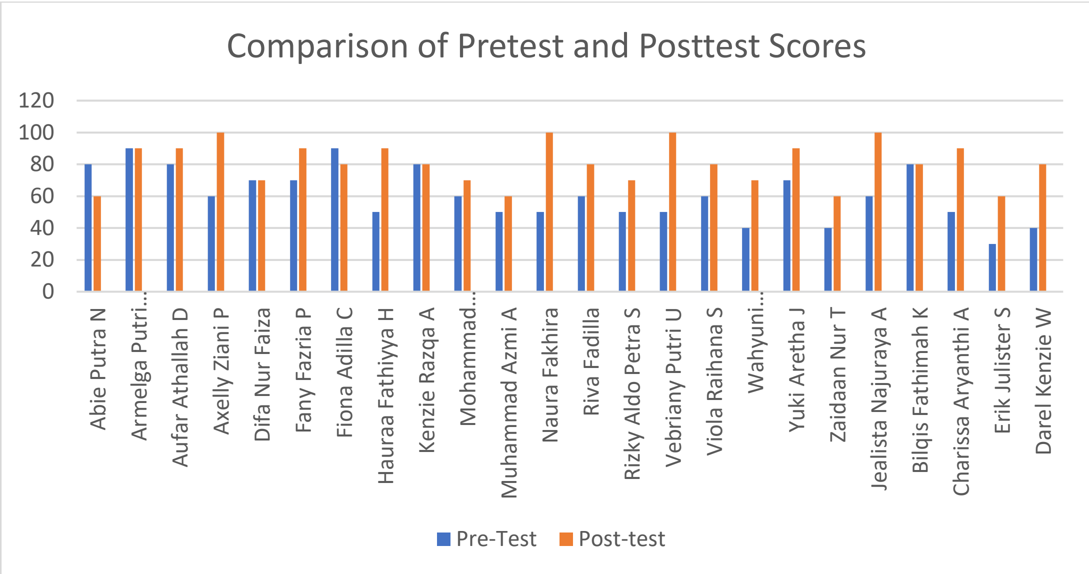


Figure 13. Comparison of pre-test and post-test

The pre-test and post-test comparison (Figure 13) shows a **20% increase in students' average scores** after playing the game. This improvement suggests that integrating mathematics exercises into game-based scenarios enhanced understanding of fractions and decimals. Importantly, the fuzzy scoring mechanism contributed to this outcome by maintaining motivation: students reported higher willingness to reattempt problems knowing that partial effort (time and persistence) was also valued in their final score. This reflects findings from prior studies that adaptive scoring can sustain engagement and promote deeper learning (Bolsinova et al., 2022; Z. Zhu & Zhu, 2022).

5 CONCLUSION

This study demonstrates that integrating the Sugeno Fuzzy Algorithm into an Android-based educational game provides an effective approach for implementing dynamic scoring in mathematics learning, particularly on fractions and decimals. Beyond its technical success, the game highlights the pedagogical potential of fuzzy-based assessment to deliver fairer evaluations by considering accuracy, time efficiency, and consistency. This multidimensional scoring approach represents a meaningful shift from conventional binary assessments, offering learners feedback that values both outcomes and processes.

The broader implication of this research lies in its contribution to the field of **adaptive game-based learning**, where assessment is increasingly recognized not only as a measure of achievement but also as a tool to sustain motivation and enhance learning engagement. For educators, the developed game provides a practical model of how fuzzy logic can be embedded in classroom practice as an alternative formative assessment tool.

Nevertheless, the study is not without limitations. The relatively small sample size (24 students in a single school) restricts the generalizability of the findings. In addition, the fuzzy rules and membership functions were designed with teacher input, which, while contextually valid, may limit transferability to broader populations. External factors such as teacher support and the novelty of digital games may also have influenced the results.

Future research should expand testing to larger and more diverse samples, explore the integration of data-driven tuning techniques such as **Adaptive Neuro-Fuzzy Inference System (ANFIS)** to refine scoring rules, and apply the model to other mathematical topics or subject areas. Comparative studies with other adaptive scoring approaches, such as Mamdani or machine learning-based assessment, would further strengthen the evidence base for dynamic scoring in educational games.

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