Faculty of Science Computer and Information Technology

Recycling Heroes: A Gamified Learning Experience using Roblox with AI Chatbot Guidance

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DECLARATION

I declare that the work in this thesis was carried out in accordance with the regulations of Universiti Malaysia Sarawak. Except where due acknowledgements have been made, the work is that of the author alone. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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ABSTRACT

The purpose of this thesis is to design and evaluate a gamified learning environment, "Recycling Heroes" that leverages Roblox to help students understand waste management and recycling concepts from the Year 6 Science curriculum. An AI chatbot powered by the Gemini API will deliver real-time feedback and guidance to students based on their in-game interactions. This method aims to increase interest, quantify past knowledge, and assess learning by incorporating quests and quizzes into the game. To preserve privacy, all in-game data will be securely saved to Roblox's Datastore service. Students rated the game as entertaining, motivating, and simple to use, according to quantitative results that demonstrated high system usability (SUS average = 4.6/5) and a strong user experience (UEQ average ≈ 6.1/7). With average scores of 4.7/5 on all items, the Educational Effectiveness Questionnaire (EEQ) demonstrated strong agreement on improved engagement and learning. Consistency in responses was validated by standard deviation analysis, particularly in learning enjoyment (SD = 0.0). According to these results, Recycling Heroes is a useful and entertaining teaching resource for elementary school pupils.

Keywords: Roblox, gamification, Gemini API, educational games, recycling, interactive learning

Pengalaman Pembelajaran Digamifikasi Menggunakan Roblox dengan Panduan Chatbot AI

ABSTRAK

Tujuan tesis ini adalah untuk mereka bentuk dan menilai persekitaran pembelajaran yang digamifikasi, "Recycling Heroes," yang menggunakan Roblox untuk membantu pelajar memahami konsep pengurusan sisa dan kitar semula dari kurikulum Sains Tahun 6. Chatbot AI yang dikuasakan oleh Gemini API akan memberikan maklum balas dan panduan masa nyata kepada pelajar berdasarkan interaksi mereka dalam permainan. Kaedah ini bertujuan untuk meningkatkan minat, mengukur pengetahuan terdahulu, dan menilai pembelajaran dengan memasukkan soalan sebelum dan selepas tugasan dalam permainan. Keputusan kuantitatif menunjukkan kebolehgunaan sistem yang tinggi (purata SUS = 4.6/5) dan pengalaman pengguna yang positif (purata UEQ ≈ 6.1/7), dengan murid melaporkan bahawa permainan ini menyeronokkan, memotivasikan dan mudah digunakan. Soal selidik Keberkesanan Pendidikan (EEQ) mencatatkan purata skor 4.7/5 bagi semua item, menunjukkan peningkatan dalam penglibatan dan pemahaman topik. Analisis sisihan piawai turut mengesahkan ketekalan respons, terutamanya dalam aspek keseronokan pembelajaran (SD = 0.0). Dapatan ini menunjukkan bahawa Recycling Heroes merupakan alat pembelajaran yang berkesan dan menarik untuk murid sekolah rendah.

.**Kata kunci:** *Roblox, pengamifikasian, Gemini API, permainan pendidikan, kitar semula, pembelajaran interaktif*

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

UNIMAS	Universiti Malaysia Sarawak
AI	Artificial Intelligence
AR	Augmented Reality
VR	Virtual Reality
STEM	Science, Technology, Engineering and Mathematics
NPC	Non-Playable Character
API	Application Programming Interface
SUS	System Usability Scale
UEQ	User Experience Questionnaire
EEQ	Educational Effectiveness Questionnaire

CHAPTER 1

INTRODUCTION

1.1 Study Background

Gamification and artificial intelligence (AI) in education have enabled new, engaging learning experiences that go beyond standard classroom methods. Gamification has evolved as an effective educational technique in the last decade, including game-based aspects such as rewards, challenges, and progression systems to increase student engagement and participation. Meanwhile, AI has demonstrated potential in personalizing learning experiences through real-time feedback, adaptive challenges, and tailored learning routes. Together, these technologies can change how students interact with and retain instructional knowledge.

These developments are critical in environmental sustainability education, particularly when teaching waste management and recycling. Traditional teaching approaches, such as lectures and textbook-based learning, sometimes fail to attract students' attention, especially when dealing with complicated and abstract ideas like sustainability. However, environmental education necessitates not just cognitive comprehension, but also a behavioural shift toward responsible and sustainable actions. Long-term knowledge retention is critical for driving these behavioural changes. Gamified learning environments have demonstrated potential in this area, making learning more interactive and engaging.

Malaysia's low recycling rates and inadequate waste management procedures underscore the need for more effective instructional strategies. The country confronts major environmental difficulties, such as waste management, pollution, and natural resource depletion, which are exacerbated by a lack of extensive recycling techniques. Children must be educated about their role in sustainability from a young age, as they will be future decision-makers and environmentalists. However, traditional educational techniques frequently fail to foster thorough awareness of how recycling affects the environment.

Gamification, when paired with AI, provides a unique solution to these difficulties by creating dynamic and interactive learning experiences that engage students more deeply. Gamified learning can help students break down complicated concepts into simple tasks that they will enjoy and find gratifying. Furthermore, AI can provide specialized assistance that is tailored to each student's learning rate, ensuring personalized support as needed. This mix of interactive games and targeted feedback has the potential to improve students' long-term awareness of environmental issues such as trash management and recycling, while also driving beneficial behavioural changes.

1.2 Problem Statement

Malaysia has serious environmental challenges in terms of low recycling rates and inefficient waste management, which requires the development of innovative educational strategies in promoting sustainable practices. Traditional classroom approaches do not instil in students the practical and long-term commitment to sustainability (Park, 2024). As future decision-makers, young learners need more interactive and engaging educational experiences that can inculcate concepts of recycling and encourage students to apply them in real life. Although gamified learning environments have shown potential in increasing students' motivation and knowledge retention, there is scant research on incorporating machine learning techniques, such as decision trees, into provide tailored assistance within such platforms.

The purpose of this study, therefore, was to propose a gamified learning tool adapted to improve student perceptions of the concept of recycling and encourage behavioral change in making informed decisions. Recent literature supports gamification in improving student engagement and enhancing learning outcomes with Mitchell & Co, (2024) ensures that it can improve overall learning in students. Similarly, AI-driven mechanisms for personalized feedback have been proved to enhance knowledge retention (Silva et al., 2024) In this respect, the research has sought to contribute to the development of more enhanced educational strategies toward raising environmental awareness and responses linked to sustainable practices among Malaysian school students.

1.3 Research Questions

The following research questions guide this study:

i. How can a gamified educational game integrate with an AI-based chatbot assist Year 6 Science students learn about waste management and recycling?

ii. How effective is a gamified learning environment with decision tree-based assistance compared to traditional classroom techniques for improving students' knowledge retention and real-world application of recycling concepts?

1.4 Objectives

The objectives for this study are:

iii. To design a gamified instructional game that uses AI-based chatbot guidance to improve students' comprehension of waste management and recycling topics.

iv. To evaluate the efficiency of the planned gamified learning environment to standard classroom techniques in terms of helping students retain knowledge and apply recycling concepts.

1.5 Methodology

This project uses an experimental design, with 10 students interacting with a gamified educational environment created in Roblox Studio using Lua scripting. Based on in-game performance and task completion, students' comprehension of waste management and recycling concepts was assessed. Figure 1.1 shows the Recycling Heroes methodology.

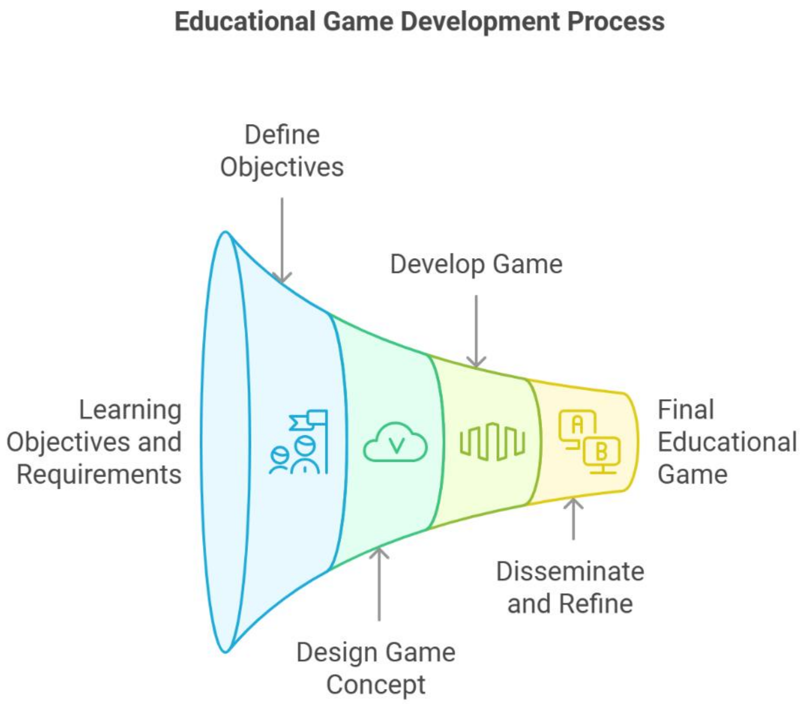

Figure 1.1: Recycling Heroes Methodology

Design:

- The game incorporates AI-based chatbot guiding, which allows students to receive real-time assistance as they advance through the game.
- The game includes quizzes prompts, which allow students to answer questions on their knowledge growth and comprehension.

Game design and implementation:

- The AI-based coaching serves as a learning companion, assisting students by delivering task-specific suggestions and feedback.
- Roblox Studio will be used to code the game in Lua Programming language, resulting in a structured and engaging learning experience.
- The Roblox Datastore Service is used to securely store in-game interaction data while protecting user privacy.

Data Collection:

- Likert-scale surveys were used to assess student engagement and the effectiveness of the game.
- Survey data will be analysed qualitatively and quantitatively to provide a complete picture of student input and game effectiveness.
- Roblox Studio will be used to code the game in Lua Programming language, resulting in a structured and engaging learning experience.
- The Roblox Datastore Service is used to securely store in-game interaction data while protecting user privacy.

1.6 Scope

This study entails developing, delivering, and testing the "Recycling Heroes" game for Year 6 Science students in Malaysia, with a focus on waste management and recycling. To deliver real-time, tailored feedback, the game makes use of Roblox's decision tree-based guiding system, which is defined as machine learning. Limitations include technological limits when developing decision trees for continuous feedback, as well as reliance on Roblox's Datastore for privacy-compliant data storage. The primary goal is to improve educational performance in Malaysia, with possible applications in other fields that need long-term behavioural change.

1.7 Significance of the Study

The outcomes of this study will benefit both academic research and practical applications in educational technology, particularly in environmental education. This research will provide vital insights into how gamification and decision tree-based advice can be used to promote student engagement, information retention, and long-term habits. The educational game created for this study could also be used as a model for combining gamified learning with machine learning in other subject areas, encouraging beneficial habits from a young age.

This initiative addresses Malaysia's critical need for more effective recycling teaching, which may have ramifications for future educational policies and practices. This study has the potential to impact curriculum design and support the wider implementation of interactive, technology-driven learning tools in other crucial areas of education by demonstrating their efficacy in promoting environmentally responsible actions. Figure 1.2 shows the study schedule for the project.

1.8 Study Schedule

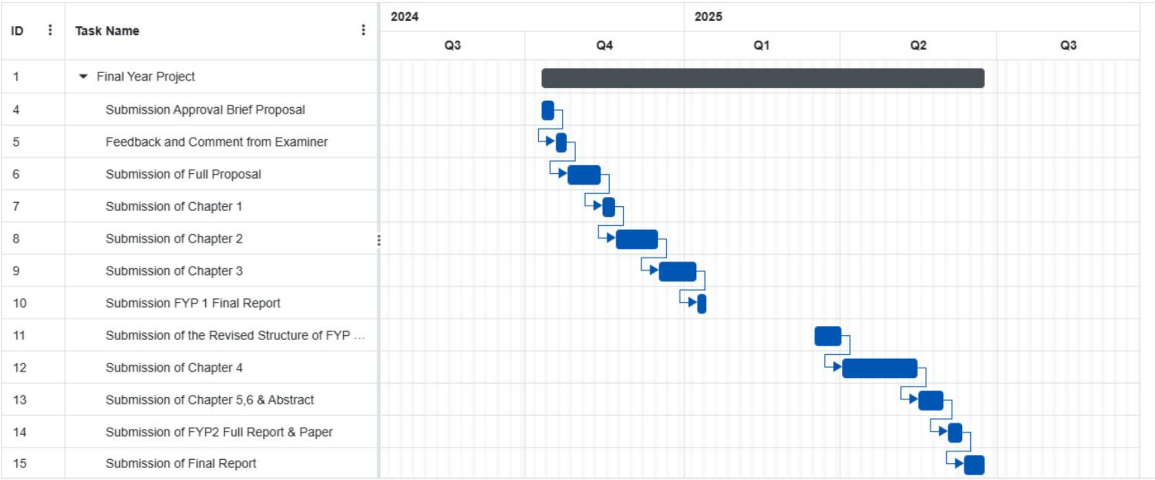

Figure 1.2: Study Schedule

Iterative prototyping and testing were used in game creation and chatbot integration to assure functioning and alignment with educational objectives. Data were collected both in-game and in the classroom, with significant milestones including regular feedback sessions with students and teachers to help enhance the game.

1.9 Expected Outcomes

This study expects to achieve the following outcomes:

1. Survey results and open-ended feedback are anticipated to indicate increased students' engagement in the learning process with gamification.

2. It is anticipated that the incorporation of an AI chatbot will provide insights into how individualized feedback can improve learning in gamified settings, possibly acting as a prototype for educational technology in the future.

By showing how game-based learning and AI integration can enhance engagement and comprehension, this project hopes to advance the field of educational innovation beyond its immediate results. The findings could guide the creation of comparable resources for a range of subjects and academic levels, setting the stage for further study and use in online learning settings.

1.10 Chapter Summary

This chapter introduces "Recycling Heroes," a gamified Roblox-based game designed to teach Year 6 pupils about trash management and recycling. It explores how traditional techniques frequently fall short in encouraging sustainable behaviours, with a focus on Malaysia's low recycling rates, and offers the study's use of gamification and decision tree-based assistance to close this gap.

The chapter describes the study's design and evaluation objectives, which center on information retention and real-world application. The study's significance lies in its ability to inform educational methods and affect environmental education policy.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

With the rapid development of digital technology, efficiency and engagement in education are under increasing pressure to be improved. Gamified learning becomes a transformative approach, integrating game design elements into educational content to improve motivation and learning outcomes. This paper discusses the design and impact of a gamified educational platform, including its features, applications, limitations, and future directions. This research provides a unique framework of gamification techniques to improve students' understanding and participation in science education.

2.2 Background

Technology integration in education has brought about new tools for improving the effectiveness of instruction and makes up-to-date changes to conventional teaching methods and learning patterns. One of the more notable developments is that virtual science laboratories on Metaverse-centred platforms have implemented immersive and interactive settings to engage learners while allowing them to investigate even the most intricate scientific concepts within a structured and stimulating environment. These platforms address the long-standing problems of science education such as accessibility to physical labs, rising costs and safety concerns, with scalable, flexible and economically feasible solutions.

Virtual labs have been shown to have transformative potential in terms of improving active learning and helping students understand scientific concepts. For instance, Tlili et al., (2022) investigated how Metaverse-based platforms allow students to interact with content in novel ways while overcoming the conventional limitations of time, money, and location. According to their findings interactive components and the necessity of creating experiences can accommodate a range of learner demands which also includes those of people with disabilities are highly valued.

On the other hand, for student engagement, studies by Parmaxi, (2023) have shown that interactive technologies can help develop 21st-century skills such as collaboration, autonomy, and critical thinking. The dynamic and immersive features of the Metaverse platforms make possible active participation and sustained interest in science learning by allowing learners to interact with virtual learning environments and peers.

Despite the benefits, the Metaverse-based science labs also present challenges in their adoption. Research by Nebel et al., (2016) pointed out the technical limitations which includes accessibility issues, infrastructure demands and the needs for teacher training to implement and employ these platforms into the curricula effectively. Those challenges must be weighted in perspective to ensure that benefits and limitations are addressed so that there is successful implementation and scalability in educational settings.

The present study tries to find out the influence of virtual science labs on students' understanding of scientific concepts and their interest in science. It is also an attempt to determine how these environments provide opportunities for collaborative learning, interaction with peers, and the development of crucial science-related skills such as critical thinking and problem-solving. This research will contribute to the fast-growing body of knowledge on the role of emerging technologies in enhancing science literacy and engagement, through an investigation of the major benefits and limitations associated with using Metaverse-based platforms for science education.

While the Metaverse with its platforms and virtual labs are full of hope for science learning, the effects are at a very preliminary stage in the investigation of specific impacts on science learning. Until now, many fundamental questions surround how these sites might enhance students' understanding of complex scientific concepts, engage learners through interactivity, support collaborative learning and skill development and have practical advantages and limitations within real-life educational settings.

To address these gaps, this study is guided by the following research questions:

- RQ 1: How do virtual science labs impact students' comprehension of scientific concepts?

- RQ 2: Which interactive elements of Metaverse-based platforms increase student engagement in science?

- RQ 3: What are the primary benefits and limitations of using Metaverse platforms for science labs?

- RQ 4: How do Metaverse science labs support collaborative learning and peer interactions?

- RQ 5: What science-related skills (e.g., critical thinking, problem-solving) do students develop in Metaverse labs?

The research questions listed above serve as a framework for a thorough investigation of the revolutionary capabilities of Metaverse science labs, which has the potential to transform science education. The current research aims to answer questions on what technologies and innovative functions these platforms provide, rigorous evaluation of educational outcomes, challenges encountered during implementation and the broader implications of fostering collaborative learning and skill development in a scientific setting.

When choosing for more engaging and inventive teaching methods, science educators are at an intersection of traditional teaching approaches and the latest technological advances. The suggested incorporation of Metaverse science laboratories, enhanced with immersive characteristics and interactive simulations, signifies a substantial advancement. This strategy presents promising resolutions to the ongoing issues of accessibility, student engagement and skills development within science education.

The following sections will explain the details on the complex subject of Metaverse Science Labs, covering the technology underpinnings that make them, how does the AR/VR is integrated in them, and the new kind of learning they will deliver to students. The present study will delve into those factors that will reshape science learning through such platforms while aiming to prepare students with skills in critical thinking, problem-solving, and collaboration to succeed in the modern-day scientific landscape.

2.3 Review Methodology

2.3.1 Search Strategy

Due to the high focus on virtual and Metaverse-based platforms in education, research in this area crosses numerous fields. This study thoroughly investigates the variety of fields such as education, computer science, psychology and engineering to make sure the function of virtual and Metaverse science labs in improving educational are carefully outlined. Although the primary focus for this study is on education, related studies on topics like design, implementation and user experiences of these platforms were also considered significant. For example, study on topics such as collaborative learning, critical thinking and skill development in virtual settings helps to gain insights into the technologies' broader applications.

The literature search was conducted across two major academic databases, namely Web of Science (WoS) and Scopus. These have been selected because of their wide range of high-quality and peer-reviewed literature in a wide array of areas. WoS is among the most popular academic research databases, while Scopus provides a wide array of interdisciplinary topics. It did not have a focus on specific subjects but rather on keywords connected to the virtual and Metaverse science labs or their applications in education-in order to guarantee inclusion. The top search terms were "virtual lab", "Metaverse platform", "immersive learning environment", "AR science lab", and "VR science lab".

The study focused on only English-language, peer-reviewed outlets to ensure the reliability and accessibility of the studies that were included. Given that this is a relatively novel area of research, it also included conference papers and dissertations to capture nascent insights and developments. Articles retrieved from the databases, using the above-mentioned keywords and search strings, were downloaded in full text by two research assistants. Since this review did not involve human participants, ethical issues concerning participant involvement are not applicable.

2.3.2 Data Analysis

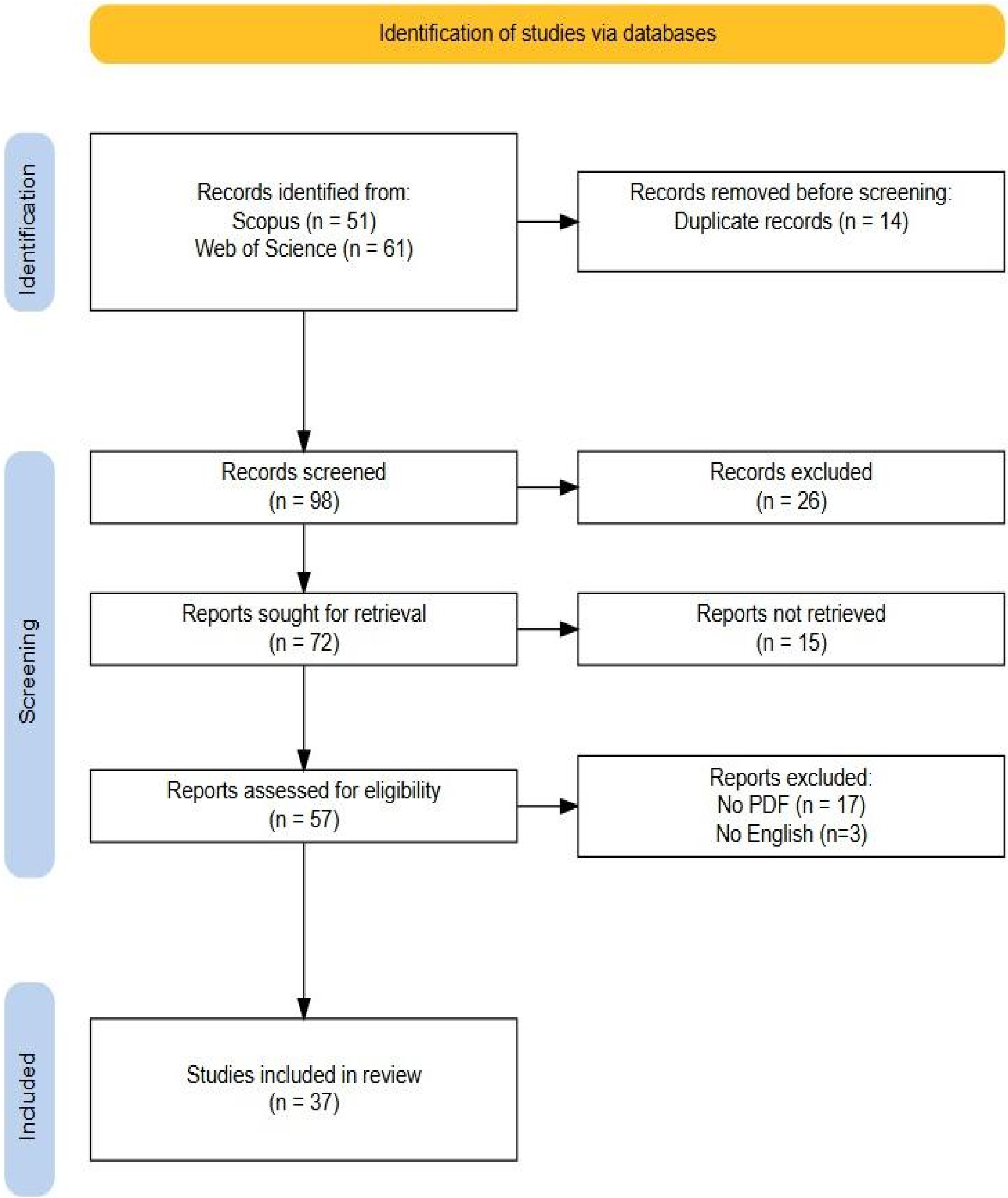

Figure 2.1: PRISMA Diagram

The PRISMA flow diagram shows in Figure 2.1 is the methodical process used to identify, screen, evaluate the eligibility of, and include studies in the review. The first step in analysis is identification; from two major databases, 112 records were retrieved: Scopus contributed 51 records, while Web of Science had 61 records. The exclusion of duplicate records resulted in a total of 14 records being removed, leaving a total of 98 distinct studies for further analysis.

During the initial screening phase, the titles and abstracts of the 98 records were critically reviewed. Of these, 26 studies were excluded for not meeting the pre-specified inclusion criteria. The remaining 72 studies were sought for retrieval. However, 15 of these could not be obtained owing to various reasons such as inaccessible files or unavailability in different databases.

Screening that was done evaluated the eligibility of the 57 studies. On abstraction eligibility, 20 studies were excluded; in particular, 17 did not have accessible PDFs, while the other 3 were in a language other than English. Finally, 37 studies met all the inclusion criteria defined and are hereby included in the present review. Such rigorous screening will ensure that the quality studies relevant to the present topic are included, and its strength and reliability increased as a result. This provided a robust dataset and a reliable foundation for the in-depth exploration of the research topic based on the primary evidence base consisting of 37 studies.

2.4 Results

2.4.1 How do Virtual Science Labs Impact Students' Comprehension of Scientific Concepts?

Virtual and augmented reality applications are a good tool in improving students' understanding of scientific subjects by providing engaging and interactive learning experiences that traditional approaches frequently lack. For example, virtual labs enable students to interact with simulations that make abstract scientific topics more concrete. Virtual labs help students understand and retain knowledge by allowing them to perceive and modify phenomena that would otherwise be difficult to grasp (Kim et al., 2023; López-Pernas et al., 2022; Shambare et al., 2022).

Simulations by Amanio et al., (2022) also provide a secure and controlled space in which students could explore complex ideas without the constraints of physical equipment or safety issues. These environments support conceptual learning, although they may not completely replace the real laboratories regarding sensory experiences and may therefore hinder deeper understanding (Rodrigues & Carvalho, 2022; Kapıcı & Coştu, 2023). One study by Cullinane et al., (2022) found that virtual laboratories improved understanding with an effect size of g = 0.587. This indicates large learning gains over traditional settings. Some features like real-time feedback may increase the likelihood of retention and understanding of the knowledge acquired (Tarng et al., 2023).

AR and VR platforms advancement in providing hands-on experiences helps students to experience simulation of real-world scenarios but in a safe way. A study by Fernandez et al., (2024) and Kulkarni & Harne, (2024) shows that students can utilize these tools to learn thermodynamics or monitor cell division processes in an interactive and engaging manner.

One of the most useful features of VR and AR tools is their ability to combine academic information with real-world situations. Virtual platforms frequently include real-world data and experiments which allow students to connect abstract concepts to practical effects. This skill bridges the gap between learning and real-world applications, which is especially useful in areas such as chemistry, physics, and biology (Clark-Stallkamp & Reis, 2024; Nungu et al., 2023). These technologies also provide important support for schools that may not have access to fully equipped physical laboratories. AR and VR enable students to study scientific subjects in previously inaccessible ways by providing a diverse set of virtual experiments and materials (Xie et al., 2022). This availability guarantees all students, regardless of location or economic status, can access high-quality instructional materials.

The impact of virtual reality and augmented reality on learning outcomes is extensively recognized. According to studies by Ateş & Garzón, (2023), Cooper et al., (2024) and Kuanbayeva et al., (2024), these technologies result in considerable learning gains with students scoring higher on tests and displaying deeper knowledge than those who only use traditional teaching approaches. Virtual environments also help to improve memory, recall and engagement which are the necessary for grasping complicated scientific topics (Anil & Batdi, 2023; Parmar et al., 2023). By immersing pupils in interactive and visually rich environments, VR and AR improve cognitive processes that are critical for information retention. Furthermore, features like real-time feedback help students to learn from their mistakes right away, which reinforces their grasp of the content.

Educators are using AR and VR tools, and they are making classes more engaging. Teachers can use many 3D visuals and lots of gamified experiences to teach difficult subjects in special ways. The success of these applications often relies on how effectively teachers can use them and while some educators excel in this area, others may battle to change. Studies by Peikos & Sofianidis, (2024) and Shambare & Jita, (2024) shows that educators often battle to adopt AR and VR tools due to a lack of training and unfamiliarity with the technology. The active development and integration of AR and VR in education, despite these challenges may transform how students learn and engage with science.

VR and AR technologies are transforming science education by making it more participatory, accessible, and effective. They are not only alternatives to established approaches, but effective complements that improve students' learning and pique their interest in the subject. For an overview of the studies discussed, refer to Table 2.1.

Table 2.1: Summary of Studies on the Impact of Virtual Science Labs on Comprehension

Author(s)	Aspect	Description
T. Kim et al., (2023); López-Pernas et al., (2022); Shambare et al., (2022)	Improved Comprehension	Virtual labs make abstract scientific topics concrete, enhancing understanding and retention through interactive simulations.
Amanio et al., (2022); Kapıcı & Coştu, (2023); Rodrigues & Carvalho, (2022)	Safe Exploration of Concepts	Provides a secure environment to explore complex ideas without the constraints of physical equipment or safety concerns.
Ateş & Garzón, (2023); Cooper et al., (2024); Cullinane et al., (2022)	Significant Learning Gains	Studies report considerable learning gains (e.g., effect size of $g = 0.587$), showing improvements in conceptual understanding over traditional methods.
Peikos & Sofianidis, (2024); Tarng et al., (2023)	Real-Time Feedback	Supports retention and learning by enabling immediate correction of errors and reinforcement of concepts.
Fernandez et al., (2024);	Interactive Hands-On Learning	AR/VR platforms allow students to experience real-

Kulkarni & Harne, (2024)		world scenarios in a safe, engaging way, supporting active learning in subjects like thermodynamics and biology.
Clark-Stallkamp & Reis, (2024); Nungu et al., (2023)	Bridging Theory and Practice	Combines academic concepts with real-world data and experiments, aiding in the application of abstract ideas to practical scenarios.
Xie et al., (2022)	Accessibility and Equity	Virtual labs provide high-quality educational resources, ensuring accessibility for students regardless of location or socioeconomic status.
Anil & Batdi, (2023); Parmar et al., (2023)	Enhances Cognitive Processes	Immersive environments improve memory, recall, and engagement, crucial for mastering complex scientific topics.
Peikos & Sofianidis, (2024); Shambare & Jita, (2024)	Educator Challenges	Some educators face difficulties in adopting AR/VR tools due to a lack of training and unfamiliarity with technology, although these tools hold transformative potential in education.
Ateş & Garzón, (2023); Kapıcı & Coştu, (2023); Rodrigues & Carvalho, (2022)	Complementary Tool to Traditional Labs	AR/VR labs enhance traditional approaches by making science education participatory, accessible, and effective, while not fully replacing the sensory experience of physical labs.

2.4.2 Which Interactive Elements of Metaverse-based Platforms Increase Student Engagement in Science?

By including features that importantly increase student participation, platforms based in the Metaverse have changed how education in science is experienced and engaged with. Many noticeable features include multiple simulations and gamification elements. These participations and gamification, reward systems and interactive simulations to encourage active participation and make learning engaging and immersive. Points and badges along with problem-solving exercises helps encourage students to stay engaged and impart a sense of achievement (Al-Muqbil, 2024; Jeffery et al., 2022). Students are enabled by simulations to investigate scientific concepts in a hands-on manner. This approach bridges the gap that exists between academic understanding and practical application (Rodrigues & Carvalho, 2022). These technologies not only make learning more exciting, but they also improve students' comprehension by creating interactive environments in which they may explore and learn from their mistakes (Acevedo et al., 2024).

Another important component of Metaverse-based platforms in increasing student involvement is collaborative features. These platforms frequently enable students to collaborate on virtual experiments and projects in developing a sense of community and teamwork (Ateş & Garzón, 2023). For example, virtual labs frequently feature capabilities for real-time communication and group projects. This will allow students to work together on problem-solving exercises and discuss scientific phenomena (Hite et al., 2024) . According to Kapıcı & Coştu, (2023), such environments allow students to share insights and learn from their peers' help motivating them while also deepening their comprehension of the content.

Instant feedback and customization features add to the attraction of Metaverse-based platforms. Students can modify variables like gravity or friction in virtual simulations, allowing them to investigate scientific subjects at their own pace and based on their interests (Clark-Stallkamp & Reis, 2024; Henne et al., 2024) . This customisation guarantees that students remain engaged in their learning journey since they can see the outcomes of their efforts and adapt their approaches accordingly (Hwang et al., 2023).

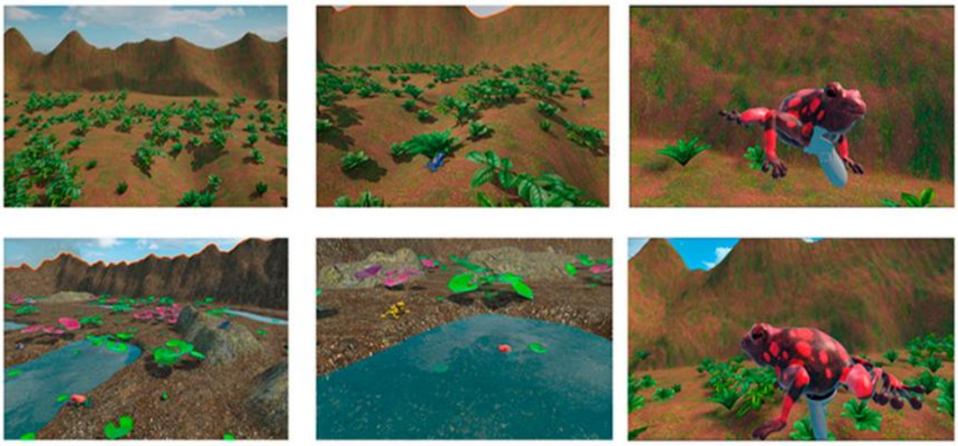

Figure 2.2: Design of Virtual Environments in Game (Villegas-Ch et al., 2024)

Immersive surroundings show in Figure 2.2 that generated with 3D and AR features are another key component of Metaverse platforms' effectiveness. These technologies provide visually dynamic and interactive environments that attract students' attention and make complex subjects more understandable (Cho & Park, 2023; Thiele et al., 2023; Thohir et al., 2023) . For example, 3D models of ecosystems or chemical reactions give pupils a realistic picture of abstract scientific concepts, making the learning process more interesting and memorable. The capacity to interact directly with these virtual worlds allows students to visualize concepts in ways that traditional techniques sometimes cannot.

Visually appealing interfaces and unexpected components like AR quizzes can act as features that will increase students' engagement. Educators say that these characteristics not only make learning more fun but also inspire students' curiosity and enthusiasm (Jafari, 2023; Sofianidis, 2022) . For example, AR quizzes will force students to reach for their smartphones and interact with virtual things and bringing learning into their actual environment which will results in a unique and engaging educational experience.

By combining all these features into Metaverse-based platforms, a dynamic learning environment will be created. This will enable students to actively engage while deepening their understanding of science. These tools not only represent a significant leap forward in educational technology but also offers new ways to inspire and involve students in meaningful learning experiences. For an overview of the studies discussed, refer to Table 2.2.

Table 2.2: Summary of Studies on the Interactive Elements of Metaverse-based Platform

Authors	**Interactive Element**	**Description**
Al-Muqbil (2024); Jeffery et al. (2022)	Gamification & Rewards	Use of points, badges, and problem-solving exercises to encourage participation, engagement, and a sense of achievement.
Rodrigues & Carvalho (2022); Acevedo et al. (2024)	Simulations	Hands-on investigation of scientific concepts, bridging academic knowledge and practical applications.
Ateş & Garzón (2023); Hite et al. (2024); Kapıcı & Coştu (2023)	Collaboration Features	Tools for real-time communication and teamwork in virtual labs, fostering a sense of community and deepened comprehension.
Hwang et al. (2023)	Instant Feedback	Immediate responses to actions in simulations, helping students adjust

		and learn dynamically.
Clark-Stallkamp & Reis (2024); Henne et al. (2024)	Customization	Adjustable variables like gravity or friction to explore concepts at an individualized pace, catering to student interests.
Cho & Park (2023); Thiele et al. (2023); Thohir et al. (2023)	Immersive 3D & AR Environments	Visually dynamic models (e.g., ecosystems, chemical reactions) offering realistic, interactive learning experiences for abstract concepts.
Jafari (2023); Sofianidis (2022)	AR Quizzes & Interactive Interfaces	Features like quizzes that integrate learning into students' physical environment, making the experience unique and engaging.

2.4.3 What are the Primary Benefits and Limitations of Using Metaverse Platforms for Science Labs?

Metaverse-based platforms provide several advantages to science education by fostering innovative and effective learning settings. One of the key benefits is flexibility and accessibility. These platforms eliminate the requirement for tangible resources, allowing experiments to be conducted remotely and asynchronously, which is particularly beneficial in geographically diverse or resource-limited contexts (Alhashem & Alfailakawi, 2023; Jeffery et al., 2022). According to research by (Henne et al., 2024; Kulkarni & Harne, 2024) , Metaverse platforms are cost-effective because they allow students to imitate expensive or dangerous experiments in safe virtual settings, like as running a Boeing turbine. (Zhang & Liu, 2023) also stated that this feature will contribute to environmental sustainability by lowering reliance on physical resources.

Another major advantage is increased engagement through immersive and interactive experiences. Gamification components such as prizes and challenges when paired with immersive technologies like 3D and AR will motivate students and make learning more pleasurable (Acevedo et al., 2024; Cho & Park, 2023) . These tools also encourage collaborative education in which students work together on experiments or simulations that encourage collaboration and information exchange (Al-Muqbil, 2024) . Furthermore, Metaverse platforms offer tailored learning routes and allowing students to advance at their own pace and focus on areas for improvement (López-Pernas et al., 2022; Xing et al., 2023) . The structured design of these platforms also helps with organization, precision and the keeping of experimental records, all of which are required for good scientific learning (Jennifer G. et al., 2022).

Another significant advantage is the opportunity to deliver hands-on experiences that would be impracticable in typical classroom settings. These platforms enable students to see and interpret scientific concepts, making complicated ideas more understandable (Kuanbayeva et al., 2024; Parmar et al., 2023; Thiele et al., 2023) . For example, virtual labs allow students to concentrate on crucial topics without the confusion that is typically associated with physical experiments (Thiele et al., 2023) . Metaverse environments can also help students develop their critical thinking and problem-solving skills by presenting them with interactive tasks that need analytical reasoning (Fernandez et al., 2024).

Nevertheless, despite these advantages, Metaverse systems have numerous drawbacks that must be addressed. Technical difficulties are a serious impediment, especially for learners and educational institutions with limited access to advanced gear, reliable internet connections, or appropriate finance (Lopatto et al., 2023). The requirement for specialized equipment such as VR headsets or high-performance devices can limit participation and generate access disparities (Peikos & Sofianidis, 2024; Shambare et al., 2022). Furthermore, these platforms frequently have a learning curve for both students and educators because they require digital literacy and training to function properly (Ateş & Garzón, 2023; Fernandez et al., 2024; Jennifer G. et al., 2022).

Another disadvantage is the risk of cognitive overload and distractions in immersive situations. The novelty of these tools is initially appealing but may cause emotional distractions or challenges in maintaining students' focus (Cho & Park, 2023; Kim et al., 2023). Furthermore, relying on preprogrammed results in virtual experiments may impair the authenticity of the experience by removing students from the unpredictability and hands-on manipulation of real materials (Jennifer G. et al., 2022; Lestari et al., 2023).

Implementation presents additional obstacles for educators. Limited training and support for instructors can lead to inadequate use of these tools, and the lack of comprehensive instructions makes it difficult to properly integrate Metaverse technology into lesson plans (Henne et al., 2024; Shambare & Jita, 2024a). There are also worries regarding a lack of strong evaluation techniques to assess the quality and impact of these platforms on student learning outcomes (Cooper et al., 2024).

Finally, Metaverse-based platforms provide transformative benefits such as flexibility, engagement and greater access to scientific learning. But they also bring problems in terms of technical accessibility, cognitive demands and implementation. Addressing these restrictions through improved training, resources and infrastructure is critical to realizing their educational potential. Table 2.3 shows the summary of findings.

Table 2.3: Summary of Studies on the Benefits and Limitations of Metaverse-based Platform

Authors	Aspect		Description
	Benefits	Limitations	
Alhashem & Alfailakawi (2023); Jeffery et al. (2022)	/		Remote and asynchronous experimentation eliminates the need for physical resources, benefiting resource-limited and geographically diverse contexts.
Henne et al. (2024); Kulkarni & Harne (2024); Zhang & Liu (2023)	/		Virtual simulations allow students to replicate expensive or dangerous experiments safely (e.g., running a Boeing turbine), promoting sustainability.
Acevedo et al. (2024); Cho & Park (2023); Al-Muqbil (2024)	/		Immersive technologies and gamification motivate students, foster collaboration, and promote knowledge sharing.
López-Pernas et al. (2022); Xing et al. (2023)	/		Students can progress at their own pace, focusing on areas needing improvement.
Kuanbayeva et al. (2024); Parmar et al. (2023); Thiele et al. (2023); Fernandez et al. (2024)	/		Enables students to visualize and interact with complex scientific concepts, improving understanding and critical thinking skills.
Jennifer G. et al. (2022)	/		Organized designs help maintain precision and records necessary for scientific learning.
Lopatto et al. (2023); Peikos & Sofianidis (2024); Shambare et		/	High costs of VR headsets or advanced devices, limited internet access, and funding

al. (2022)			create participation barriers.
Ateş & Garzón (2023); Fernandez et al. (2024); Jennifer G. et al. (2022)		/	Requires digital literacy and training for both students and educators
Cho & Park (2023); Kim et al. (2023)		/	Immersive environments may distract students, causing emotional or cognitive challenges.
Jennifer G. et al. (2022); Lestari et al. (2023)		/	Preprogrammed results can hinder hands-on learning by limiting exposure to real-world unpredictability.
Henne et al. (2024); Shambare & Jita (2024); Cooper et al. (2024)		/	Lack of educator training and robust evaluation methods complicates integration and limits effectiveness.

2.4.4 How do Metaverse Science Labs Support Collaborative Learning and Peer Interactions?

Metaverse science laboratories improve interactive education by allowing students to work together in shared virtual spaces. These platforms encourage peer connection, which is critical for improving communication and teamwork skills. Students can participate on experiments and projects in real time and being independent of their physical location which allows them for more meaningful conversations and problem-solving (López-Pernas et al., 2022; Zhang & Liu, 2023) . This collaborative feature is especially visible in systems such as EDVL and Telelab where students can exchange insights, results and ideas to better their learning experience (Anil & Batdi, 2023; Xie et al., 2022).

One of the key advantages of Metaverse science laboratories is their capacity to imitate communal experiences, allowing students to participate in group activities and investigate scientific subjects collectively (Kuanbayeva et al., 2024). According to Thohir et al., (2023), these shared virtual experiments promote active engagement and motivation as students become more involved in their learning process.

Figure 2.3**:** Virtual Molecular Biology Lab in the VR Environment (Ewais et al., 2024)

The immersive nature of VR and AR environments enhances cooperation by generating dynamic and interactive environments that promote teamwork and cooperative learning (Wee et al., 2022). Integration of multimodal interactions in Metaverse platforms empowers more collaboration and engagement. Scientific phenomena learning process becomes more interactive and effective as students able to manipulate virtual objects and discuss the observations in real time (Cooper et al., 2024; Kim et al., 2023; Xing et al., 2023) . Teachers have also underlined the value of Metaverse tools in fostering group discussions and peer learning because these platforms support co-construction of knowledge and iterative learning processes (Lopatto et al., 2023; Nungu et al., 2023).

Moreover, Metaverse labs support collaborative problem-solving, one of the critical features that develop higher-order cognitive skills. Furthermore, during discussing this complex scientific concept, learners can collaboratively analyse data, construct arguments and in the process refine their thoughts based on peer feedback (Ateş & Garzón, 2023; Canoz et al., 2022) . The cooperative aspect is quite crucial in STEM education as collaborative teamwork mirrors the real-world setting of scientific research and discoveries (Clark-Stallkamp & Reis, 2024; Henne et al., 2024). However, the success of collaborative learning in Metaverse science labs highly depends on the design and functionality of the platform. The availability of avatars, common areas and interactive tools can enhance peer interaction and make teamwork more engaging (Parmar et al., 2023; Thiele et al., 2023). Learners can work in teams to design experiments, discuss results and refine their methods in an online environment that simulates many of the experiences of collaborating in real life (Al-Muqbil, 2024) . Their scientific inquiry will be enhanced together with their confidence in working collaboratively.

To conclude, Metaverse science labs able to create a fresh and effective medium for shared learning experiences where shared experiences, interaction among equals and mutual problem-solving promote teamwork, increase communication and build social skills in learners. Since they are interactive and participatory in nature, such learning spaces become indispensable tools for creating collaboration in the classroom while developing the potential of the students to solve real scientific problems and deepening their understanding of the subject area. Table 2.4 shows the summary of findings.

Table 2.4: Summary of Studies on How Metaverse Science Labs Supports Collaborative Learning and Peer Interactions

Authors	**Aspect**	**Description**
López-Pernas et al. (2022); Zhang & Liu (2023); Anil &	Collaborative Features	Enables students to collaborate on experiments and projects in

Batdi (2023); Xie et al. (2022)		shared virtual spaces, fostering teamwork and meaningful problem-solving.
Kuanbayeva et al. (2024); Thohir et al. (2023); Wee et al. (2022)	Group Activities	Simulates communal experiences where students collectively explore scientific subjects, promoting active engagement and motivation.
Cooper et al. (2024); Kim et al. (2023); Xing et al. (2023)	Multimodal Interaction	Supports real-time manipulation of virtual objects and discussion of observations, enhancing interactive and effective learning processes.
Lopatto et al. (2023); Nungu et al. (2023)	Knowledge Co-Construction	Facilitates group discussions and peer learning, allowing co-construction of knowledge and iterative learning processes.
Ateş & Garzón (2023); Canoz et al. (2022)	Collaborative Problem-Solving	Develops higher-order cognitive skills by encouraging learners to analyze data, construct arguments, and refine ideas based on peer feedback.
Clark-Stallkamp & Reis (2024); Henne et al. (2024)	STEM Relevance	Mirrors real-world scientific collaboration, enhancing teamwork and problem-solving skills in STEM education.
Parmar et al. (2023); Thiele et al. (2023); Al-Muqbil (2024)	Platform Design	Avatars, common areas, and interactive tools enhance peer interaction, making teamwork engaging and realistic.
Clark-Stallkamp & Reis (2024); Henne et al. (2024);	Impact on Social Skills	Builds confidence in collaboration, communication,

Kuanbayeva et al. (2024)		and teamwork, while promoting shared inquiry and deeper understanding of scientific concepts.

2.4.5 What Science-related Skills (e.g., critical thinking, problem-solving) do Students Develop in Metaverse Labs?

Through virtual and Metaverse laboratories students able to develop critical thinking and problem-solving skills. These platforms create interactive and immersive settings in which students can conduct inquiry-based learning. Hypothesizing, testing and analysing data help students improve their capacity to think critically about scientific challenges and propose novel solutions (López-Pernas et al., 2022; Shambare et al., 2022). The hands-on nature of these virtual settings promotes experimentation, allowing students to learn via trial and error in a risk-free environment, which is critical for scientific inquiry (Lopatto et al., 2023; Zhang & Liu, 2023).

One of the main advantages of these labs is their emphasis on real-world events and simulations. Metaverse platforms engage students with complicated problems that necessitate analytical thinking and decision-making. For example, in regulated virtual situations, to solve issues students must examine data and form conclusions which improves their cognitive and practical skills (Fernandez et al., 2024; Kuanbayeva et al., 2024) . These exercises are intended to reflect real-world scientific research, allowing students to apply their knowledge in relevant ways (Ateş & Garzón, 2023; Cho & Park, 2023; López-Pernas et al., 2022).

This is nurtured through the collaborative and iterative processes. Usually, students work in groups to analyse experiments, share insights and get better approaches through feedback from peers. These kinds of interactions allow knowledge to be co-constructed and it enhances learners' ability to reason and evaluate evidence appropriately (Nungu et al., 2023; Thohir et al., 2023; Xing et al., 2023) . Also, such iterative activities as revising hypotheses or trying new approaches inculcate persistence and adaptability is a very important aspects of problem-solving (Henne et al., 2024; Xie et al., 2022).

This further enhances the students' higher order thinking skills because the experience in an immersive environment is coupled with the manipulative use of digital tools. Due to the AR and VR environment, students can visualise information and manipulate it where complex concepts are now possible to be perceived by an abstract idea (Cooper et al., 2024; Jafari, 2023; Wee et al., 2022) . This experiential learning supports analysis of information and synthesis related to mastering advanced scientific ideas (Anil & Batdi, 2023; Canoz et al., 2022; Parmar et al., 2023).

The ability of the Metaverse labs to provide structured feedback is another great advantage. By their very nature, many of these interactive platforms incorporate real-time feedback mechanisms which allow students to reflect on their learning and adjust their strategies accordingly. This reflection forms part of developing the ability to think critically and solve problems (Peikos & Sofianidis, 2024; Sofianidis, 2022) . Moreover, accessibility of virtual resources enables learners to repeat experiments as well as re-evaluate their approaches to solidify their understanding and skills over time (Henne et al., 2024; Jeffery et al., 2022).

This paper summarizes how virtual and Metaverse labs serve transformative purposes in education, preparing learners with basic critical thinking and problem-solving skills. Platforms that provide immersive simulations, means of collaboration, and learning iteratively are very exciting to engage in and extremely efficient in preparing students for challenges they will encounter in scientific pursuits in real life. The only way students can get hands-on experience, confidence and self-efficacy and something needed for successful contemporary science research is by being put through complicated situations that would analyse data and interact with sophisticated technologies. Table 2.5 shows the summarization findings.

Table 2.5: Summary of Studies on What Science-related Skills do Students Develop in Metaverse labs

Authors	Aspect	Description
López-Pernas et al. (2022); Shambare et al. (2022); Lopatto et al. (2023); Zhang & Liu (2023)	Critical Thinking	Students hypothesize, test, and analyse data, enhancing their ability to critically assess scientific challenges and propose solutions.
Fernandez et al. (2024); Kuanbayeva et al. (2024); Ateş & Garzón (2023); Cho & Park (2023)	Problem-Solving	Real-world simulations engage students in analyzing data, forming conclusions, and solving complex problems, fostering cognitive and practical skills.
Nungu et al. (2023); Thohir et al. (2023); Xing et al. (2023)	Collaboration	Group work promotes shared insights, co-construction of knowledge, and refining approaches through peer feedback.
Henne et al. (2024); Xie et al. (2022)	Persistence and Adaptability	Iterative activities such as revising hypotheses and trying new approaches foster persistence and adaptability in problem-solving.

Cooper et al. (2024); Jafari (2023); Wee et al. (2022); Anil & Batdi (2023); Canoz et al. (2022); Parmar et al. (2023)	Higher-Order Thinking Skills	Immersive environments enable students to visualize, manipulate, and synthesize information, making complex concepts more accessible.
Peikos & Sofianidis (2024); Sofianidis (2022)	Structured Feedback	Real-time feedback mechanisms allow reflection and strategy adjustment, fostering critical thinking and problem-solving.
Henne et al. (2024); Jeffery et al. (2022)	Repetition and Mastery	Virtual resources enable repeated experiments and re-evaluation of approaches, solidifying understanding and skills.
Jafari (2023); Peikos & Sofianidis (2024); Wee et al. (2022)	Preparation for Real-Life Challenges	Immersive simulations and sophisticated technologies prepare students for contemporary scientific research and real-world problem-solving scenarios.

2.5 Discussion

2.5.1 Theoretical Implications

The virtual and Metaverse science labs have given much more credence to the theoretical framing of how immersive technologies change the way educational paradigms transform. Discussions central to this debate include the integration of both constructivist and experiential learning theories, hence placing great emphasis on active engagement and hands-on interaction in knowledge construction (Amanio et al., 2022) . Such virtual and metaverse platforms can offer learners a chance to participate in simulated experiments and immersive experiences that would help them stick to theoretical frameworks, finding experiential learning an important component of education. This will agree with Vygotsky's aspect of social constructivism, where collaboration and interaction within these digital spaces support the co-construction of knowledge.

Similarly, Metaverse lab architectures and capabilities are challenging basic ideas on cognitive load and the balance between interactivity and knowledge absorption needs to stay very thin. As shown with virtual and augmented reality use cases, badly designed systems result in cognitive overload to users, whereas great designs enhance the ability to retain and grasp the knowledge (Lestari et al., 2023) . In a similar way, gamification elements can be included to increase motivation and promote self-directed learning through rewards, challenges, and interactive activities (Almurtadha, 2024).

Furthermore, the labs could help address systemic inequalities in education by providing scalable and resource-efficient alternatives to traditional science labs, making high-quality STEM education available to underserved populations.

An expanded contribution to the theory is for cognitive load: design and functionality of the Metaverse labs question assumptions currently held about how learners' minds process and retain information. Leading scholars must revisit and adjust their models to allow for the new complexities these virtual learning spaces introduce and balance engagement with a proper level of cognitive load. For instance, the interactivity and realism of such e-learning platforms can make for improved retention and understanding but also carry risks of cognitive overload if not properly designed. This invites a much-needed deeper exploration into how virtual learning environments could be optimized to support effective learning.

One more area enriched by this research is the role of gamification in education. The theoretical insights into the motivational and behavioural impacts of gamified elements within Metaverse labs elucidate how rewards, challenges, and interactive tasks may be used to better engage students and foster self-directed learning. These findings add to the presently small but growing body of literature on educational gamification, hence offering evidence-based strategies for integrating game-like features in digital learning environments.

Finally, it bears theoretical implications for equity and access in education: the availability of scalable, resource-efficient alternatives to traditional labs by virtual and Metaverse platforms challenges existing notions of access and inclusion. This falls in line with critical theories of education that call for addressing systemic inequities. A very valuable theoretical lens that would offer great value for research in the future pertains to how these platforms might close gaps for underserved populations.

2.5.2 Practical Implications

The virtual and Metaverse science labs have very important practical implications, hence serving actionable insights for educators, institutions and policymakers. First and foremost is the potential to increase student engagement and skill development. These platforms provide dynamic and interactive environments where students can carry out experiments, manipulate variables and explore complex scientific concepts in ways that traditional classrooms cannot achieve. This hands-on approach develops critical thinking and problem-solving skills to equip students with competencies that are key to success in these fields.

Metaverse labs offer innovative tools to help teachers diversify their teaching strategies. Teachers can create an inclusive and engaging learning environment by integrating virtual simulations in curricula that cater to diverse learning styles. 3D model will become a good tool for visual learners while kinaesthetic students will excel in interactive simulations. It allows for collaborative learning opportunities, where students can work together in a shared virtual space which will develop much-needed teamwork and communication skills in modern scientific inquiry.

The institutions will equally benefit from the cost efficiency and scalability of virtual labs. Traditional science labs usually involve huge investments in physical infrastructure, equipment and materials. The virtual and Metaverse labs wipe out most of the costs and makes them sustainable alternatives with a wider potential reach. Schools and universities in resource-constrained regions use these technologies to provide quality STEM education without the logistics of maintaining physical labs.

The results of the implementation can be applied by policymaker decisions regarding budgetary allotments to education and integration with technology. The ease by which virtual labs can make access has its advantages because it levels systemic inequalities, ensuring that students within under-resourced groups gain access to high-quality educational experiences. In addition, virtual laboratories support global moves towards sustainable development by possibly reducing wastes from traditional laboratory practices, in terms of chemicals and electricity consumption.

This has implications for teacher professional development as well. It would be essential that teachers are trained to use virtual labs and the Metaverse effectively to bring out the best in them. Workshops and digital pedagogy certification can empower educators to seamlessly integrate tools like these into their practices, fostering innovation in education.

Ultimately, the results of this study can lead to informing the design and development of future educational technologies. Developers of practices can use the evidence from this study to enhance user interfaces, increase interactivity, and address problems such as cognitive overload and technology barriers. By matching technological advances with educational needs, virtual and Metaverse platforms are poised to continue evolving as powerful tools for learning.

In the final analysis, the practical implications of this study point out the enormous transformative potentials of virtual and Metaverse laboratories for improving engagement, accessibility, and effectiveness in learning in a variety of contexts.

2.5.3 Review Limitations

While this review provides valuable insights on the transformative capabilities of virtual and Metaverse science laboratories, there are important limitations that need to be acknowledged. First, the review was delimited to publications in the English language. Such linguistic limitation might have precluded the inclusion of research conducted in non-English-speaking regions, potentially possessing different perspectives and outcomes especially in diverse educational contexts. A gap in such kind of study entails a limitation of the literature review that universally constrains the applicability of the conclusions made.

One would not expect otherwise, since reliance on just two main databases like Web of Science and Scopus could have been delimiting. As extensive as these databases are, it remains highly likely that important publications originating from sources other than those mentioned have been missed out. It means a partial presentation of existing research and most nascent disciplines with novel leading-edge breakthroughs tend to be reported in non-conventional sources.

Grey literature sources are not included in the review, which might relate to government reports, white papers, and industry publications. Focusing on peer-reviewed literature might ensure the inclusion of studies of quality and relevance, but excluding grey literature might ignore valuable practical insight into or application of virtual and Metaverse laboratories that have not found their way into academic discourse yet.

The rapid development of technology poses an additional challenge. The area of virtual and Metaverse science laboratories is one of constant technical improvement and educational innovations. Therefore, articles published after the review's inclusion period concluded were excluded, potentially omitting recent trends and developments.

Additionally, the inclusion criteria favoured those studies that showed clear connections with educational outcomes. This might have excluded potentially relevant exploratory or theoretical research that could help deepen the understanding of the subject. Such a narrow focus risks limiting the review's ability to capture the full range of opportunities and challenges presented by the platforms.

Lastly, while the review followed a rigorous methodology, subjective decisions made during the screening and analysis phases may lead to bias. While certain steps were taken to maximize consistency such as the involvement of multiple researchers and resolution of disagreements through discussion, subjectivity is to some degree inherent in the review process.

In conclusion, these limitations mean that future reviews need to have wider and more inclusive approaches. It may be that extending the scope to include non-English literature and further databases and grey literature in the review might make the vision of the field more holistic. Also, it is a good idea to perform periodic review updates to add newer research and technologies since it's a very fast-changing world. It remains only at the first stage despite some inherent limitations; hence, it provides important guidance on where virtual and Metaverse science labs stand at present in education.

2.6 Conclusion

Integration of virtual and Metaverse science labs in an academic setting will be a paradigm shift in the way of teaching and learning science. These platforms are overcoming some of the biggest challenges of education through experiences that are both interactive, immersive, and collaborative. The review proved the technologies have many other advantages, including critical thinking, collaboration enhancement, and provision of scalable alternatives to traditional physical science labs.

The findings also bring to light some of the challenges that need to be overcome to realize the full potential of these platforms. Challenges such as cognitive overload, digital literacy gaps and inequitable access to technology remain great barriers. Addressing these will require a concerted effort on the part of researchers, educators, policymakers and developers to create environments that are not only technologically advanced but also pedagogically sound and inclusive.

This paper contributes to the rapidly growing literature on the topic by synthesizing the existing knowledge and identifying gaps for future research. To that end, this review strongly encourages interdisciplinary approaches and collaborative efforts in working toward the optimization of using virtual and Metaverse labs in education. One can safely bet that, with how science education is, the platforms are going to be very instrumental in preparing students for the complexities of today's world by arming them with skills and knowledge relevant for excelling in STEM fields and all other discourses.

Virtual and Metaverse science labs are more than just technological novelties as they act as catalysts in the reimagining of science education. Such platforms, if well integrated by the teacher or institution, could bring about engaging, effective and equitable learning experiences that would see the next generation of scientists and innovators flourish.

2.7 Chapter Summary

This chapter reviews the role of gamified and Metaverse-based virtual labs in science education. It highlights their potential to enhance engagement, accessibility, and learning outcomes by allowing immersive simulations and collaborative tools. Technologies enhance critical thinking and problem-solving skills but are challenged by technical barriers and teacher training. Despite the limitations, they offer a transformative potential to modernize science education.

CHAPTER 3

METHODOLOGY

3.1 Overview

This chapter describes the methodology of the gamified learning application called Recycling Heroes in developing and testing it. In developing this educational tool, a very employed system model used is the 4D Model which consists of define, develop and disseminate. It embodies four steps that ensure that all objectives of the technical, educational, and usability nature of the project are achieved. Integration of the game with a rule-based decision tree machine learning technique would widen player engagement and improve the learning outcome. This methodology reflects a balance between the technical implementation and educational objectives necessary to make this project appropriate for elementary school students. Visual aids, timelines and iteration are used to enhance clarity and structure

3.1.1 Purpose of Study

This study is designed to create, develop and evaluate a gamified educational tool for recycling called Recycling Heroes. With gamification and interactive chatbot support, it aims at improving understanding related to waste management among Year 6 students. The study will find solutions to the shortcomings that have been faced approaches to teach students engagement and sustainable behavioural change.

3.2 Research Design

To assess how a gamified learning environment affects students' comprehension of recycling concepts, this study uses an experimental single-group design. The Recycling

Heroes game, which combines curriculum-based assignments and real-time chatbot assistance, were played by all participating students.

Observations and post-game surveys with open-ended and Likert-scale questions are used to gather additional data. Both quantitative and qualitative assessments of the educational process are possible with this mixed-methods approach.

3.3 Target Population and Sample Design

3.3.1 Population

The target population includes 10 Year 6 students from SK Sri Suria (2). Students in that targeted population are at a more mature development stage where interactive approaches would enhance their understanding through knowledge and practical experiences associated with recycling and environmental sustainability.

3.3.2 Sample

Purposive sampling was used to choose the 10 Year 6 students from SK Sri Suria (2) for the sample based on their cooperation with the school and ease of access. Every student takes part in the Recycling Heroes gamified learning process. This sample is thought to be appropriate for investigating the game's immediate effects on participation, understanding, and recycling-related behavior.

3.4 Instructional Materials

Recycling Heroes, a gamified educational tool created in Roblox Studio, is the focal point of the study's instructional strategy. With a particular emphasis on waste management and recycling, the game is made to correspond with the Year 6 Science curriculum.

3.4.1 Gamified Learning Tool

Recycling Heroes, a game-based learning environment that incorporates AI chatbot guidance is used by all participating students. The tasks, challenges, and quests in the game mimic actual recycling activities. Students will learn by doing and applying concepts in a virtual setting thanks to this immersive environment, which provides them with instant feedback.

3.4.2 Learning Integration

The game's content is organized to satisfy the curriculum's learning objectives. Every task, including garbage sorting, cleaning contaminated areas, and crafting new items with recyclable items, are linked to learning goals. All the teaching content is presented through gameplay, with post surveys that include both quantitative and qualitative analysis.

3.4.3 Reflective and Feedback Components

Students must also finish post-game surveys that include both open-ended and Likert-scale questions to assess the learning process more comprehensively. These ensure that the effectiveness of instruction is assessed from a variety of angles by capturing both cognitive gains and emotional engagement.

3.5 Procedures

3.5.1 Participant Selection

Students were selected with the help of SK Sri Suria (2) administrators. The collaboration with these officers greatly facilitated easy recruitment of participants and obtaining consent from parents or guardians. The school is chosen for convenience as an existing professional relationship allowed for ease of access and communication.

3.5.2 Data Collection

The tools used for data collection are:

- Questionnaires on the gamified tool and effectiveness.
- Open-ended surveys to gain new insights.

3.5.3 Data Analysis

Quantitative data were analyzed using statistical methods to oversee the effectiveness of gamification. Qualitative data obtained through open-ended survey responses were analyzed to provide richer detail about student experiences.

3.6 Methodology

The 4D model is chosen to be the method adopted in this work as it suits the development of educational game. This model defines four stages, which are Define, Design, Develop and Disseminate. Figure 3.1 illustrates the 4D model applied in this project.

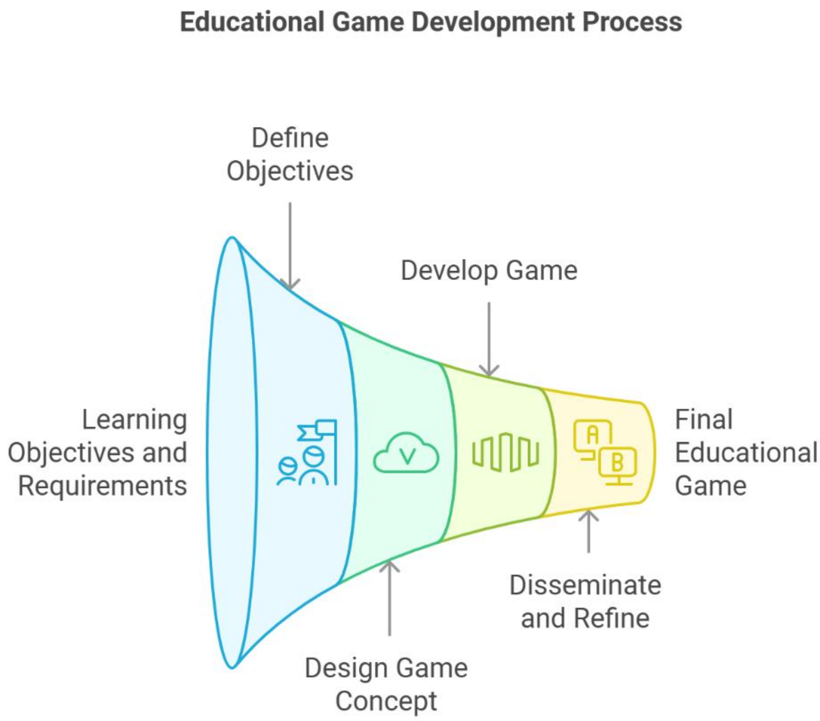

Figure 3.1: 4D Model Methodology

The four stages are explained as follows:

3.6.1 Defining Analysis Stage (Define)

With the assistance of SK Sri Suria 2 science teacher, an experiment was conducted to observe the difference in students' recycling behavior before and after playing "Mystic Forest: Recycling Heroes". This stage adopts theoretical insights from gamification theories and educational frameworks into creation at an engaging yet pedagogically healthy level once more. Based on previous research, this first stage consists of five activities (Hariyanto, 2022). Figure 3.2 shows the activities in the defined stage.

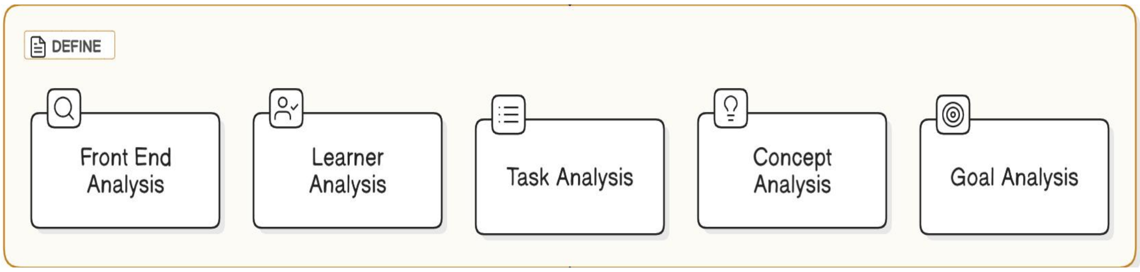

Figure 3.2: Activity in Defined Stage

3.6.1.1 Front End Analysis

The development of 'Mystic Forest: Recycling Heroes' is driven to enhance environmental education in the Year 6 Science curriculum, which often not fully engaging for students through traditional methods or leading to long-term behavioural changes. Gamification in research has been noted as a useful tool to address such challenges because it couples entertainment with educational content in impactful learning experiences (Aikowe, 2021).

In congruence with self-determination theory, the game designs the arousal of intrinsic motivation through offering autonomy, competence, and relatedness. Players were given meaningful tasks to accomplish in an engaging virtual environment, which would, in turn, make them own the learning process. This would fill the gap between the aims of the curriculum and students' engagement in recycling education in a manner that is pleasurable yet effective.

3.6.1.2 Learner Analysis

The main target for this project is Year 6 students who are 12-year-old pupils. According to Vinogradova et al., (2020) , primary school students benefit most from activities that encourage investigation, critical thinking, and self-regulation. At this stage, students are curious and thus may be efficiently involved in some work that is able to simulate reality. Traditional approaches to teach the concepts of recycling do not easily capture their interest or lead to attitude modification. This game addresses those gaps with an interactive and gamified approach for motivating students and creating sustained interest in recycling practices.

Game design is in concord with the constructivist theory of learning. Students can build their knowledge on waste management by being active in a quest or solving some problem while they are also induced to explore, analyse and synthesize information to solve a problem which again deepens the learning and forms sustainable behaviours.

3.6.1.3 Task Analysis

The tasks designed to be carried out in the game match directly with the curriculum, hence students will be having fun playing and reifying learning objectives. For example, the tasks of sorting waste into appropriate bins, identifying recyclable items, crafting new products with recyclable items which are put into the quests to make them appealing, and every activity has clear instructions along with immediate feedback for improving learning results. The tasks include game-like features like points meant to engage players but with learning outcomes as the focus. These provide a balance of cognitive, psychomotor, and affective learning experiences.

3.6.1.4 Concept Analysis

At this level, the material created for the 'Mystic Forest: Recycling Heroes' game highlights the main topics that include waste types, their appropriate disposal, and reasons for recycling. With an emphasis on the cognitive development components of environmental education, the tasks were created to correspond with students' competencies based on the Science Year 6 curriculum. Through playing the game, students will gain knowledge about identifying waste types, appropriate disposal and comprehending how recycling affects the environment. Through participatory gaming, this method intends to improve students' understanding of waste management.

3.6.1.5 Goal Analysis

The primary purpose of creating the game 'Mystic Forest: Recycling Heroes' is to promote recycling knowledge and practices among Year 6 primary school children. This study was performed to discover the precise learning objectives that were achieved through the game. The general aim of the game is to raise the students' knowledge about recycling concepts and at the same time promote sustainable behaviour. For example:

- Enhancing the student's ability to identify and categorize waste materials.
- Inculcating good eco-friendly behaviour through engaging gameplay.
- Making learning more enjoyable to increase engagement with the learning content.

3.6.2 Designing Stage

According to Chang & Chen (2023) , mobile game education is noted to improve environmental awareness knowledge and practice by 60%. A game environment was created on the Roblox engine with realistic settings like parks, rivers and recycling centres. These are places where players can find themselves and take part in recycling-related activities while learning through play. In this stage, the educational objectives were transformed into a systematic game design. Attention is paid to the creation of an immersive environment, clear game mechanics and an intuitive chatbot system. Figure 3.3 shows the activity involved in designed stage.

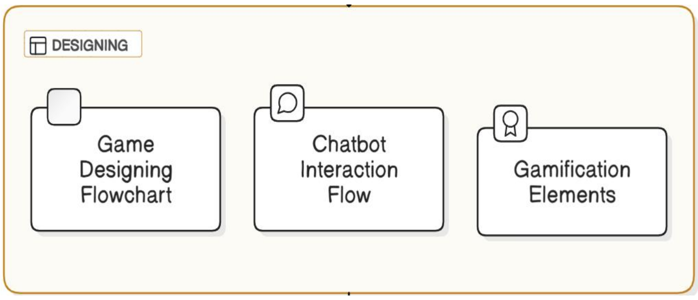

Figure 3.3: Activity in Designed Stage

3.6.2.1 Game Design Flowchart

First, it drew the visual flow of the game development and interaction processes. This flowchart shows in detail every stage that happens for each 4D to bring out the result, showing the integration in detail between environment design, character modelling, and quest development.

The design of the game is based on constructivist learning, in which students are supposed to be more active in constructing knowledge through practical activities. It uses a chatbot, the main guide throughout for the players.

3.6.2.2 Chatbot Integration Architecture

An external AI backend and client-server communication were combined to create a multi-step interaction flow that allowed for a responsive and intelligent chatbot experience within the Roblox environment. An external Flask server hosted on Replit serves as a secure middleware to relay messages between the game and the Gemini API because Roblox does not support direct access to third-party APIs like Google Gemini.

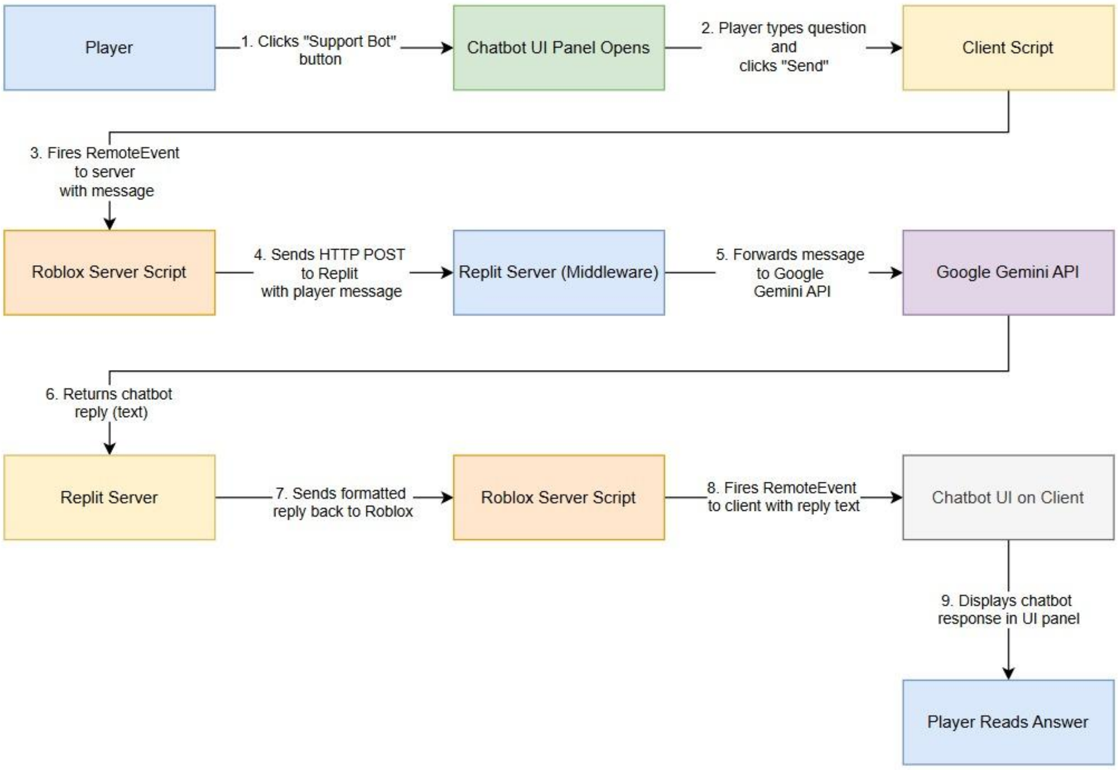

Figure 3.4: Chatbot Interaction Flow

The following is how the entire chatbot communication as in Figure 3.4 process:

1. When the player clicks the game's "Support Bot" button, the interaction starts. By doing this, the chatbot interface panel appears on the screen.

2. After that, the player clicks "Send" after typing a message or query (for example, "Where should I throw this can?").

3. Roblox's client script records this input and transmits the message to the server via a RemoteEvent.

4. The Roblox server creates an HTTP POST request and forwards it to the Replit server, which serves as a middleware API, after receiving the message.

5. After receiving the player's message, the Replit server formats it so that it can be used with the Gemini API. This can entail adding system instructions like "You are a helpful recycling assistant."

6. The server then waits for a response after sending the formatted request to the Gemini API.

7. After processing the input, Gemini produces a pertinent response in natural language, such as offering recycling advice, hints, or error corrections.

8. After receiving the response from Gemini, the Replit server returns it to the Roblox server with any necessary formatting.

9. After receiving the reply content, the Roblox server sends a RemoteEvent back to the client.

10. Lastly, the player's screen's chatbot user interface panel changes to display the chatbot's response, enabling the discussion to go on.

The chatbot can serve as a helpful guide during the game thanks to this interaction flow, providing tailored assistance based on the player's actions. The chatbot offers prompt, helpful answers in a conversational style, regardless of whether the player is stuck on a quest, confused about a recycling task, or interested in environmental issues.

Despite platform constraints, this architecture provides an intelligent, scalable, and user-friendly chatbot solution that improves gameplay and learning outcomes by fusing Roblox scripting with a Replit-based Flask API and the Gemini language model.

3.6.2.3 Gamification Elements

To keep the game interesting, several gamification techniques were used for example, points for correct actions, unlocking new levels and leaderboards that create a healthy competition among players, which motivates them to improve. The game is designed to include structured quests such as the sorting of waste, quizzes, and crafting new items with recyclable items.

3.6.3 Development Stage

The develop phase is the development of the design into a playable prototype of the game. The main elements of this phase included environment design, character modelling and integration of game elements. Figure 3.5 shows the activity involved in development stage.

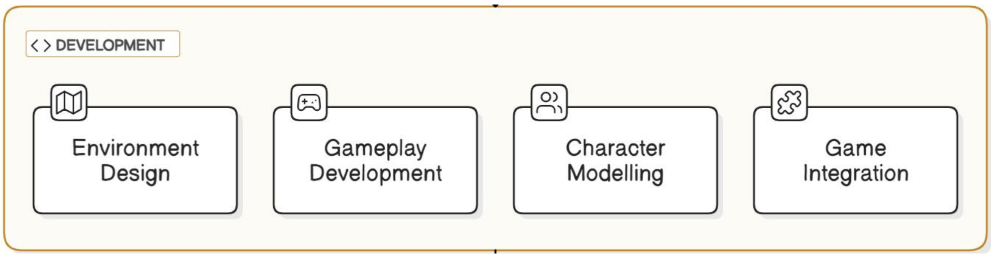

Figure 3.5: Activity in Development Stage

3.6.3.1 Environment Design

The environment in the game were designed to represent real-life situations regarding recycling. For example, a polluted zone contains littered streets and overflowing trash bins that are visually representing the problems of the environment. After one recycles garbage or cleans up areas of pollution the physical environment begins to change into a clean and green area. Visually, such an intervention reinforces the recycling behaviour for positive actions the players can associate their behaviours with tangible changes. Interactive elements were also included in the environment, such as waste bins, piles of garbage, and NPCs with which players can interact to play the game by performing various tasks.

3.6.3.2 Gameplay Development

The game mechanics were scripted to make the game engaging, intuitive and educational for players. A sequence of quests were developed to sequentially teach recycling concepts, such as:

- Sorting waste items into recycling, composting or general waste bins.
- Cleaning polluted parks by identifying waste and removing it correctly.
- Crafting a new useful item with recyclable items.

The players get points by completing tasks. These rewards motivate continuous participation and reinforce learning through rewarding correct actions. The game design ensures that there is no disengagement, as players learn the importance of recycling interactively.

3.6.3.3 Character Modelling

Characters in the game were tailored to enhance relatability and engagement for the target audience. The protagonist was designed with vibrant and eco-friendly attire, embodies the recycling message. This character guides players through the game, inspiring them to take on the role of environmental champions. An interactive game system message provides real-time assistance, hints, and motivational feedback. For instance, during a waste-sorting quest, it guides the player with helpful tips and encouragement. All character models will be developed and customized using Roblox Studio. This ensured consistency with the platform's visual style while allowing for unique designs that resonate with the game's educational goals. By combining functional roles with visually appealing designs, the characters add depth to the gameplay experience.

3.6.3.4 Game Integration

All the essential elements such as mini games, quest systems, chatbot support, scoring, and user data were combined into a seamless and engaging experience during the game integration phase. Native Roblox APIs, which offered crucial tools for controlling gameplay logic, persistent data storage, and real-time interaction across various devices, were used to achieve this.

The DataStore API was used to store and retrieve individual player data, such as quest status, accumulated scores, and earned badges, in order to facilitate player progress tracking. To guarantee gameplay continuity, for example, when a player finishes a quest and logs out, their progress is saved and automatically restored upon their subsequent login. A global leaderboard was also put in place to monitor and show player scores in real time. This feature encourages users to work together and compete with one another, which pushes them to perform better and increases engagement.

When it came to managing player-related tasks like task progression, tool interaction, and avatar movement, the Player API was essential. For instance, the system uses this API to initiate the proper scoring logic and provide immediate feedback when a player gathers an item and successfully disposes of it in the appropriate bin. Similarly, Roblox's integrated character mechanics allow for easy management of tool usage, including picking up or crafting items.

The seamless transitions between quests, mini-games, and other systems were made possible by the effective use of RemoteEvents and BindableEvents to connect all features. This architecture also included the chatbot system, which was integrated using a Replit-based middleware and driven by an external Gemini API. It improves learning without interfering with gameplay by giving players context-aware feedback and real-time in-game help.

A strong, user-friendly environment that not only facilitates game-based learning but also improves retention through feedback, progression, and interaction was provided by the seamless integration of all modules. The product is an educational game that strikes a balance between entertaining gameplay and significant environmental awareness.

3.6.4 Disseminate Stage

The disseminate stage involves assessing the educational impact and usability of the game by piloting with 10 students from SK Sri Suria 2 aged 7-13 years. These sessions are meant to show if the gamified design can enhance student learning and engagement through the course of the game.

Students were first introduced to the game and guided on the features and quests within the game. The chatbot were used as a companion for them while providing real-time instructions and feedback while playing. For example, the chatbot guided them on how to categorize waste into appropriate categories, emphasized the need for cleaning areas with pollution and encouraged the players to complete the tasks in a timely manner. This interaction ensured that students could navigate the game independently without additional external assistance.

To evaluate the game, a combination of quantitative and qualitative methods will also be employed. The feedback will be collected using questionnaires which consists of Likert-scale questions and open-ended questions. According to students, the chatbot helped them go through tasks and gave timely hints and motivational messages. Based on the feedback, the game was fine-tuned in such a way that the chatbot will remain central to the design, providing optimum guidance throughout the learning journey.

3.6.5 Alignment with Curriculum Learning Outcomes

The game "Recycling Heroes" were developed to suit closely the "Waste Management" unit in the Year 6 Science curriculum, attached as Appendix B. In this manner, the learning will become meaningful in gamified ways. Accordingly, quests and the mechanics of games were created in such a way that their aims meet the requirements of learning standards and performance level indices presented within the curriculum framework. This aligns to ensure that students enjoy the game while reinforcing their understanding of waste management concepts in a practical and interactive way.

This module supports the curriculum directly by being able to identify and categorize wastes and apply appropriate disposal methods. The ability to observe what results from each were combined in the environment of the game for the students to motivate themselves, explore, and practice these leading principles concerning waste management.

Table 3.1 shows how the following lessons connect the aims of the "Recycling Heroes" game to the learning criteria outlined in the curriculum.

Table 3.1: Alignment Between Recycling Heroes and Year 6 Science Learning Standards

Learning Standard	**Game Element in Recycling Heroes**
9.1.1 Identify waste materials based on the types of materials	The players identify different types of wastes, such as paper, plastic, and food waste, in the surroundings and continue the game accordingly.
9.1.2 State the meaning of biodegradable and	Tutorials and NPC dialogue explain the

non-biodegradable materials	differences between biodegradable and non-biodegradable materials.
9.1.3 Classify the waste materials into biodegradable and non-biodegradable materials	The players sort correctly to differentiate the biodegradable items from non-biodegradable items for points.
9.1.4 Provide reasoning on the usage of biodegradable and non-biodegradable waste materials wisely	The players are then engaged in reasoning-based challenges, like deciding ways of disposing of waste in various circumstances.
9.1.5 Describe proper ways of waste management for sustainable life	The players have to craft a new useful item using recyclable items that they find around the polluted area.
9.1.6 Explain the observations of waste management through written or verbal forms, sketches or ICT in a creative way	In this final reflection task, players will summarize their actions in the game through a creative in-game journal.

Integration such as this makes this game effective for educational and entertainment purposes. Since Recycling Heroes tackles each learning standard through interaction and gamification, students will gain more knowledge of waste management while still being entertained. In the practical ability to apply knowledge within the game in a simulated real-world setting, students reinforce their critical thinking and decision-making abilities. Rewards and progression systems also raise the motivation of students to be more active in participating and internalizing waste management in a more enjoyable and memorable way.

3.7 Requirement Analysis

The success of the project relies on clearly defined requirements. These include hardware and software specifications, as well as functional and non-functional requirements.

3.7.1 Hardware Requirements

The hardware required for development and gameplay is listed in Table 3.2 for the developer and Table 3.3 for the user:

Table 3.2: Hardware Requirements for the Developer

Hardware	Requirements
Laptop	Required to develop the game using Roblox Studio. List of specifications are as below: i. Intel Core i5 ii. 8GB RAM iii. 256GB SSD
Smartphone	Used to test the game's performance on various devices

Table 3.3: Hardware Requirements for the User

Component	Minimum Specification	Description
Device	Any device capable of running Roblox	To ensure users can play the game without hardware limitations
Internet Connection	Stable Wi-Fi or data	Necessary for downloading and playing the game

3.7.2 Software Requirements

The software required for development and gameplay is listed in Table 3.4:

Table 3.4: Software Requirements

Software	Description
Roblox Studio	Development tool used to create the game and spirit interactions using Lua

3.7.3 API Integration

Recycling Heroes was created by combining a third-party AI service with Roblox Studio's built-in APIs to guarantee smooth operation and a fun gaming experience. These APIs are crucial for managing several game-related tasks, such as data storage, real-time communication, and customized player assistance.

The DataStore API, which consistently protects and provides access to all player-specific data, including progress, achievements, and scores, is one of the most widely used APIs. This guarantees that even after logging out, players can pick up where they left off in the game. A responsive and organic gameplay experience is facilitated by the Player API, which is essential for controlling player interactions and offering fluid movement, tool usage, and scoring mechanics. Additionally, player actions like jumping, navigating, and interacting with in-game elements are registered using the User Input API.

The in-game chatbot was powered by an external integration in addition to Roblox's native APIs. The system uses a Replit-hosted middleware server to connect to the Gemini AI API. Players send an HTTP request to the Replit server, which forwards it to the Gemini API, when they type a question into the chatbot panel. A pertinent response produced by the AI is sent back to the game and shown in the user interface. This integration enhances the learning process and gives players access to real-time, context-aware support.

When combined, these APIs give the game a strong technical base. A layer of intelligent support that increases player engagement and interactivity is added by the Gemini-powered chatbot, while the native Roblox APIs guarantee safe data management and seamless gameplay. Together, these systems provide a comprehensive educational experience that is suited for young students.

3.8 AI Chatbot Assistance for Personalized Feedback

This project uses an AI-powered chatbot to provide players with individualized support and direction rather than a conventional rule-based decision tree. A middleware server hosted on Replit is used to integrate the chatbot system with a cloud-based Gemini API. As a result, during gameplay, the game can provide real-time educational support, hints, and corrective feedback by dynamically responding to player inputs in natural language.

Throughout the player's journey, the AI chatbot acts as a learning companion. Students can communicate with the chatbot through an integrated support panel when they run into problems, like sorting errors, unclear quest instructions, or unfamiliar terms. Player inquiries are recorded by the system and sent to the Gemini API, which provides situation-specific, context-aware answers.

For several reasons, this strategy was selected over a rule-based one:

- Flexibility: Without the need for hard-coded rules, the AI can process a variety of player inputs.
- Scalability: A decision tree doesn't need to be manually updated to accommodate new queries and use cases.
- Realism: Young users benefit from a more engaging, human-like support experience thanks to the natural language responses.

With artificial intelligence, the chatbot enhances the game's educational value without complicating the local codebase by supporting differentiated learning in a lightweight and scalable way. This design decision supports the project's objective of developing an educational resource for primary school students that is responsive and easy to use.

3.9 Functional Requirements

The functional requirements specify the features of the gamified learning application:

1. The game should provide interactive quests related to the Recycling topic.
2. The chatbot must assist players by offering guidance on their tasks.
3. Players should be able to complete quest assessments within the game.

3.10 Non-functional Requirements

The non-functional requirements ensure that the performance and usability of the game:

1. The game must run smoothly on devices that meet the minimum specifications.
2. Data must be stored securely and comply with the privacy requirements.
3. The user interface should be intuitive and accessible to students.

3.11 Game Design and Interface

3.11.1 Database Architecture Diagram

The database design for Recycling Heroes is designed to manage data effectively, scale easily and provide players with a seamless experience. It utilizes Roblox's built-in systems, such as DataStoreService, in storing data safely and following security rules. The diagram in Figure 3.6 shows how the parts work together.

3.11.1.1 Game Clients (Frontend)

Players will use a device such as a PC, mobile phone or console to interact with the game. These are the frontend, and they interact with the game servers to send and receive data using Roblox APIs. This allows for real-time updates and smooth gameplay.

3.11.1.2 Game Servers (Backend)

The in-game logic and player interactions are handled by the backend infrastructure, which will be hosted on Roblox's servers. Game servers link directly to the Roblox DataStoreService to get and save player data like scores, achievements and progress.

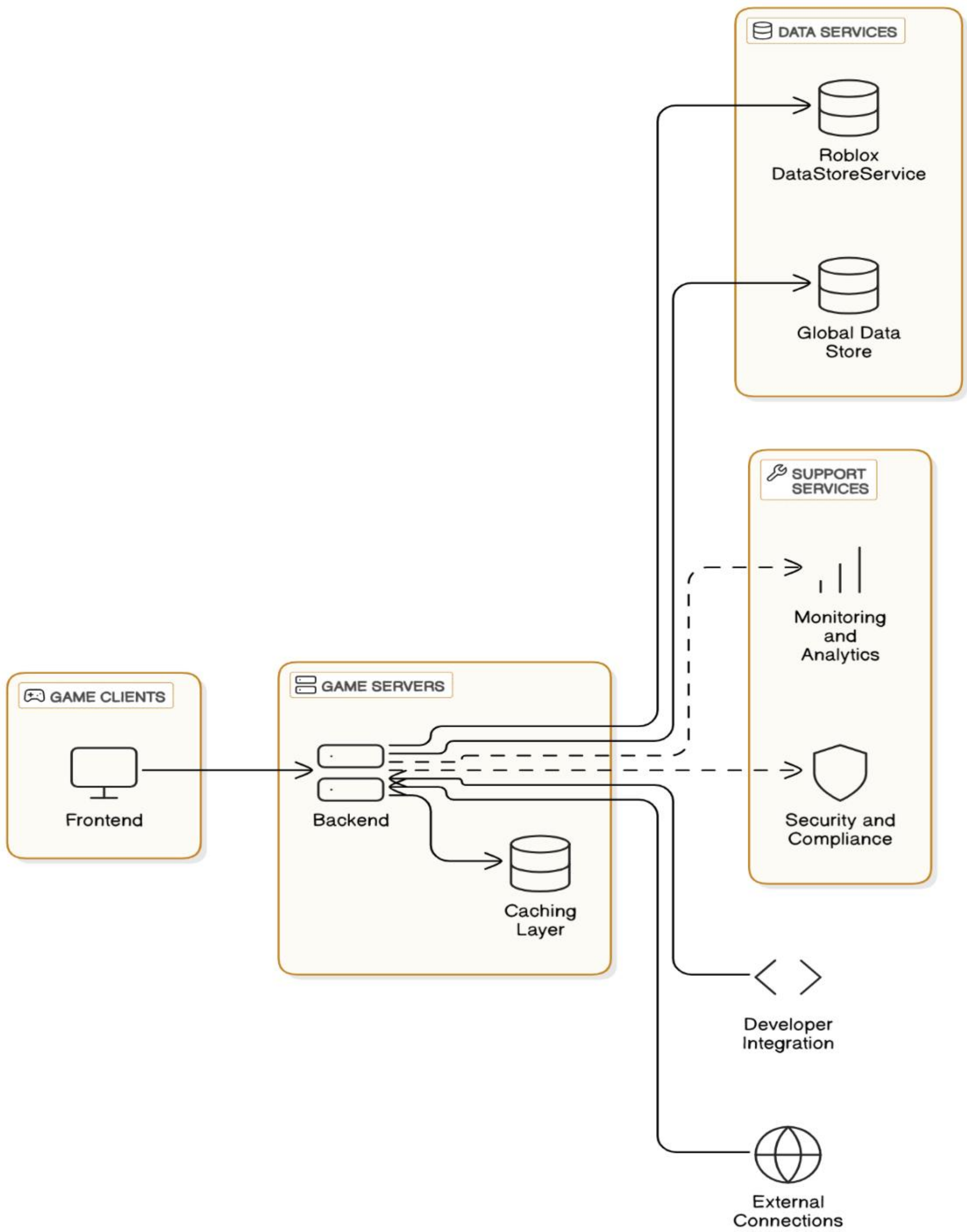

Figure 3.6: Database Architecture Diagram

3.11.1.3 Roblox DataStoreService

The DataStoreService is the main interface through which developers can manage persistent data. It provides secure and scalable data storage by using a sharded architecture to efficiently spread data across several nodes.

3.11.1.4 Global Data Store (GDS)

On the back end, it will save within Roblox's proprietary distributed database system to provide fault tolerance, redundancy and high availability.

3.11.1.5 Caching Layer

There is a caching layer in memory to minimize delays for typical read and write operations which improves performance during gameplay.

3.11.1.6 Monitoring and Analytics

The internal systems of Roblox collect data for debugging, logs and analytics. These insights help improve the game by providing developers with detailed usage reports.

3.11.1.7 Developer Integration

Developers access the database through Lua scripts and Roblox APIs. *rSQL* and similar tools will allow developers to perform structured queries on the data efficiently.

3.11.1.8 Security and Compliance

Roblox makes sure that all player information is kept safe and sent securely. The platform follows global data protection laws like GDPR and COPPA to stay legal and keep player trust.

3.11.1.9 External Connections

Even though the game only uses Roblox APIs for this project, the setup allows for optional connections with outside services like leaderboards or money-making platforms through webhooks or external APIs.

3.11.2 Loading Page

The loading screen in Recycling Heroes acts as an intermediate interface for improving the user experience during the initialization phase of the game. Made with a simple and minimalist approach, this page informs players that the game is in the process of starting up. This will reduce any irritation linked to delays. Its presence assures a flawless shift from the launching of the game to the main gameplay setting, preserving player interest right from the beginning. Figure 3.7 shows the loading page for this gamification.

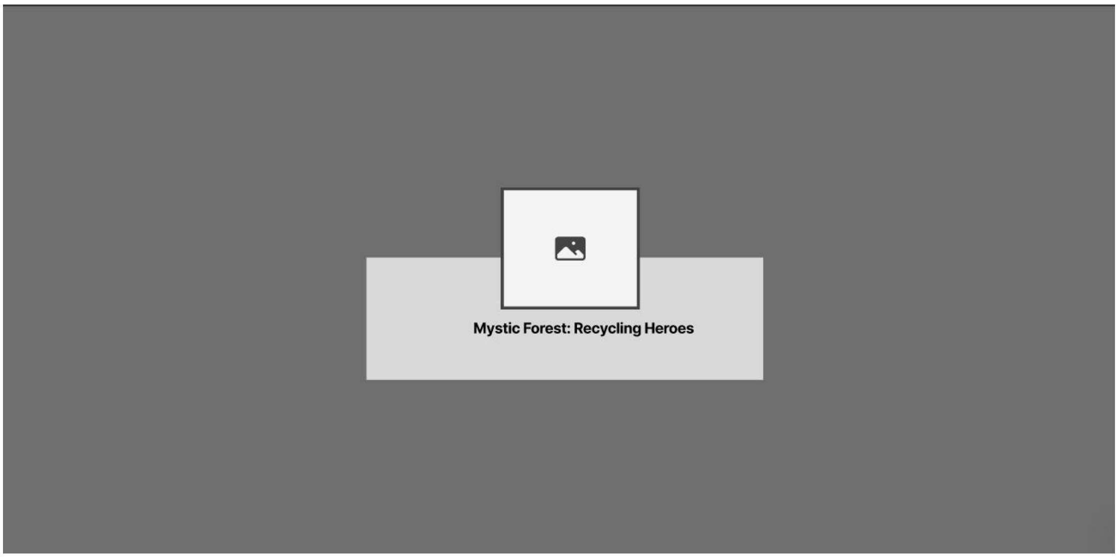

Figure 3.7: Load page

This feature is especially useful in cases where the loading of assets in Roblox Studio could take a long time as gives visual feedback rather than showing users an empty or frozen screen. Adding this page makes the game feel much more polished and professional.

3.11.3 Main Page

A time display is located at the middle top of the screen and keeps track of the time spent playing helps the player to manage his or her speed and accomplish all tasks on time.

This develops time management skills while retaining an element of challenge. The top right quadrant of the display player's score. These elements emphasize the social implications of recycling while encouraging engagement and recognizing progress. Figure 3.8 shows the main game interface of Recycling Heroes which is designed with great care to offer clear, engaging and user-friendly layout fit for young players.

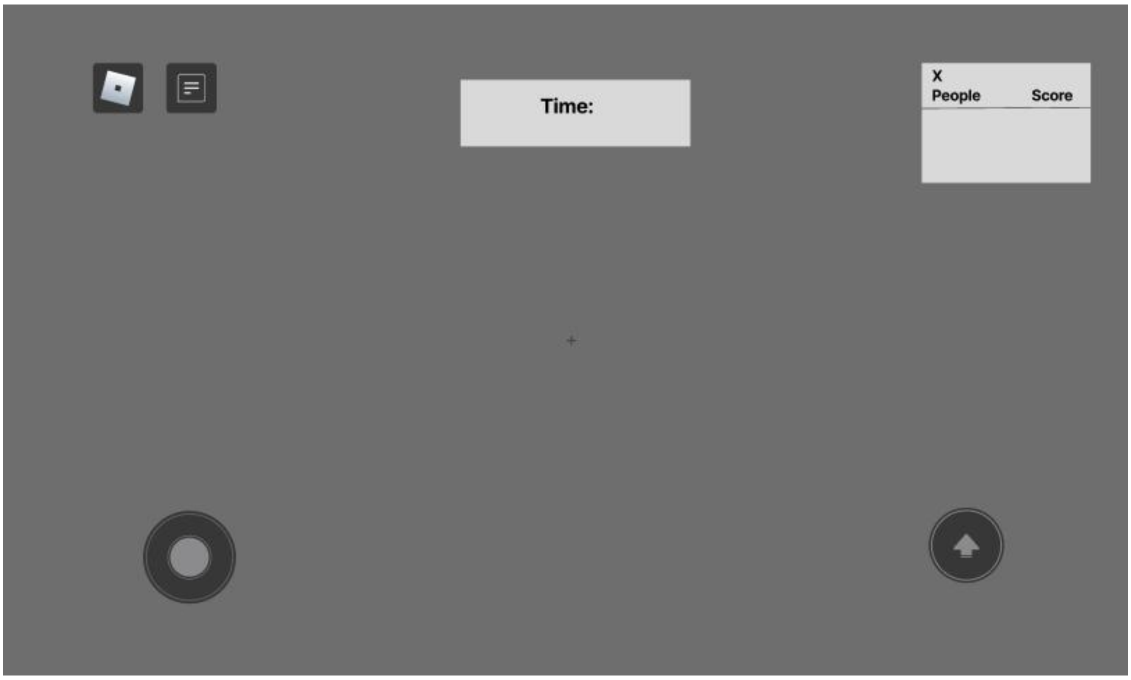

Figure 3.8: Main page

On the bottom of the screen, there are the directional controls including a joystick on the bottom-left corner which makes it very intuitive to navigate and a jump or action button on the bottom-right represented by an upward arrow. All the controls have been designed with usability in mind, especially for mobile devices to really encourage interaction and a fun experience in playing games. Its minimalist design means it focuses on clarity so players can focus on their goals without distractions. Sometimes, players coming from the loading page to the main interface benefit from its simple and intuitive design that blends in perfectly with the dynamic environment of the game.

3.11.4 Menu Page

The menu page in Figure 3.9 is the core navigation center of an application where the user will engage with every other feature an application can provide.

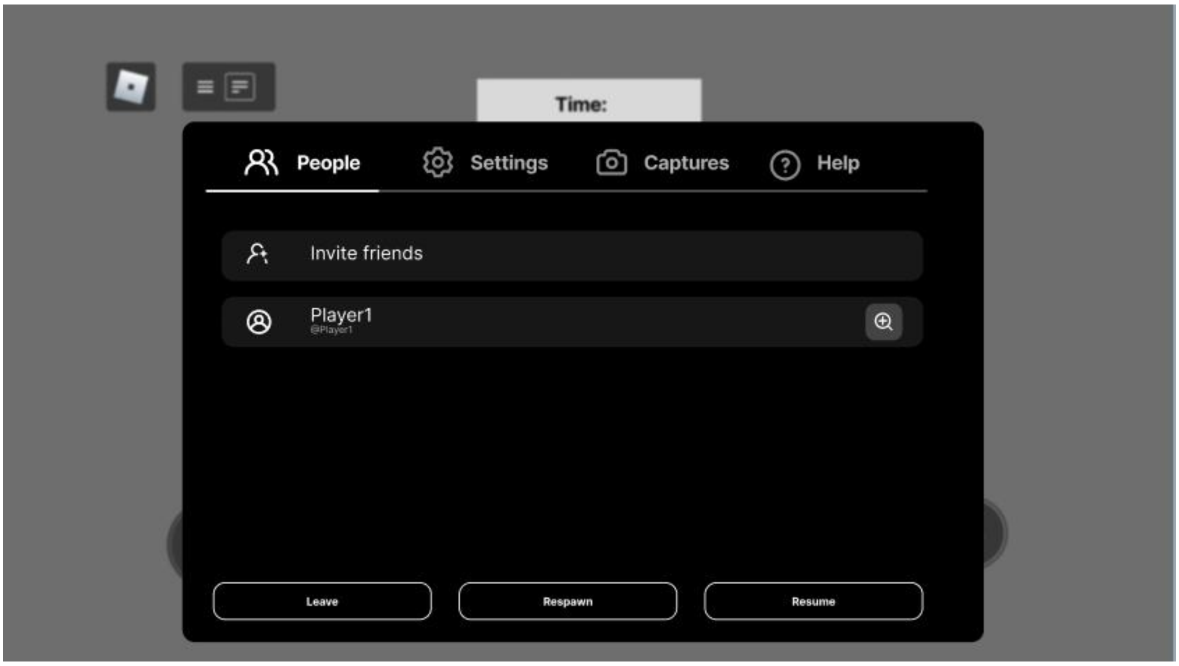

Figure 3.9: Menu page

Some of the buttons include in this page are "Respawn", "Setting", "Help" and "Capture". Player also can invite their friends to play together, making the learning process more enjoyable. A good design of a menu promotes intuitive execution of the desired action on behalf of the user.

3.11.5 Settings Page

The settings page is for personalization such as audio controls, camera mode, graphics mode and much more. The layout should be simple with toggles or sliders to enable easy navigation and access. Different personalization options would therefore cater to different needs which helps improving user satisfaction and engagement. Figure 3.10 shows the wireframe for the settings page.

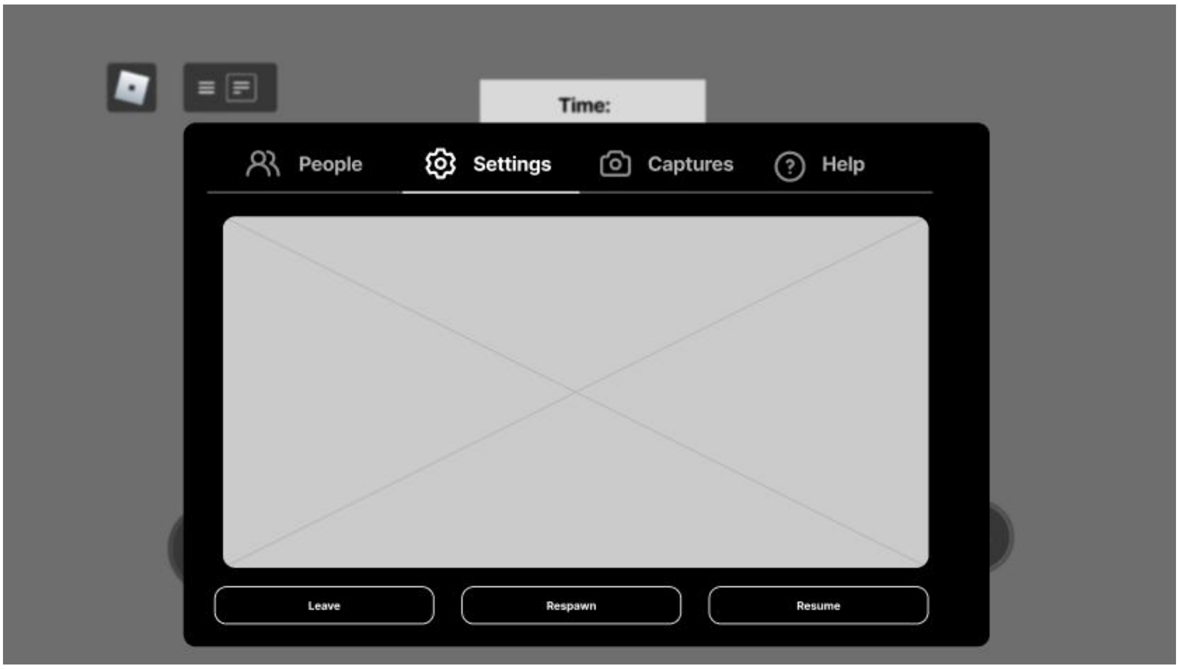

Figure 3.10: Settings page

This page reflects the flexibility and inclusiveness of this game in giving users the chance to optimize their interaction. The settings page will always be accessible, smoothly refining preferences and improving overall usability.

3.11.6 Quest Page

A Quest Page is the main activity hub of this game that showcases tasks or challenges in action-packed glory. It includes clear instructions, elements of interaction and a progress bar to show completion. This format is user-friendly for maintaining focus and engagement, laced with gamified factors like points or badges for motivations. Figure 3.11 shows the quest page for the Recycling Heroes.

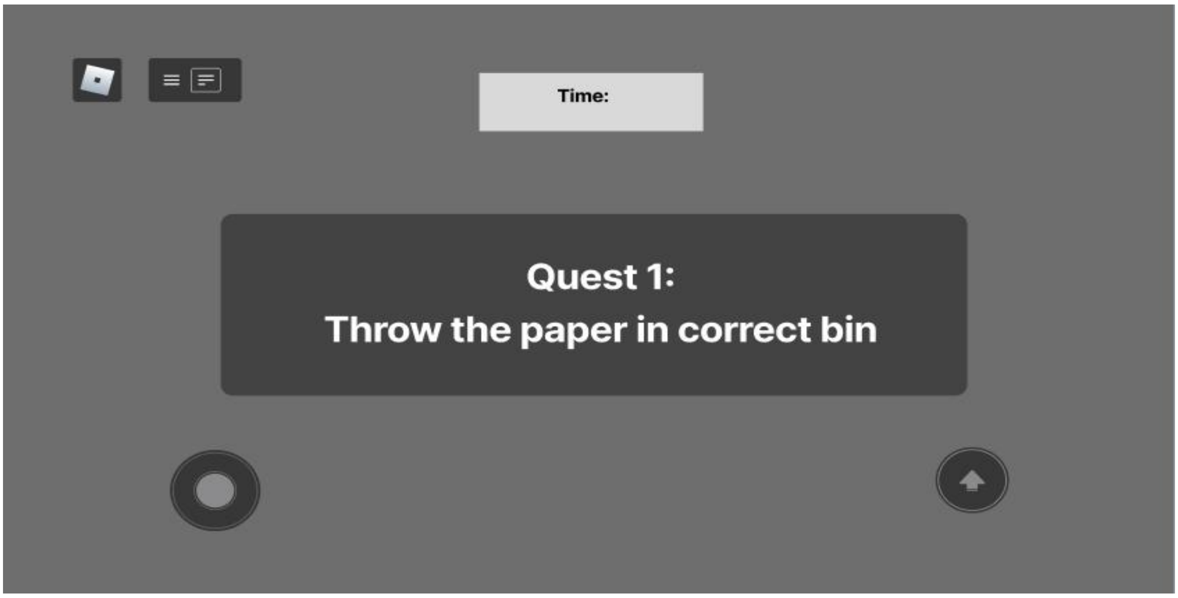

Figure 3.11: Quest page

This page constitutes the central point of the app's value by encouraging active participation and learning. Its design easily allows for different types of content and caters to diverse user needs.

3.11.7 Correct/Incorrect Pages

Correct page will act as positive feedback with visual effects such as confetti or stars with encouraging texts. This strengthens the achievements and encourages further work. On this page, points received, or rewards unlocked are shown thus a feeling of achievement could be attained. This will also act as a motivation for players to do better in the next quests. Figure 3.12 shows the correct page for Recycling Heroes that will act as motivation for players to do better.

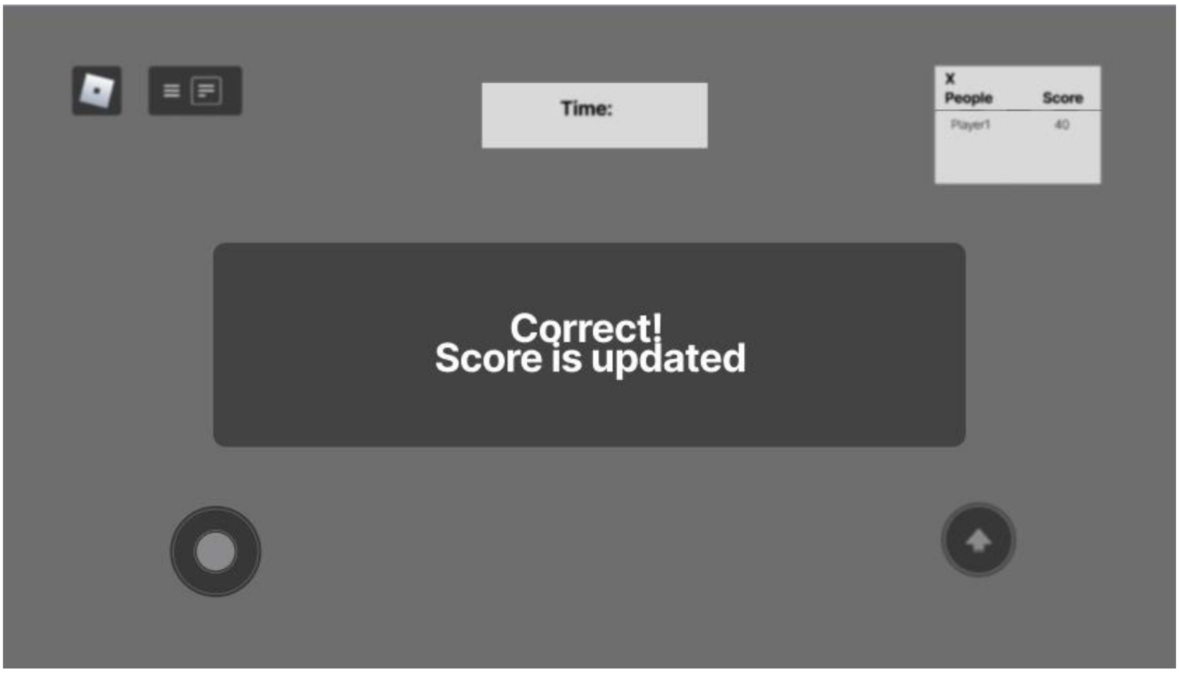

Figure 3.12: Correct page

The incorrect or error page in Figure 3.13 constructively presents feedback that

Figure 3.13: Incorrect page

would help users learn further from their mistakes.

It includes the opportunity for hints or retries to enable learning without frustration. It will be supportive yet encourage problem-solving and iterative improvement. Through instructions and tips reassure users-create a safe and engaging place for learning. This page flips the errors into opportunities for improvement enhancing user journeys while sustaining motivation toward further participation.

3.11.8 Leaderboard Page

Figure 3.14 shows the leaderboard page which creates some competition and engagement by showing user rankings and achievements on the leaderboard.

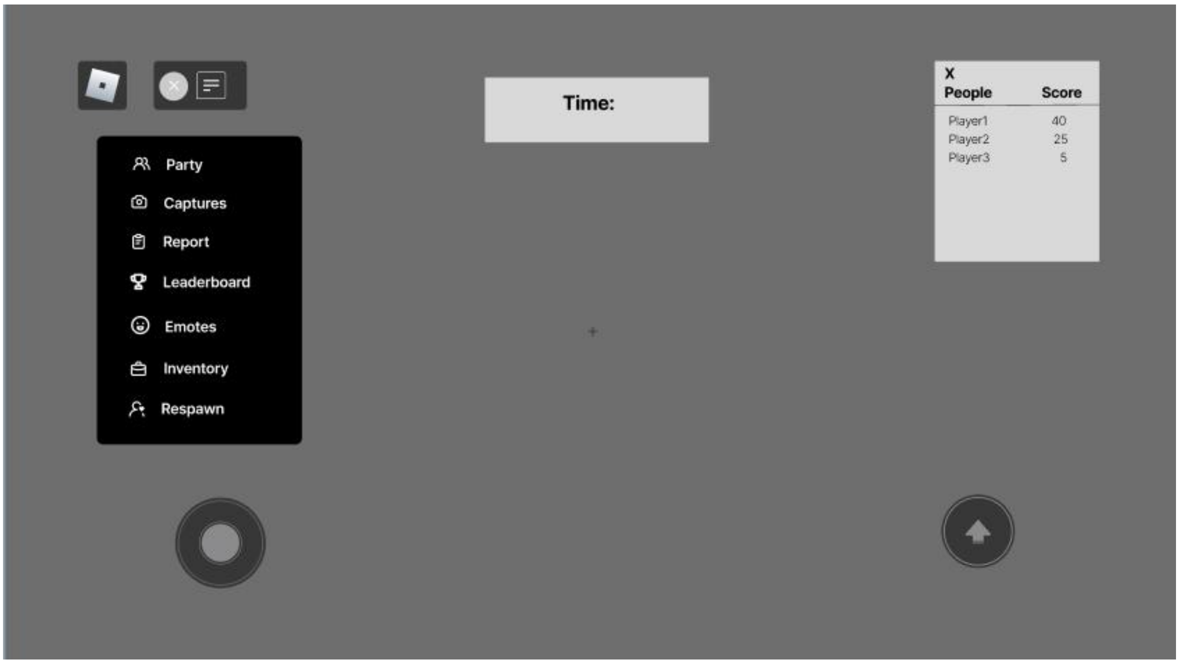

Figure 3.14: Leaderboard page

The top performer in each category is highlighted in the well-structured layout, including options to view personal standing. Incentivizes users to achieve better scores, making it engage and rewarding. This page fosters healthy competition along with accomplishments that help in user retention.

3.11.9 Time’s up Page

The time’s up page in Figure 3.15 deals with inactivity by asking users to either resume or exit a session.

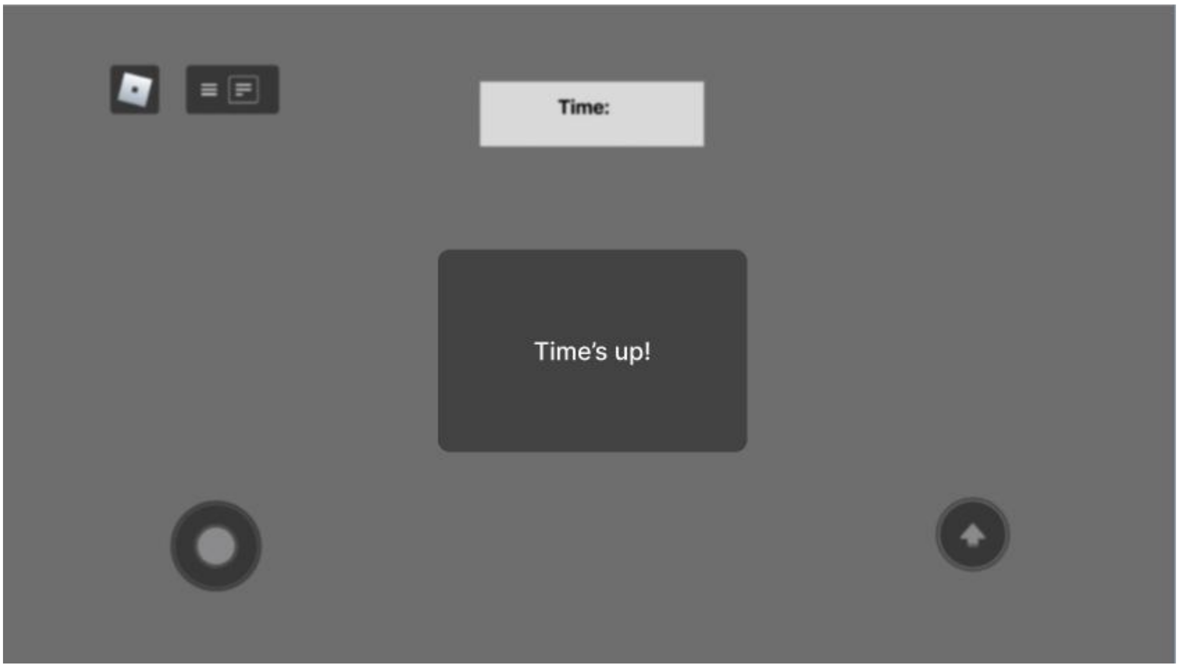

Figure 3.15: Time’s up page

It avoids data loss or disruptions while encouraging users to re-engage. The page shall provide clear options and may include motivational messages or a countdown timer to nudge users back into activity. It is designed as a proactive safeguard to balance session continuity with user convenience. It ensures a frictionless experience by thoughtfully managing idle sessions, minimizing potential frustrations.

3.11.10 Leave Page

The leave page in Figure 3.16 confirms that users intend to exit the application, thereby reducing accidental disruptions. It provides explicit options, such as "Leave" or "Don’t' Leave" which protect the progress of users while providing a smooth user experience.

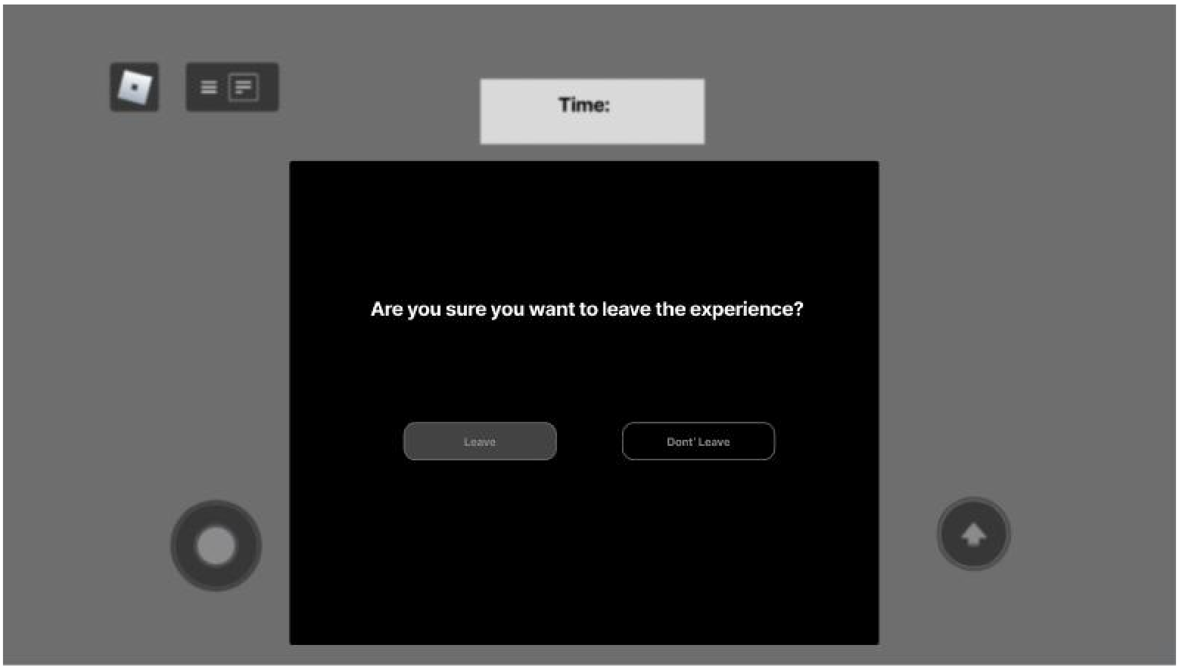

Figure 3.16: Leave page

A simple, intuitive design limits confusion and promotes deliberate decision-making. Placed at critical exit points, it acts as an important failsafe against unintentional actions yet maintains user agency. This page can also be used to include a polite message to enhance the overall experience.

3.12 Testing and Evaluation

The testing phase will involves evaluating the game for functionality, usability and learning effectiveness. The following methods will be used:

3.12.1 Functional Testing

This is the functionality testing stage to ensure that all the different parts of the game worked from high scores to reset. The heavy testing will be needed in knowing with great confidence that the chatbot can really offer players guidance properly within a given time for action when playing the games. The sensitivity of the rule-based decision tree which is the basis for the adaptive feedback system will also be tested regarding different player performance metrics such as task completion time and scores. Any issues identified, like incorrect feedback or delayed responses will be fixed during this phase to ensure a seamless user experience. The functional testing focused on the validation of those critical components that will ensure the game can effectively deliver its educational objectives without technical disruption.

3.12.2 User Testing

User testing will be conducted with Year 6 students to understand the level of engagement and learning outcomes achieved through gameplay. Structured gameplay sessions will be observed to gather insights into how students interacted with the game's features which includes the chatbot and adaptive feedback system. Qualitative data will be obtained through feedback surveys, regarding the perceptions of the students about the usability and interactivity of the game and the learning experience in its entirety. These observations and surveys provide an overview of how well the game fit the needs and expectations of students. Some adjustments will be done based on the feedback received to improve user satisfaction and make the game engaging yet educationally effective. Figure 3.17 shows the user testing process for Recycling Heroes

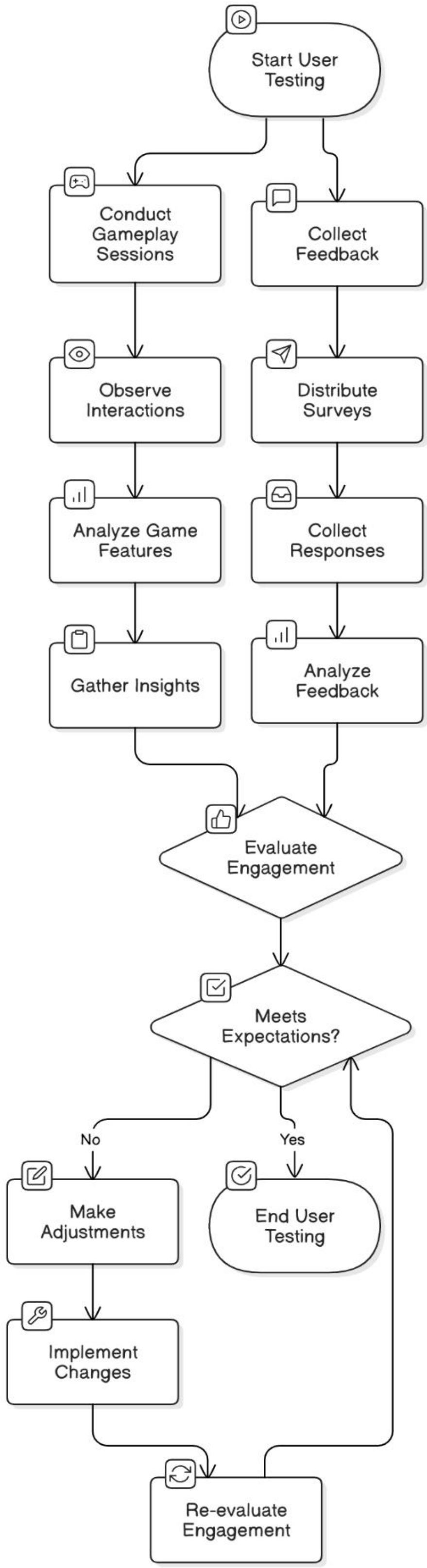

Figure 3.17: User Testing Process

3.12.3 Data Analysis

Data analysis will focus more on assessing the game for the improvement it could bring in the understanding of the concepts of recycling among students. Post test assessments will be done to quantitatively assess learning gains. Statistical tests on the results of the tests will be made to identify significant gains in knowledge or areas where further improvement was needed. Qualitative insights will be derived, along with quantitative data, from feedback surveys regarding the experiences of the students and their suggestions about the game. This dual approach in the analysis of data provided a wide scope in the impact of the game and informed subsequent refinements in optimizing both its educational and interactive elements.

3.12.4 System Usability Scale (SUS)

The System Usability Scale, commonly known as SUS, will be used in evaluating the usability of Recycling Heroes. The SUS is a widely recognized tool in the evaluation of the usability of systems, especially interactive applications like educational games (Blattgerste et al., 2022) . It is a simple, 10-item questionnaire that captures participants' perceptions of the system's usability.

The SUS was applied to all subjects after they were exposed to the game. Respondents answered different statements on a 5-point Likert response scale ranging from "Strongly Disagree" (1) to "Strongly Agree" (5). For this, the statements were also positively and negatively worded for reliable and unbiased responses. Refer to Appendix C for SUS items.

3.12.4.1 Scoring

Responses will be scored to generate a single usability score for each participant. Scores will be interpreted using standard benchmarks, which identified usability levels, such as Excellent, Good, and Acceptable. The SUS provided a concise and efficient way to evaluate the ease of use of the game and thus helped identify areas where usability could be improved.

3.12.5 User Experience Questionnaire (UEQ)

The UEQ has been run in parallel to the SUS with respect to the measurement of more general user experiences regarding the game. While the SUS is a focus for functional usability, the UEQ measures emotional and experiential dimensions, thus giving more nuance to the understanding of how users engaged with the game (Schankin et al., 2022). The UEQ consists of 26 items rated on a 7-point semantic differential scale. Each item is used to estimate specific dimensions of user experience:

- Attractiveness: How appealing and enjoyable the game is to the users
- Efficiency: The perceived speed and smoothness of task completion.
- Dependability: The reliability and predictability of the game's functionality.
- Simulation: The level of excitement and engagement experienced by the users.
- Novelty: The creativity and originality of the game design.

Participants will have to complete the UEQ immediately after gameplay. Their responses will be used to create scores for each dimension, thus pointing out strengths and weaknesses of the game. For example, a high score on Stimulation indicates that the game was found enjoyable and stimulating by players and a moderate score on Dependability indicates areas that might need development regarding the game's reliability or consistency. Studies by Juric et al., (2024) confirms the UEQ's reliability and validity, making it a robust tool for understanding user experiences in various contexts, including virtual reality and online learning environments. Refer to Appendix D for UEQ items.

3.12.6 Educational Effectiveness Questionnaire (EEQ)

The Educational Effectiveness Questionnaire (EEQ) is created by adapting a questionnaire from (Wang et al., 2024) study to examine the perceived success of Recycling Heroes as a gamified learning resource. The EEQ consists of five elements intended to assess engagement, motivation, appeal, enjoyment, and readiness to continue using gamification. The questions were scored on a scale of 0 to 3, with 0 being the lowest rating and 3 being the highest.

3.12.6.1 Key Areas Assessed

The EEQ will consists of a short, 5-item questionnaire rated on a 5-point Likert scale, ranging from 1 = Strongly Disagree to 5 = Strongly Agree. Items address the following aspects:

- How effective do you perceive Recycling Heroes in enhancing your engagement with the topic of waste management?

- After using Recycling Heroes, how do you perceive its impact on improving your motivation to learn about waste management?

- In your opinion, how do the incorporated game elements enhance the appeal of waste management education?

- Did you find learning about waste management to be more enjoyable and stimulating while playing Recycling Heroes?
- Are you willing to use Recycling Heroes in the future to further explore waste management concepts?

Participants will be completed the EEQ after gameplay, along with SUS and UEQ. Responses will be analyzed to understand the strengths of the game in promoting learning and areas needing improvement in delivering educational content. Refer to Appendix E for EEQ items.

3.12.7 Combined Insights from SUS, UEQ and EEQ

Combining the results from the SUS, UEQ, and EEQ will provide a comprehensive evaluation of Recycling Heroes. SUS will assess the usability of the game focusing on ease of use and clarity. Meanwhile, the UEQ is going to denote the emotion and experience due to gameplay by engaging in more creativity. From there, EEQ will assess the game's learning outcome and relevance to curriculum goals, along with promoting real-world application of the concepts learned. By integrating these three tools, the study made sure that the effectiveness, usability, and overall experience of the gamified tool were robustly and multidimensionally assessed.

3.12.8 Qualitative Feedback Collection

To gather students' subjective experiences and reflections, open-ended questions were included in the post-task questionnaire along with structured survey tools (SUS, UEQ, and EEQ). Deeper understanding of students' perceptions, learning difficulties, and general involvement with the Recycling Heroes game was the goal of these qualitative responses.

Among the examples of open-ended questions were:

"What was your favorite aspect of the game?"

“Did the game teach you anything that improved your understanding of recycling? Could you please elaborate?”

"What aspect of the game was unclear or unhelpful to you?"

"How would you sum up your overall gaming experience?"

Thematic analysis was used to examine student responses. Key findings pertaining to learning outcomes, usability, and engagement were derived from the identification, coding, and classification of recurring themes.

3.13 Methodological Limitations

It is important to recognize the various limitations of this study. First, only 10 students from one school (SK Sri Suria 2) make up the sample size, which restricts how broadly the results can be applied. Furthermore, because of its brief duration, the study only examines short-term shifts in behaviour and knowledge; it does not evaluate long-term impact or retention. The study cannot conclusively separate the impact of the gamified learning intervention from other outside factors because there is no control group to compare. Instructor observations and self-reported surveys may also be biased because students may give answers that are more socially acceptable than ones that accurately reflect their experiences. Finally, despite the fact that Recycling Heroes provides an interesting learning environment, technical limitations may limit the breadth and complexity of the instructional materials and interactions when using the Roblox platform.

3.14 Ethical Considerations

Ethical approval will be obtained from relevant authorities. Participation is entirely voluntary, with informed consent from parents or guardians. Data privacy is guaranteed by anonymizing the students' identities and following appropriate practices for storing data. The gamified tool will be designed in such a way that no sensitive information could be collected by it, ensuring that ethical standards in educational research were met.

3.15 Chapter Summary

This chapter detailed the methodology and design process for the project. By following the 4D model and specifying clear requirements, the development ensures a robust and user-friendly game that meets the objectives of fostering waste management awareness among students. The system design and prototypes provide a strong foundation for implementation and evaluation.

CHAPTER 4

IMPLEMENTATION

4.1 Overview

This chapter presents the implementation details of the educational recycling game developed using Roblox Studio. The game aims to teach young players about proper recycling habits through interactive gameplay. The key components implemented in this project include the “Sort It Out!” mini-game, a quest system led by an NPC character, and a child-friendly quiz system that reinforces recycling knowledge through simple, engaging questions.

4.2 Tool and Technologies

The development of the recycling education game was carried out using tools and technologies available within the Roblox ecosystem. Table 4.1 summarizes the primary tools used and their respective roles in the implementation:

Table 4.1: Summary of Tools and Roles

Tool	Description
Roblox Studio	The main development platform used to design 3D environments, UI, and gameplay.
Lua Scripting	The scripting language used in Roblox for implementing game logic and behaviours.
Explorer & Properties	Tools within Roblox Studio used to structure game objects and adjust settings.

4.3 Game Structure Overview

The recycling game is structured into three main interactive components, each designed to support the learning objectives of teaching children about proper recycling habits:

4.3.1 "Sort It Out!" Mini Game

This is the core activity of the game where players must correctly sort trash items into their respective bins. The items fall from above or appear on a conveyor belt, and players must act quickly to place them in the correct bin: Plastic, Paper, Glass, Organic, or E-waste. Each correct action increases the score, while incorrect sorting results in a penalty. The game is timed, and players are rewarded based on performance. Figure 4.1 below shows

Figure 4.1: Recycling Bin

the recycling bin in game.

4.3.1.1 Gameplay Mechanics

Players must drag or direct items like plastic bottles, food, cans, and papers into one of the four bins:

- Plastic Bin
- Paper Bin

- Can Bin
- Bio-Waste Bin

Each item contains a hidden attribute (TrashType) which is used to determine whether the player sorted it correctly. The bins are color-coded and labeled with images to assist players in identifying them easily. Feedback is provided immediately through sound effects and score changes. Figure 4.1 shows the visual design of the trash bins used in the game.

4.3.1.2 Trash Item Design

To support the gameplay experience and enhance player understanding, a variety of trash items were visually designed and included in the game. These items represent common waste categories such as plastic bottles, newspapers, banana peels, soda cans, broken glass, and used batteries. Each item was modeled or selected from Roblox's asset library to ensure they are child-friendly, simple to recognize, and visually distinct from one another.

The items are also embedded with a TrashType property, which determines their correct bin classification. This invisible attribute is used during gameplay logic, while the item's appearance helps guide the player visually. These visuals are critical for helping younger players associate in-game objects with real-world waste. These visual assets serve both an aesthetic and functional purpose, enabling players to quickly identify and interact with trash in a way that promotes learning and fast-paced decision-making during the game. Figure 4.2 displays several of the trash items that players can pick up and sort in the "Sort

It Out!” mini game.

Figure 4.2: Trash in Playground

4.3.1.3 Technical Implementation

The mini-game was implemented using a combination of server-side and client-side Lua scripts in Roblox Studio. A dedicated trash spawner script was used to generate random trash items at set time intervals. Each item is assigned a TrashType property, such as “Plastic,” “Paper,” or “Can,” which identifies the correct bin it belongs to. These items fall into the play area where the player must sort them correctly.

Each recycling bin in the game is scripted to detect contact using Roblox’s Touched event. When a trash item touches a bin, the game checks whether the item’s TrashType matches the name or identifier of the bin. If the sorting is correct, the player is rewarded with 10 points, and a positive sound effect plays to reinforce the behavior.

4.3.1.4 Educational Purpose

The educational objective of the “Sort It Out!” mini game is to teach children the importance of recycling in an engaging and interactive way. Through repeated gameplay, players begin to recognize different types of waste and associate them with the appropriate recycling categories. This hands-on approach helps reinforce real-life recycling habits by visually and physically demonstrating the process of sorting waste.

By integrating gameplay with immediate feedback, the mini game ensures that players learn from both correct and incorrect actions. The use of color-coded bins, familiar trash items, and positive reinforcement through sound and visuals helps create an enjoyable learning experience for young players. Ultimately, the mini game is designed to raise environmental awareness and build positive recycling habits in a format that is fun, accessible, and easy to understand for children.

4.3.2 Quiz System

4.3.2.1 Quiz Content Design

The quiz consists of ten carefully designed questions targeting young children, typically between the ages of 7 and 12. Each quiz entry contains:

- A short, clear question
- Three answer options
- The correct answer
- A reason or explanation, presented after the player selects an option

These explanations are crucial to reinforce learning, especially if the player answers incorrectly. The questions avoid complex terminology and focus on real-world, relatable items such as bottles, cans, and food waste.

4.3.2.2 Quiz Interface

The quiz system is built using Roblox's user interface (UI) components, such as buttons and text labels. When the player starts the quiz, the system randomly selects a question that has not been answered yet and displays it along with three possible answer choices. The player then selects one of the answers by clicking a button.

Once an answer is chosen, the system checks whether it matches the correct answer. If the player is correct, they receive positive feedback such as cheerful sounds, animations, or score increases. If the answer is wrong, the system highlights the correct answer and provides a simple explanation to teach the player the right concept.

The quiz continues either until a set number of questions have been answered or until all questions in the quiz bank have been attempted. The quiz system may also reward players with EcoPoints or badges based on their performance. Figure 4.3 shows the quiz interface design in game.

4.3.2.3 Quiz Data Management

To manage the quiz content efficiently, each question and its associated information is stored in a structured data format. This format is inspired by how data is organized in JSON (JavaScript Object Notation), though it is implemented using Lua tables in Roblox.

Each quiz question entry includes four key components:

- The question text – This is the sentence that is shown to the player (e.g., "Why do we recycle?").
- A list of answer options – Each question has three possible answers for the player to choose from.

- The correct answer – The system uses this to check the player's response and determine if it's right or wrong.
- An explanation or reason – After answering, the player is shown a simple explanation that supports learning, such as "Recycling helps protect the Earth and save resources."

This structured format makes it easier to manage the quiz content, randomize the question order, and add new questions in the future. It also ensures that all questions follow a consistent layout, which is important for maintaining the quality and clarity of the user experience.

The quiz data is stored in memory when the game runs and is accessed by the quiz system to display questions and check answers during gameplay. The display of right and wrong

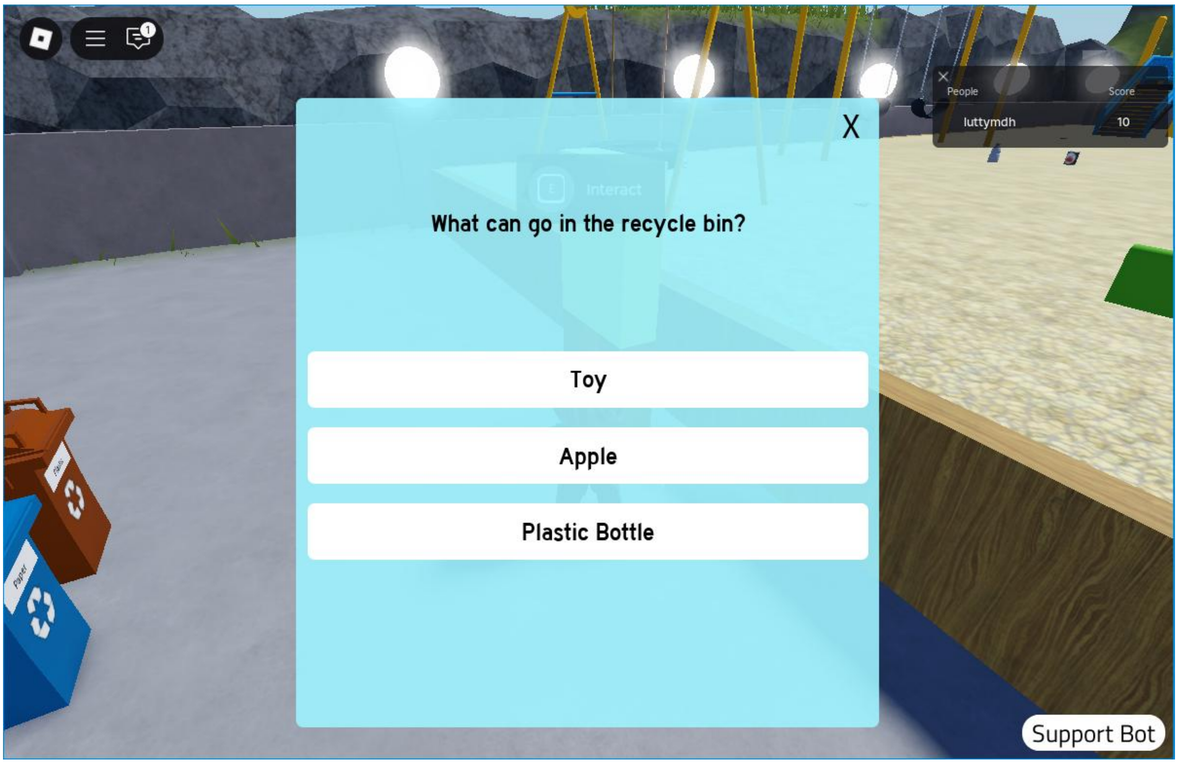

Figure 4.3: Quiz Interface Design

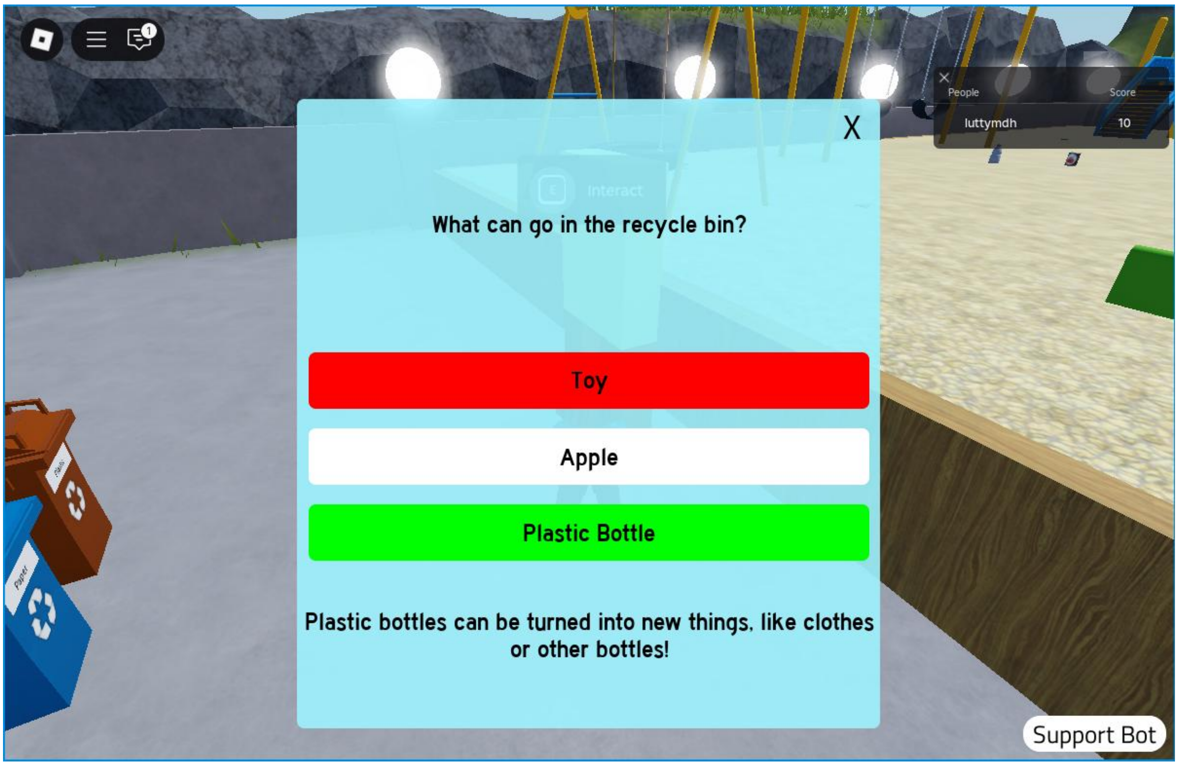

Figure 4.4: Quiz Data Management

with explanation can be seen in Figure 4.4.

4.3.2.4 Quiz Educational Purpose

While the “Sort It Out!” game helps players recognize and sort items visually, the quiz system ensures that players also understand the underlying reasons for recycling correctly. By including explanations after each question, the system helps transform mistakes into learning opportunities. The use of colourful UI, simple vocabulary, and familiar examples ensures that even younger children can enjoy and benefit from the quiz. Overall, the quiz system promotes reflection and knowledge retention, making it a vital part of the game's educational goals.

4.4 Chatbot Integration

4.4.1 Purpose of Chatbot Integration

The chatbot is designed to simulate a supportive in-game character such as a recycling assistant or digital teacher that responds to player queries using natural language. It serves as an alternative learning path for players who may be curious about specific recycling topics or who require clarification during gameplay. The chatbot fulfils several key educational functions, including explaining recycling concepts in simple, child-friendly terms (for example, answering questions like "What is compost?"), responding to basic queries about sorting waste and bin usage (such as "Where do I throw paper?"), and offering positive feedback and encouragement. By creating a conversational learning environment, the chatbot promotes self-directed exploration and reinforces recycling knowledge beyond the core game mechanics, making the learning experience more interactive and personalized.

4.4.2 Chatbot Interface

The chatbot interface was designed to be simple, friendly, and accessible to young users. It appears as a pop-up window or dialogue box on the screen when activated, by clicking a chatbot button on the bottom right screen. The interface consists of a clearly labelled input text box where players can type their questions on the bottom part of the interface, and a response area where the chatbot's replies are displayed. To ensure readability, the response area uses a large. This visual design helps children stay focused and understand the content without feeling overwhelmed. Figure 4.5 illustrates the chatbot interface design. The central box serves as the main interaction area where users can communicate with the chatbot. To open the chatbot, users simply click the "Support Bot" button located at the bottom-right corner of the screen.

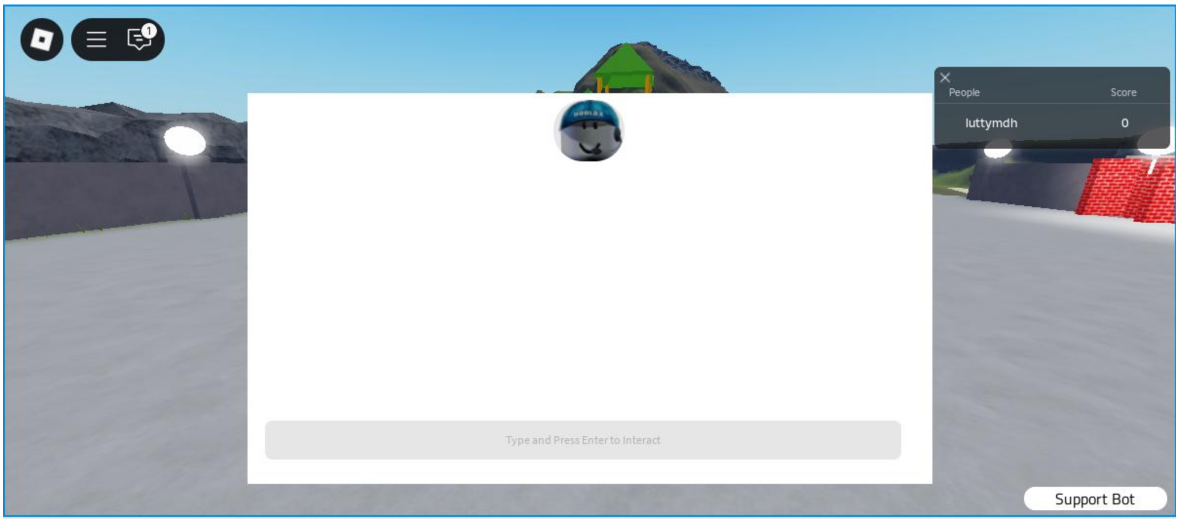

Figure 4.5: Chatbot Interface Design

4.4.3 Chatbot Backend Integration

The chatbot's backend is powered by Gemini, a conversational AI model developed by Google, which processes user questions and returns appropriate answers in natural language. To connect the Roblox game with this external AI model, a lightweight server was developed using Replit, an online cloud-based development environment. This server acts as a middle layer between the Roblox client and the Gemini API, allowing the game to send user input and receive intelligent, human-like responses.

When a player interacts with the chatbot in-game, their message is sent from Roblox to the Replit backend using an HTTP request. The server receives the text, formats it as a prompt for Gemini, and forwards the request to the Gemini API. Once Gemini generates a response, the backend server sends it back to the Roblox client, where it is displayed in the chatbot UI.

4.4.3.1 Chatbot Flow

The process begins when a player sends a message through the chatbot interface in Roblox. This message is passed to the Replit backend server, which acts as a bridge between the

Roblox game and the external Gemini AI service. Due to Roblox's networking limitations and security policies, direct communication with Gemini is not possible from the Roblox client; therefore, all requests must be routed through this backend server.

Upon receiving the message, the Replit backend formats it into a suitable prompt and forwards it to Gemini, a large language model developed by Google. Gemini processes the prompt and generates a response based on its training and understanding of the topic. The response is then returned to the Replit server, which may clean or format the text to ensure it is concise and child friendly.

Finally, the response is sent back to the Roblox client, where it is displayed in the chatbot UI, allowing the player to view the answer. This architecture ensures smooth interaction while maintaining security, content control, and API compatibility. It enables dynamic, intelligent conversations that enhance the educational experience through real-time, AI-

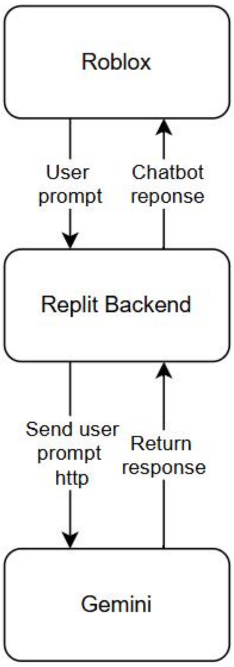

Figure 4.4.6: Chatbot backend workflow

powered feedback. Figure 4.6 shows the flow of chatbot in the backend.

4.4.3.2 Roblox Security

Roblox cannot directly connect to the Gemini API due to strict platform security and networking limitations. Roblox Studio does not allow outbound HTTP requests to external services like Gemini from the client or server scripts without going through an approved HTTP service. This restriction exists to prevent misuse, protect user data, and avoid unauthorized access to external servers. Additionally, Gemini requires authentication using API keys and headers that Roblox does not support directly in its HttpService due to sandboxing and security design.

To work around this limitation, a proxy server hosted on Replit is used. This server acts as a secure bridge between Roblox and Gemini. It handles the Gemini API key securely, manages request formatting, and controls how data is exchanged. By using Replit as an intermediary, the system remains safe, scalable, and compliant with both Roblox's restrictions and Gemini's API requirements.

4.5 Conclusion

The main implementation components of the Recycling Heroes educational game have been described in this chapter, along with the incorporation of interactive systems intended to encourage children's recycling and environmental awareness. The "Sort It Out!" mini-game, the structured quiz system, and the AI-powered chatbot were all developed with Roblox Studio's Lua scripting, with a focus on both usability and kid-friendly design.

Players sort virtual trash into the proper bins in the "Sort It Out!" game, which provides a quick and interactive learning experience. The quiz system adds knowledge-based reinforcement to this gameplay by giving kids ages 7 to 12 customized explanations and feedback. In the meantime, the AI chatbot goes beyond learning by providing conversational, real-time guidance via Google's Gemini API, which is connected via a secure Replit backend to get around Roblox's HTTP restrictions.

These mechanisms were put in place to guarantee that the game would always be instructive, entertaining, and available. In addition to teaching recycling principles, this age-appropriate learning environment fosters critical thinking, problem-solving, and sustainable practices through the integration of interactive gaming, structured evaluation, and dynamic support.

4.6 Chapter Summary

Chapter 4 outlined the development and implementation process of the Recycling Heroes gamified learning platforms. Using Roblox Studio, the game was created with the Year 6 Science curriculum in mind, emphasizing recycling and waste management ideas. The system architecture, key game features, and chatbot integration through the Gemini API were all covered in detail in this chapter. Important elements included leaderboard mechanisms, point systems, interactive gameplay tasks like recycling mini-games, and real-time AI chatbot guidance based on decision-tree logic. The gameplay and interface were designed with elementary school students in mind, guaranteeing accessibility, interest, and alignment with learning objectives. All things considered, this chapter detailed the project's technical implementation as well as the conversion of the instructional materials into an interactive learning environment.

CHAPTER 5

TESTING

5.1 Overview

This chapter covers the testing and assessment procedures used to guarantee that the recycling education game runs properly and achieves its intended educational and technical goals. The testing concentrates on essential components like the sorting mini game, the NPC quest system, the quiz module, the chatbot integration, and general performance. Each component was tested for functionality, accuracy, responsiveness, and user engagement, with a focus on the game's intended demographic of young learners. The evaluation was carried out through manual playtesting, script-based troubleshooting, and observations of user input. Test cases were created to emulate normal player activities such as sorting objects, answering quiz questions, performing quests, and interacting with the chatbot. The results of each test are documented, including findings, consequences, and suggestions for changes.

5.2 Testing Objectives

The main objective of testing was to ensure that all system components functioned properly under various settings and with different devices. This involved ensuring the accuracy of important logic including item sorting, scoring processes, and chatbot answers. The testing also assessed the responsiveness and real-time behaviour of gameplay elements, delivering an uninterrupted and engaging experience. The user interface was given special care to ensure that it was easy to use, intuitive, and appropriate for children. Additionally, the system was tested for cross-device interoperability, which included PC, mobile, and tablet platforms. Finally, the assessment was designed to ensure that the system effectively supported its educational objectives by reinforcing recycling principles and encouraging learning through interaction.

5.3 Functional Testing

This section describes how each feature of the recycling game was tested to ensure it works as planned. It features the primary mini-game mechanics, a quiz system, and chatbot integration.

5.3.1 Sort It Out Mini-Game

By dragging and dropping different waste items into the appropriate bins, the "Sort It Out" mini game teaches players how to properly categorize recyclable materials. To make sure the game mechanics operated smoothly and that the learning objectives were successfully conveyed, functional testing was done. A variety of objects, including glass jars, newspapers, plastic bottles, food scraps, and electronic parts, appeared on the screen at random during testing. The ability to precisely select and drag each item using both mouse and touch input was confirmed by the testers.

The system responded appropriately to both correct and incorrect placements and accurately determined which bin each item belonged to. While unsuccessful sorting attempts were gently flagged, encouraging the player to try again without penalty, successful sorting actions resulted in positive feedback, such as sound effects or score increases. Additionally, testing made sure that the game would end smoothly and show the final score after everything had been sorted.

Extra tests verified that the game managed odd player actions like dragging objects quickly, dropping them outside of bins, or interacting with several items at once. The mini game was responsive and stable in every situation. Additionally, the interface's compatibility with desktop and mobile platforms was confirmed through testing on various devices. All things considered, the "Sort It Out" mini game operated dependably and effectively aided in the objective of instructing players on recycling in a fun and interactive manner.

5.3.2 Quiz System

The quiz's progression, response handling, and question display accuracy were all examined. Functional tests verified that each question had clickable answer options that updated the internal “isAnswered” flag and that they appeared in the correct order. Only the right response received points or feedback. To prevent corruption of the state, the system handled repeated attempts or skipped questions with grace. To reinforce the instructional message, testers also confirmed that the explanations for responses were presented in an approachable manner following the test.

5.3.3 Chatbot Integration

Both the backend interaction and the chatbot's appearance were functionally tested. Testers verified that the text input and response sections were functional and that the chatbot panel displayed on the front end when the "Support Bot" button was clicked. HTTP request logs were used to validate simulated communication with the Gemini-powered chatbot hosted on Replit on the backend. Although HTTP service limitations prevent Roblox from connecting directly to external services like Gemini, the system was able to successfully route player queries through an intermediary API endpoint on Replit. Fallback handling for connection errors or empty inputs was verified, and the chatbot's response time was within an acceptable range.

5.3.4 Crafting Mini Game

The main interactive component is the crafting mini game, in which players gather recyclable materials and turn them into usable objects. Verifying the entire flow, including item spawning, touch detection, crafting completion, and dialogue triggers, was the main goal of functional testing. Testers made sure that items vanished appropriately upon contact and that only players with the quest active could collect them. It was confirmed that the crafting logic would only activate once all necessary components had been gathered. Following crafting, Tinker Tim's appropriate dialogue was activated, and rewards like badges or point increases were given out as planned. Edge cases like early interaction, missing items, or touching unrelated objects were also handled by the system.

5.4 Test Results Summary

Every significant element of the recycling education game underwent extensive testing to ensure that it was stable, functional, and in line with the desired learning goals. These elements included the crafting quest, chatbot integration, quiz system, and sorting mini game. To guarantee consistent behaviour across platforms, tests were carried out on desktop and mobile devices. Through scenario-based interaction, simulated edge cases, and manual playtesting, every feature was evaluated.

The "Sort It Out" mini game showed reliable bin classification, score tracking, and object placement detection. Both mouse and touch input interactions were flawless, and the user interface was always responsive and easy to use. After each response, the quiz system provided prompt, age-appropriate feedback and explanations, processed user selections accurately, and successfully displayed questions in the right order.

Using a backend Gemini API hosted on Replit, the chatbot component functioned efficiently, offering real-time conversational support. Response latency stayed within a reasonable range, and every query was routed successfully. To provide a stable user experience, the system also used fallback messaging to handle edge conditions like empty input or lost connections.

From item spawning and quest validation to reward distribution and the last conversation with the NPC, Tinker Tim, the crafting mini game passed all functional checks. Crafting logic only started when the right materials were collected, and players could only gather items while the relevant quest was active. When it was finished, the reward and conversation systems worked as planned.

Table 5.1 below summarizes the testing outcomes for each core features:

Table 5.1: Summary of Testing Outcomes

Feature	Result	Remarks
Sort It Out Mini Game	Passed	Accurate sorting, smooth input on all devices, responsive UI
Quiz System	Passed	Correct sequencing, answer validation and feedback messaging.
Chatbot Integration	Passed	Stable connection to Replit backend, acceptable response time, fallback handled
Crafting Mini Game	Passed	Functional quest flow, correct item checks, reward and dialogue triggers verified

In conclusion, every major game system performed as expected and made a significant contribution to the game's instructional goal. Player engagement and overall stability were improved by small tweaks made during testing.

5.5 Bug Fixes and Improvements

To enhance gameplay stability and user experience, a number of minor bugs and usability issues were found during the testing phase and fixed. Repeated manual playtests and the observation of unexpected behaviours during gameplay sequences and quest interactions were used to identify these problems.

During the "Sort It Out" mini-game, one of the first problems was that some recyclables were not properly registering when dropped close to the bin's edge. To fix this, the hitbox detection was improved, and the drag-and-drop sensitivity was changed to better support both touch and mouse input. Furthermore, the scoring logic was examined and revised to guarantee accurate feedback regardless of item classification because score updates were not always triggered on incorrect placements.

When users skipped questions and came back to them later, an early version of the quiz system did not correctly update the isAnswered flag. As a result, completed questions were not accurately tracked. To prevent multiple attempts from overriding correct responses and to accommodate non-linear answering patterns, the logic was modified.

One problem with the chatbot integration arose when users sent blank messages, which had previously resulted in an error or no response. To identify blank input and show a polite reminder to users to enter a question, a fallback handler was put in place. By improving GUI placement and scaling, it was also possible to guarantee consistent chatbot panel visibility on smaller screens, like those found on mobile devices.

A bug in the crafting minigame made it possible for players to gather duplicate items before accepting the quest, which led to improper quest progression. By adding a quest state check prior to spawning or permitting item pickup, this was fixed. Additionally, misaligned variable states prevented the final dialogue with the NPC from triggering in some situations. This was fixed by synchronizing quest flags and player status checks.

Together, these improvements and fixes made the learning process more reliable, user-friendly, and pleasurable. Early resolution of these problems improved the game's final version's dependability, playability, and compatibility with its educational objectives.

5.6 User Testing and Feedback

A group of young students, ages 11 to 12, participated in informal user testing to evaluate the recycling game's usability and educational efficacy. The participants were watched as they used laptops and tablets to play the game. With interactive elements like sorting, quizzes, and crafting, the testing aimed to gather real-world feedback on how well students grasped the tasks, participated in the gameplay, and internalized recycling concepts.

Students needed little assistance to navigate the interface on their own during testing. The majority had no trouble completing quests, correctly sorting items, and interacting with the chatbot. Players expressed enjoyment of dragging and dropping items into the bins in the "Sort It Out" mini game, which received especially positive feedback. Throughout the exercise, the sound effects and visual feedback helped keep participants' focus and motivation high while reinforcing accurate responses.

Additionally, the quiz module was well received. The quick, cordial feedback that players received after responding to questions was well received by them and reinforced their learning. Some students enjoyed selecting from the vibrant answer buttons and said the questions were simple to understand. Some recommended changing the order of the questions to make them more replay able or adding more diverse questions. An additional degree of interaction and support was provided by the chatbot integration. Many students used it to clarify recycling terms or to ask questions about how to accomplish specific tasks. Students valued having a helpful assistant available during gameplay, even though their responses weren't always flawless.

All things considered, the input gathered during this user testing stage confirmed that the game was understandable, instructive, and entertaining for its target market. Students' interest was sustained, and critical environmental awareness was raised thanks to the interactive recycling education method. Small usability recommendations were made and will be taken into consideration for future updates, such as adding more hints or providing clearer instructions in specific quests.

5.7 Usability and Experience Evaluation (SUS, UEQ, EEQ and open-ended feedback)

Four evaluation tools, the System Usability Scale (SUS), User Experience Questionnaire (UEQ), Educational Effectiveness Questionnaire (EEQ), and a series of open-ended survey questions were used to evaluate the Recycling Heroes game's overall usability, user experience, and educational effectiveness. Both quantitative and qualitative information about how students viewed and engaged with the game was offered by these tools.

5.7.1 System Usability Scale (SUS)

The findings of a systematic usability assessment of the educational game Recycling Heroes using the System Usability Scale (SUS) are shown in this section. SUS is a commonly used, standardized tool for gauging user satisfaction and perceived usability (Brooke, 1995) Participants were given the post-test SUS questionnaire following their engagement with the game's primary elements, such as the chatbot, quiz system, and sorting mini game.

5.7.1.1 Participant

Ten elementary school pupils (n = 10) in the age range of 11 to 12 took part in the usability assessment. Following the session, every participant finished the SUS questionnaire and played through the main game content. The sample offered valuable insight into the usability and accessibility of the game's features and interface, and it was representative of the game's target audience, which consists of young students in upper elementary school.

5.7.1.2 SUS Scoring Methodology

To reduce bias, the SUS questionnaire has 10 items with ratings on a 5-point Likert scale that alternate between positive and negative statements. The following was the scoring procedure:

- The rating minus one was used to determine the score contribution for odd-numbered items (1, 3, 5, 7, 9).
- The contribution was 5 minus the rating for even-numbered items (2, 4, 6, 8, 10).

A score on a scale of 0 to 100 was then obtained by multiplying the total score (0–40) by 2.5. Better usability is indicated by higher SUS scores.

5.7.1.3 Descriptive Statistics

According to SUS interpretation standards, the average SUS score for all ten participants was 87.0, indicating excellent usability. The important statistical values are compiled in Table 5.2.

Table 5.2: Statitical Value

Statistics	Value
Mean SUS Score	87.0
Standard Deviation (SD)	0.49
Median	87.5
Minimum Score	85.0
Maximum Score	90.0
Number of Participant	10

5.7.1.4 Item-Level Analysis

Item-level average scores were calculated to obtain a better understanding of user perceptions, and the results are displayed in Table 5.3.

Table 5.3: SUS Average Scores *(N=10)*

SUS Item	Original Mean Rating	Adjusted Mean Rating	SD
Navigation ease	4.6	4.6	0.52
Layout clarity	1.8	4.2	0.79
System speed	4.4	4.4	0.52
Visual appeal	1.8	4.2	0.79
Feature integration	4.5	4.5	0.53
Consistency	1.5	4.5	0.53
Learning ease	4.7	4.7	0.48
Learning simplicity	1.4	4.6	0.52

User confidence	4.6	4.6	0.52
Low prior knowledge	1.5	4.5	0.53

Several SUS items have negative wording to reduce acquiescence bias. To guarantee consistency in interpretation, these items were reverse scored before analysis; higher scores consistently denote better usability. The original score was subtracted from 6 to accomplish this transformation (Adjusted Score = 6 – Original Score). For example, a score of 1 for the item "Confusing layout" is converted to an adjusted score of 5, which corresponds to a positive interpretation like "Clear layout." This modification supports precise visualization and aggregation and guarantees comparability across items.

Items like "Learning ease" (M = 4.7), "User confidence" (M = 4.6), and "Navigation ease" (M = 4.6) received high ratings, indicating that users thought the game was simple to use and easy to understand. Interestingly, reverse-scored items like "Visual appeal" (original M = 1.8 adjusted M= 4.2) and "Layout clarity" (original M = 1.8 adjusted M = 4.2) also received strong adjusted scores, highlighting the game's visual appeal and clarity. Overall, the findings show that participants thought there were few usability obstacles and that the interface was easy to use and accessible.

5.7.1.5 Interpretation and Benchmarking

A SUS score of 80.3 or higher is considered "excellent," (Grier et al., 2013). With a final mean score of 87.0, the students who played the Recycling Heroes game thought it was very usable. When compared to more than 500 usability studies, this score puts the game above the 90th percentile, indicating that the user interface and experience are simple and suitable for young players.

5.7.1.6 Visual Summary

Each System Usability Scale (SUS) item's adjusted mean ratings are shown in Figure 5.1 along with standard deviation error bars.

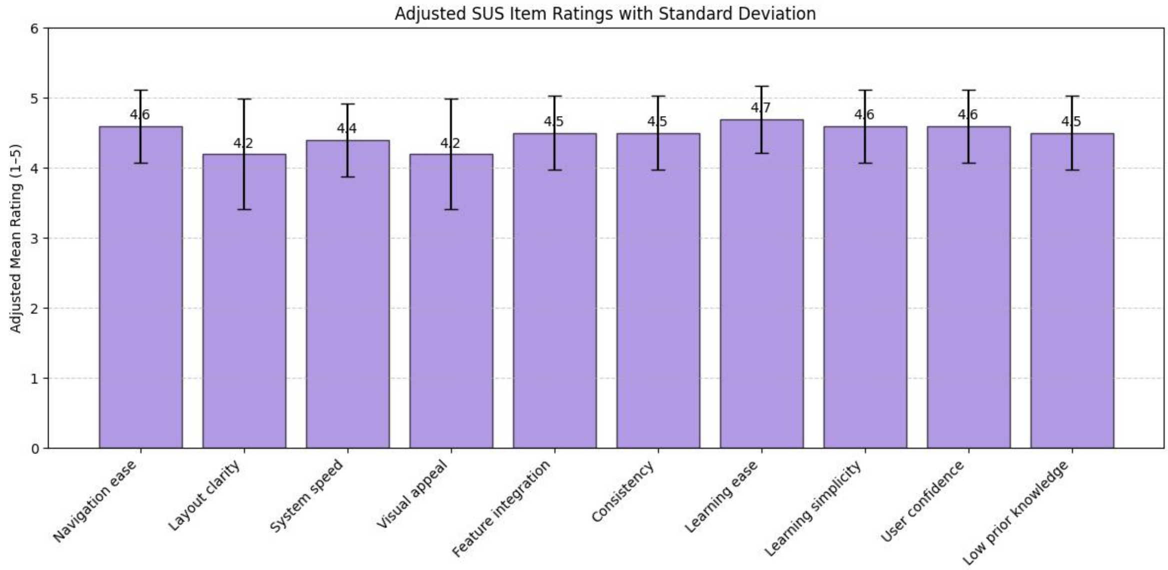

Figure 5.1: Adjusted SUS Ratings with Standard Deviation

To guarantee that higher scores consistently reflect better usability, each item has been reverse-scored where appropriate. With adjusted mean scores ranging from 4.2 to 4.7 on a 5-point scale, the results show consistently high usability perceptions. According to the highest ratings, users found the game to be intuitive, simple to learn, and confidence-boosting. These items include "Learning ease" (M = 4.7), "Navigation ease" (M = 4.6), "Learning simplicity" (M = 4.6), and "User confidence" (M = 4.6). Originally reverse-worded items like "Layout clarity" and "Visual appeal" also obtained favorable adjusted ratings (M = 4.2), suggesting little confusion and a generally favorable perception of the interface. The consistency and dependability of participant responses are further supported by the low variability across standard deviations (all ≤ 0.79).

5.7.1.7 Limitation

Even though SUS offers trustworthy usability feedback, there are a few things to keep in mind:

1) Sample Size: There were only ten participants in the sample, which might have an impact on generalizability.

2) Age Group: Since all participants were school-age children, findings might not apply to more experienced students or teachers.

3) Subjectivity: Because ratings are subjective, they could be influenced by personal prejudices.

5.7.1.8 Summary

According to the Recycling Heroes game's SUS-based evaluation, the system provides young learners with exceptional usability. The game appears to be user-friendly, entertaining, and intuitive based on its consistently high item-level ratings and mean SUS score of 87.0. These findings support the game's use as an efficient teaching tool in elementary school settings and validate the design decisions made.

5.7.2 User Experience Questionnaire (UEQ)

The User Experience Questionnaire (UEQ) is used in this section to provide a systematic assessment of the Recycling Heroes game. The UEQ is a validated instrument that evaluates the hedonic and pragmatic aspects of user experience. It records users' perceptions of a variety of elements, such as efficiency, clarity, stimulation, and attractiveness. The purpose of this assessment is to gauge how entertaining, intelligible, and useful the game is from the viewpoint of young students.

5.7.2.1 Participant

Ten (n = 10) students, ages 11-12, took the UEQ test after playing the entire game, which included sorting activities, quizzes, and chatbot support. Immediately following the play session, each participant finished the UEQ. The answers provide information about how kids view the educational game's overall experience, interface, and content design.

5.7.2.2 Instrument Description

Bipolar adjective pairs on a 7-point semantic differential scale, with 1 denoting "very negative" and 7 denoting "very positive," are used in the UEQ. Twelve carefully chosen UEQ items were used in this study, with an emphasis on characteristics that are most pertinent to young users and educational game contexts. Attractiveness, Perspicuity, Efficiency, Dependability, Stimulation, and Novelty were the six user experience domains covered by these items.

Higher scores indicate greater agreement with the positive attribute. Each item pair represents a contrast (for example, "Annoying – Enjoyable"). The mean scores and standard deviations for each attribute were calculated by combining all the responses.

5.7.2.3 Descriptive Results

Table 5.4 summarizes the average sore and standard deviation for each pair.

Table 5.4:UEQ Average Scores *(N=10)*

Attribute Pair	Average Score	SD
Annoying – Enjoyable	6.3	0.67
Not understandable – Understandable	6.0	0.47
Dull – Creative	6.0	0.47
Difficult to learn – Easy to learn	6.0	0.47
Inferior –Valuable	5.9	0.32
Boring – Exciting	6.6	0.52
Not safe – Secure	6.6	0.52

Demotivating – Motivating	6.3	0.67
Inefficient – Efficient	5.9	0.32
Confusing – Clear	5.9	0.32
Impractical – Practical	5.9	0.32
Cluttered – Organized	6.0	0.47

Average ratings for each pair of attributes were higher than 5.9, suggesting a consistently favourable user experience. Users found the game to be both stimulating and reliable, as evidenced by the highest-rated attributes, "Boring – Exciting" (M = 6.6) and "Not safe – Secure" (M = 6.6).

5.7.2.4 Dimension-Level Interpretation

The data are consistent with important UEQ dimensions, despite the evaluation's use of selected items rather than complete UEQ scales. The following conclusions can be made:

1) Attractiveness: High ratings for "Annoying – Enjoyable" and "Demotivating – Motivating" indicate that the game was entertaining and welcoming.

2) Perspicuity: The game was easy to understand, as evidenced by the strong results for "Difficult to learn – Easy to learn" and "Confusing – Clear."

3) Efficiency: Items with high scores, such as "Impractical – Practical" and "Inefficient – Efficient," indicate that players found it fluid and goal-oriented.

4) Dependability: A "Not safe – Secure" score of 6.6 indicates that the game felt dependable and steady.

5) Stimulation and Novelty: High ratings for "Dull – Creative" and "Boring – Exciting" indicate a novel design and high levels of engagement.

5.7.2.5 Benchmarking and Implications

In accordance with the benchmark interpretation standards of UEQ:

1) "Excellent" refers to scores higher than 6.0 on a 7-point scale.

2) "Good" scores fall between 5.0 and 6.0.

Recycling Heroes provides both practical utility and emotional engagement, as evidenced by the fact that every attribute pair falls between "Good" and "Excellent." These results confirm that gamification and chatbot integration are useful tactics for promoting learning and sustaining motivation.

5.7.2.6 Visual Summary

Figure 5.2 shows the UEQ mean scores across six core user experience dimensions (N=10)

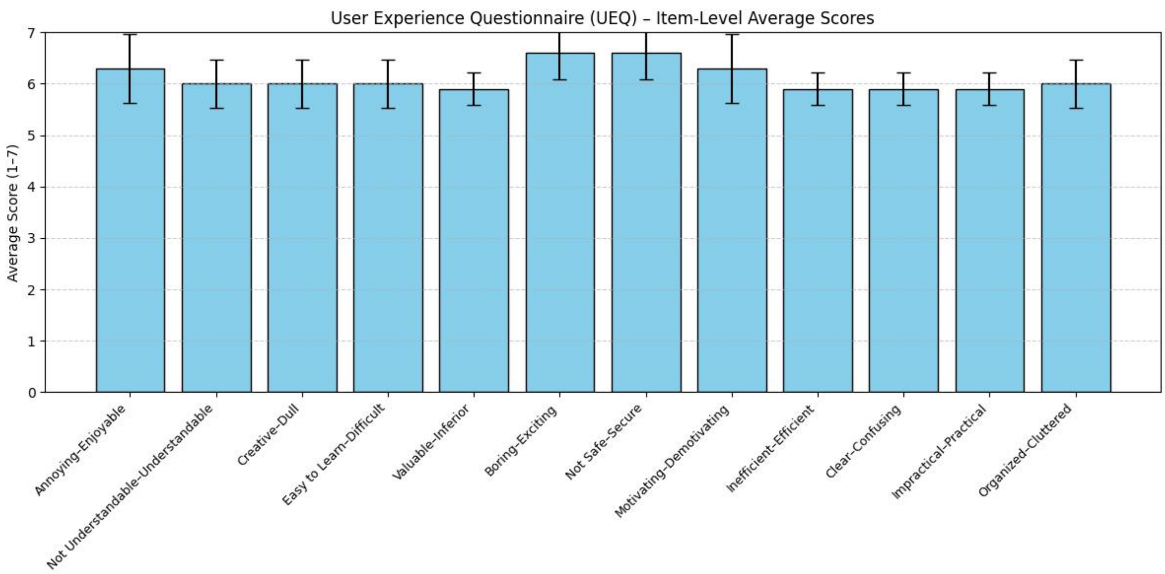

Figure 5.2: UEQ Mean Scores

The user experience across the six UEQ dimensions is summarized in this graph. High mean scores for "Stimulation," "Attractiveness," and "Novelty" suggest that players thought the game was inventive, captivating, and thrilling. With the majority of scores falling into the "Good" to "Excellent" benchmark categories, all dimensions had scores above 1.4, indicating a consistently positive experience.

5.7.2.7 Limitations

Even though this condensed UEQ offers insightful feedback, there are a few things to keep in mind:

1) Some full-scale validations present in the original 26-item model are not included in the condensed UEQ version.

2) Although it restricts more extensive generalization, the sample size (n = 10) is appropriate for formative research.

3) Response consistency and interpretation can vary when children are used as participants.

4) Responses may be positively skewed by novelty effects and environmental influences.

To improve dimensional robustness and enable statistical modelling across constructs, future research might increase the sample size and incorporate the entire UEQ.

5.7.2.8 Conclusion

According to the findings of the UEQ evaluation, Recycling Heroes offers its target audience a fun, intelligible, and inspiring user experience. The consistently high scores for every tested feature imply that the game is entertaining and instructive. Strong results in the categories of "Exciting," "Secure," and "Enjoyable" demonstrate how well the system works to create a secure and engaging learning environment. These results validate the game's suitability for broader classroom use and offer guidance for future enhancements to the dependability and clarity of the interface.

5.7.3 Educational Effectiveness Questionnaire (EEQ)

The findings of the Educational Experience Questionnaire (EEQ), which was used to gauge the Recycling Heroes game's perceived educational value, are shown in this section. Within the framework of a gamified learning environment, the EEQ focuses on student motivation, engagement, and perceived learning effectiveness. This assessment sought to ascertain how the game affected players' motivation to learn, interest in recycling, and readiness to play through the learning content again.

5.7.3.1 Instrument Description

Five targeted statements, each with a 5-point Likert scale from 1 (strongly disagree) to 5 (strongly agree), made up the EEQ instrument. The purpose of the items was to gauge how young players perceived the game's level of motivation, engagement, and education. After finishing the entire game cycle, which included sorting, quizzes, and chatbot interaction, each participant was asked to reply to these statements right away.

5.7.3.2 Participants

Ten pupils (n = 10) between the ages of 11-12 took part in the EEQ assessment. Before responding to the questionnaire, everyone had finished the game. The group provided insightful information about how young learners viewed the game's educational benefits and represented a pertinent target demographic for Year 6 Science curriculum topics.

5.7.3.3 Descriptive Results

Table 5.5 provides a summary of the EEQ results, presenting the average score and standard deviation for each item.

Table 5.5: EEQ Average Scores *(N=10)*

Statement	Average Score	SD
Enhanced engagement with waste management topic	4.7	00.48
Improved motivation to learn about waste management	4.7	0.48
Game elements enhanced the appeal of waste management education	4.7	0.48
Learning was more enjoyable and stimulating	5.0	0.00
Willingness to use the game again to explore recycling concepts	4.7	0.48

The statement "Learning was more enjoyable and stimulating" received the highest rating (5.0), while all other items received average ratings of 4.7 or higher. This clearly indicates that students' interest and excitement for learning about recycling were greatly increased by the game.

5.7.3.4 Interpretation

The game was successful in providing a useful and entertaining educational experience, as evidenced by the high mean ratings for each of the five items. Notably:

1) All participants found the game to be very engaging, as evidenced by the perfect score of 5.0 for "Learning was more enjoyable and stimulating."

2) Strong motivation, engagement, and positive attitude shifts toward waste management education are indicated by the consistent 4.7 ratings for the other items.

3) The game's potential for frequent use in classroom or independent learning contexts is reflected in the students' willingness to use it again (M = 4.7).

These findings support the educational potential of gamified learning environments, especially for subjects like waste management that are frequently disregarded or viewed as uninteresting.

5.7.3.5 Visual Summary

Figure 5.3 shows the Educational Experience Questionnaire (EEQ) average scores (N=10)

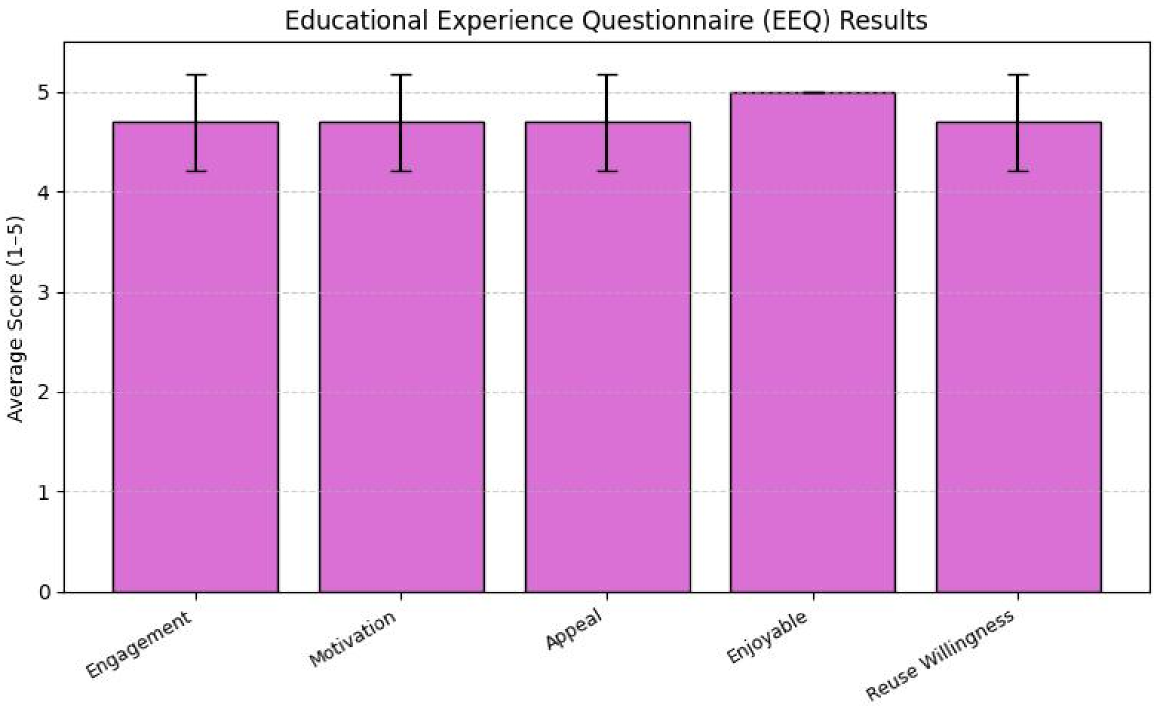

Figure 5.3: EEQ Average Scores

Participants' evaluations of five EEQ statements pertaining to motivation and engagement are displayed in this chart. Scores close to the top (4.7–5.0) show how well the game does at making recycling education entertaining, alluring, and inspiring. The game's efficacy as a teaching tool is demonstrated by the highest score (5.0) for "Learning was more enjoyable and stimulating."

5.7.3.6 Implications for Educational Design

According to the EEQ results, Recycling Heroes improved student motivation and emotional connection to the material in addition to successfully communicating recycling concepts. The game produced an enjoyable and fulfilling learning experience by fusing gameplay with educational quizzes and real-time chatbot assistance. This model can be applied to different age groups and subjects where learning success depends on student engagement.

5.7.3.7 Limitations and Future Considerations

Despite the positive feedback from the EEQ, it is important to recognize a few limitations:

1) Because of its small sample size (n = 10), it was appropriate for pilot testing but not for generalization to larger populations.

2) Since each response was self-reported, individual interpretations and moods may vary.

3) Immediate post-play responses were recorded by the EEQ; behavioural change or long-term retention were not evaluated.

4) Environmental and cultural influences on recycling attitudes were not considered.

To better measure educational impact, follow-up assessments, teacher observations in the classroom, and the inclusion of control groups may be beneficial in future evaluations.

5.7.3.8 Conclusion

Recycling Heroes is a fun and successful educational tool for raising recycling awareness among elementary school pupils, according to the EEQ results. High ratings for motivation, enjoyment, and engagement confirm that the game met its learning goals while making the process enjoyable and unforgettable. These findings lend credence to the game's continued application in science education and offer a solid foundation for expansion and future iterations.

5.7.4 Open-Ended Survey Feedback

Students' learning experiences were qualitatively revealed by open-ended questions. Thematic analysis was used to group the responses into themes. The recurring themes and sample quotes are highlighted in Table 5.5.

Table 5.6: Thematic Summary of Open-Ended Response (N=10)

Participant	Theme	Response
P1	Enjoyment and Engagement	“I like to walk around collecting rubbish”
P2	Learning and Understanding	“I know which bin to place trash”
P3	Enjoyment and Engagement	“It’s fun when I get points after recycle.”
P4	Learning and Understanding	“I learned what is compost”
P5	Suggestions for Improvement	“I want more levels.”
P6	Enjoyment and Engagement	“Chatbot help answer my questions.”
P7	Learning and Understanding	“Now I know how to

		recycle paper, plastic and metal."
P8	Suggestions for Improvement	"The instructions sometimes are a little bit confusing."
P9	Enjoyment and Engagement	"I like the leaderboard. I want to be number one!"
P10	Learning and Understanding	"I know how to recycle"

5.8 Qualitative Analysis of User Feedback on Recycling Heroes Application

A thematic analysis of the open-ended student responses gathered during the Recycling Heroes game evaluation is presented in this section. This analysis synthesizes insights about learning outcomes, student-driven suggestions for improvement, and engagement based on qualitative data from 10 participants (coded P1–P10). Three main themes are identified by the analysis, which adheres to (Braun & Clarke, 2006) thematic approach:

1) Pleasure and Involvement

2) Education and Conceptual Knowledge

3) Expectations of Users for Enhancement

5.8.1 Theme 1: Enjoyment and Engagement

Positive emotional reactions to the game were expressed by many participants. They took pleasure in engaging with the chatbot, gathering trash, and moving up the leaderboard, among other in-game activities. These components increased motivation and enhanced the immersion of the learning process.

P1 shared, for instance, *"I like to walk around collecting rubbish."* P3 added, *"It's fun when I get points after recycling,"* in a similar vein. P9 stated, *"I like the leaderboard. I* *want to be number one!"* highlighting the competitive element as well. "*Chatbot help answer my questions,"* P6 observed, highlighting the chatbot's function in sustaining engagement.

These answers demonstrate the game's capacity to maintain focus and pique interest in recycling-related activities on an intrinsic level, which is consistent with gamification concepts that increase user motivation.

5.8.2 Theme 2: Learning and Conceptual Understanding

Additionally, students reported gaining concrete knowledge about recycling procedures. According to their comments, the game helped players gain a better understanding of composting, material separation, and appropriate disposal techniques.

"I know which bin to place trash in," said P2. P4 said, *"I now understand what compost is,"* and P7 added, *"I now know how to recycle paper, plastic, and metal." "I know how to recycle,"* said P10.

These claims attest to the fact that Recycling Heroes successfully and learner-centeredly conveyed key ideas from the Year 6 Science curriculum.

5.8.3 Theme 3: User Expectations for Improvement

Although they were generally satisfied, students offered helpful criticism to enhance the gameplay and the clarity of the instruction. Several participants expressed a wish for more levels and more precise directions. P5 said, *"I wish there were more levels,"* and P8 said, *"The instructions are a little bit confusing at times."*

These findings highlight the value of iterative design, where student input guides subsequent development cycles, and reflect students' rising expectations for digital learning environments.

5.8.4 Synthesis and Implications

Recycling Heroes effectively blended curriculum-aligned content with gameplay mechanics to promote learning and engagement, according to feedback from all ten participants. Strong user involvement was facilitated by the most cherished features, which included clear recycling missions, real-time chatbot feedback, a scoring system, and movement-based exploration.

Clearer instructional guidance and expanded content (e.g., more levels) are two areas that still require improvement. Future students' experiences could be greatly enhanced by resolving these problems through frequent playtesting and user-centered design techniques. The notion that gamified learning can be a potent teaching tool when properly designed is supported by this feedback, particularly when student opinions are considered at every stage of the creation process.

5.9 Conclusion

The testing stage was essential in confirming the recycling game's usability, dependability, and instructional value. From the chatbot integration to the “Sort It Out” mini game, every system component was evaluated for accuracy, responsiveness, and user engagement using a combination of functional testing, user observation, and input from young learners.

The tests verified that the main game features such as chatbot support, crafting flow, quiz progression, and sorting logic, all worked as planned on desktop and mobile devices. Usability, clarity, and the overall player experience all improved as a result of the methodical resolution of minor bugs found during development.

Additionally, user testing showed that the game's interactive style successfully and kid-friendly communicated recycling concepts. Through practical instruction and individualized support, players were able to finish tasks on their own, navigate the interface with ease, and retain environmental knowledge.

In conclusion, the testing results show that the system accomplished its technical and instructional goals. The game was both entertaining and educational, providing a smooth fusion of learning and gameplay that encourages environmental consciousness in an enjoyable and participatory manner. This chapter offers a solid basis for upcoming improvements and attests to the project's readiness for wider distribution.

5.10 Chapter Summary

Chapter 5 presented the testing and evaluation of the Recycling Heroes game prototype. 10 Year 6 students participated in the study, which used a mixed-methods approach. The System Usability Scale (SUS), User Experience Questionnaire (UEQ), and Educational Effectiveness Questionnaire (EEQ) were used to collect quantitative data, and open-ended survey questions were used to collect qualitative input. The findings showed positive learning outcomes (EEQ avg. 4.7/5), high usability (SUS score: 87.0), and strong user satisfaction (UEQ scores $\geq$ 6.0). Three main themes emerged from the thematic analysis of open-ended responses: learning and comprehension, engagement and enjoyment, and recommendations for enhancement. These results confirmed the game's efficacy as a useful teaching tool and an entertaining tool. The feasibility of gamified AI-assisted learning in elementary science education was affirmed in the chapter's conclusion.

CHAPTER 6

CONCLUSION

6.1 Overview

This chapter describes potential future improvements and provides an overview of the main results attained during the creation of the educational Roblox game Recycling Heroes. The project's goal was to create and execute an interactive, gamified learning environment that uses quests, mini-games, and real-time chatbot support to teach elementary school pupils about recycling concepts. The game was successfully developed and tested with actual users by utilizing Lua scripting, Roblox Studio, and Gemini-powered chatbot integration through Flask and Replit.

6.2 Conclusion

The Recycling Heroes game serves as an example of the viability and efficacy of employing a game-based approach to encourage environmental education in young students. The game blends meaningful learning objectives with entertaining gameplay elements, like crafting activities, NPC-driven quests, quizzes, and sorting mini-games. Roblox APIs including DataStoreService, Players, and GUI services were used to implement and integrate core systems like the item sorting logic, real-time quest tracking, and personalized chatbot guidance.

Through a middleware server, the chatbot system was successfully connected, allowing for smooth communication with the Gemini API to support contextual learning. Students could ask for assistance and get AI-generated answers in real time based on how far along they were in the game.

The System Usability Scale (SUS), User Experience Questionnaire (UEQ), Educational Experience Questionnaire (EEQ) and open-ended questions were among the structured tools used to assess system usability. The findings showed a high level of educational impact, engagement, and usability. Every game element operated dependably on both desktop and mobile platforms, according to functional testing. While user feedback pointed out areas for improvement, like more quest content and improved touch input, it also highlighted strengths, like the user-friendly interface, educational value, and motivating game loops.

All things considered, the project met its main goals of providing a worthwhile and entertaining educational experience. It shows how recycling can be taught in an engaging and interactive way by combining gamification and AI-driven support.

6.3 Future Work

Although Recycling Heroes' current iteration achieved its objectives, there are still several chances to improve and broaden the system. Expanding the content is one of the main areas that needs work. To offer a more comprehensive and in-depth environmental education experience, future iterations might cover additional recycling subjects like composting, e-waste, and upcycling. New quests, challenges, and crafting recipes might accompany this.

Adaptive learning mechanisms are another improvement. The system could modify quiz difficulty or chatbot hints to match the player's level of knowledge by monitoring student performance. Both advanced and struggling learners would benefit more from this personalization.

Enhancements to server-side data management for more seamless real-time interactions, performance tuning for mobile play, and optimization for lower-end devices are examples of technical improvements. Including text-to-speech or voice feedback in the chatbot would also make it more accessible to younger kids and people who struggle with reading.

The creation of a teacher dashboard is an important future direction. Teachers would be able to review quiz results, keep an eye on students' progress, and discover patterns in learning with this tool. Language localization and multiplayer capabilities could be added to the system to make it suitable for a wider range of user groups and classroom settings.

6.4 Chapter Summary

The creation, testing, and assessment of the Recycling Heroes game were outlined in this chapter, which also highlighted the game's effective use as a gamified learning tool for recycling instruction. The system's educational and engagement objectives were met by incorporating interactive quests, a rule-based chatbot, and real-time player feedback mechanisms.

While the future work section provided useful strategies to increase the game's scope, adaptability, and long-term impact, the conclusion highlighted the game's potential to improve environmental literacy through immersive gameplay. When taken as a whole, these thoughts lend credence to Recycling Heroes' mission as a scalable educational resource that meaningfully combines enjoyment and education.

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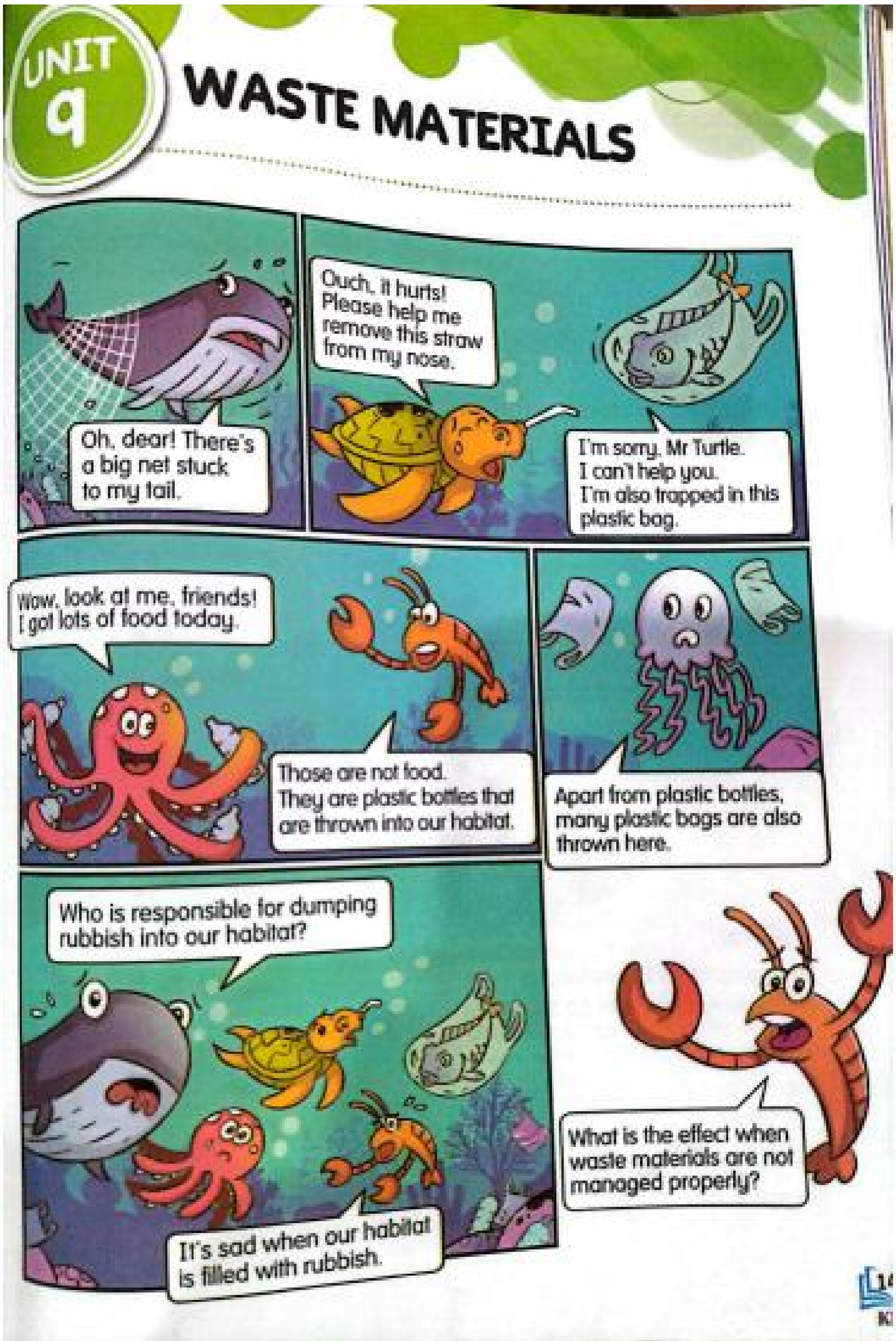
APPENDICES

Appendix A: Science Year 6 Textbook

This project will focus on Waste Management topic



Managing Waste Materials

A lot of garbage is thrown away every day. Garbage is a type of waste material.

Waste materials are materials that we no longer need and want to keep. Waste materials can be categorised based on their types.

Glass

Examples of glass waste are glass bottles and drinking glasses.

Metal

Examples of metal waste are aluminium, cans, and scrap metals.

Paper

Examples of paper waste are newspapers, boxes, books, and magazines.

Faeces

Faeces is the waste matter of humans and animals.

Plastic

Examples of plastic waste are plastic food containers and plastic bottles.

Food waste

Food waste is domestic waste such as onion skin, chicken bones, egg shells, leftover vegetables, and used cooking oil.

Toxic waste

Toxic waste such as smog and chemical waste are released from vehicle workshops and industrial sectors.

Waste materials consist of glass, metals, paper, faeces, plastic, food waste, and toxic waste.

Based on the types of waste shown above, state other examples of waste materials.

Biodegradable and Non-biodegradable Waste

Jesy's father asked her to sort out the domestic waste based on the different types before throwing them into the bin. Let us follow their conversations.

Biodegradable Waste

Biodegradable waste is materials that can be decomposed by microorganisms such as bacteria and fungi. When decomposition process occurs, nutrients will be absorbed back into the soil. Biodegradable waste consists of organic materials as shown in the pictures below.


food waste


paper and boxes


dry leaves


faeces

4.1.2
4.1.3

Non-biodegradable Waste

Non-biodegradable waste is materials that cannot be decomposed by microorganisms. They will continue to be around us for a long time and will cause pollution to the environment. Non-biodegradable waste consists of materials as shown in the pictures below.


plastic


metals


glass


toxic waste

FUN ACTIVITY Biodegradable and Non-biodegradable Waste

Group Activity

Apparatus and materials: glue, cardboard, scissors, pictures of waste materials, Internet access, computer, printer

Be careful when using scissors.

Steps:

1. Find and download pictures of waste materials using the Internet.
2. Print the downloaded pictures of the waste materials.
3. Observe each picture.
4. Identify the types of biodegradable and non-biodegradable waste materials.
5. Present the work of your group creatively.

Questions:

1. What are the biodegradable and non-biodegradable waste that can be identified?
2. What do biodegradable and non-biodegradable waste mean?

Uses of Biodegradable and Non-biodegradable Materials

The latest development of technology has produced various products made of biodegradable and non-biodegradable materials. We need to use biodegradable and non-biodegradable materials wisely.

Biodegradable Materials

152 9.1.4


Non-biodegradable Materials
Why do we need to use non-biodegradable materials wisely?
Do you need a straw?
Oh, there's no need. Thank you.
How do we reduce the use of non-biodegradable materials to avoid environmental pollution?
Flash floods are happening more frequently in this city.
Maybe the drains in our city are clogged.
SHOPPING MALL
How do non-biodegradable materials contribute to flash floods?

National News

Pollution in Kim Kim River

PASIR GUDANG: The illegal dumping of chemical waste into the Kim Kim river by factories has caused serious pollution.

The pollution has caused the river water to change colour, produce bad odour, and also kill aquatic lives.

These chemical waste also released toxic fumes which caused more than 100 people living around the Kim Kim river to be hospitalised. The victims suffered from shortness of breath from inhaling the toxic gases.

How do non-biodegradable materials affect human health?

Based on your understanding, summarise the purpose of using biodegradable and non-biodegradable materials wisely.

SCIENCE INFO

Non-biodegradable materials such as plastic bottles can be recycled into new products such as clothing. The bottles are collected, cleaned, and later sorted according to their colours. Clear plastic bottles can be recycled into white threads. Green plastic bottles can be recycled into green threads.

The bottles are crushed into smaller pieces and processed into plastic fibres. The plastic fibres are spun into plastic yarns. The plastic yarns are woven into fabric. To make a shirt, only eight plastic bottles are needed.

FUN ACTIVITY Classifying Waste Materials

Apparatus and materials: A4 paper, flip chart paper, coloured pencils

Steps:

1. Observe the waste materials that are thrown out from your house for one week.
2. Record your observations in the table.

Waste material	Type of material	Quantity of waste material	
		Biodegradable	Non-biodegradable
Total			

3. Based on the data collected, discuss the results of the observations in your group.
4. Classify the waste materials into biodegradable and non-biodegradable.
5. Make a classification chart on the flip chart paper.
6. Plan ways to reduce each waste material wisely.
7. Present the result of your discussion to the class.

Questions:

1. What is the most discarded material within one week?
2. How do you classify the biodegradable and non-biodegradable waste?
3. How can you reduce each waste wisely?
4. Explain proper waste management. Give examples.

Proper Ways of Waste Management

A planned and proper waste management needs to be carried out to reduce the harmful effects to the environment. This also ensures a sustainable life for the future generations.

Waste materials should be wrapped and tied up properly in plastic bags before disposal. This can help to prevent waste materials from being exposed to pests such as rats and flies that carry diseases.

Waste materials such as leftover food can be decomposed and made into compost fertiliser.

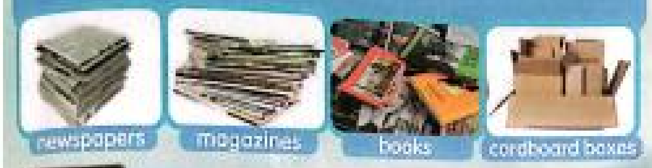

I'm using a special container to dispose oil waste.
Use special containers to dispose waste materials such as oil waste.
I sort out the waste materials according to their types.
Waste materials must be sorted out according to their types to ease the disposal process.
I will donate these items.
Waste materials that are in good condition can still be used and can be donated to those in need.
My father made this swing using a used tyre from a lorry.
I used old newspapers to make this kite.
Waste materials can be reused for different purposes.
157
KPM


RECYCLING CENTRE
We need to sort out the waste materials before sending them to the recycling centre.
Waste materials can be recycled into new products.
We can save money by repairing any damage on our own.
Repairing faulty equipment can save money.
Would you prefer a plastic bag?
Oh, there is no need. I'm using a reusable bag.
CASHIER
Reusable bags can be used to reduce waste such as plastic bags.
How does your neighbourhood conduct waste management? Suggest more sustainable ways to manage waste.
158

What are the types of waste that can be disposed into the recycling bins?

Waste materials can be sorted out using recycling bins as shown in the pictures.

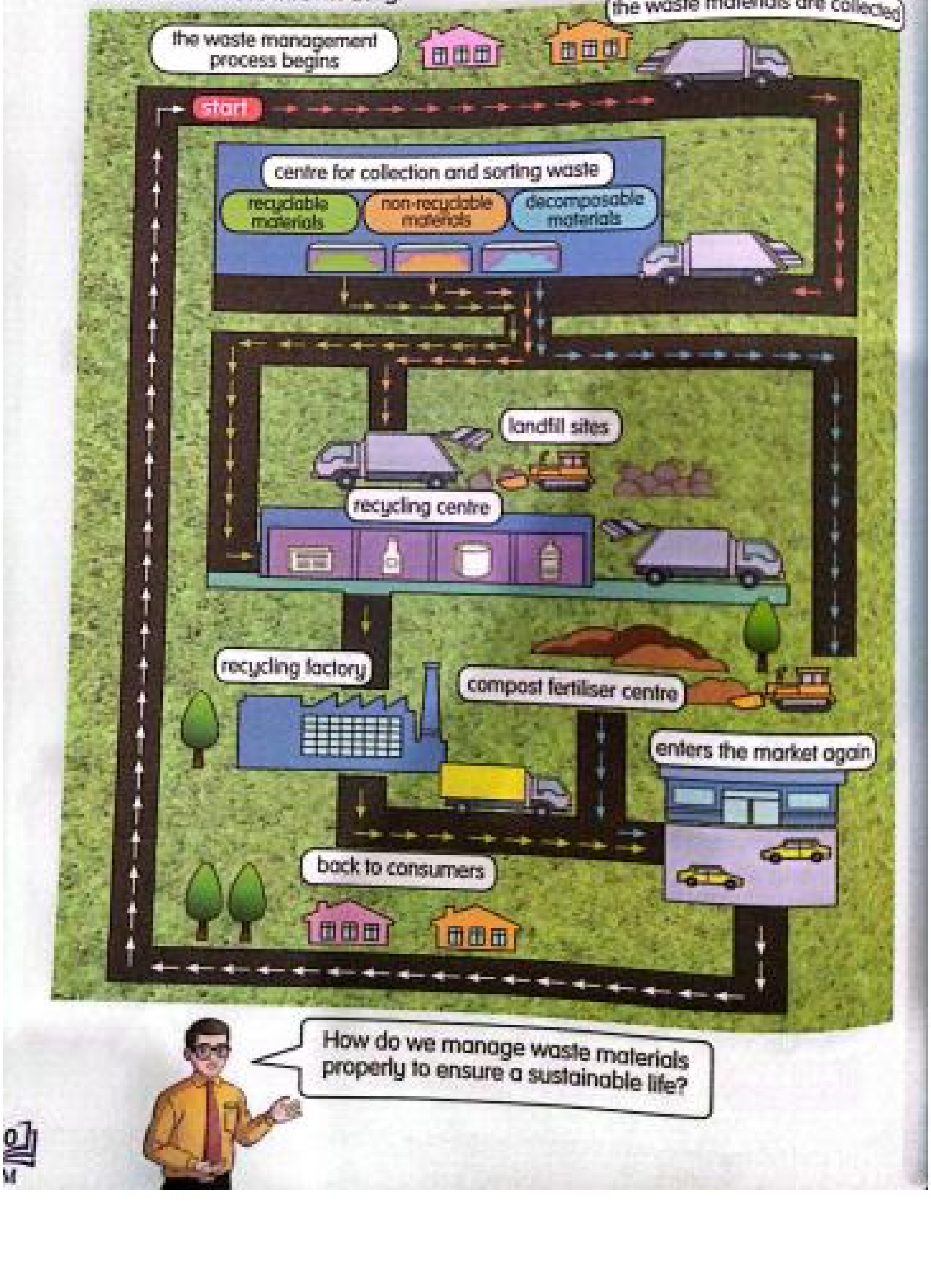
The blue recycling bin is used to dispose waste materials that are made of paper. Examples of waste materials that can be disposed into this bin are as follows.



The brown recycling bin is used to dispose waste materials that are made of glass. Examples of waste materials that can be disposed into this bin are as follows.

The orange recycling bin is used to dispose waste materials that are made of aluminium, steel, and plastic. Examples of waste materials that can be disposed into this bin are as follows.

Proper ways of waste management is also under the responsibility of the local municipal authority. Let us understand the process of managing waste materials that are thrown daily.



FUN ACTIVITY 5R Project (Reuse, Reduce, Recycle, Repair, Refuse)

Group Activity

21st Century Learning Skills

Apparatus and materials: camera, computer, printer, scissors, glue, pencils, paper, coloured pencils, manila cards

Steps:

Be careful when using scissors.

1. The table below shows the 5R Project that will be carried out by your class.

5R activity	Description
Reduce	reduce waste materials
Reuse	reuse waste materials
Recycle	recycle waste materials
Repair	repair materials that can become waste
Refuse	refuse materials that can cause waste

2. The leader of each group chooses one 5R activity by voting. The chosen activity will be carried out by the group.
3. Plan each task to be carried out during the activity. For example, the group members can carry out a recycling activity by collecting waste materials near their school and neighbourhood to be recycled. Examples of waste materials that can be collected include aluminium cans, paper, and plastic bottles.
4. Carry out the 5R activities for one week.
5. Take pictures while carrying out the activity.
6. Print and paste the pictures on a manila card.
7. Present the results of the activity creatively.

Questions:

1. Give a suggestion to improve the awareness of 5R practices among your friends.
2. State the effects of improper waste management to the environment.

FUN SCIENCE

Compost Fertiliser

Make compost fertiliser using water, soil, and biodegradable waste such as leftover vegetables, egg shells, banana peels, newspapers, and dry leaves. Prepare a special container to place the compost fertiliser.

Steps:

1. 

Make a hole at the bottom of a flowerpot.

2. 

Cut the biodegradable waste into small pieces.

3. 

Put in the soil as the first layer.

4. 

Put in the biodegradable waste as the second layer.

5. 

Put the soil and biodegradable waste alternately until all the materials are used up.

6. 

Spray some water onto the mixture every day.

7. 

Make sure the container is covered after the water is sprayed.

8. Leave the mixture in the container. Stir it once a week until all the materials are decomposed into compost fertiliser.

compost fertiliser

MIND REFLECTION

1. Waste materials are materials that we no longer need and want to keep.
2. The seven types of waste materials are as follows:
   - glass
   - plastic
   - metal
   - food waste
   - paper
   - toxic waste
   - faeces
3. Biodegradable waste is materials that can be decomposed by microorganisms.
4. Non-biodegradable waste is materials that cannot be decomposed by microorganisms.
5. Examples of biodegradable waste are food waste, paper, boxes, dry leaves, and faeces.
6. Examples of non-biodegradable waste are plastic, metals, glass, and toxic waste.
7. Some of the effects of biodegradable and non-biodegradable materials if they are not used wisely are as follows:
   - Environmental pollution such as water pollution and air pollution will occur.
   - Aquatic lives die due to lack of oxygen.
   - Aquatic lives die from eating plastic that are thrown into the oceans.
   - Drains become clogged and cause flash floods.
   - Human lives become threatened by the disposal of toxic waste.
8. Some proper ways of waste management to ensure a sustainable life are as follows:
   - Waste materials should be wrapped and tied up properly in plastic bags before disposal.
   - Waste materials such as leftover food can be decomposed and made into compost fertiliser.
   - Use special containers to dispose waste materials such as oil waste.
   - Waste materials must be sorted out according to their types to ease the disposal process.
   - Waste materials that are in good condition can still be used and can be donated to those in need.
   - Waste materials can be reused for different purposes.
   - Waste materials can be recycled into new products.
   - Repairing faulty equipment can save money.
   - Reusable bags can be used to reduce waste such as plastic bags.

MIND TEST

Answer all questions in the Science exercise book.

1. Complete the following table by writing the examples of waste materials.

Type of waste	plastic	paper	glass	metal
Example of waste material	/	/	/	/

2. What is the meaning of:
   (a) biodegradable waste?
   (b) non-biodegradable waste?

3. The picture below shows a pile of waste by the roadside.

   (a) State the types of waste materials that can be seen in the waste pile.
   (b) Classify the waste materials above into biodegradable and non-biodegradable.
   (c) What are the effects of these waste to the environment?
   (d) Suggest ways to improve the practice of disposing these waste materials.

Appendix B: Learning Outcomes for Waste Management

Waste Management is one of the topics in Science Year 6 curriculum. The learning outcomes are:

9.0 WASTE MATERIAL				
CONTENT STANDARD	**LEARNING STANDARD**	**PERFORMANCE STANDARD**		**REMARKS**
		PERFORMANCE LEVEL	**DESCRIPTOR**	
9.1 Waste Management	Pupils are able to: 9.1.1 Identify waste materials based on the types of materials. 9.1.2 State the meaning of biodegradable and non-biodegradable waste materials. 9.1.3 Classify the waste materials into biodegradable and non-biodegradable materials. 9.1.4 Provide reasoning on the usage of biodegradable and non-biodegradable waste materials wisely.	1	State the examples of waste materials.	Notes: Examples of waste materials such as glass, paper, plastic, metal, toxic waste, leftover food and faeces. Suggested activities: (i) Produce organic fertiliser. (ii) Record and analyse waste materials discarded by oneself and plan ways to reduce them. (iii) Conduct 5R projects (Reuse, Reduce, Recycle, Repair and Refuse).
		2	Classify the waste materials into biodegradable and non-biodegradable materials.	
		3	Explain through examples the proper ways of waste management.	

CONTENT STANDARD	LEARNING STANDARD	PERFORMANCE STANDARD		REMARKS
		PERFORMANCE LEVEL	DESCRIPTOR	
	9.1.5 Describe proper ways of waste management for sustainable life. 9.1.6 Explain the observations of waste management through written or verbal forms, sketches or ICT in a creative way.	4	Summarise the uses of biodegradable and non-biodegradable waste materials wisely.	
		5	Generate ideas on the effects of improper waste disposal.	
		6	Communicate creatively and innovatively one's role in managing waste materials in the environment for a sustainable life.	

Appendix C: System Usability Scale (SUS) Items

Please rate the following statements based on your experience with the Recycling Heroes game prototype. Choose one option for each statement, where:

1 = Strongly Disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly Agree

1. I think that I would like to play this game frequently.

   [1][2][3][4][5]

2. I found the game unnecessarily complex. *(Reverse-scored item) *

   [1][2][3][4][5]

3. I thought the game was easy to use.

   [1][2][3][4][5]

4. I think that I would need assistance to play this game. *(Reverse-scored item) *

   [1][2][3][4][5]

5. I found the various features in this game well integrated**.**

   [1][2][3][4][5]

6. I thought there was too much inconsistency in this game**.** *(Reverse-scored item) *

   [1][2][3][4][5]

7. I would imagine that most people would learn to play this game very quickly.

   [1][2][3][4][5]

8. I found the game very cumbersome to play. *(Reverse-scored item) *

   [1][2][3][4][5]

9. I felt very confident when playing this game.

   [1][2][3][4][5]

10. I needed to learn a lot of things before I could get going with this game. *(Reverse-scored item) *

    [1][2][3][4][5]

Appendix D: User Experience Questionnaire (UEQ) Items

Please rate the following statements based on your experience with Recycling Heroes. Choose one option for each pair of attributes on the scale:

1 = Strongly Lean Towards Left Attribute, 7 = Strongly Lean Towards Right Attribute

1. Annoying [1 2 3 4 5 6 7] Enjoyable
2. Not understandable [1 2 3 4 5 6 7] Understandable
3. Dull [1 2 3 4 5 6 7] Creative
4. Difficult to learn [1 2 3 4 5 6 7] Easy to learn
5. Inferior [1 2 3 4 5 6 7] Valuable
6. Boring [1 2 3 4 5 6 7] Exciting
7. Not safe [1 2 3 4 5 6 7] Secure
8. Demotivating [1 2 3 4 5 6 7] Motivating
9. Inefficient [1 2 3 4 5 6 7] Efficient
10. Confusing [1 2 3 4 5 6 7] Clear
11. Impractical [1 2 3 4 5 6 7] Practical
12. Clutter [1 2 3 4 5 6 7] Organized

Appendix E: Educational Effectiveness Questionnaire (EEQ) Items

Please rate the following statements based on your experience with the game Recycling Heroes. Choose one option for each statement, where:

1 = Strongly Disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly Agree

1. How effective do you perceive Recycling Heroes in enhancing your engagement with the topic of waste management?

   [1][2][3][4][5]

2. After using Recycling Heroes, how do you perceive its impact on improving your motivation to learn about waste management?

   [1][2][3][4][5]

3. In your opinion, how do the incorporated game elements enhance the appeal of waste management education?

[1][2][3][4][5]

4. Did you find learning about waste management to be more enjoyable and stimulating while playing Recycling Heroes?

   [1][2][3][4][5]

5. Are you willing to use Recycling Heroes in the future to further explore waste management concepts?

   [1][2][3][4][5]

Appendix F: Open-Ended Survey Questions Used in Post-Task Survey

1. How would you describe learning experience in this game? Any suggestions to make this game better?

Appendix G: Participant Responses for Survey Instruments (P1-P10)

The following tables contain individual responses from participants P1 to P10 for each questionnaire. The data is divided into 4 for each questionnaire (SUS, UEQ, EEQ and open-ended survey) for ease of understanding.

A. System Usability Scale (SUS)

Participant	Q1	Q2*	Q3	Q4*	Q5	Q6*	Q7	Q8*	Q9	Q10*
P1	5	2	4	2	4	2	5	1	5	2
P2	4	3	4	3	4	2	4	2	4	2
P3	5	1	5	1	5	1	5	1	5	1
P4	4	2	4	2	5	2	4	2	4	2
P5	5	2	5	1	4	1	5	1	5	1
P6	4	3	4	3	4	2	5	2	4	2
P7	5	1	5	2	5	1	5	1	5	2
P8	4	2	4	2	4	2	4	2	4	1

P9	5	1	5	1	5	1	5	1	5	1
P10	5	1	4	1	5	1	5	1	5	1

B. User Experience Questionnaire (UEQ)

Participant	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12
P1	6	6	6	6	6	7	7	6	6	6	6	6
P2	5	5	5	5	5	6	6	5	5	5	5	5
P3	7	7	7	6	7	7	7	6	6	6	6	7
P4	6	6	6	6	6	6	7	6	6	6	6	6
P5	7	6	6	6	6	7	7	7	6	6	6	6
P6	6	6	6	6	6	7	6	6	6	6	6	6
P7	7	6	6	6	6	7	7	7	6	6	6	6
P8	6	6	6	6	6	6	6	6	6	6	6	6
P9	7	6	6	6	6	7	7	7	6	6	6	6
P10	6	6	6	6	6	6	6	6	6	6	6	6

C. Educational Effectiveness Questionnaire (EEQ)

Participant	Engagement	Motivation	Appeal	Enjoyable	Reuse
P1	5	5	5	5	5
P2	4	4	4	5	4
P3	5	5	5	5	5
P4	5	5	5	5	5

P5	5	5	5	5	5
P6	4	4	4	5	4
P7	5	5	5	5	5
P8	4	4	4	5	4
P9	5	5	5	5	5
P10	5	5	5	5	5

D. Open-Ended Survey Responses

Participant	Theme	Response
P1	Enjoyment and Engagement	"I like to walk around collecting rubbish"
P2	Learning and Understanding	"I know which bin to place trash"
P3	Enjoyment and Engagement	"It's fun when I get points after recycle."
P4	Learning and Understanding	"I learned what is compost"
P5	Suggestions for Improvement	"I want more levels."
P6	Enjoyment and Engagement	"Chatbot help answer my questions."
P7	Learning and Understanding	"Now I know how to recycle paper, plastic and metal."
P8	Suggestions for Improvement	"The instructions sometimes are a little bit confusing."
P9	Enjoyment and Engagement	"I like the leaderboard. I want to be number one!"
P10	Learning and Understanding	"I know how to recycle"

Appendix H: Screenshots of Recycling Heroes Interface

1) This is the main page when player enter the game.

2) This is the game interface before quests started.

3) Player must press "E" to interact with Joe.

4) This is Joe, the NPC in charge of giving out quests.

5) The changes in game environment after receiving trash.

6) Since there is a quest ongoing, player cannot receive another quest. Ongoing quest is available at left side of the screen.

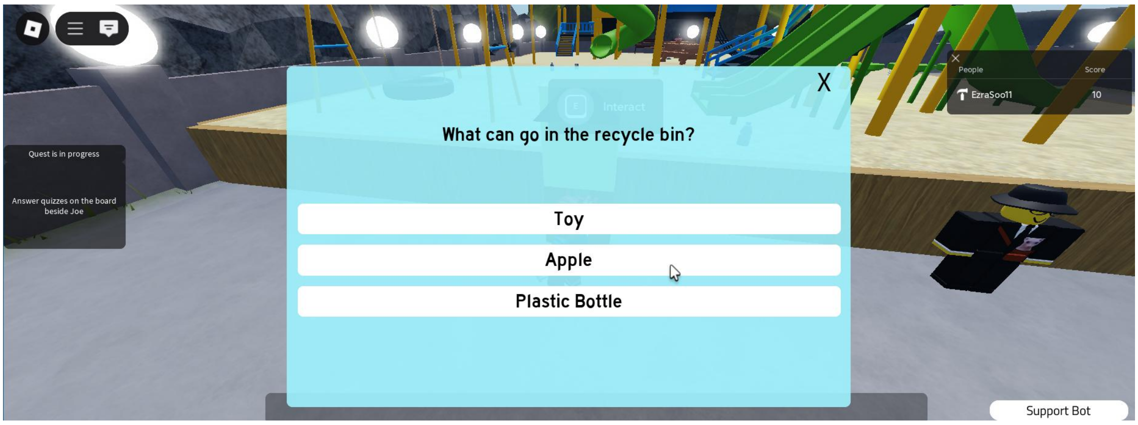
7) This is the recycling centre, where the bins are placed.

8) Popup message after player pick up any trash.

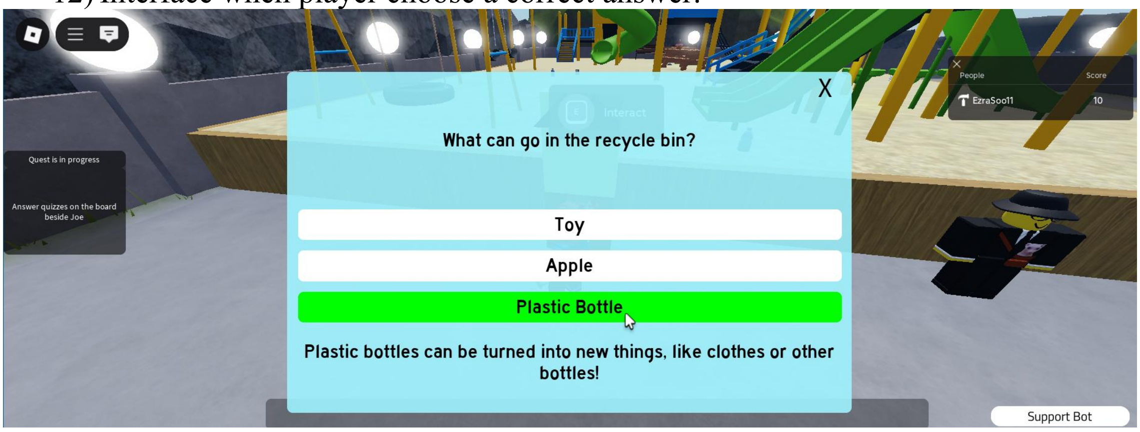
9) Popup message after player disposed in a correct bin. Player score is updated

10) Player receives next quest.

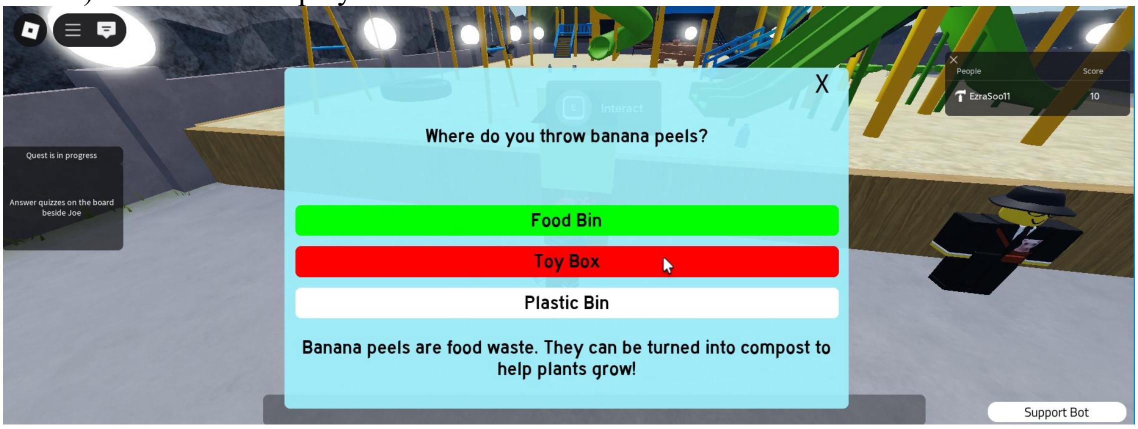
11) Quizzes interface.



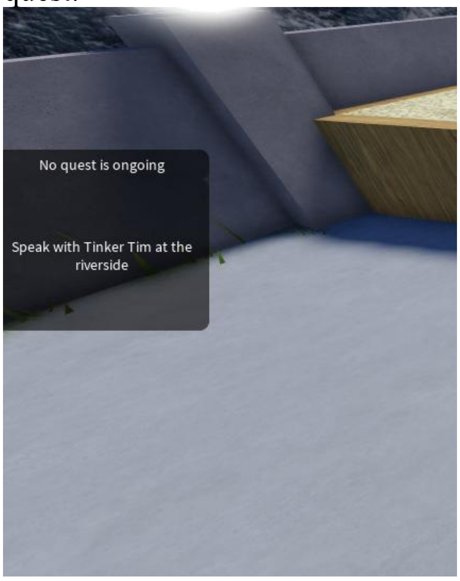
12) Interface when player choose a correct answer.



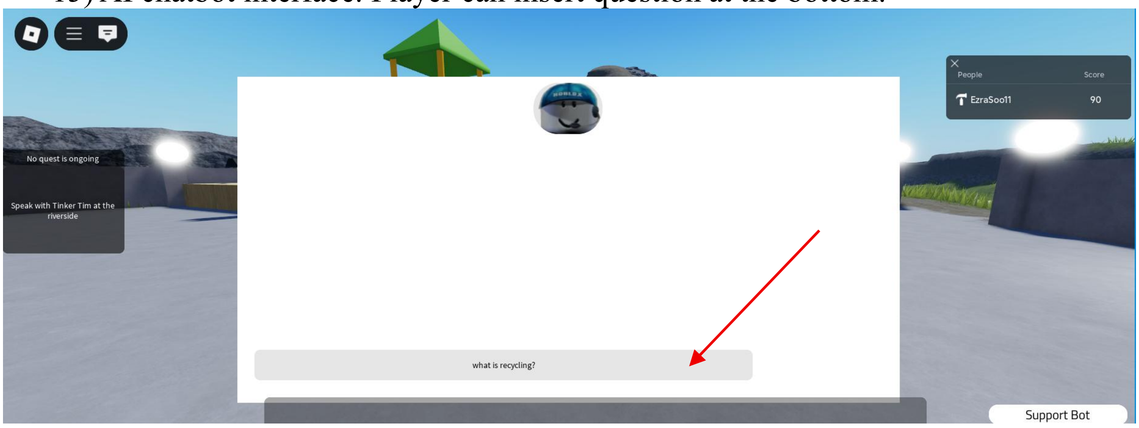
13) Interface when player choose an incorrect answer.



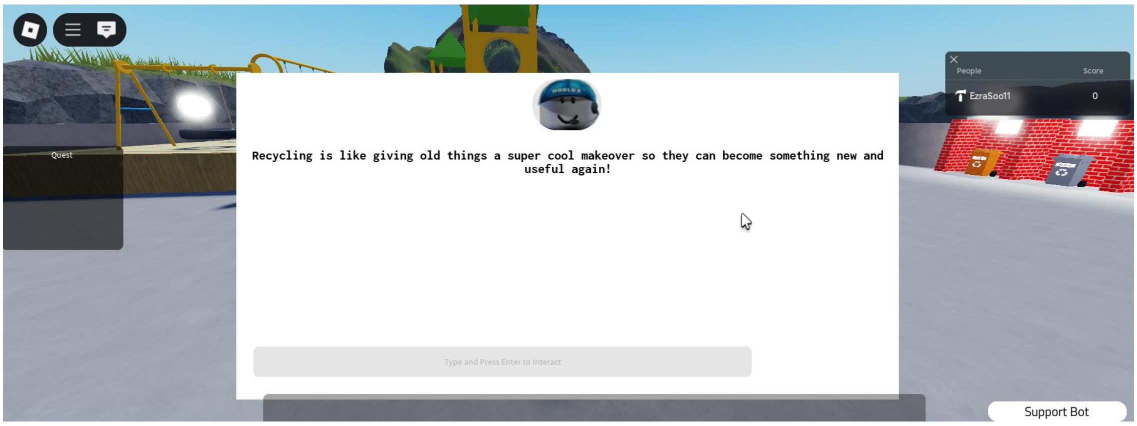
14) Player receives new quest.



15) AI chatbot interface. Player can insert question at the bottom.



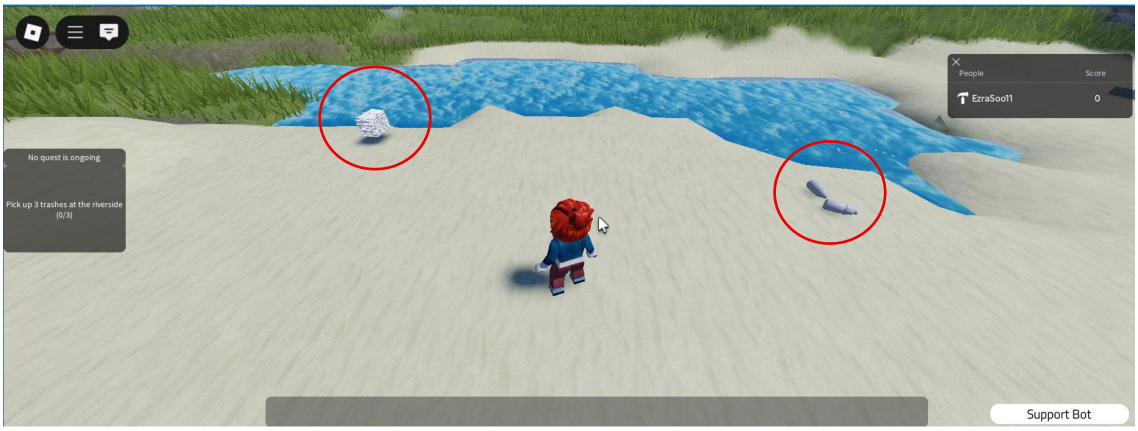
16) The answer provided by the AI chatbot.



17) This is the place where player can craft new items.

18) This is Tinker Tim and player will craft useful items here.

19) Player will have to pick up scattered trash, and craft new items.



20) By placing the recyclable items on the table, an option of new item will appear at the bottom screen.

21) Then, new item will appear.