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Optimizing Adaptive Rewards Using Sugeno Fuzzy Logic in an Android Educational Game

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Abstract

This study developed an Android-based educational game to teach children about waste management, with an adaptive reward system using Sugeno fuzzy logic. The aim of the study was to increase student motivation and engagement in environmental learning by providing rewards tailored to player performance. The development method referred to the Game Development Life Cycle (GDLC), covering the development stages up to beta testing. Media expert validation results showed good game quality in terms of visual appearance and ease of use, with an average score of 4.6/5. Material validation also showed the suitability of the material for learning objectives with a score of 4.7/5. Trials with 26 primary school students resulted in an average score of 4.6/5 for ease of use and 4.8/5 for visual appeal. The Sugeno fuzzy logic-based reward system proved effective in adjusting rewards to player performance. Test data showed that 70% of students received 3 stars, 20% received 2 stars, and 10% received 1 star. This system increased student motivation and engagement in learning. This research contributes to the development of fuzzy technology-based educational games by demonstrating the great potential of Sugeno fuzzy logic in creating adaptive reward systems that enhance learning. This game is expected to be an effective alternative in teaching waste management and can be expanded to other educational topics.

Keywords : Educational Games, Sugeno Fuzzy Logic, Waste Management, Gamification, Environmental Education

1. Introduction

The issue of waste management is an increasingly complex environmental challenge in many countries, including Indonesia. The increase in the volume of poorly managed waste not only causes environmental damage, but also worsens the quality of life of communities through soil, air and water pollution. Ineffective waste management also increases the risk of natural disasters, such as floods and landslides, which are becoming more frequent in certain areas.(Kahfi, 2021; Mustofa & Arifin, 2020). One of the main causes of this problem is the low level of public awareness, especially among children, of the importance of sustainable waste management. Therefore, a more innovative approach to environmental education is needed, particularly for children, in order to increase their understanding of the importance of waste management from an early age.(Larsson, 2020; Wahyuni et al., 2020).

Digital-based educational games have emerged as an effective medium for conveying educational messages in a fun and interactive way. Educational games combine elements of play with learning, which can increase children's engagement and motivation in understanding various concepts, including waste management.(Brown & Cohen, 2021; Nikiforidou, 2020). Gamification for Environmental Education: A Study on Eco-friendly Learning shows that the application of gamification elements in educational games has great potential to increase awareness of sustainability and environmental issues among children.(Sharma & Kumar, 2021). Meanwhile, Educational Games as a Tool for Promoting Environmental Awareness emphasises that educational games can be an effective means of teaching sustainability values in an engaging and enjoyable way(Sari & Widodo, 2020). However, although there are many educational games available, most still use non-adaptive reward systems, which can reduce player engagement and motivation in the long term. The rewards given are often static and not tailored to the individual achievements or abilities of the player(Chandra & Wahyu, 2022; Larsson, 2020). Furthermore, research on Game-Based Learning for Sustainability Awareness Among Children shows that game-based learning can significantly increase environmental awareness and active learning(Peterson & Lee, 2021). And The Role of Educational Games in Fostering Environmental Responsibility emphasises that educational games not only increase knowledge, but also shape environmental responsibility in students(Chong & Lim, 2021).

Kumar & Singh (2022) state that educational games with interactive elements can improve children's learning behaviour and environmental

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awareness, making them an effective tool in changing the mindset of the younger generation regarding sustainability issues(Kumar & Singh, 2022). In line with this, Singh & Shukla (2021) emphasise that gamification in environmental education is highly effective in increasing student engagement in learning about sustainability (Singh & Shukla, 2021). This study also supports the use of gamification to educate children about waste management. Wang & Xu (2021) highlight the importance of adaptive learning systems in educational games, which tailor the material to the player's abilities and progress, improving understanding of environmental material.(Wang & Xu, 2021). Tiwari & Sharma (2021) added that educational games are highly effective in raising environmental awareness among children, especially those of primary school age, through interactive learning experiences(Tiwari & Sharma, 2021). Lee & Kim (2021) explain that fuzzy logic in educational games enables more personalised and relevant learning (Lee & Kim, 2021). Zhang & Wang (2021) added that the application of artificial intelligence (AI) in educational games can improve the quality of the learning experience by making the system more interactive and responsive to players(Zhang & Wang, 2021).

In line with this, Putra et al. (2021) developed an Android-based educational game, Covid Shooter, which aims to educate children about COVID-19 prevention. The game successfully demonstrated that educational games can be used to convey important messages while increasing engagement through interesting game elements(Putra et al., 2021). A similar approach was used in this study to develop an Android-based educational game that teaches waste management, utilising Sugeno fuzzy logic to create an adaptive reward system to increase children's motivation to learn more about effective waste management.

This study is also in line with several previous studies that developed Android-based educational games for children. Syaifudin & Permadi (2020) developed an Android-based educational game using the A* algorithm pathfinding method in an ‘enemy’ themed game, which aims to improve children's understanding of navigation and strategy. A similar study was conducted by Margareta et al. (2018), who designed an Android-based educational game for learning Javanese script. Both studies demonstrate the great potential of Android-based educational games in enhancing children's understanding in a fun and interactive way (Margareta et al., 2018; Syaifudin & Permadi, 2020). In this study, a similar approach was used to teach waste management by utilising Sugeno fuzzy logic so that the reward system would be more adaptive to the players' achievements.

In addition, Kurniawati & Perdana (2021) developed educational games that focus on environmental issues in schools. Their research shows that educational games can be used to raise students' awareness of environmental issues, which is in line with this study's objective of educating children about waste management through interactive and enjoyable media(Kurniawati & Perdana, 2021). Indriani & Fadilah (2020) researched the role of gamification in environmental education, which showed that the application of game elements in the learning context can increase students' awareness and involvement in environmental issues, resulting in the development of this educational game on waste management(Indriani & Fadilah, 2020).

With the development of technology, Sugeno fuzzy logic has shown great potential in optimising reward systems in educational games. Sugeno fuzzy logic is capable of managing uncertainty and generating decisions based on uncertain inputs, enabling games to provide feedback that is more tailored to the needs of players(Hariri, 2021; Oktavia, 2022). The application of Sugeno fuzzy logic in educational games allows the reward system to be more adaptive and dynamic, tailored to the player's performance and achievements. This is expected to increase player motivation to continue participating in learning and understanding the material presented, particularly in relation to waste management.

Although previous studies have demonstrated the effectiveness of fuzzy logic in educational games, very few have applied Sugeno fuzzy logic in educational games focused on waste management. This study aims to fill this gap by developing an Android-based educational game that optimises adaptive rewards using Sugeno fuzzy logic. This game is designed to teach waste management through fun and educational gameplay, as well as providing rewards tailored to the player's abilities.

The main objective of this study is to develop an educational game that uses Sugeno fuzzy logic to provide more personalised and relevant rewards for players, which in turn can increase their motivation and engagement in learning about waste management. Thus, this study is expected to make a significant contribution to the development of fuzzy technology-based educational games, as well as paving the way for the application of this technology in environmental education in the future(Salim et al., 2021; Wahyudi & Yulianti, 2020).

This study is expected to make a significant contribution to the development of fuzzy technology-based educational games, particularly in creating a more adaptive and personalised reward system. By applying Sugeno fuzzy logic, it is hoped that this educational game can increase children's motivation and engagement in learning about waste management and have a positive impact on waste management at the individual level. It is hoped that this game will become an effective alternative in raising environmental awareness among the younger generation. This research is also in line with previous

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studies, such as that conducted by Mashuri et al. (2021), which demonstrated the effectiveness of games as an attractive and useful educational medium and opened up opportunities for the development of fuzzy technology-based educational games in other educational topics(Mashuri et al., 2021).

2. Research Method

This research is development research that focuses on the design and evaluation of an Android-based educational game on waste management with an adaptive reward system using Sugeno fuzzy logic. The development method used refers to the Game Development Life Cycle (GDLC), which includes the stages of initiation, pre-production, production, testing, beta, and release. In this study, the development process was limited to the beta testing stage to evaluate the feasibility and user response to the developed game, as presented in Figure 1.

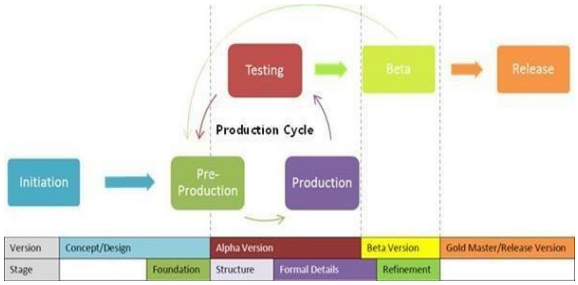


Figure 1 Game Development Life Cycle Methodology

2.1. Research Data and Subjects

Research data consists of two types, namely:

a. Expert validation data, obtained from media experts and material experts' assessment of the developed game products.
b. User response data, obtained from primary school pupils after using educational games.

Media experts are lecturers or practitioners in the field of information technology who are competent in developing learning media and user interfaces. Subject matter experts are primary school teachers who teach subjects related to the environment and waste management.

The subjects of the user trial were primary school students at SDN Bulu, Kraksaan Subdistrict, Probolinggo Regency. The population consisted of 35 students. The sample size was determined using the Slovin formula with an error rate (e) of 10%, resulting in a sample of 26 students for the trial. The students were asked to try the game and then fill out a response questionnaire.

2.2. Game Development Procedures

The game development procedure is structured in stages and integrated with the stages in the GDLC. Broadly speaking, the procedure is divided into three main stages, namely: the initial stage, the processing and execution stage, and the gameplay design and implementation stage.

In the initial stage, problems related to students' low understanding and awareness of waste management were identified. The need for game-based learning media was assessed through literature studies and preliminary discussions with teachers, thereby providing an overview of the desired competencies and user characteristics (primary school children).

During the processing and implementation stages, data on requirements was collected through interviews with teachers and observations of the learning context. This information was used to formulate the functional and non-functional requirements of the game, including the selection of game genres, level design, and the compilation of quiz material related to waste management.

During the gameplay design and implementation stage, the following was carried out:

a. Designing game flows in the form of flowcharts, use case diagrams, and activity diagrams to illustrate user interactions with the system;
b. Mechanical design of the game, namely sorting waste into the correct categories and solving quizzes using golden tickets;
c. Game implementation using the Android platform (e.g. Android Studio) with the appropriate programming language.

The resulting game was then tested internally (functionality and usability testing), followed by beta testing with a group of students as end users. Feedback from the testing process was used to improve the design of the interface, gameplay, and presentation of material.

2.3. Designing a Reward System Based on Sugeno Fuzzy Logic

The adaptive reward system is designed using Fuzzy Sugeno to determine the number of stars earned by players at the end of the game. This system uses two main input variables, namely:

a. The total score (S) obtained by the player during the game, and
b. Number of golden tickets (N) successfully collected.

The output variable is the number of stars with a discrete domain of 1 to 3. Each input variable is modelled with a fuzzy set (low, medium, high) using ascending and descending linear membership functions. The boundaries of the fuzzy sets are determined based on the range of scores and the number of golden tickets that players can achieve.

The rule base is organised in the form of IF–THEN rules that combine score conditions and golden tickets to generate a star rating. Example rules:

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a. IF high score AND golden ticket successful, THEN star = 3
b. IF the score is average AND the golden ticket fails, THEN the star rating is 2
c. IF low score AND golden ticket fails, THEN star = 1

The inference process is carried out using the Sugeno method with the MIN operator to obtain the degree of truth for each rule, then the crisp output is calculated using the weighted average method. The output values obtained are rounded to the nearest integer (1, 2, or 3) to be displayed as the number of stars received by the player. This system is integrated directly into the game logic and tested alongside game trials. The following is the Fuzzy Sugeno process in determining rewards in the form of Stars in the game to be built, as shown in Figure 2.

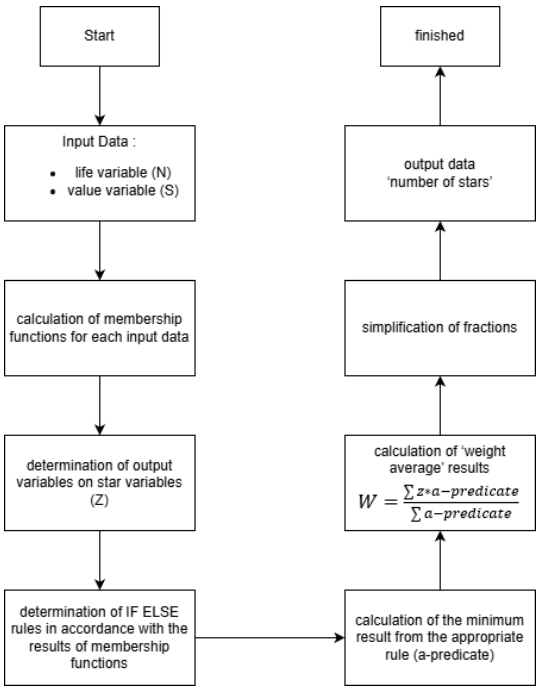


Figure 2 Flowchart Fuzzy Sugeno

2.4. Data Collection Instruments and Techniques

Data collection was conducted using several instruments based on the Likert scale and observation sheets, namely:

a. Media validation questionnaire

Used to assess the quality of media from a technical and visual perspective. Aspects assessed include ease of use, clarity of navigation, text readability, icon consistency, graphic quality, layout, and audio/effects support. Assessors are media experts.

b. Material validation questionnaire

Used to assess the suitability of learning materials contained in games with expected competencies. Aspects assessed include the suitability of content with learning objectives, the accuracy of waste management concepts, the level of difficulty of questions, the clarity of language, and the ability of materials to motivate students. Assessors are subject matter experts (primary school teachers).

c. Student response questionnaire

Used to measure students' responses to games in terms of ease of use (operability), ease of learning (learnability), ease of understanding (understandability), and attractiveness. Students fill out the questionnaire after playing the game to completion.

d. Observation of game usage

Observations were conducted during the trial to record technical obstacles, patterns of student interaction with the game, and non-verbal responses that were not captured in the questionnaire. The observation notes were used as material for consideration in interpreting the results and improving the product.

2.5. Data Analysis Techniques

Quantitative data from the questionnaire was analysed by calculating the total score obtained for each assessment aspect, then converted into a percentage of suitability using the formula:

$$V = \frac{Score\ obtained}{Maximum\ score} \times 100\%$$

The percentage results are then interpreted based on eligibility categories, for example:

a. ≥ 90% : very good/excellent
b. 75%–89% : suitable/good
c. 65%–74% : sufficiently acceptable/requires minor revision
d. 55%–64% : unsuitable/requires major revision
e. < 55% : unsuitable

An educational game is deemed acceptable if the average assessment score from media experts, subject matter experts, and student responses is at least in the 'good' category (≥ 75%). Qualitative data obtained from expert and student comments are analysed through reduction, presentation, and conclusion drawing to identify product weaknesses and aspects that need improvement (e.g., visual appearance, game flow, question wording, or level duration).

2.6. Research Hypothesis

The hypothesis proposed in this study is:

H_1 : An Android-based educational game on waste management with an adaptive reward system using Sugeno fuzzy logic is suitable for use as a learning medium, as indicated by expert assessment scores and student responses that are at least in the 'good' category (≥ 75%).

This hypothesis was tested through the results of expert validation data analysis and student responses to the developed game.

2.7. Ethical Considerations

This study involved primary school children, so product trials were conducted after obtaining

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permission from the school and consent from parents/guardians through class teachers. Student identities were not included in the research report, and the data collected was used solely for academic analysis purposes. Thus, the confidentiality and comfort of the subjects were maintained throughout the research process.

3. Results and Discussion

3.1. Media Expert Validation Results

Media expert validation was conducted to assess the technical quality and user interface of the educational game developed. A validation questionnaire was given to one expert in the field of learning media to assess various aspects, such as ease of use, visual appeal, text readability, and user interface consistency. The results of the media expert validation show that the game has good quality in terms of appearance and interactivity, as can be seen in Table 1.

Table 1 average score for each aspect assessed by media experts

Assessment Aspects	Average Score	Categories
Ease of Use	4.8	Very good
Text Readability	4.5	Good
Visual Appeal	4.7	Very good
User Interface Consistency	4.6	Good
Audio Quality and Effects	4.4	Good

The average score for all aspects is 4.6, indicating that this game is suitable for use in terms of media and appearance. The user interface is considered very accessible to children and has an attractive visual design. Figure 3 shows a screenshot of the game's main menu, which displays the user-friendly interface design and visual elements.



Figure 3 Main Menu

Although validation showed good results, media experts provided input to improve audio quality and sound effects, to create a more enjoyable playing experience. This shows that audiovisual elements are very important in increasing student engagement, especially in children.

3.2. Results of Subject Matter Expert Validation

Subject matter validation was conducted to ensure that the content in the game was in line with the learning objectives and relevant material. A material validation questionnaire was given to a primary school teacher who assessed the suitability of the material, the accuracy of the information, and the game's ability to motivate students. In Table 2, the validation results show that the material in the game is in line with the expected competency standards.

Table 2 scores from subject matter expert validation

Assessment Aspects	Average Score	Categories
Appropriateness of Materials to Learning Objectives	4.9	Very good
Accuracy of Information	4.8	Good
Level of Difficulty of Questions	4.5	Good
Motivation and Engagement	4.7	Very good
Variety of Questions	4.6	Good

The average score for all aspects is 4.7, which indicates that the material in the game is excellent and in line with the expected learning objectives. Some feedback from subject matter experts includes adding more variety to the questions and increasing the level of difficulty to maintain the challenge and engagement of students.

3.3. Student Response Results

A total of 26 students from SDN Bulu participated in the trial of this game. They were asked to play the game and fill out a questionnaire regarding ease of use, ease of learning, understanding of the material, and visual appeal. The results of the student response questionnaire showed very positive average scores, as seen in Table 3.

Table 3 Results of the student response questionnaire

Assessment Aspects	Average Score	Categories
Ease of Use	4.6	Very good
Ease of Learning	4.7	Very good
Understanding Information	4.5	Good
Visual Appeal and Interactivity	4.8	Very good
Overall Satisfaction	4.6	Very good

The average score for all aspects was 4.64, indicating that the game was very well received by students. The majority of students found the game easy to understand, enjoyable, and provided an

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interactive learning experience. Figure 4 shows one part of the game, which illustrates student interaction with the system.



Figure 4 Screenshot of the game level showing player interaction with waste sorting elements in the game

These results indicate that this game is effective in increasing student engagement in waste management learning. Several students noted that they enjoyed the concept of the game, which combines questions with play activities, and felt more motivated to learn.

3.4. Evaluation of the Sugeno Fuzzy Reward System

The evaluation of the adaptive reward system based on Sugeno fuzzy logic showed positive results. In testing, the reward system gave rewards appropriate to player performance, based on scores and the number of golden tickets collected. Data from testing showed the distribution of the number of stars received by players as follows:

Table 4 Distribution of star numbers

Player Scores	Number of Golden Tickets	Stars Earned
80–100	3	3 star
60–79	2	2 star
40–59	1	1 star

The results in Table 4 show that the Sugeno fuzzy logic-based reward system works well in adjusting rewards to player performance. Thus, this system successfully maintains student engagement and provides additional motivation to play better. This approach also shows that the use of fuzzy logic in educational games can enhance the personalisation of the learning experience. Figure 5 shows the flowchart of the Sugeno fuzzy logic-based reward system.

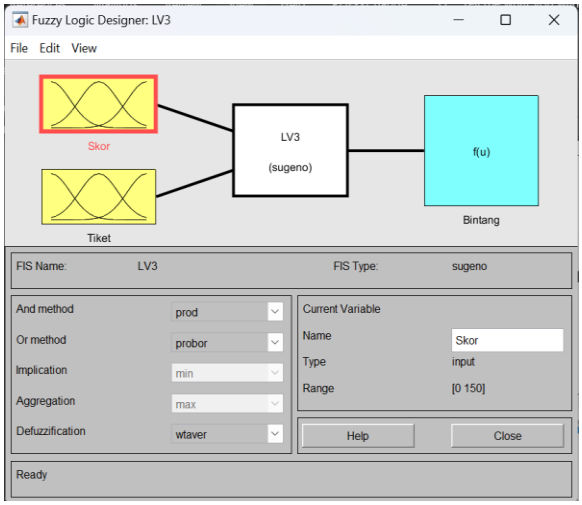


Figure 5 Flowchart of the Sugeno fuzzy logic-based reward system

3.5. Discussion

Based on the results obtained from media expert validation, material validation, student responses, and reward system evaluation, it can be concluded that this Android-based educational game is effective in improving students' understanding of waste management. Sugeno fuzzy logic was successfully applied to provide adaptive rewards tailored to player performance, which increased student motivation and engagement.

The results obtained from validation by media experts and subject matter experts indicate that this game is not only appropriate for learning objectives but also interesting and easy for students to understand. This is in line with the findings of Putra et al. (2021), which demonstrate the effectiveness of educational games in improving students' understanding of important topics such as health and the environment.

Overall, this game has great potential to be used as a fun and effective learning medium in environmental education, particularly on the topic of waste management. However, there are several suggestions for improvement, such as adding more variety to the questions and improving the audio quality, which can be addressed in the next iteration.

4. Conclusion

This study successfully developed an Android-based educational game aimed at improving children's understanding of waste management, using an adaptive reward system based on Sugeno fuzzy logic. The results of expert validation, material validation, and student feedback show that this game is effective in increasing student engagement and teaching important concepts related to waste management. The Sugeno fuzzy logic-based reward system, which is tailored to player performance, has been proven to

increase student motivation and maintain their engagement throughout the learning process.

This game has received high praise for its user-friendly interface design, visual appeal, and educational content, with an average score of 4.6 out of 5 in assessments by media experts and students. The system's ability to personalise the learning experience through dynamic feedback based on player performance has been identified as a key factor in increasing engagement and ensuring that students remain motivated to learn.

However, feedback from experts and students pointed out several areas for improvement, such as adding more variety to the tasks and improving the audio quality. Future iterations of the game could address these issues to further enhance its effectiveness as a learning tool.

This study makes a significant contribution to the development of educational games by demonstrating the potential of Sugeno fuzzy logic in adapting reward systems that are more suited to the needs of individual learners. These findings support the idea that adaptive reward systems in educational games can significantly increase engagement and learning outcomes. Furthermore, this research provides valuable insights into the use of game-based learning for environmental education, which is increasingly relevant given the growing global challenges related to waste management and sustainability.

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