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Implementation of Conversational Artificial Intelligence in a 3-Dimensional Game on Waste Impact

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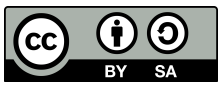
ABSTRACT

The escalating volume of waste in Indonesia presents significant environmental challenges, primarily due to insufficient public awareness and engagement. **This study aimed** to develop a dynamic three-dimensional simulation game to enhance young people's understanding of the environmental impacts of waste. The game integrates conversational artificial intelligence technology to create non-playable characters that engage users in natural text and voice dialogues. The research employed a research and development approach following the Software Development Life Cycle waterfall **Method**, encompassing stages of analysis, design, implementation, testing, and maintenance. The game design adopted the Mechanical, Dynamic, and Aesthetic framework method. It implemented a first-person perspective to create an immersive learning experience: evaluation involved functionality tests, expert reviews, and user trials. The functionality testing achieved a perfect score of 100 percent, while evaluations by educational technology experts yielded an average score of 94 percent for content quality and interface design. User trials, conducted with individuals aged 10 to 18, indicated a high level of satisfaction with an average score of 86 percent. **These results** conclude and demonstrate that integrating conversational artificial intelligence into a simulation game provides an engaging and effective educational tool to raise environmental awareness. Nonetheless, the study highlights the need for ongoing support from parents and educators to cultivate sustainable waste management practices among young people. Future research should focus on expanding the game's scope and evaluating its long-term impact on users' environmental literacy.



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1. INTRODUCTION

The lack of public awareness about waste management resulted in the persistent habit of littering in vacant land, forests, rivers, and other areas [1]. Based on data from the Central Statistics Agency (BPS), Indonesia has experienced a demographic bonus since 2015, with its peak estimated to occur in 2020-2035. During this period, the productive age population (15-64 years) will dominate the population, reaching more than 60% of the total population, while the non-productive age (65 years and over) will be smaller [2]. Given this fact, the younger generation could potentially become the main contributor to waste in the future. Therefore, education about the impact of waste on the environment and its management needs to be provided to the younger generation from an early age and comprehensively, to reduce the negative impact of waste in the future [3]. A recent study emphasizes the crucial role of educational interventions in addressing waste management challenges [4]. Another study demonstrated the power of student-driven approaches in reducing food waste through strategic actor analysis, showcasing the potential of youth-led initiatives to contribute to zero-waste goals [5]. Another research revealed that innovative educational media, such as infographics, significantly increased youth awareness of the importance of recycling organic coffee waste, promoting proactive environmental stewardship in Boyolali Regency [6]. Investigating this issue is crucial because, if left unaddressed, the increasing waste generation by the productive age group may exacerbate environmental challenges, including pollution and inadequate waste management infrastructure. By equipping the younger generation with comprehensive education and skills, we can proactively shape a sustainable future and cultivate environmentally conscious communities capable of addressing the growing waste crisis.

Game-based content is considered an effective method to approach the younger generation of Indonesia in education. The results of this analysis are based on one study, which reported that the Southeast Asian region, including Indonesia, has an extremely high rate of internet and gaming addiction, reaching over 90% [7]. Thus, it is hoped that the younger generation will easily accept the educational game model and can increase their awareness of the dangers of waste to the environment. Non-playable Characters (NPCs) are characters in games that give a more lively and interactive impression to the game [8]. The existence of NPCs plays an important role, especially in games that are played offline or single-player, because they contribute greatly to the user's gaming experience. In the modern game era, NPCs are expected to be more natural and intelligent by being equipped with abilities that can complete some player needs, so that players can still enjoy the game excitingly, even though there are no other players involved [9]. Here, artificial intelligence (AI) technology acts as a brain to make NPCs more human and able to make actions, decisions, and movements dynamically [10].

Conversational artificial intelligence (AI) is defined and understood as "the study of techniques for creating software agents that can interact naturally with humans through conversation [11]. This is in line with human desires. For many years, humans have imagined creating intelligent artificial agents, which can communicate with humans to help them complete various tasks or simply to provide entertainment [12]. Today, conversational AI is increasingly attracting the attention of governments, researchers, and industries, especially since the emergence of famous text or voice-based conversational AI software. Specifically in this research, the use of conversational AI functions as a tool for users to understand the context of the impact of waste on the environment, by providing each existing NPC with the ability to dynamically answer questions about the impact of waste that are adjusted to the environment where the NPC is placed.

This study aims to create a dynamic 3D game simulation that highlights the environmental impact of waste by integrating conversational AI technology into Non-Playable Characters (NPCs) to engage users, especially the younger generation, in an interactive and educational experience about the impact of waste. The simulation game prototype will be developed in 3D format. 3D technology was chosen because it provides a more realistic experience. Through this technology, characters, objects, and environments can be displayed more vividly and closer to their original form, because 3D objects have more realistic dimensions, volumes, and spaces [13]. The media is designed based on a personal computer (PC) by utilizing a PC in the school computer lab as a tool to carry out educational activities. The game model chosen for this media is first-person view, also called first-person shooter, one of the game genres that uses a first-person perspective, where the player seems to be the main character who interacts directly with the environment, using tools, weapons, and other elements in the game [14]. Through the game model, it is hoped that media users can directly experience the experience of being in an environment affected by waste pollution, with visualizations made as similar as possible to the original conditions. The content in the media is taken from the book "Book of Garbage and Pollution" by Wiwik Sulistyorini, which was published directly by the Ministry of Education and Culture of the Republic of Indonesia [15].

Several related studies have emphasized the positive impact of game-based learning on the education of young learners across various subjects [16]. Notably, research examining the influence of games in mathematics education has shown that incorporating game-based approaches can significantly increase students' interest and engagement in mathematics [17]. Another study found that game-based media can also effectively support students in managing food waste more efficiently [1]. In addition, several studies have highlighted the role of educational games in promoting recycling behavior among students [18]. Subsequent related studies further explain that educational games can help students learn about waste management more quickly and in a way that is easier

to understand [19–21]. It is also mentioned in one of the studies related to the importance of placing dynamic NPCs in a game to maintain the level of the game and anticipate the reduction in game dynamics that occurs when a game is played repeatedly by the user [22]. Other studies have suggested that implementing AI in games is essential, not only to simplify the design process but also to create more complex behavior with more diverse decision-making, so that in-game behavior becomes less predictable from the player's perspective [23]. This study differs from previous research by emphasizing waste impact rather than focusing solely on waste processing or sorting. It introduces conversational AI to facilitate real-time, interactive dialogues with non-player characters. The novelty of this research is the educational approach through the first-person perspective 3D game on the content of the impact of waste on the environment, as well as the implementation of conversational AI on NPCs to add dynamics to the flow of the game media offered. This approach model is expected to reach Generation Z, who cannot be separated from technology in their daily lives.

2. RESEARCH METHOD

This study uses the research and development method by following the stages of the Software Development Life Cycle (SDLC) waterfall model [24]. This method was chosen because SDLC is considered more flexible in adjusting to changes in needs submitted by users. Thus, research can be carried out more efficiently and effectively. This methodology consists of five stages carried out sequentially, namely: 1. Requirements analysis; 2. Design; 3. Implementation; 4. Testing; 5. Maintenance [25]. At the analysis stage, a literature study and analysis of field facts, problem formulation, and research objectives were conducted. The game concept is determined at the design stage based on the Mechanical, Dynamic, and Aesthetic (MDA) Framework. All design requirements, such as use cases, game flowcharts, NPC character designs, and 3D environments, are met.

The implementation stage is the game design stage based on all the materials obtained in the previous stage. At this stage, the NPC configuration is carried out with the Conversational AI (CA) generator, and the game prototype is finalized regarding the system and overall function. The testing stage is a testing event for media that has been developed. Testing is carried out completely regarding system functionality, system compatibility, material, and user interface, and testing for potential users. Meanwhile, the maintenance stage is a media repair activity based on input results from the testing stage. Every detail of the activities of each stage will be explained in Figure 1.

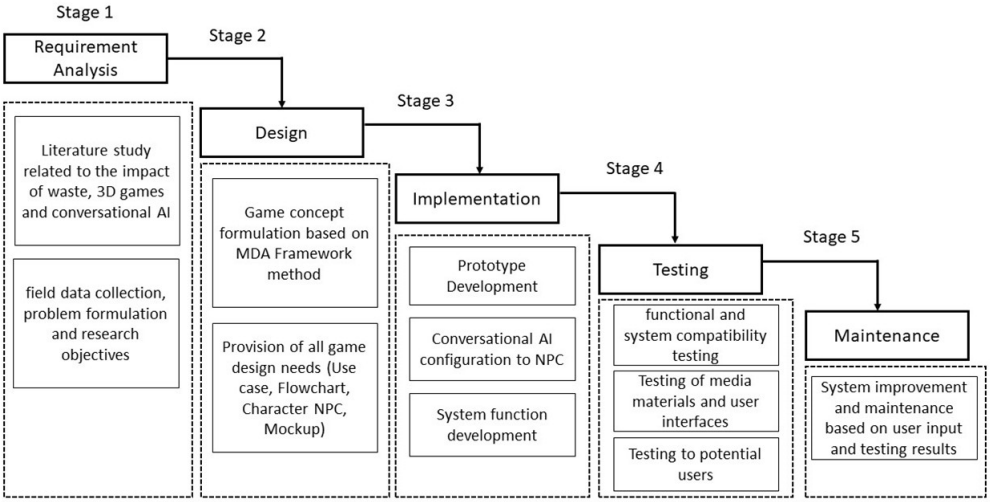

Figure 1. Details of research activities at the SDLC Waterfall method stage

3. RESULT AND ANALYSIS

3.1. Requirements Analysis Stages

This stage is the initial initiation, Exploration is carried out through literature studies by looking for references related to the subject matter and research objects, problem formulations and solutions offered, and the technology that will be used in its development, which are listed in Table 1.

Table 1. Explains The Details of Media Development Needs

No	Activities	Result
1	Identification of problem background	1. The young generation's awareness of the impact of waste on the environment is still low. 2. The absence of technology-based media that suits the needs of Generation Z to increase their literacy regarding the impact of waste on the environment
2	Goals and solutions offered	Interactive media based on 3D simulation games to introduce the impact of waste on the environment
3	Technology plan used	A personal computer-based simulation game, utilizing conversational AI for smart NPCs
4	Source content	The book "*Sampah dan pencemarannya*" by Wiwik Sulistyorini.
5	Media user targets	Teenagers aged between 10 and 18 years

3.1.1. Design Stages

The design stage prepares each element's needs in a game. The steps taken are to design various designs needed by the media. Game design concept follows the conceptual framework of the Mechanics, Dynamics, and Aesthetics (MDA) framework. This method has often been used in game design. This method emphasizes three crucial aspects, namely 1. mechanical aspects; 2. dynamic aspects; and 3. aesthetic aspects. Details of the activities carried out in each aspect of the MDA Framework can be found in Figure 2 [26].

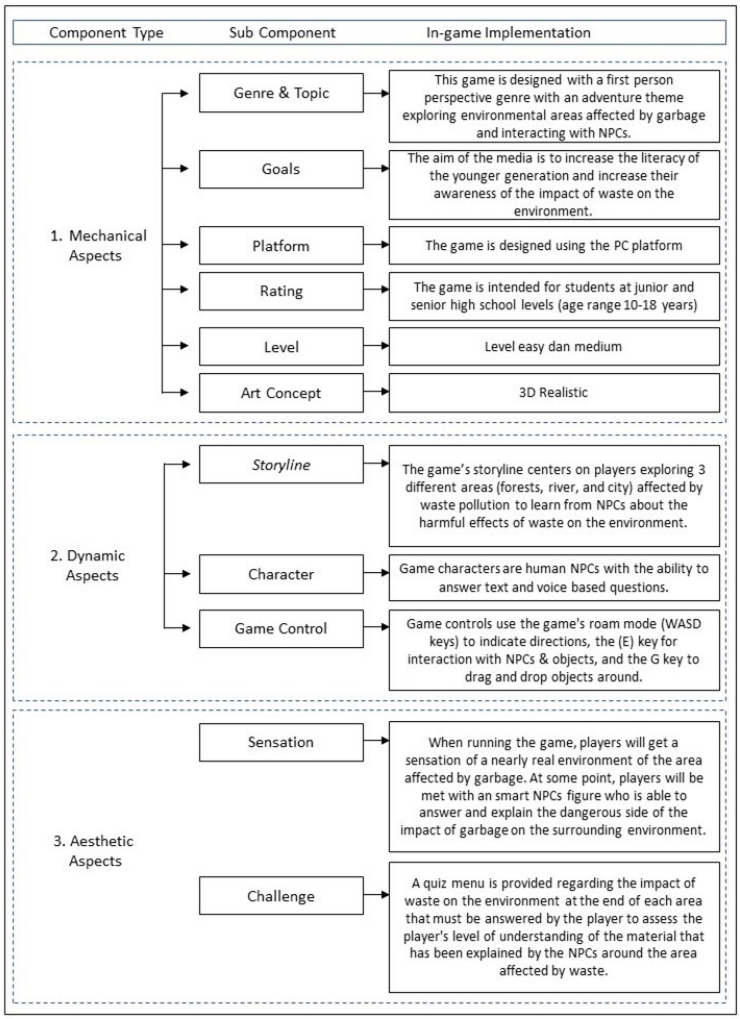

Figure 2. Implementation of the MDA Framework method on game concepts

Figure 3 is a flowchart design of the application. The flowchart makes it easier for developers to design media and read the flow of the simulation game to be created. The flowchart explains the user's initial position and access to all operations contained in the application from start until finish or exit. The flowchart also illustrates the positions of AI NPCs in the game. The player could roam around the waste-affected environment, interact with each NPC they encountered, and discover various waste objects along with their descriptions. A pause menu was also provided if the player wanted to stop the game temporarily.

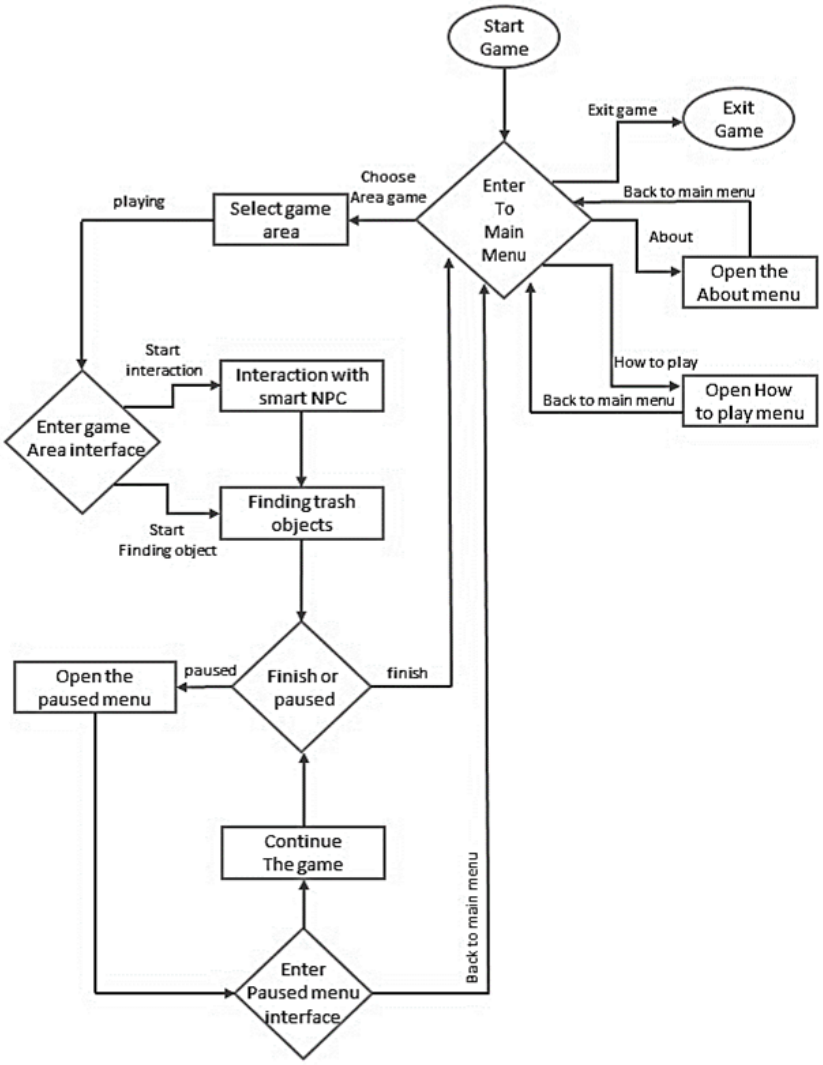

Figure 3. Game flowchart

The next design needs are character design and application mockup. The characters are designed using Blender 3D software and then refined with the Metahuman plugin provided by Unreal Engine 5 (UE5). Figure 4 shows an example of NPC characters planned to be placed in several spots of the garbage-affected area. The character models are designed to resemble several professors and researchers in neat suits, with the aim that users will assume that the NPCs have high intelligence and stimulate the user's level of trust in the answers given by each NPC. The next design requirement is a game mockup consisting of the main menu and game area template that explains the spots where the NPC is placed. The mockup also clearly explains the position of the dialogue between the NPC and the character, making it easier for 3D designers to design the environment according to the position and dialogue scene between the user and the NPC.

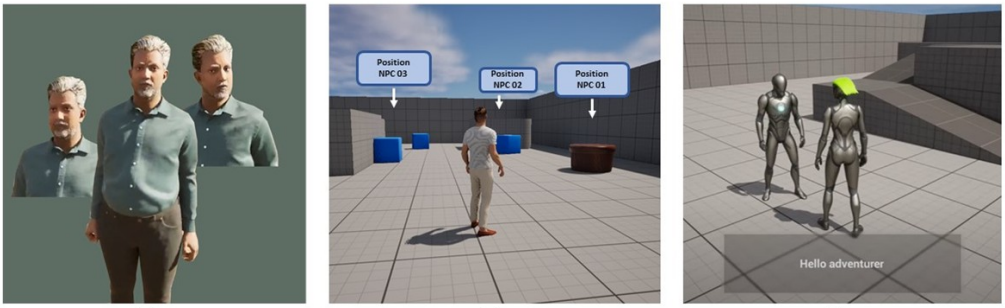

Figure 4. (a). The example of NPC character, (b). NPC placement plan in the game, c. example of user dialogue activity with smart NPC

Figure 5 displays the design of several 3D environments impacted by waste. According to the predetermined concept, the garbage-affected area is divided into 3: the river, the forest, and the city. Each area is designed to be as similar as possible to the original appearance, with various additional garbage that adds to the user's sensation when playing the game. Several visual effects were added to realistically depict the impact of waste on the three environments, aiming to enhance the player's experience and raise awareness about the dangers of waste.

Figure 5. 3D environment area design (river area, forest area, and city area)

3.2. Implementation Stages

At the implementation stage, a prototype of a 3D simulation game media was developed. The development activity was carried out based on the materials designed in the previous stages regarding architectural design, game flow, characters and so on. The game design uses the Unreal Engine 5 (UE5) application, a powerful game engine from Epic Games that can be used for free by all developers. The team also utilizes various plugins affiliated with UE5 provided by Epic Games, such as Quixel Megascan, Metahuman, Easy Element, Convai, etc. The system development activity was carried out based on the blueprint model on UE 5 with the C++ programming language.

The process of configuring conversational AI technology in this study utilizes the Convai AI tool, a generative conversational AI that provides conversational AI facilities for NPCs in text and voice. Convai AI has an API for conversational characters called API Docs. Currently, the API can be integrated into several game engine models such as unreal engine, Unity 3D, Roblox, etc. Initial configuration is done on convai by creating an account and adding a complete description of the NPC to be used. Convai AI is part of Conversational Artificial Intelligence, a rapidly evolving technology that significantly transforms how organizations interact with consumers. At its core, Conversational AI utilizes Natural Language Processing (NLP) and Machine Learning (ML) techniques to enable computers to understand and respond to human language naturally and intuitively [27]. Description related to name, type of job, field of expertise, and other needs. The next step is to add voice samples for the NPC. The last step is to connect the results of inputting data into the API Docs and generate API code to be configured on UE5. From the UE5 side, 3D design of NPC characters is done, equipped with skin and animation using metahumans plugins. The next step is to add NPC function configurations, such as movement and interaction, using blueprints, and configure the API Docs code from Convai on the NPC. Figure 6 explains the complete configuration activities carried out for the smart NPC.

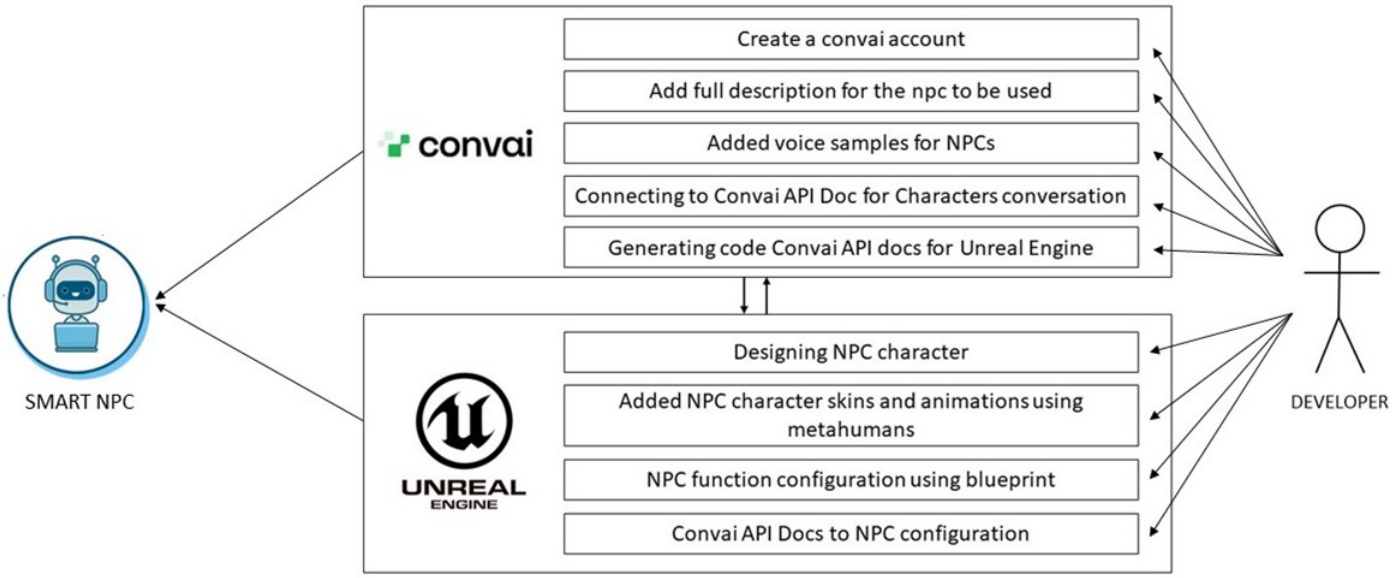

Figure 6. Conversational AI configuration on NPC characters

Figure 7 shows the final result of implementing conversational AI in a smart NPC within a 3D simulation game focused on the environmental impact of waste. The NPC is designed to answer various user questions about the dangers of waste to the surrounding environment. In addition to the NPC character designs being modeled after professors to create a positive impression on the player, the NPCs were strategically placed to be easily accessible while roaming the waste-affected areas. The player was expected to engage in smooth dialogues with the AI NPCs, either through text displayed in the dialogue box at the corner of the screen or by listening to the NPCs' explanations directly through their voices.

The main challenge in developing the game was creating a realistic 3D environment that could still run smoothly on mid-range devices. Using high-resolution textures from Quixel Megascan and Metahuman-based NPC modeling introduced significant performance demands, especially when enabling interactive voice features. Asset optimization, level streaming, and the implementation of Level of Detail (LOD) and distance culling techniques were applied to address this. Additionally, to ensure that interactions with NPCs felt natural and contextually relevant, each character was equipped with distinct descriptions and the ability to respond to questions based on their assigned environmental area, such as rivers, forests, or urban settings. Figure 8 presents the details of the conversation between the player and the NPC regarding the impact of waste on the environment, with the NPC providing real-time responses.

Figure 7. The display of the implementation results of conversational AI on the smart NPCs

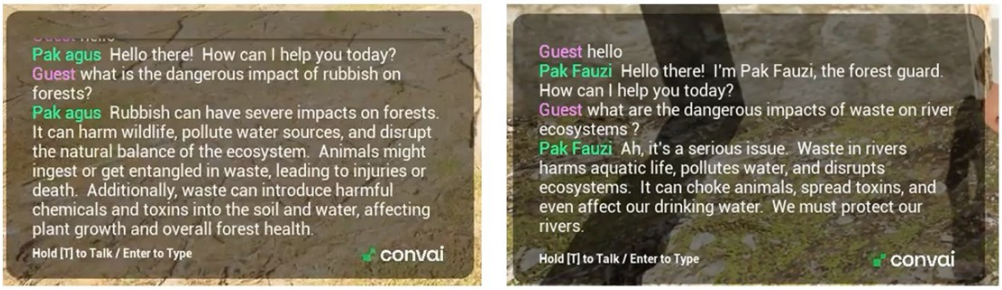

Figure 8. Details of the real-time chat with the smart NPC on waste impact education

3.3. Testing Stages

At the testing stage, several types of testing are carried out to verify and validate the educational media that will be distributed. The first test carried out is the software functionality test. carried out using the Blackbox method to validate that all functions in the game can run properly according to the initial design [28]. Table 2 explains the results of the software functionality test. The results are that all game functions and features can run 100% smoothly.

Table 2. Blackbox Method-Based Media Functionality Test Results

No	Types of Function	Expected Test Result	Result
1	Main Menu	The main menu can appear smoothly when the game is running.	Succeed
2	Play Button	When selected, play button can direct user to the game area properly	Succeed
3	Tutorial Button	When selected, tutorial button redirects to the tutorial page properly	Succeed
4	Exit Button	When selected, the exit button works fine.	Succeed
5	NPC interaction	NPCs are able to interact well and smoothly when meeting players.	Succeed
6	NPC Dialogue	NPC is able to answer the related questions asked properly and correctly	Succeed
7	Roaming function	Players can move around the trash-affected area smoothly	Succeed

The next test is verification of the material and user interface of the media. The testing activity was carried out by testing the simulation game with Dr. Mohammad Ahsanudin, S.Pd., M.Pd., a technology expert from the State University of Malang. From the trial results, the expert gave an average value to the media of 94%. Table 3 shows the results of the media assessment from the experts. The percentage is calculated using a Likert scale with a rating scale of 1, strongly disagree; 2, disagree; 3, neutral; 4, agree; and 5, strongly agree. strongly agree [29]. Using a Likert scale, the average formula uses equation 3.3., while the percentage uses equation 2.

$$Average = \frac{Total\ Score}{Number\ of\ respondent\ x} \tag{1}$$

$$Percentage = \frac{Average\ Likert\ Score}{Maximum\ Likert\ Score} \times 100 \tag{2}$$

Table 3. Media Test Results to Learning Technology Experts

No	Question Types	Test Result
1	Conformity of the content of the material with the content of the source book	5
2	The material is delivered in language that is easy for students to understand	4
3	The material presented by NPCs contains the core material in a complete and comprehensive manner	4
4	The character designs of the NPCs and the environment of the waste-affected area are presented clearly and attractively.	5
5	The character designs of the NPCs and the environment of the waste-affected area are presented clearly and attractively.	5
6	Audio clarity in games	5
7	Ease of players in accessing and understanding game usage tutorials and ease of playing game media	5
8	Players can easily access all menus in the game	5
9	The color quality in the game matches the real conditions in the actual environment.	5
10	Elements in the game can increase students' enthusiasm for learning about the dangerous impacts of waste on the environment.	4

$$Average = \frac{5+4+4+5+5+5+5+5+4}{1 \times 10} = 4.7$$

$$Percentage = \frac{4.7}{5} \times 100 = 94\%$$

The third is a game performance test, especially NPC performance, to potential users. This test is given by distributing questionnaires to prospective users who act as testers after playing the simulation game. 20 prospective users were selected based on the age range of 10-18 years, from elementary to senior high school students. The team provided 15 questionnaire questions that potential users had to answer. From the results of the field test, users played the game enthusiastically with an average result of answering the questionnaire given of 86.2% calculated using a Likert scale. Table 4 shows the detailed results of application performance testing on potential users. Testing activities were held at Al-Umm Islamic Elementary School, Jetis 01 Junior High School and Gontor Modern Islamic Boarding School at the senior high school level. The sample was selected using purposive sampling to target the early productive age group. All participants received a briefing before playing and were given approximately 20 minutes to explore the game, followed by completing a user experience evaluation questionnaire. The data were analyzed using a quantitative descriptive approach and qualitative interpretative analysis.

Table 4. Media Performance Test Results for Potential Users

No	Test Area	Question Types	Average Test Result	Final Percentage
1	River	NPC response accuracy to player arrival	4.55	
	Area	NPC performance level in answering related questions from players	4.50	
		NPC speed performance in answering related questions from players	4.25	
		NPC's ability to answer random questions from players.	4.15	
		The suitability of the surrounding area design in strengthening the NPC's argument	4.35	
2	Forest	NPC response accuracy to player arrival	4.40	
	Area	NPC performance level in answering related questions from players	4.45	
		NPC speed performance in answering related questions from players	4.20	
		NPC's ability to answer random questions from players.	4.10	
		The suitability of the surrounding area design in strengthening the NPC's argument	4.30	
3	City	NPC response accuracy to player arrival	4.40	
	Area	NPC performance level in answering related questions from players	4.35	
		NPC speed performance in answering related questions from players	4.15	
		NPC's ability to answer random questions from players.	4.10	
		The suitability of the surrounding area design in strengthening the NPC's argument	4.25	
		Total average and percentage (Using Likert Scale)	**4.31**	**86.2%**

3.4. Maintenance Stages

Maintenance activities are carried out based on several inputs from experts and potential users. Although the functionality tests returned a perfect score and user satisfaction averaged 86.2%, several limitations emerged. Maintenance activities that have been completed include adding trash objects in several strategic spots that are considered incomplete, adding instruction text at the beginning of each game area, and adding several objects and boundary walls to limit players from going too far from the game area. When compared to similar educational games in previous studies [18, 19], the user satisfaction score in this study is slightly higher. However, the limited scope of environmental topics and the user sample restricted to early-age and student participants require cautious interpretation. Future comparisons using established educational game usability standards across a broader age range may provide more comprehensive insights.

4. CONCLUSION

This study demonstrates the potential of conversational AI in enhancing educational media through 3D simulation games aimed at raising environmental awareness, particularly among the younger generation. The successful integration of smart NPCs powered by conversational AI has created an engaging and interactive learning environment where players can explore real-world waste issues and their environmental impacts. Functionality testing confirmed that the game operates flawlessly, expert evaluations highlighted the media's effectiveness and content alignment with an impressive score, and user trials confirmed high levels of engagement and satisfactory on NPC performance. While this game serves as an innovative supplementary tool to foster environmental consciousness,

its long-term impact relies heavily on continued guidance from parents and educators to instill sustainable waste management habits. Future work should focus on expanding the game's scope and evaluating its effectiveness in broader educational settings.

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6. DECLARATIONS

AUTHOR CONTIBUTION

Faisal Reza Pradhana: Conceptualization, Methodology, Investigation, Data Curation, Writing - Original Draft Ilham Mufandi: Concept Review, Resources, Validation, Supervision
Aziz Musthafa: Formal analysis, Software, Validation, Resources, Writing - Review & Editing, Visualization, Supervision Dian Afif Arifah: Validation, Writing - Review & Editing, Supervision.
Khairul Munzilin Al Kahfi: Modelling Characters, 3D Object, 3D Environment, Metahuman Skin, NPC Interaction.

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COMPETING INTEREST

This study uses original data from schools ranging from elementary to high schools in East Java, Indonesia. All stages of research were carried out objectively and transparently. All authors contributed to the article's research and writing, adhering to the authority and receiving approval before submitting the manuscript.

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