Robotic Gamification Model for Climate Change Literacy for Green Innovation and Entrepreneurship Education

Submitted in fulfilment of the requirements of the degree of

DOCTOR OF PHILOSOPHY IN INFORMATION TECHNOLOGY

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DECLARATION

I, Stephen Ochieng Oguta, declare that this thesis submitted for the degree of Doctor of Philosophy in Information Technology at Durban University of Technology is my own original work and has not been previously submitted to any other higher institution of learning. Furthermore, the cited work from various sources such as journals, conference papers, and books are properly acknowledged by means of a comprehensive reference list.

13 August 2025

SO Oguta [redacted] --------------------------

Date

Approval for final submission

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Date

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ABSTRACT

This thesis proposes a Robotic Gamification Model for Climate Change Literacy for Green Innovation and Entrepreneurship (RGM-4-CCL4GIE) education, as a sub-Saharan Africa (SSA) contextualized innovative educational solution. Current gamification designs in educational settings often fail to sustain long-term learner motivation and engagement, in that they rely predominantly on predictable extrinsic reward schemes. While these systems can generate initial interest, they struggle to maintain engagement over time, leading to diminished learning outcomes. This challenge is particularly critical in the context of complex, evolving subjects such as climate change education, in which continuous learner involvement is essential for fostering lasting awareness and actionable outcomes. To address this gap in gamification systems design, this research proposes a RGM-4-CCL4GIE education. The model draws upon concepts from the Self-determination Theory, the Operant Conditioning Theory (OCT), and the Mechanics-Dynamics-Aesthetics (MDA) framework, to create a dynamic system that enables sustained intrinsic motivation and learner engagement. The RGM-4-CCL4GIE education incorporates a randomized badge-awarding plugin which is an intrinsic reward mechanism. This model includes interactive assessments infused with points as gamification elements, utilizing the social robot Nao to enhance learner interaction. This is particularly necessary in sub-Saharan Africa (SSA), where climate literacy is critical for mitigating the socio-economic impacts of climate change. The study employs a Design Science Research Methodology (DSR) to guide the development and validation of the model, which is prototyped on the Moodle e-learning platform and the social robot Nao (SRN). The system's gamification components such as points, badges, and dynamic rewards are integrated into both desktop and robotic platforms to foster sustained intrinsic motivation and long-term engagement in climate-change literacy and green-innovation entrepreneurship. The RGM-4-CCL4GIE was evaluated with 20 university students, revealing enhanced sustained intrinsic motivation (mean score of 4.58) and long-term engagement (95%). The evaluation data reflected strong positive perceptions, with all subscales (motivation, user engagement, perceived usefulness, perceived ease of use, aesthetics) scoring above 4 (on a 5-point scale), showing significant differences from the neutral point ($p<.001$) and large effect sizes (Cohen's $d > 1.77$). Individual items reflected high agreement on motivation (e.g., "inspires me to continue training", $M=4.75$), engagement (e.g., random badges, 95% agreement, $p < 0.001$), usefulness (e.g., understanding climate change, 75% strongly agree), ease of use ($M=4.65$), and aesthetics (NAO robot, 95% agreement). Expert evaluation ($n=11$) further validated the system, with strong ratings for gamification elements (means 4.27-4.55),

Carbon Literacy content (4.45-4.64), and HCI (4.27-4.64), although navigation showed slightly more varied opinions (SD=0.78). These findings demonstrate the RGM-4-CCL4GIE's potential to address limitations of existing gamification systems by promoting sustained motivation and engagement, thus achieving learning outcomes.

In offering the innovative approach that combines robotics and gamification with motivational theories, this research contributes to the advancement of educational gamification. The study shows how the theories are combined to generate the robotic gamification theoretical framework, with specific relevance to climate change education. The study not only bridges gaps in current gamification systems but also provides a foundation for future research into sustainable, technology-driven learning models. Through its integration of robotic interaction, random rewards, and motivational frameworks, the RGM-4-CCL4GIE offers a new approach to educational gamification, particularly in addressing the challenges of sustained motivation and long-term engagement in climate-change education.

RESEARCH OUTPUTS FROM THE THESIS

Refereed Journal Articles

1. Oguta, S., Ojo, S., & Maake, B. (2024). A Robotic Gamification Model for Climate Change Literacy for Green Innovation and Entrepreneurship in sub-Saharan Africa. *International Journal of Computing Sciences Research*, *8*, 2905-2932.
2. Oguta, S., Ojo, S. and Maake, B., 2025. Prototype Implementation of a Robotic Gamification Model for Climate Change Literacy for Green Innovation and Entrepreneurship with Social Robot Nao. *Journal of Computing Sciences Research*, *9*, pp.3491-3523.
3. Oguta, S., Ojo, S. and Maake, B. (2024). Robotic Gamification Frameworks and Models for Sustained Educational Engagement and Motivation: A Systematic Literature Review Article ID: HELIYON-D-23-44759R3. Accepted for publication in Heliyon Elsevier journal.

Refereed Conference Papers

4. Oguta, S., Akinyinka, A., Ojo, S. and Maake, B. (2023). The Constraints of The Adoption of Gamification for Education and Training in Higher Education Institutions: A Systematic Literature Review. In: Proceedings of the *2023 International Conference on Artificial Intelligence, Big Data, Computing and Data Communication Systems (icABCD)* 3-4 Aug. 2023, 1-6.
5. Oguta, S., Ojo, S. and Maake, B. (2024). Concepts, Components, Frameworks and Limitations of Gamification: Systematic Literature Review Paper presented at the *19th Iberian Conference on Information Systems and Technologies*. University of Salamanca, Spain, 25th and 28th of June 2024, IEEE.
6. Oguta, S., Ojo, S. and Maake, B. (2025). Expert Analysis of a Robotic Gamification Training Model for Climate Change Literacy for Green Innovation and Entrepreneurship. Accepted for the *52st International Conference on Computers and Industrial Engineering (CIE51)*, Sydney Australia, Under review

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ACRONYMS

Acronym	Full Meaning
CCL4GIE	Climate Change Literacy for Green Innovation and Entrepreneurship
DSR	Design Science Research Methodology
GIE	Green Innovation and Entrepreneurship
IPCC	Intergovernmental Panel on Climate Change
MDA	Mechanics, Dynamics and Aesthetics
OCT	Operant Conditioning Theory
RGM	Robotic Gamification Model
SSA	Sub-Saharan Africa
SDT	Self-Determination Theory
SLR	Systematic Literature Review
TAM	Technology Acceptance Model
HCI	Human-Computer Interaction
ISSN	International Standard Serial Number
HTML	Hypertext Markup Language
CSS	Cascading Style Sheets
UTAUT	Unified Theory of Acceptance and Use of Technology
PU	Perceived Usefulness
PEOU	Perceived Ease of Use
SE	Skills Engagement
IE	Interaction Engagement
TRA	Theory of Reasoned Action
LMS	Learning Management System
AE	Aesthetic Experience
EI	Emotional Impact
VA	Visual Appeal
AP	Auditory Pleasure

CHAPTER ONE: INTRODUCTION

1.1 Background and Motivation

Climate change presents an urgent global challenge in the 21st century, with devastating implications for sub-Saharan Africa (SSA). The region's vulnerability stems from its geographical location, socio-economic conditions, and heavy reliance on climate-sensitive sectors such as agriculture (MAHAT, 2020; Vázquez-Vílchez, 2021). Recent data has highlighted the urgency of the situation: between 1960 and 2020, the average annual temperature in SSA increased by 0.3°C per decade, with some areas experiencing even more rapid warming (Engelbrecht et al., 2015). This trend of increasing temperatures has correlated with a rise in the frequency and severity of extreme weather phenomena, including droughts and floods, which have profoundly destabilized the region's food security and economic systems.

The impact of climate change on SSA is not merely theoretical but has manifested in very real and devastating ways. In 2022, the Horn of Africa experienced its worst drought in 40 years, affecting over 36 million people across Ethiopia, Kenya, and Somalia (Halakhe, 2022). This drought led to widespread crop failures, livestock deaths, and human displacement, underscoring the direct link between climate change and human welfare in the region. Similarly, in Southern Africa, countries such as Zambia and Zimbabwe have faced recurrent droughts, with the 2019 drought leaving 45 million people food-insecure (Wudil et al., 2022). The economic impact of climate change in SSA has been equally significant. A World Bank report estimated that by 2050, climate change could cost the region $50 billion annually, or 2-4% of Gross Domestic Product (Lomborg, 2020). This economic burden is of particular concern given that SSA countries are among the least responsible for global greenhouse gas emissions, contributing only 4% of the global total, despite making up 17% of the world's population (Lomborg, 2020).

In this context, climate-change literacy has become crucial for fostering informed decision-making, promoting adaptive strategies, and driving mitigation efforts. Climate-change literacy encompasses not only knowledge and awareness but also the capability to comprehend and address climate-related issues. This literacy involves understanding scientific insights into climate systems. However, promoting climate-change literacy within SSA has presented considerable challenges.

Traditional educational methods have struggled to maintain learners' engagement and motivation over extended periods, particularly when dealing with complex and evolving subjects(Hilario et al., 2022; Lu et al., 2023). The challenge not only occurs in SSA, but is particularly acute in the region due to resource constraints and competing educational priorities. In response to these challenges, innovative approaches to education have emerged, with gamification showing particular promise. Gamification, defined as the integration of game-like features into activities outside traditional gaming environments, has emerged as a recognized educational approach for tackling issues related to learner engagement and motivation (Lu et al., 2023). However, current gamification designs used in education fail to achieve long-term motivation, and engagement towards achieving sustained learner outcomes (Gené, 2014; Porto, 2021; Šćepanović, 2015). The intersection of gamification and robotics in education presents an innovative approach to addressing the challenges of sustained engagement and motivation in climate-change education.

A systematic literature review (SLR) conducted as part of this research, analysing 19 studies published between 2018 and 2023, revealed that 90% of the articles concluded that the incorporation of gamification and robotics in learning environments led to increased learner motivation, engagement, and enthusiasm (Madariaga et al., 2022). Two studies in this review, however, concluded that robots did not increase motivation (Donnermann, 2021). This research sought to establish whether or not robotics add motivation. Furthermore, SLR also highlighted significant gaps in the current research landscape. Notably, there was a scarcity of studies focusing on the application of robotic gamification in climate-change education, particularly in the context of sub-Saharan Africa. While mathematics and science were the most frequently addressed subjects in robotic gamification applications in this study (47% of selected publications), there was a significant gap in research related to climate-change literacy (Vrochidou et al., 2018). The geographical disparity in research was also evident, with the majority of studies conducted in Europe (23.8% in Spain alone) and Asia, and a notable absence of research from African contexts (Hilario et al., 2022).

To address these gaps, this research developed a Robotic Gamification Model and prototype-implemented and validated it as a system, for Climate Change Literacy for Green Innovation and Entrepreneurship (RGM-4-CCL4GIE) Education application. The implementation incorporated the robot and gamification principles, aiming at increasing continued intrinsic motivation, engagement towards achieving learning outcomes, and the development of actionable solutions among learners. At the intersection of these challenges lies the concept of green innovation and entrepreneurship (GIE), which highlights the creation of environmentally sustainable solutions and business opportunities. GIE emphasizes the integration of innovation with environmental stewardship, promoting practices that mitigate climate change while fostering economic growth. For SSA, this approach holds significant potential to address climate-related challenges while advancing youth employability, empowering communities, and driving sustainable development (BC-IAU, 2024). This research situates itself at the convergence of these critical themes—climate-change literacy, robotic gamification, and green innovation and entrepreneurship. By exploring how gamified robotics can transform climate-change education, this study seeks to contribute to sustainable learning that not only informs but also inspires learners to act as agents of change.

The study utilized a Design Science Research Methodology (DSR) with the research process involving model design through theoretical and mathematical processes, prototyping the desktop module mode of the model on the Moodle e-learning platform, initially without the social robot Nao, thereafter, integrating the SRN. The prototype featured gamified learning content, assessment and random-badge plugin designed and implemented in the Moodle e-learning platform, as well as the incorporation of the Nao robot, which enhanced the aesthetic appeal and engagement in the learning process. The model was grounded on a combination of the SDT, OCT and MDA) framework, besides the mathematical modelling (Donnermann, 2021; Donnermann et al., 2021; Heljakka et al., 2020).

This research involved model validation by conducting training sessions using the prototyped RGM-4-CCL4GIE system, thereafter, empirically evaluating its effectiveness. A total of 20 students from diverse academic backgrounds at the Durban University of Technology (DUT) participated in the training. The evaluation phase, crucial in assessing the model's impact, utilized a survey based on the Technology Acceptance Model (TAM) framework, which has been widely used and validated in technology adoption studies ((Schez-Sobrino et al., 2020; Marangunić and Granić, 2015).

This study addresses the research gap in current gamification designs, which often fail to sustain learner motivation and engagement due to their reliance on predictable extrinsic rewards. By focusing on intrinsic motivation through design and implementation of robotic gamification, the research aims to develop more effective CCL education strategies. As SSA continues to grapple with the increasing impacts of climate change and massive youth employability, innovative approaches such as the one developed in this research may play a crucial role in fostering a more informed, engaged, and proactive citizenry capable of addressing the complex challenges of our changing world, thus driving sustainable development in the region.

1.2 Research Problem Statement

Current educational gamification designs lack ability to sustain learner motivation and engagement towards achieving learning outcomes, because they predominantly rely on predictable extrinsic reward schemes (Dah et al., 2023; Dichev & Dicheva, 2017; Xu et al., 2021). While these systems initially boost engagement, they often fail to maintain long-term user interest and motivation, ultimately falling short in achieving learning outcomes (Dichev & Dicheva, 2017; Xu et al., 2021). This issue is particularly critical in complex, evolving subjects such as climate-change education, in which continuous engagement is crucial for fostering lasting awareness and action towards learning outcomes. Various researchers have attempted to address the motivation and engagement decline in educational gamification designs through adaptive difficulty mechanisms (Oliveira et al., 2023), narrative-based approaches (Chen et al., 2023), and personalized learning pathways (Lu et al., 2023). However, these solutions often maintain the same extrinsic reward structures that become predictable over time, leading to diminishing returns in motivation (Darmawansah et al., 2023). To bridge this gap, this study proposes a RGM-4-CCL4GIE that integrates SDT, OCT and MDA framework (Donnermann, 2021; Donnermann et al., 2021; Heljakka et al., 2020). The model incorporates random reward mechanisms and intrinsic motivational elements, aiming to infuse long-term engagement and thus to improve learning outcomes. This research develops, implements, and validates the RGM through theoretical and architectural frameworks, mathematical modelling, prototyping, and practical implementation, focusing on CCL4GIE education in sub-Saharan Africa (Donnermann, 2021) as the application domain. By addressing the limitations of conventional educational gamification systems, this study seeks to contribute to the field of computing and human-computer interaction through new gamification architectures and interaction paradigms, while providing valuable spin-off benefits to climate-change literacy education and pedagogical approaches.

1.3 Thesis Statement:

A Robotic Gamification Model for Climate Change Literacy for Green Innovation and Entrepreneurship (RGM-4-CCL4GIE) education, using the social robot Nao, random badge awards, points, and leaderboards, will enhance sustained intrinsic motivation and engagement, to achieve learning outcomes.

1.4 Research Questions and Objectives

1.4.1 Research questions

1. What are the requirements for a robotic gamification model for an SSA contextualized Climate Change Literacy for Green Innovation and Entrepreneurship (CCL4GIE) education that enhances sustained learner motivation and long-term engagement to achieve learning objectives?
2. How can a robotic gamification model based on a combined SDT, OCT, and MDA framework with mathematical modelling of gamification elements, be developed, to address the design needs, contextual factors, and challenges related to learner motivation and sustained engagement in CCL4GIE education within SSA context?
3. How can the robotic gamification model be prototype-implemented for an SSA contextualized CCL4GIE education?
4. How can the robotic gamification model prototype be validated in terms of sustained motivation and long-term engagement?

1.4.2 Research objectives

1. To critically assess the requirements for a robotic gamification model for an SSA contextualized CCL4GIE education that enhances sustained learner motivation and long-term engagement to achieve learning objectives.
2. To develop a robotic gamification model based on a combined SDT, OCT, and MDA framework with mathematical modelling of gamification elements, to address the design needs, contextual factors, and challenges related to learner motivation and sustained engagement in CCL4GIE education within SSA context.
3. To implement the robotic gamification model prototype for an SSA contextualized CCL4GIE education.
4. To empirically validate the model for sustained motivation and long-term engagement to achieve learning outcomes.

1.5 Methodology Overview

The Design Science Research Methodology (DSR) used in this study is structured into six phases to systematically address research questions and deliver evidence-based outcomes. Phase one identifies the problem using a systematic literature review (SLR) to highlight gaps in existing gamification models, particularly the need for sustained learner motivation in climate change education. Phase two defines objectives and research questions refined through further synthesis. In phase three, a theoretical framework—drawing from Self-Determination Theory, Operant Conditioning Theory, and the MDA framework—is developed to guide model design, incorporating mathematical modeling and architectural frameworks for both desktop and semi-humanoid robot systems. Phase four involves prototyping the RGM-4-CCL4GIE system, while phase five focuses on evaluation through pilot testing, using TAM-based surveys and statistical analysis to assess engagement and effectiveness. Phase six communicates the findings through scholarly publications and presentations, contributing to both academic knowledge and practical advancements in robotic gamification for climate change literacy.

1.6 Thesis Contributions to Knowledge

1.6.1 Thesis Contributions to Knowledge

1. Contribution to Theory: The study introduces a novel Robotic Gamification Model for Climate Change Literacy for Green Innovation and Entrepreneurship (RGM-4-CCL4GIE), grounded in a robust theoretical foundation. This model uniquely integrates Self-Determination Theory (SDT), Skinner's Operant Conditioning Theory (OCT), and the Mechanics-Dynamics-Aesthetics (MDA) Framework to inform the design of gamified learning systems. By harmonizing intrinsic and extrinsic motivation with game design elements, the model advances the theoretical understanding of sustained learner motivation and engagement in climate-change education. The originality of this contribution lies in the structured fusion of psychological and game-based frameworks into a cohesive, adaptable model, offering a theory-driven basis for educational gamification.
2. Contribution to Methodology: The research contributes a hybrid methodological framework that integrates mathematical formalization, iterative design, robotic prototyping, and mixed-methods validation. The mathematical component introduces formal equations to quantify gamification variables, including random badge allocation (via probability theory), point aggregation (competence accrual), and aesthetic impact (through weighted values), as shown in Equations 2, 3, 5–7, and 11. This enables data-driven optimization of learner engagement mechanisms. Additionally, the methodological design incorporates principles of human-computer interaction and robotics into an educational context.

3. Contribution to Practice: This study demonstrates the practical utility of the RGM-4-CCL4GIE through the development and empirical validation of a functional prototype. The prototype integrates a random plugin design that enhances user interactivity and system adaptability, offering learners dynamic engagement opportunities. The validation process revealed positive indicators of sustained learner motivation and educational effectiveness in climate-change literacy initiatives. This practical contribution provides educators and educational technologists with a tangible tool and implementation framework that can be replicated or adapted for similar educational environments, particularly in under-resourced or technology-challenged regions such as Sub-Saharan Africa.

1.6.2 Scholar's Contributions

The scholar's contribution comprises articles published from the study in conference proceedings and journals, the synopsis of which is succinctly presented in this sub-section:

1.6.2.1 Refereed Conference Papers

1. Oguta, S., Ojo, S., & Maake, B. (2024). A Robotic Gamification Model for Climate Change Literacy for Green Innovation and Entrepreneurship in sub-Saharan Africa. *International Journal of Computing Sciences Research*, *8*, 2905-2932.

This article outlines the theoretical and methodological framework underpinning the proposed robotic and gamification model for college education. Furthermore, it details the model's design, mathematical underpinnings, and architectural framework. Chapters 4 and 5 of the thesis provide a comprehensive exposition of the information presented in this article.

2. Oguta, S., Ojo, S. and Maake, B., 2025. Prototype Implementation of a Robotic Gamification Model for Climate Change Literacy for Green Innovation and Entrepreneurship with Social Robot Nao. *Journal of Computing Sciences Research*, *9*, pp.3491-3523.

This article details the prototype implementation of a robotic gamification model designed to foster climate change literacy for green innovation and entrepreneurship, utilizing the social robot Nao. It outlines the specific steps undertaken to actualize this prototype within the Moodle e-learning platform and on the social robot Nao, as further elaborated in Chapter 6 of the thesis.

3. Oguta, S., Ojo, S. and Maake, B. (2024). Robotic Gamification Frameworks and Models for Sustained Educational Engagement and Motivation: A Systematic Literature Review Article ID. Accepted for publication in Heliyon Elsevier journal.

This article presents a systematic literature review of robotic gamification frameworks and models aimed at fostering sustained educational engagement and motivation. It details the current state of the art in the application of gamification and robotics within education, thereby establishing the theoretical foundation for this thesis. Further details regarding this review can be found in Chapter 3 of the thesis.

4. Oguta, S., Ojo, S. and Maake, B. (2024). Validation of a Robotic Gamification Training Model for Climate Change Literacy for Green Innovation and Entrepreneurship. *Int. J. of Computer Applications in Technology*. Under review.

This article presents the empirical validation process of the Robotic Gamification Model (RGM). It illustrates the user recruitment, experimental setup, results, analysis, and subsequent discussion. Comprehensive details regarding this validation can be found in Chapter 7 of the thesis.

1.6.2.2 Refereed Conference Papers

1. Oguta, S., Akinyinka, A., Ojo, S. and Maake, B. (2023). The Constraints of The Adoption of Gamification for Education and Training in Higher Education Institutions: A Systematic Literature Review. In: Proceedings of the *2023 International Conference on Artificial Intelligence, Big Data, Computing and Data Communication Systems (icABCD)* 3-4 Aug. 2023, 16.

This article is a Systematic Literature Review (SLR) that highlights the constraints encountered in the adoption of gamification for education and training within higher education institutions. It illustrates the problems identified in existing gamification systems currently employed in educational settings. This article served as a foundational basis for this thesis in establishing the problem statement, with further details available in Chapter 1 of the thesis.

2. Oguta, S., Ojo, S. and Maake, B. (2024). Concepts, Components, Frameworks and Limitations of Gamification: Systematic Literature Review Paper presented at the *19th Iberian Conference on Information Systems and Technologies*. University of Salamanca, Spain, 25th and 28th of June 2024, IEEE.

This Systematic Literature Review paper on concepts, Components, Frameworks, and Limitations of Gamification. It details the current state of the art in the application of gamification and robotics within education, thereby establishing the theoretical foundation for this thesis. Further details regarding this review can be found in Chapter 3 of the thesis.

3. Oguta, S., Ojo, S. and Maake, B. (2024). Expert Analysis of a Robotic Gamification Training Model for Climate Change Literacy for Green Innovation and Entrepreneurship. Accepted for the *51st International Conference on Computers and Industrial Engineering (CIE51)*, Sydney Australia 9th to 11th Dec 2024.

The article presents the empirical validation process of the Robotic Gamification Model (RGM). It illustrates the expert recruitment, experimental setup, results, analysis, and subsequent discussion. Comprehensive details regarding this validation can be found in Chapter 7 of the thesis.

1.7 Thesis Structure

This thesis presents the development, implementation, and evaluation of a novel RGM-4-CCL4GIE education. The research begins in Chapter One by introducing the critical need for innovative educational approaches in climate-change literacy, particularly in sub-Saharan Africa. Chapter Two establishes the contextual foundation by examining the context of the study, highlighting specific challenges and opportunities within this educational domain. Chapter Three conducts a comprehensive review of the state of the art, analysing existing approaches in educational gamification and robotics while identifying gaps in current research and practice. The theoretical underpinnings and methodological approach are detailed in Chapter Four, which integrates relevant frameworks to create a robust foundation for the proposed model. Chapter Five presents the novel RGM4CCL4GIE education, detailing its architecture and components. The technical implementation of this model is documented in Chapter Six, demonstrating ways in which theoretical concepts are transformed into a functional prototype. Chapter Seven presents a rigorous evaluation of the implemented system, analysing results and discussing the effectiveness of enhancing student engagement and learning outcomes in climate-change literacy education. The thesis concludes in Chapter Eight with a summary, conclusion, and recommendations for future work, synthesizing the findings, discussing implications for educational practice, and suggesting directions for further research in robotic gamification for climate-change education. This research contributes to the field by developing and validating an innovative approach that combines gamification principles with robotic technology for CCL4GIE in SSA.

CHAPTER TWO: THE CLIMATE CHANGE LITERACY FOR GREEN INNOVATION AND ENTREPRENEURSHIP CONTEXT OF THE STUDY

2.1 Introduction

This chapter explores the critical intersection of climate-change challenges, education, and innovative teaching approaches in SSA. The purpose of this chapter is to examine the current state of climate-change literacy in the region, identifying key challenges, and introducing gamification as a promising educational strategy for addressing these challenges. The chapter is structured into five main sections that build a comprehensive understanding of the topic. Section 2.2 discusses the unique climate-change challenges facing sub-Saharan Africa, highlighting the region's vulnerability to environmental shifts and the projected impacts on agriculture, water resources, and economic stability. Section 2.3 examines the current state of climate-change education in SSA, revealing concerning gaps in awareness and curriculum integration across the region. Section 2.4 introduces gamification as an innovative approach to climate-change education, exploring ways in which game-based learning methodologies can enhance engagement and knowledge acquisition despite resource constraints. Section 2.5 delves into the importance of contextualizing CCL4GIE education specifically for SSA, emphasizing the need to incorporate local knowledge systems and to address regional socio-economic realities. Section 2.6 outlines the specific requirements for developing an effective robotic gamification model for CCL4GIE education in the SSA context, addressing the first research question of this study. Finally, section 2.7 presents the CCL4GIE knowledge domain and curriculum, detailing the content delivered through Moodle and a social robot. Through this structured exploration, the chapter establishes the foundation for understanding both the challenges and opportunities in climate-change education across SSA, particularly through innovative approaches such as robotic gamification.

2.2 Climate Change in Sub-Saharan Africa

Climate change presents an unprecedented and multifaceted challenge to SSA, a region characterized by its inherent vulnerability to environmental shifts and its limited adaptive capacity. The Intergovernmental Panel on Climate Change (IPCC) has consistently identified SSA as one of the most susceptible regions to the adverse impacts of climate change (Emediegwu et al., 2022). The IPCC’s Sixth Assessment Report

(2022) projects that, under all emissions scenarios, mean surface temperatures in Africa will rise at a rate exceeding the global average, with the continent projected to experience between 1.5°C and 3°C of warming by 2050. This accelerated warming is anticipated to exacerbate existing environmental stressors, with profound and far-reaching implications for food security, water availability, economic stability, and overall human well-being across the region (Bouramdane, 2022; Emediegwu et al., 2022).

The urgency of addressing climate change in SSA is statistically evident. Agriculture, a vital sector representing around 23% of the region's GDP and employing 60% of its workforce, is significantly jeopardized by the evolving climate. Projections suggest that crop yields could decline by up to 30% by 2050 in certain areas with devastating consequences for food security and livelihoods (Bouramdane, 2022; Emediegwu et al., 2022). Water scarcity is another critical concern, with projections indicating that up to 250 million Africans could be living in areas of high-water stress by 2030, representing a substantial 180% increase from 2011 levels. The economic impact is equally alarming, with climate change potentially costing SSA up to 4% of its GDP annually by 2040 (du Plessis, 2023). These interconnected vulnerabilities highlight the urgent need for effective climate-change adaptation and mitigation strategies.

2.3 The State of Climate Change Education in SSA

Despite the pressing need for climate action, climate-change awareness and education in SSA remain alarmingly low (BC-IAU, 2024). A comprehensive study conducted by Selormey et al. (2019) across 34 African countries revealed that only 28% of respondents demonstrated familiarity with the concept of climate change. Awareness levels varied significantly across countries, ranging from a low of 9% in Mozambique to a high of 74% in Mauritius (Selormey et al., 2019). This disparity underscores the need for targeted interventions to raise awareness and improve understanding of climate change across the region (Smith et al., 2021).

Furthermore, education systems across SSA have been demonstrably slow to effectively integrate climate change into their curricula. A United Nations study found that, while 95% of the 100 countries surveyed worldwide included some mention of climate change in their national curriculum, the depth, breadth, and quality of this inclusion varied widely (Smith et al., 2021). Specifically within SSA, the situation is of particular concern: only 32% of countries had a stand-alone subject dedicated to climate change or environmental education, 58% integrated climate-change topics into existing subjects, primarily geography and science, and a significant 10% had no formal inclusion of climate change within their national curricula (Obrecht et al., 2022). This lack of comprehensive climate-change education leaves a significant gap in learners' understanding of this critical global issue.

While climate change poses serious threats to SSA, it also creates significant opportunities for job creation and economic growth, especially for the region's large youth population. The high youth unemployment rate in SSA can potentially be addressed through climate-responsive industries and green entrepreneurship (BC-IAU, 2024; World-Bank-Group, 2019). For example, renewable energy sectors such as solar and wind-power installation and maintenance continue to expand, with advancements in distributed energy systems and off-grid solutions creating localized employment hubs (IEA, 2023). Waste management and recycling industries are also evolving, with new technologies for plastic upcycling and e-waste processing generating specialized roles (UNEP, 2024). Climate-smart agriculture is becoming increasingly data-driven, requiring youth with skills in digital agriculture and precision farming to implement water-efficient irrigation systems, sustainable farming practices, and soil-health management (FAO, 2023). Additionally, ecosystem restoration projects, such as mangrove rehabilitation and reforestation, are gaining momentum, driven by carbon offset initiatives and biodiversity conservation efforts, providing opportunities for youth engagement in nature-based solutions. Green construction, utilizing sustainable building materials and energy-efficient designs, is also on the rise in urban centres, creating demand for skilled labour in areas such as green building design and installation. By transforming climate challenges into economic opportunities, SSA can simultaneously address youth unemployment, while building resilience against climate impacts, creating a positive cycle in which environmental solutions drive job creation and economic development (BC-IAU, 2024).

The effective deployment of climate change education in SSA is constrained by several fundamental challenges. It is vital to confront these obstacles to empower learners with the requisite understanding and competencies to navigate the intricacies of climate change.

- Resource Constraints**:** Limited financial resources pose a significant barrier to the development and implementation of specialized climate-change education programmes. The African Development Bank reported that SSA countries allocate an average of 4.5% of their GDP to education, compared with the global average of 4.8% (World-Bank-Group, 2019). This underfunding often translates to a lack of resources for teacher training, development of appropriate learning materials, and the integration of technology into the classroom.

- Teacher Preparedness**:** The preparedness of teachers to effectively teach climate-change topics is another critical issue. A survey conducted across ten SSA countries revealed that only 23% of science teachers felt adequately prepared to teach climate change effectively (Smith et al., 2021). This lack of confidence and expertise among educators can lead to less effective instruction, potentially reinforcing misconceptions or oversimplifying complex scientific concepts.
- Linguistic and Cultural Diversity: The region's rich linguistic and cultural diversity, with over 2,000 languages spoken, presents significant challenges in developing standardized climate-change curricula and materials. This diversity necessitates the development of culturally relevant and linguistically appropriate educational resources to ensure effective communication and understanding (Smith et al., 2021).
- Basic Literacy and Access to Technology: In a region in which basic literacy remains a significant challenge, with adult literacy rates averaging 64%, climate-change education often takes a secondary role to more immediate educational priorities. Furthermore, limited access to technology, with only 28% of the SSA population having access to the internet in 2020, further restricts the reach and effectiveness of digital educational initiatives (Emediegwu et al., 2022).

2.4 Gamification in Climate-Change Education

Despite the considerable difficulties in implementing effective climate change education in SSA, innovative strategies like gamification present encouraging avenues for progress. By applying game design elements and principles in non-game settings, gamification holds the potential to boost learner engagement, motivation, and knowledge absorption (Rajanen, 2019). As the region grapples with resource constraints, linguistic diversity, and urgent adaptation needs, gamification presents a compelling opportunity to increase engagement and enhance understanding of complex climate issues. By leveraging the power of interactive, game-based learning, educators can potentially overcome some of the traditional barriers to effective climate-change education (Douglas & Brauer, 2021). Technology, and specifically the use of robotic platforms, has the potential to further enhance climate-change literacy in SSA by providing interactive and engaging learning experiences.

2.5 SSA-Contextualized CCL4GIE Education

CCL4GIE in sub-Saharan Africa demands a fundamentally contextual approach that acknowledges the region's unique challenges and opportunities (CL4YEJC, 2023). Current educational models often fail to integrate local knowledge systems, environmental conditions, and socio-economic realities that shape climate vulnerability and resilience across SSA's diverse landscapes. Contextualization of CCL4GIE education requires moving beyond simple translation of Western educational frameworks towards a comprehensive redesign that centres African perspectives. This includes incorporating indigenous knowledge about sustainable resource management, recognizing traditional ecological practices, and addressing the specific climate adaptation needs across SSA's varied ecological zones (Douglas & Brauer, 2021). The British Council's CCL4GIE project highlighted significant gaps in higher education institutions across SSA, in which climate-change education remains peripheral despite its critical importance to regional development. The report also confirms the huge unemployment among youths in the SSA, hence the need for green innovation (BC-IAU, 2024).

Effective SSA contextualization must address several dimensions: linguistic accessibility (leveraging English as a common language while respecting multilingual contexts), technological appropriateness (designing solutions for varied infrastructure capabilities), and cultural relevance (aligning with communal learning practices and values) (Emediegwu et al., 2022). The CL4YEJC initiatives demonstrated that educational interventions are most effective when they reflect local environmental challenges and economic opportunities in green sectors. A robotic gamification approach provides a promising platform for contextualizing CCL4GIE, because it allows for interactive scenarios that simulate SSA-specific climate challenges while developing practical entrepreneurial skills (BC-IAU, 2024). This approach can bridge theoretical knowledge with application, creating experiential learning opportunities that resonate with SSA learners lived experiences and aspirations in emerging green economies. The ultimate goal of contextualization is not simply to make CCL4GIE education more accessible, but to empower SSA youth as agents of climate innovation who can develop locally appropriate solutions that address both environmental sustainability and economic development needs within their communities.

2.6 Requirements for Robotic Gamification Model for a SSA contextualized CCL4GIE Education

This section addresses the first research question: What are the requirements for a robotic gamification model for an SSA contextualized Climate Change Literacy for Green Innovation and Entrepreneurship (CCL4GIE) education that enhances sustained learner motivation and long-term engagement to achieve learning objectives. The requirements identified emerge from a critical analysis of existing educational gamification approaches in SSA, and their limitations in effectively addressing climate-change literacy. Current gamification designs often fail to sustain long-term learner motivation and engagement towards learning outcomes, particularly in complex subjects such as climate change, in which continuous engagement is essential for developing actionable knowledge and skills.

Based on evidence from implementation studies and theoretical frameworks, effective robotic gamification for CCL4GIE must address the urgent need to integrate climate-change education within learning institutions across SSA. English serves as a critical cross-cutting medium of instruction that facilitates knowledge transfer across the region's diverse linguistic landscape, making it a necessary component of any scalable educational model (BC-IAU, 2024). The system requirements must prioritize intrinsic reward schemes that move beyond traditional extrinsic motivation approaches, which typically demonstrate diminishing effectiveness over time. This necessitates the integration of readily available technological equipment, such as NAO robots and established e-learning platforms such as Moodle, which provide cost-effective solutions within the resource constraints prevalent across African educational institutions.

Drawing from the SDT, OCT and MDA Framework, the gamification elements must be specifically designed to foster intrinsic motivation through a theoretical framework that acknowledges both psychological and pedagogical dimensions. This requires dynamic reward mechanisms set in a gamified training context (Emediegwu et al., 2022). Technical accessibility considerations for varying infrastructure capabilities across the region are essential, as is the thoughtful integration of multimodal interaction capabilities through robotic interfaces that enhance engagement across diverse learning contexts. The model must incorporate assessment structures that balance knowledge acquisition with practical application in green entrepreneurship contexts of job creation, addressing both the educational imperative and economic opportunity that climate-change literacy presents for SSA's large youth population (BC-IAU, 2024). These requirements collectively address the documented engagement limitations of traditional gamification approaches, while responding to SSA's specific educational challenges in promoting climate-change literacy that leads to innovation and entrepreneurship in green sectors.

2.7 CCL4GIE Knowledge Domain and Curriculum

This section gives the highlights of the CCL4GIE lesson that was implemented in the Moodle e-learning platform and the social robot Scripting. The lesson provides comprehensive coverage of zero carbon concepts, stakeholder engagement in climate change, and green innovation entrepreneurship, delivered through a structured question-and-answer format designed to promote student understanding and practical application.

The lesson begins with an introduction to zero carbon, defining it as a state in which "no carbon emissions are being produced from a product or service". This foundational concept sets the stage for understanding sustainable practices. The lesson then addresses the causes of carbon emissions. Major sources include burning of fossil fuels for electricity and transportation, industrial processes, deforestation, and agricultural practices that release greenhouse gases. These human activities have significantly increased atmospheric carbon dioxide levels, contributing to climate change. Next, the lesson moves on to explain why carbon reduction is necessary. Four critical reasons are presented: carbon is affecting the environment, destroying wildlife, impacting human health, and retarding economic growth. These points establish the urgency of addressing carbon emissions. The lesson explores sustainable actions toward achieving zero carbon. Five key approaches are outlined: circular economy, cleaner cities, sustainable businesses, climate action, and greener homes. These practical strategies demonstrate ways in which zero carbon goals can be implemented across different sectors (BC-IAU, 2024).

The discussion then shifts to stakeholder analysis. First, a stakeholder is defined as an "individual or group that is directly or indirectly affected by the products, programs, processes or systems." Building on this definition, the lesson identifies six important stakeholders in climate change: international organizations, national governments, donor agencies, learning institutions, technocrats, and citizens. The lesson continues by introducing green entrepreneurship, described as the "creation of business model that is economically profitable, environmentally conscious and creates social value." This three-dimensional approach highlights ways in which business can simultaneously achieve financial, environmental, and social objectives.

To illustrate green entrepreneurship in practice, the lesson presents six examples of green innovation ventures: Mazi mobility for electric motorcycles, leather production from fish skin wastes, rain-maker technology for solar irrigation, eco posts for fencing, eco bricks for building, and plastic roads (BC-IAU, 2024). These case studies demonstrate real-world applications of sustainable business principles. The lesson concludes with a call to action, challenging students to think of their own green innovation entrepreneurship (GIE) project. Students are instructed to report to their tutor after three days with their ideas. The final instruction directs students to computer resources for further development of their concepts before returning to wrap up the session.

2.8 Chapter Summary

This chapter has established the critical context for this research by highlighting the urgent need for effective climate-change education in SSA. The region faces significant environmental and socio-economic vulnerabilities intensified by climate change, yet current educational practices are failing adequately to equip learners with the necessary knowledge and skills. This research directly addresses this gap by proposing the development and evaluation of a robotic gamification training model for an SSA-contextualized CCL4GIE education. By leveraging the potential of gamification and technology, and building upon existing initiatives, this study aims to contribute to a more engaging and effective learning experience, empowering SSA youth to become active agents of change and thus to contribute to a sustainable future.

CHAPTER THREE: STATE OF THE ART

3.1 Introduction

This chapter explores the convergence of gamification and robotics in education, focusing on their potential to enhance learning outcomes, particularly in the context of climate-change literacy. Chapter Three begins by defining gamification, examining its core elements, underlying theories, and established frameworks, including the Mechanics-Dynamics-Aesthetics (MDA) framework, the Octalysis Framework, and Werbach and Hunter's 6D Framework. The chapter then discusses the role of robotics in education, highlighting its theoretical foundations in constructivism and constructionism, and its potential to foster engagement and hands-on learning. Chapter Three further investigates the intersection of robotics and gamification, exploring current trends in robotic gamification research, including publication trends, robot types, study domains, class size, number of sessions, and age of learners. Finally, this chapter identifies key research gaps and opportunities within this emerging field, setting the stage for the development and evaluation of a new RGM-4-CCL4GIE, which is the focus of this research.

3.2 Gamification

Gamification, a term that has garnered significant attention in various fields, is broadly understood as the incorporation of game-design elements into non-game contexts to enhance user engagement and motivation. However, its definition varies slightly depending on the context of its application and the perspectives of different scholars. Hunter and Werbach (2012) define gamification as the application of game-design techniques and game elements in non-game contexts (Werbach et al., 2012). These researchers emphasize the importance of carefully selecting game elements and considering game design concepts. Additionally, the authors highlight the necessity of understanding the psychology of motivation to effectively design gamified systems that achieve their intended purposes. This focus on motivational psychology aligns with the broader aim of gamification to engage users and drive specific behaviour.

Previously, Deterding et al. (2011) offered a foundational definition, describing gamification as the adoption of game technology and game-design methods in non-game contexts. Deterding et al. identified core game-design elements, including challenges, points, rewards, badges, leaderboards, feedback, reputations, ranks, and levels. These elements are crucial in creating a game-like experience that motivates users through a sense of achievement and progression (Deterding, 2015; Ghai, 2022). The application of gamification extends across various domains, each with its tailored definition. For instance, Alahäivälä et al. define gamification in the health sector as the use of game mechanics and elements to design health systems that encourage behaviour change. This approach aims to motivate patients to adopt healthier behaviour, such as regular physical exercise and adherence to medical treatments. By integrating game elements into health interventions, patients are more likely to engage in and sustain activities that improve their health outcomes (Alahäivälä & Oinas-Kukkonen, 2016; Higgins & Thompson, 2002). Hamari define educational gamification as applying game design elements in learning to increase learner motivation and engagement. The goal of this approach is to make learning more interactive and rewarding, thus increasing student participation and improving outcomes. Analyzing these scholars' definitions reveals a commonality: the strategic use of game elements to boost motivation and engagement in non-game contexts (Hamari et al., 2014). However, the effectiveness of gamification depends heavily on understanding the underlying psychological principles (Morschheuser et al., 2018). For instance, intrinsic motivation, as described by Deci and Ryan's Self-Determination Theory, plays a pivotal role in the way in which gamification influences behaviour (Ryan & Deci, 2000). Gamified systems that support autonomy, competence, and relatedness are more likely to sustain user engagement over time (Fernández Galeote & Hamari, 2021).

Moreover, the specific context in which gamification is applied significantly influences its design and implementation. In education, for example, the challenge lies in balancing educational content with engaging game mechanics to ensure that learning objectives are met without compromising educational integrity (Yang et al., 2023) Similarly, in health, the gamified interventions must be designed to address the unique motivational needs of patients to effectively promote behaviour change. Furthermore, empirical evidence supporting the efficacy of gamification varies across studies. While some research highlights significant improvements in engagement and performance, other studies caution against over-reliance on extrinsic rewards, which can potentially undermine intrinsic motivation over time (Porto, 2021). Therefore, a nuanced approach to gamification is essential, one that considers both the benefits and potential drawbacks.

In conclusion, gamification is a multifaceted concept that encompasses the integration of game-design elements into non-game contexts to enhance motivation and engagement. Definitions by various scholars highlight the importance of understanding motivational psychology and the specific context of application. While gamification holds promise in areas such as education and health, its successful implementation requires careful consideration of design principles and potential limitations. A critical and analytical approach to gamification can help maximize its benefits while mitigating its challenges.

3.3 Gamification Elements

At its core, gamification draws upon several key elements typically found in games, as illustrated in Figure 3.1 showing the Gamification Elements Hierarchy. The elements include points, badges, leaderboards, challenges, levels, progress bars, avatars, and narrative elements (Yang et al., 2023). Points serve as a quantifiable measure of achievement, often used to track progress and unlock rewards. Badges act as visual representations of accomplishments, providing a sense of status and recognition. Leaderboards add a sense of competition by enabling users to measure their achievements against those of their peers. Challenges and quests provide clear goals and a sense of purpose, while levels and progress bars offer a structured path of advancement (Oliveira et al., 2023).

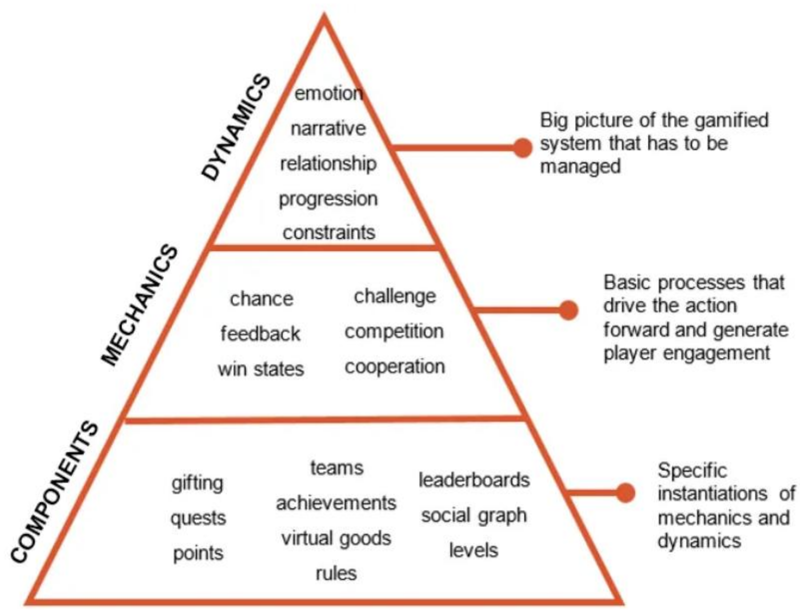

Figure 3.1 Gamification Elements Hierarchy

Avatars allow for personalization and identity creation within the gamified system, and narrative elements provide context and meaning to the user's actions. Game dynamics and game mechanics have sometimes been used interchangeably. Game dynamics refers to the overarching elements that drive users to continue playing (Navarro-Espinosa et al., 2022). Other authors call it the big picture. Game dynamics is seen as the main goal for participating in a game. The dynamics can be for progression to another level, to develop relationships with other players, or for emotional fulfilment. Game dynamics work to enhance enjoyment, motivation, and engagement.

Game mechanics refer to the processes, rules, and data central to the functioning of a game. The mechanics dictate the way in which the play progresses from one step to another, and the conditions that determine either winning or losing. Game mechanics encompass constructs and rules that encourage users to explore and advance within a gamified system (Al-Rayes, 2022). Widely used game mechanics include challenge, cooperation, feedback, competition, and chance processes. In challenges, users are assigned tasks requiring solutions, with rewards such as points or badges for winners (Aguiar Castillo et al., 2022). Users must employ strategy and effort to overcome these challenges. In gamification design, challenges can be tailored to varying levels of difficulty, ensuring that users progress through increasingly complex tasks (Tuah, 2021). Statistical analysis indicates that challenge-based mechanics can significantly enhance user engagement and motivation, as reflected in a study by (Hamari & Koivisto, 2015).

Cooperation is another vital game mechanic, requiring users to work together as a team to win. Successful collaboration hinges on effective communication and a strong team spirit. This mechanic taps into the relatedness aspect of intrinsic motivation, as explained in the Self-Determination Theory (SDT) (Ghai, 2022). Research by Deci and Ryan suggests that cooperative tasks in gamification can improve social bonds and collective efficacy (Ryan & Deci, 2000). Competition, as a game dynamic, involves participants striving to outperform their peers. This mechanic leverages the competence aspect of intrinsic motivation, fostering a sense of accomplishment and mastery among participants (Ghai, 2022).

Effective feedback mechanisms can enhance motivation and learning outcomes. Feedback loops in gamified systems help users adjust their strategies and improve their performance, contributing to a more engaging and productive experience (Galeote, 2021). Game mechanics play a critical role in the design and effectiveness of gamified systems. By incorporating elements such as challenge, cooperation, competition, chance, and feedback, designers can create engaging and motivating experiences that promote sustained user engagement and improved performance. The integration of these mechanics should be carefully considered and tailored to the specific goals and context of the gamified system, leveraging empirical evidence and theoretical frameworks to maximize their impact.

Game components are specific elements of gamification that users or participants interact with as they use the gamified systems. The gamification components include badges, leaderboards, points, goals, avatars, levels, challenges and feedback, among others (Klock et al., 2019). Badges are digital tokens or awards that are given to users of gamified systems after participation or winning. Badges can be placed at various stages of a system and are used to enhance motivation by increasing the intrinsic motivation. Badges appeal to the autonomy need of human beings as supported by SDT (Ryan & Deci, 2000). Points which are also synonymously used as scores are found in gamification to provide feedback on one's performance or competence. Players are considered successful if they have higher marks or grades in whatever challenge that they are handling. Points increase motivation by meeting the inert need for competence which is a subset of intrinsic motivation, as explained by SDT (Ryan & Deci, 2000).

Leaderboard is another gamification component that is used to rank users in a system depending on their performance (Jia et al., 2017). A research conducted in 2024 reveals that leaderboard was the most commonly used gamification element in most gamified systems used in education, followed by badges, points and levels, in that order, as shown in Figure 3.2 (Heljakka et al., 2020).

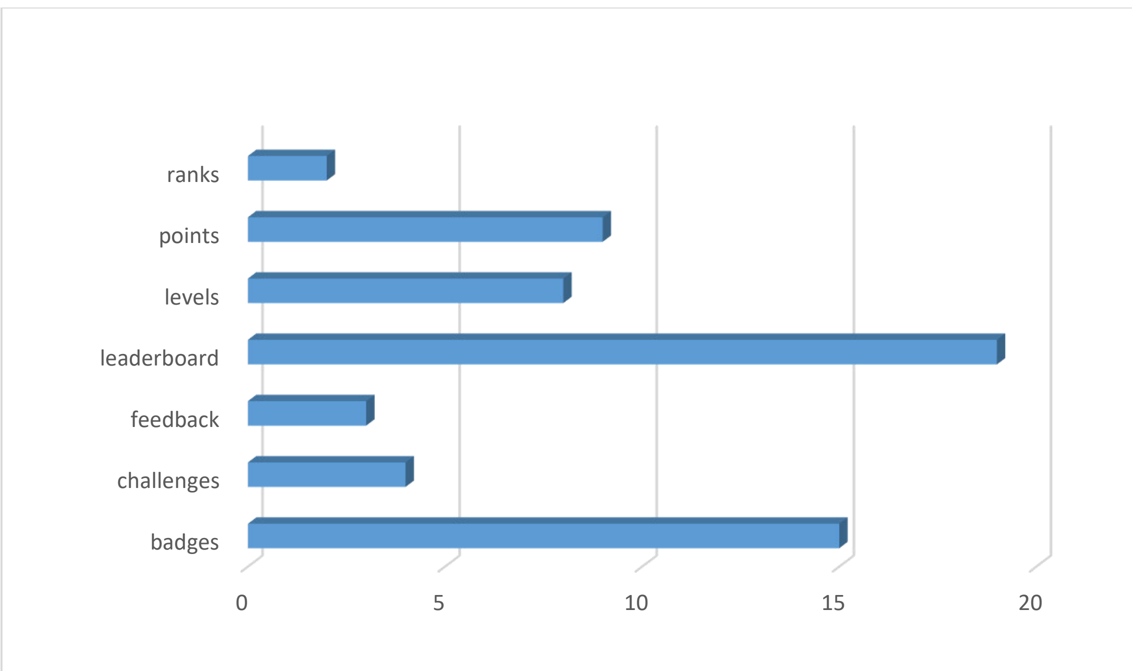

Figure 3.2 Gamification Elements

Leaderboard increases motivation through introducing the relatedness aspect of intrinsic motivation. Human beings normally have an inert need for relatedness or a connection with others; and leaderboards introduce this through the ranking SDT (Ryan & Deci, 2000). Social graphs are closely connected to leaderboards. Levels is another gamification component that is used to indicate the stage or level of progress in a gamified system (Galeote, 2021). Levels increase motivation through incorporating milestones that users anticipate to achieve, hence levels bring about a feeling of mastery. Rules are a component of gamification that introduces order and enables users to have increased engagement. As the game progresses, participants work to adhere to the set protocols which must be respected if one is to continue on the winning trend (Jamshidifarsani et al., 2021). Rules define boundaries of a game. Leaderboard is the most commonly used gamification element, followed by points and badges because these avail motivation. SDT explains why leaderboards, points and badges take the lead: they support an inert need in humans by availing competence, autonomy, and relatedness SDT (Ryan & Deci, 2000).

A separate systematic literature review conducted on robotic gamification identified seven gamification elements from the 19 articles that were chosen for that study. From that study, the leading element was assessments, appearing in 62% of the selected studies (Peura et al., 2023). Assessments were used to test whether the students had achieved the learning objectives. Most gamification systems use assessments in line with SDT, which describe the human need for competence (Donnermann, 2021; Riedmann, 2022). Points appeared in 33.3% of the studies, followed by badges and leaderboards which both appeared in 28.5% of the selected studies. Assessments, points, badges and leaderboards dominate because they best instil motivation by helping the users achieve the need for autonomy, relatedness, and competence, as stipulated by the SDT (Donnermann, 2021; (Ryan & Deci, 2000). In the selected studies, points were awarded after assessments. Leaderboards were then developed to rank the students in line with their marks, followed by the awarding of badges for excellence. Other gamification elements used include levels which appeared in 14.2% of the studies, narratives appearing in 19% of the studies and finally challenges appearing in 9% of the articles. In the four cases of narratives, the robots were programmed to narrate a story in order to provide fun in the learning set-ups. These gamification elements work to add fun, motivation, and engagement in learning settings (Riedmann et al., 2022).

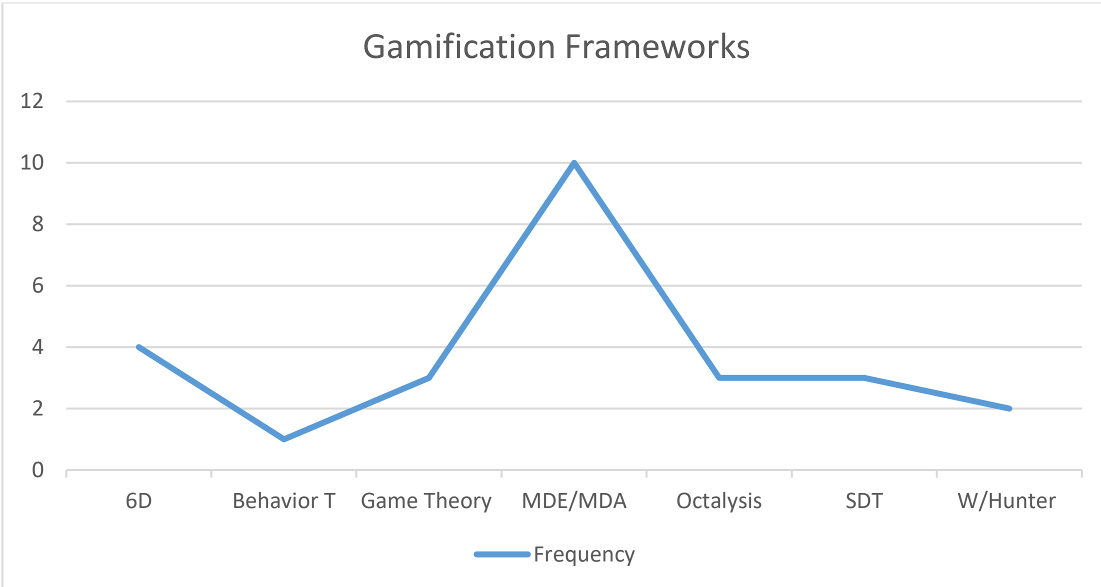

Figure 3.3 Gamification frameworks.

3.4 Gamification Theories and Frameworks

Gamification theories and frameworks examine how elements of game design—like points, badges, and leaderboards—can be utilized in non-game settings to boost user engagement, foster motivation, and support learning outcomes. These frameworks guide the design of gamified systems, drawing from psychological principles such as motivation, behaviour, and user experience to improve outcomes (Mora et al., 2015; Mora et al., 2017). The most common gamification theories and frameworks include MDA, Octalysis, Bartley Player, Werbach and Hunter design and 6D frameworks, among others, as shown in Figure 3.3. The summary of this SLR is assembled in Table 3.1.

Table 3.1 Summary of Elements, Frameworks, Definitions and Limitations of Gamification

Author	Gamification Elements	Frameworks	Definition of Gamification	Limitations
Deterding et al. (2011)	Feedback; reputations, ranks, and levels	MDA	Adoption of game technology and game-design methods	Need for long-term systems
Zichermann and Cunningham (2011)	Leaderboards, avatar, points, progression	Game theory, MDA	Game elements in non-game contexts	Need for long-term systems

Kapp (2012)	Badges, avatars, leaderboards, storytelling	6D, MDA	Game elements in non-game contexts	Design challenges
Huotari and Hamari (2012)	Feedback, points, badges,	SDT	A rule-based formal system	Need for better designs
Werbach and Hunter (2012)	Badge, leaderboard, level	Werbach and Hunter, Game theory, MDA	Game elements in non-game contexts	Need for long-term systems
Barata et al. (2013)	Scoring, levels, leaderboards, challenges and badges	MDA	Use of game-design elements in non-game contexts	Design challenges
Hakulinen and Auvinen (2014)	Badges, leaderboards and avatars	N/A	Engaging elements of games in other settings	Need to include more elements in design
Hamari et al. (2014)	Points, social interaction, cooperation, leaderboards, and badges	Octalysis, 6D	Process of enhancing services with (motivational) affordances	Design problems
Šćepanović et al. (2015)	Leaderboards, avatar, points	MDA	Including game-based items in a system	Poor designs
Seaborn and Fels (2015)	Badges, leaderboards, levels	Werbach and Hunter	Incorporation of game elements into an interactive system	Need for better designs
Robson, 2015	Mechanics and dynamics	MDE	Use of game-design elements	Design challenges
Dicheva et al. (2015)	Points, badges, leaderboards, avatars	SDT	Use of game-design elements in non-game contexts	Design challenges
Peixoto and Silva (2017)	Dynamics and mechanics	MDA, Octalysis, 6D	Application of game elements in a non-game context	NA
Sailer et al. (2017)	Avatars, badges, leaderboards, points and teams	MDA, Octalysis	Implementation of game-design elements in real-world contexts	Design challenges

Dichev and Dicheva (2017)	Badges, leaderboards, points and avatars	6D	Application of game-design elements to traditionally non-game contexts	Need for long-term systems
Mora et al. (2017)	Challenges, points and levels	MDA	Use of game elements	Need for better designs
Rutledge (2018)	Points and leaderboards	Game theory	Application of game-design elements to traditionally non-game contexts	Poor designs
Koivisto and Hamari (2019)	Challenges, quests, missions, tasks, competition, clear goals	NA	Design approach of enhancing services and systems with affordances for experiences like those created by games	Design challenges
Araine et al. (2019)	Points, leaderboards, badges/achievements, levels, stories/themes, clear goals, feedback, rewards, progress, and challenges.	Behaviour theory	Use of game-design elements in non-game contexts	Need for long-term systems
Wesseloh, 2020.	Points, badges and leaderboards	SDT, MDA	Use of game elements in a non-game context	Need for long-term designs
Porto (2021)	Points and leaderboards	NA	Game elements in non-game contexts	Lack of long-term designs
Wang et al. (2022)	Points, badges, leaderboards	Octalysis	Use of game-design elements in non-game contexts	Need for better designs
Cravinho et al. (2022)	Points, leaderboards, levels or stages, missions, and achievements	N/A	Application of elements which are part of game environments	Design challenges
Saleem et al. (2022)	Challenges, levels, leaderboards/ranks, badges	Many educational frameworks	Application of digital-game components	Lack of practical application

Al-Rayes et al. (2022)	Feedback, points, badges, certificates, leaderboards, challenges or quests, customization, levels, avatars	N/A	Introducing “game-like” dynamics	Need for better designs

The mechanics, dynamics, and aesthetics (MDA) framework, introduced by Hunicke, LeBlanc, and Zubek (2004), is a foundational model in game design, widely applied in gamification. The MDA framework breaks down game experiences into three core components: Mechanics-Dynamics-Aesthetics (Ghai, 2022). Mechanics refers to the rules and systems that structure gameplay, such as point systems and badges, which motivate user participation. Dynamics encompasses the interactions between players and mechanics, driving engagement through competition, collaboration, and feedback loops. Aesthetics, or emotions, shape the sensory and emotional appeal of the game, enhancing user satisfaction. Deterding et al. (2011) highlight aesthetics’ importance in creating enjoyable and emotionally resonant experiences (Deterding et al., 2011).

The Octalysis Framework, developed by Yu-Kai Chou in the year 2012, is another influential model in gamification design, grounded in behavioural psychology (Medina-Gómez et al., 2024). This framework posits that eight core motivational drives underpin human behaviour in interactive systems: social influence, scarcity, avoidance, empowerment, meaning, unpredictability, accomplishment, and ownership (Ghai, 2022). Each drive corresponds with a specific motivational mechanism, allowing gamification designers to tap into diverse psychological triggers, thus enhancing user motivation. Social influence leverages community dynamics and peer pressure, while scarcity and avoidance appeal to users’ fear of missing out, or of experiencing negative consequences. Empowerment provides users with a sense of control and agency over their actions, while meaning instils a sense of purpose, elevating the perceived significance of tasks.

Werbach and Hunter’s 6D Framework offers a process-oriented approach to gamification design. This framework outlines six sequential steps: define, delineate, decipher, devise, deploy, and debrief, each critical to the development of a well-structured, goal-oriented gamification system (Ahmad et al., 2024; Werbach et al., 2012). The ‘define’ stage establishes the objectives of the gamification project, ensuring alignment with organizational or educational goals. ‘Delineate’ focuses on identifying and understanding the target audience, particularly their motivations and preferences. 'Decipher' involves gathering and analysing data to refine the gamification model, while 'devise' marks the creative phase in which game mechanics and elements are crafted (Ahmad et al., 2024; Rodrigues et al., 2016). 'Deploy' entails implementing the system, and 'debrief' focuses on evaluating its outcomes and making iterative adjustments. In a complementary model, Werbach and Hunter provide a six-step framework for designing gamified systems: defining objectives, identifying the target audience, creating user personas, designing activity loops, adding elements of fun, and deploying appropriate tools (Werbach et al., 2012).

3.5 Current Trends in Robotics and Educational Gamification

The use of robots in education presents a transformative approach to teaching and learning, integrating robotics technology into educational environments to enhance engagement, promote hands-on learning, and develop crucial skills in science, technology, engineering, and mathematics (Donnermann, 2021). This field has evolved significantly since its inception in the 1960s with the development of the Logo programming language by Seymour Papert, which laid the foundation for the constructionist approach to learning through technology (Solomon et al., 2020). The educational foundation of robotics in learning is based on constructivist and constructionist theories, which assert that learners build knowledge actively through hands-on experiences and meaningful interactions with their surroundings. In this context, robots serve as tangible objects that students can manipulate, programme, and observe, thereby creating concrete representations of abstract concepts (Chen et al., 2023).

Prior examinations of social robots within educational contexts have revealed that children can form strong and trusting connections with these devices (Darmawansah et al., 2023; Lu et al., 2023). In educational settings, social robots have found prominent usage among children with autism and in the realm of second-language acquisition. For instance, social robots have demonstrated their potential in aiding young children with autism in grasping appropriate physical boundaries during social interactions. Robots show promise in enhancing reading abilities, grammar proficiency, and emotions associated with learning in the context of language acquisition (Davison et al., 2020). Extensive research has also been dedicated to exploring the incorporation of social robots in language learning. Numerous studies focus on language as the subject taught in robot-assisted learning. There is need to conduct more research on settings in which robots are programmed to deliver other subjects. The following section covers the analysis of publication patterns, study domains, robot types, class sizes, and evaluation methods, providing insights into the evolving landscape of this field.

3.5.1 Years of research

The analysis of publication trends provides insights into the growing research interest in robotic gamification within education. Such analysis examines the distribution of studies over time, highlighting key patterns and emerging focus areas.

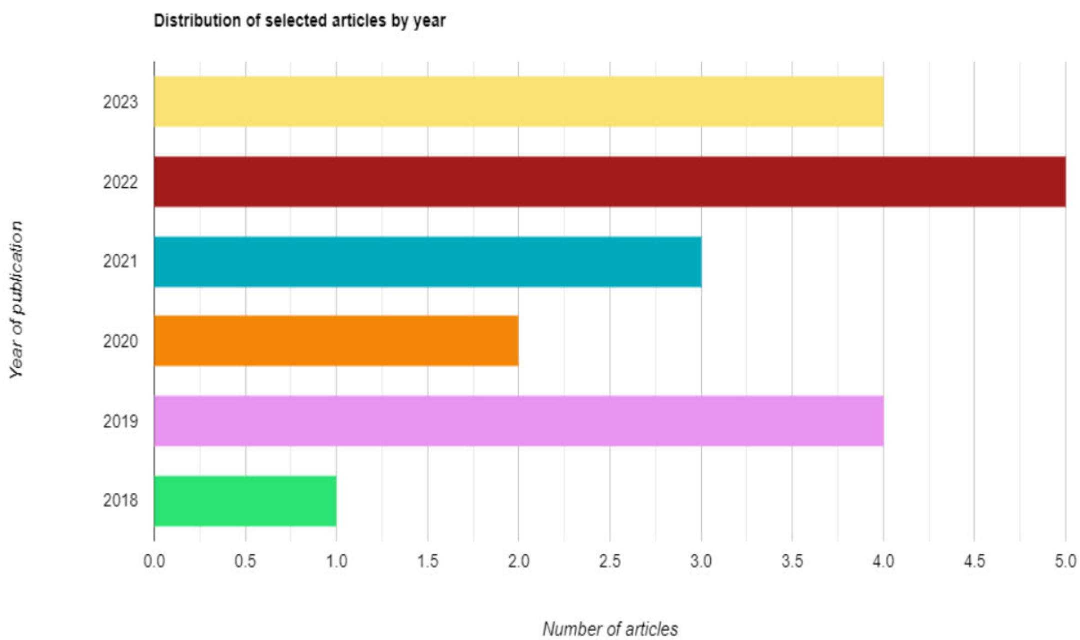

Figure 3.4 Years of article publication

In a 2024 systematic literature review on robotic gamification frameworks used in education, 19 articles were selected for analysis. Among these, one article had been published in 2018, accounting for 5% of the total, as illustrated in Figure 3.4. In 2019, four articles (21%) were published, followed by two articles in 2020 (10%). The highest number of publications occurred in 2022, namely, five articles (26%). In 2021, three articles (16%) were published, while 2023 saw four articles, also accounting for 21%. Notably, 14 of the articles (73%) were published from 2020 onwards, indicating a growing interest in the gamification of robots in educational settings (Ghai, 2022). This trend reflects the increasing research focus on this topic and highlights the relevance of the most up-to-date findings in this field. The studies were conducted in various learning environments, with Spain being the most dominant country, hosting three studies (16% of the selected articles). Australia, Germany, Greece, and Finland each conducted two studies, accounting for 10.5% of the selected articles. Additionally, one study was conducted in each of the following countries: Malaysia, USA, Chile, Taiwan, China, Netherlands, Brazil, and Israel (Ahmad et al., 2024; Medina-Gómez et al., 2024). Spain's prominence in this field may be due to the government's commitment to implementing technology-assisted learning in schools (Ghai, 2022; Riedmann et al., 2022). No African country was featured, probably because few studies have explored robotic learning in Africa. There is a need for more studies on the incorporation of technology-enabled education within African educational contexts.

3.5.2 Robot types and study domains of research

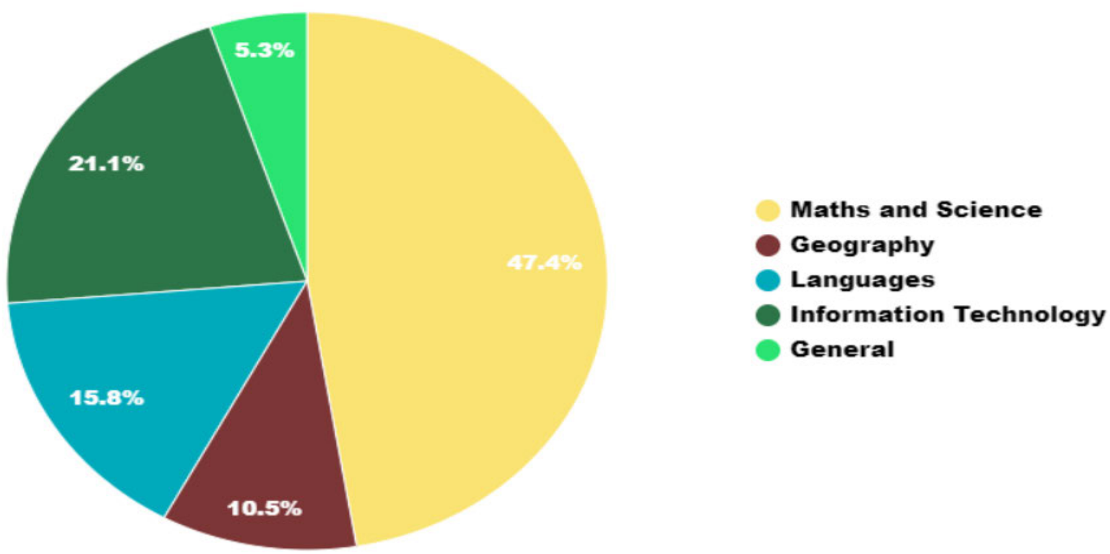

Figure 3.5 Subjects distribution

Furthermore, the studies selected in their SLR revealed that mathematics and science are the subjects that took the lead in robotic gamification application, as shown in Figure 3.5 (Hilario et al., 2022; Madariaga et al., 2022). This means that mathematics and science accounted for 47.4% of the distribution in this study. This research also shows that robots were included in classroom settings in which language was taught. Three of the articles had languages as the subject delivered (Riedmann et al., 2022) which represents 15.8%. In a research conducted by Riedmann, Schaper & Lugrin, the tutors set up the robot to aid in teaching the Spanish language (Riedmann et al., 2022). Information technology (IT) was the subject delivered in four of the studies, accounting for 19%. The IT topic that was delivered was mainly coding or programming. It is apparent that limited research has been carried out specifically on the topic of climate change. The most relevant work identified in this area was a study conducted by Lee and his collaborators. (Lee et al., 2022). This SLR had a keen interest in climate-change education in which robots and gamification were included in one setting; however, only this one study by Lee was obtained. This means that more studies must be conducted on robotic gamification in which climate-change literacy is the subject of interest.

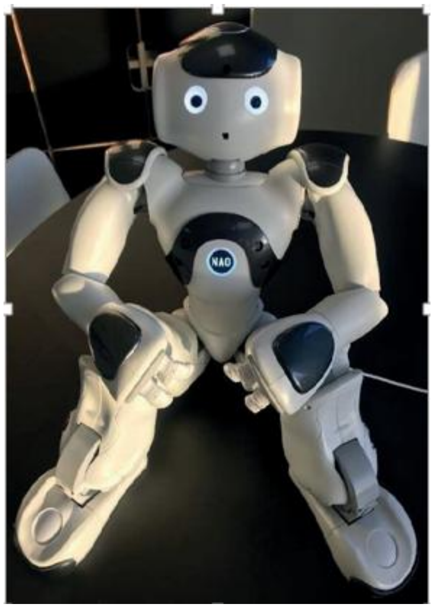

Figure 3.6 Nao Robot (Peura et al., 2023)

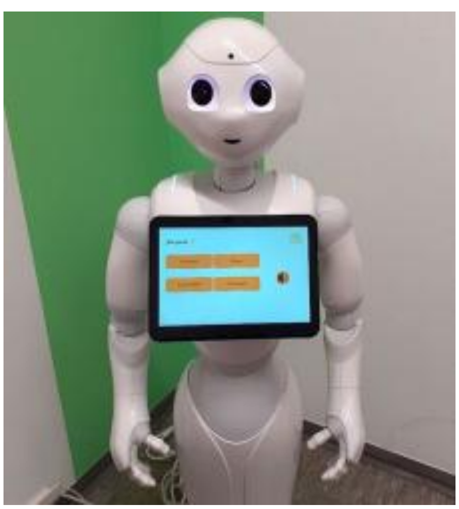

Figure 3.7 Pepper Robot (Riedmann, 2022)

Additionally, various robots were used in the education settings selected in this SLR by Manining et al. who developed a framework that could accommodate any robot (M. A. B. Manining et al., 2022). Lego

Mindstorms and Mindstorms EV3 were also used in research conducted by Hilario et al. (Hilario et al., 2022). The most dominant robot used in the selected studies was Nao (Figure 3.6), appearing in 32% of the studies (Ahmad et al., 2019; Kurtz & Kohen-Vacs, 2022; Vrochidou et al., 2018). Pepper robot (Figure 3.7) came second as the most preferred robot in this research after three scholars integrated Pepper into the learning environments, accounting for 16% (Riedmann, 2022). With some researchers, Nao and Pepper were given personal names (Domenic, Paula and Kindsar) to elevate tailor-made settings and to create relatedness in the learning scenarios. Other robots that were included in the studies include moving robotic agents, Educational Robot, Reeti, Anthropomorphic, Robotic, Zeno-R, Dash and Botley (Heljakka et al., 2020). Pepper robot and its counterpart Nao were used severally because they feature a non-threatening design that mitigates the "uncanny valley" dilemma (Woo et al., 2021). Additionally, these robots are equipped with motion sensors, voice-recognition capabilities, and emotion-sensing software, enabling these robots to partake in modest social interactions with humans. Nao is an autonomous, programmable, humanoid robot developed by Aldebaran and Softbank Robotics (Ahmad et al., 2019; Peura et al., 2023). Pepper robot is a product of Softbank robots. Its production was temporarily halted in 2020, but with a promise of restoration (Huang & Moore, 2023; Schneider et al., 2022). One possible reason for the dominance of Nao in the robotic learning environment could be due to this halt in production of the Pepper robot (Huang & Moore, 2023).

This SLR also delved into the models to establish the ways in which the robot and gamification was implemented in the learning environments. Riedmann, Schaper & Lugrin programmed Pepper (Paula) as a tutor. Within this context and similar scenarios, the robot's main functions included introducing and clarifying tasks, presenting information, and offering assistance as required (Peura et al., 2023; Riedmann, 2022). The robots also conducted evaluations and even gave away rewards through comments. In most of the selected studies, a setting for gamification was also included without the inclusion of the robot. This was intended to create a comparison and to help in analysis. In all these studies, the inclusion of the robot was aimed at adding aesthetics and increasing learner engagement and motivation. While the included robot delivered content in most studies, Westlund's research integrated the Tega robot as a peer learner (Heljakka et al., 2020). Heljakka's research-integrated robot plays with children in a programming class.

3.5.3 Class size, number of sessions and age of learners

Trends in robotic gamification reveal that training sessions incorporating robot-integrated studies were conducted in classes ranging from 9 to 140 students. The majority of the sessions were conducted in settings in which the number of students ranged between 21 and 40, accounting for 31% of the selected studies, as shown in Figure 3.8 (Ahmad et al., 2019; Manining et al., 2022). Figure 3.8 reveals that four sessions were conducted with students between 0 and 20, representing 21% of the selected articles (Kurtz & Kohen-Vacs, 2022).

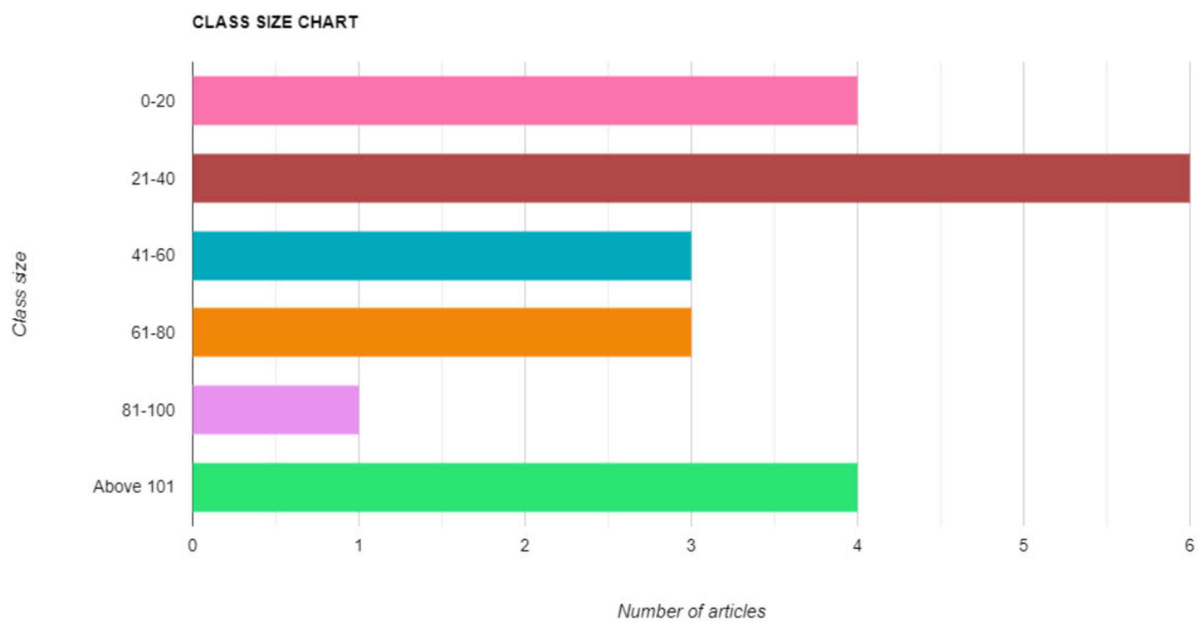

Figure 3.8 Class size

The largest student population was 140 in a study session of mathematics in which the robot increased dynamism in learning mathematics (Reyes et al., 2021). The student number is sometimes not significant in research because students may be needed for validation. However, in quantitative scenarios, researchers have recommended the addition of students and the number of sessions in order to arrive at credible statistical conclusion (Kurtz & Kohen-Vacs, 2022; Vrochidou et al., 2018). In reviewing the literature on robotic gamification, it is evident that participant demographics play a crucial role in shaping the outcomes of technology-based interventions. The studies analysed reveal interesting trends in the age distribution of learners engaged in these initiatives. The age groups of the study populations fall into three categories, as illustrated in Figure 3.9. A significant portion of the studies (44%) involves children as learners, reflecting the strong focus on early education in technology integration (Fridin, 2014; Kurtz &

Kohen-Vacs, 2022). University students, often classified as adults in some studies, make up 33% of the participant pool in gamification research (Burns et al., 2018; Vrochidou et al., 2018). Meanwhile, high school students feature in 22% of the studies (Hilario et al., 2022; Manining et al., 2022). The predominance of children in studies may be attributed to educational policies that prioritize the early introduction of technology (Woo et al., 2021). This focus suggests that exposing younger learners to technology could yield long-term benefits, cultivating a tech-savvy generation prepared for future advancements.

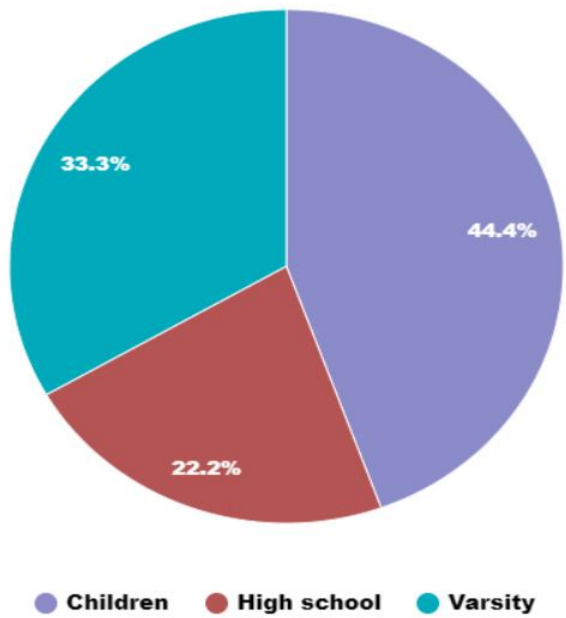

Figure 3.9 Age distribution

The studies are conducted in various sessions depending on the objectives of the researchers. Most studies take place only in a single session (Ahmad et al., 2019; Hilario et al., 2022; Vrochidou et al., 2018) in which learners engage with the robot in a gamified setting, followed by an assessment. Other studies take place in more sessions depending on the dynamics or the research. The type of data collection and evaluation methods can determine the number of sessions allocated to each study setting.

3.5.4 Study methods and evaluation strategies

The majority of gamification studies use experiments as the study method to deliver lessons in gamified robotic settings. (Research reveals that 90% of the studies use experiments). About 5% use quasi experiments 5% (Manining et al., 2022). Amram, Singh & Wardani selected a quasi-experiment in their proposed conceptual framework to access the effectiveness of robotic games in motivating geography students. In robotic-aided learning research, experiments are utilized to rigorously assess ways in which robotic interventions influence educational outcomes and interactions between humans and robots. Most of the studies employ experiments because students and the gamified robotic agents must be set up in a real-time environment in which learning takes place (Donnermann et al., 2021).

The evaluation methods used in gamification studies vary depending on the learning setting. The majority of studies employ pre- and post-test assessments and questionnaires (Ahmad et al., 2019; Donnermann et al., 2021; Kurtz & Kohen-Vacs, 2022) accounting for 19% preference for these methods in gamified robotic-learning research. Surveys are also used in these studies, representing a 15% preference. The user engagement scale short form (UESSF) is also utilized in some studies, accounting for 10% (Vrochidou et al., 2018). Schez-Sobrino et al. apply the Technology Acceptance Model (TAM) (Schez-Sobrino et al., 2020) and Reyes et al. (2021) use the unified theory of acceptance and use of technology (UTAUT). The selection of an evaluation approach in robotic research experiments is guided by the defined research objectives, focusing on aspects such as robot performance, user interactions, task efficiency, and human-robot cooperation, all aimed at achieving precise and effective outcome measurement (Jung et al., 2021). Additionally, the choice considers resource availability, equipment suitability, and ethical considerations. Questionnaires are commonly used in robotic experiments due to their ability to systematically collect user perceptions, preferences, and experiences, providing valuable insights into human-robot interactions and system usability. Their scalability also makes them a practical tool for gathering diverse feedback from large participant groups (Jung et al., 2021). The TAM is chosen for this robotic gamification research because it effectively captures users' perceptions of the technology's ease of use and perceived usefulness, which are crucial for understanding their acceptance and engagement with robotic interventions. By applying TAM, we gain valuable insights into the factors influencing user motivation, engagement and interaction.

3.6 Related Work and Gaps in the Literature

The use of technology in education has garnered significant scholarly interest, particularly in the wake of the Covid-19 pandemic, which necessitated restrictions on physical gatherings and prompted a shift toward remote learning solutions (Burlacu et al., 2023;) Gamification systems and robotic models have been employed both independently while sometimes in a combination within numerous technically-enhanced educational settings. Amram et al and his team proposed a theoretical model aimed at examining the impact of robots on both underperforming and average-performing students in the subject of geography (Hilario et al., 2022). A model referred to as sBotics was designed by Moura for educational robotics. Its key innovation lies in its user-friendly interface combined with the flexibility to generate diverse scenarios, offering limitless opportunities for learning and exploration (Asadullah et al., 2023; Nascimento et al., 2021). No comparable alternatives possessing these characteristics were found within the K-12 educational spectrum targeted by this study. Previously, Alexandre Coninx carried out research focused on long-term social interaction between children and robots, utilizing multi-activity switching techniques to sustain engagement among young learners. Scholars have established that robots put in settings involving children primarily focus on isolated activities like games, which frequently present problems because they become repetitive. As an alternative approach, there have been proposals for developing robots with greater adaptability that can seamlessly transition between different activities during a single interaction period with children (Coninx et al., 2015). Lately, Madariaga et al piloted studies illustrating use of educational robots in both offline and online settings (Madariaga et al., 2022). Studies have indicated that the integration of physical robots within classroom settings can lead to greater student drive and involvement. Nevertheless, these researchers suggested employing a randomized method for choosing participants to mitigate the potential influence of social dynamics among friends. Further, Chen et al discovered that incorporating robots with elements of gamification in STEM subjects encouraged creative thinking among learners. Based on their research, these authors emphasized the importance of conducting studies in diverse geographical locations beyond Taiwan. This suggestion creates an opportunity to investigate the applicability of Chen, Lin, and Hung's findings within the Sub-Saharan Africa (SSA) context to confirm their validity (Chen et al., 2023).

Yang et al created an artificial intelligence enabled robot. Their aim was to improve both learning results and conduct within laboratory safety courses designed for undergraduate students (Yang et al., 2023). The findings of this study indicated that the use of this robot led to greater student motivation and involvement (Yang et al., 2023). Building on their findings, these researchers recommended future inquiries into the possibilities of a cyclical GAFCC model combined with a variety of robot types. Maartje de Graaf, in an independent study, highlighted the importance of humanoid robots like Nao and Pepper in exploring factors behind people's hesitancy toward long-term robot engagement, emphasizing the necessity of their human-like features Yang et al., 2023).

In contrast to some findings, certain studies investigating the application of robots and gamification in educational settings have indicated that simply incorporating these technologies does not guarantee adequate learner motivation. For example, research by Riedmann et al showed lack of substantial increase in student engagement and motivation when robots were gamified (M. de Graaf, 2017; Riedmann et al., 2022). This study centred on how incorporating a social robot and gamification impacted adult learners' engagement and performance in various settings. The settings comprised standard devoid of technological aids, learning enhanced solely by gamification, learning involving only robots, and an integrated approach using both robots and gamification within one session. (Riedmann et al., 2022). An earlier investigation by Donnermann and associates examined the use of social robots and gamification in technology-enhanced learning. A key objective of their research was to merge gamification and robots within a single environment, as previous studies had not explored this combination. Astonishingly, their empirical analysis revealed no substantial improvement in motivation when social robot and gamification were introduced separately. Unexpectedly, they found an interaction effect where combining both elements led to decreased engagement. This counterintuitive result suggested that students experienced distraction when learning with gamified robots. Consequently, the study recommended further research into the integration of robots and gamification, manipulating variables like the number of sessions, participants involved, and the subject matter being taught (Donnermann, 2021).

Melissa Donnermann and her collaborators examined the effectiveness of robots in long-term learning scenarios. Findings indicated that the robot helped learners achieved positive outcomes, as evidenced by improved examination results (Donnermann, 2021). These conflicting results underscore the intricate nature of incorporating robotics and gamification into education, stressing the ongoing need for research to fully grasp the subtleties and thereby maximize the educational benefits of these tools. The results of the study showed that there was no notable difference in student motivation or overall learning experience across the various conditions. This implies that the use of the gamified robot did not have a significant effect on learners' engagement or motivation. Nonetheless, this was the conclusion drawn from the research. The researchers, however, suggested extending the duration of future experiments to validate their current findings (Donnermann, 2021). The research discussed in this related work section generally suggests that incorporating gamified robots can lead to increased motivation and better learning results (Donnermann, 2021). Research on the educational application of robots and gamification has been largely centred in Europe, with Spain contributing approximately 24%

of the studies—a trend likely influenced by the country's robust governmental support for technology-integrated learning. (Hilario et al., 2022).

The GAFCC model, in contrast, targeted out-of-class tasks. The RGM-4-CCL4GIE model was created to address the need for a model relevant to sustainable climate change training, using the Nao robot for its availability, dynamism, and Softbank robotics support

3.7 Chapter Summary

This chapter provided a comprehensive overview of the landscape of gamification and robotics in education, laying the groundwork for the subsequent development and evaluation of the RGM-4-CCL4GIE. Chapter Three explored the multifaceted nature of gamification, defining its key elements, theoretical underpinnings, and established frameworks. The chapter highlighted the potential of robotics in education to foster constructivist learning and to enhance student engagement. This chapter then examined the emerging field of robotic gamification, analysing current research trends related to publication activity, robot types, learning domains, and learner demographics. This analysis revealed a growing interest in the field, with a concentration in STEM subjects and a dominance of robots such as Nao and Pepper. The chapter identified a significant gap in research exploring the application of robotic gamification to climate-change education, particularly within the context of green innovation and entrepreneurship. This gap provided the impetus for the present research, which aims to develop and validate a new model leveraging the combined power of gamification and robotics to enhance climate-change literacy while promoting sustainable solutions.

CHAPTER FOUR: THEORETICAL AND METHODOLOGICAL FRAMEWORK

4.1 Introduction

This chapter details the theoretical and methodological foundations of the RGM-4-CCL4GIE. Chapter Four is divided into two primary sections. The theoretical framework articulates the core learning theories and frameworks that underpin the design and development of the RGM-4-CCL4GIE. This section explores how the OCT, MDA and SDT framework are integrated to create a cohesive theoretical foundation for the model. Chapter Four explains how these theories inform the design choices and contribute to the overall learning experience, aiming to foster intrinsic motivation and sustained engagement with climate-change education. The methodological framework outlines the research methodology employed in this study. This chapter details ways in which the theoretical framework discussed in the previous section guides the research process, specifically the application of the Design Science Research Methodology. Chapter Four explains the iterative phases of the research, from problem identification and objective definition to model design, prototyping, evaluation, and communication. The chapter emphasizes the systematic and rigorous approach taken to develop and validate the RGM-4-CCL4GIE within the specific context of SSAs.

4.2 RGM-4-CCL4GIE Education Theoretical Framework

4.2.1 Self-Determination Theory

Deci and Ryan's Self-Determination Theory (SDT) stands as a prominent psychological framework examining human motivation and personality. SDT argues that individuals are intrinsically driven by the desires for relatedness, competence and autonomy and this drives general motivation. Autonomy stands as a crucial element, signifying the basic human requirement for self-governance and the capacity to make choices aligned with personal values. The RGM-4-CCL4GIE training design leverages autonomy as a motivator by including badges, a gamification element shown in Table 4.1. The model also features assessments, done to provide badges after award of points (Ryan & Deci, 2000). Deci and Ryan posit that as individuals experience a greater feeling of autonomy, their engagement in activities also tends to rise. Competence connects with the desire to feel accomplished, and relatedness signifies one's desire for social fitting. The RGM-4-CCL4GIE assessment design is guided by SDT's competence aspect, as assessments allow individuals to feel competent when they demonstrate their abilities (Chen et al., 2018). Leaderboards, a gamification element ranking students by post-evaluation points, are included in the model to address relatedness. This allows students to feel connected by comparing their performance. The model also uses group work to build relatedness, which in turn increases engagement and intrinsic motivation.

Table 4.1 SDT and RGM Elements

SDT Aspects	**Description**	**Gamification Elements**	**Connection to RGM-4-CCL4GIE Training**
Autonomy	Inert need of self sufficiency	Badges	Badges reward students based on their decisions and achievements, offering a sense of control over learning and task completion, which increases autonomy.
Competence	The desire to feel proficient and effective in one's activities (Chen et al., 2018).	Assessments, points	Assessments allow students to prove their competence, with points and badges serving as tangible markers of achievement and mastery in the subject.
Relatedness	The aspiration to feel connected and to form meaningful social bonds (Ryan & Deci, 2000; Huang & Hew, 2018).	Leaderboards, group work	Leaderboards foster competition and social comparison, while group work encourages collaboration, both increasing students' sense of belonging.

4.2.2 Operant Conditioning Theory

In the 1950s, B.F. Skinner, a behaviourist, suggested that positively rewarding new behaviours helps form habits. He advised beginning with constant reinforcement for steady rewards and then switching to intermittent reinforcement to keep curiosity alive once the behaviour is mastered (Skinner, 1953). Virtual badges are integrated into the RGM-4-CCL4GIE training as part of a random rewards scheme, recognizing user achievements and providing positive reinforcement. The unpredictable nature of badge distribution helps maintain learner motivation by fostering anticipation. As a result, these badges are instrumental in fostering and strengthening desired behaviours, which in turn leads to enhanced engagement and motivation. (Rowe et al., 2017)

4.2.3 MDA framework

MDA is a framework used to analyse game elements. It's also sometimes referred to as MDE, where the 'E' represents emotions. Notably, the 'aesthetics' component of the MDA framework is occasionally used interchangeably with 'emotions' (Hunicke et al., 2004). Mechanics in the MDA framework encompass game procedures and rules, while dynamics refers to the interactions within the game. Aesthetics, on the other hand, represents the overall emotional appeal and experience, including visual and auditory elements. The RGM-4-CCL4GIE training design employs the MDA framework to integrate the social robot Nao with the aim of enhancing the aesthetic dimension (Hew et al., 2016; Madariaga et al., 2022; Ryan & Rigby, 2020; Su & Su, 2015).

As illustrated in Figure 4.1, the RGM-4-CCL4GIE training optimizes learner motivation and engagement by integrating SDT, OCT and MDA framework. SDT cultivates intrinsic inspiration through autonomy, competence, and relatedness, while leaderboards and group work build social connections. OCT sustains engagement using random badge rewards to reinforce desired behaviours and maintain curiosity (Vázquez-Vílchez, 2021). The MDA framework's focus on aesthetics, applied through the robot, adds originality and enthusiasm that boost motivation and sustain engagement. By blending internal drivers with external incentives and social connections, it creates a compelling and motivating learning experience in the RGM-4-CCL4GIE model.

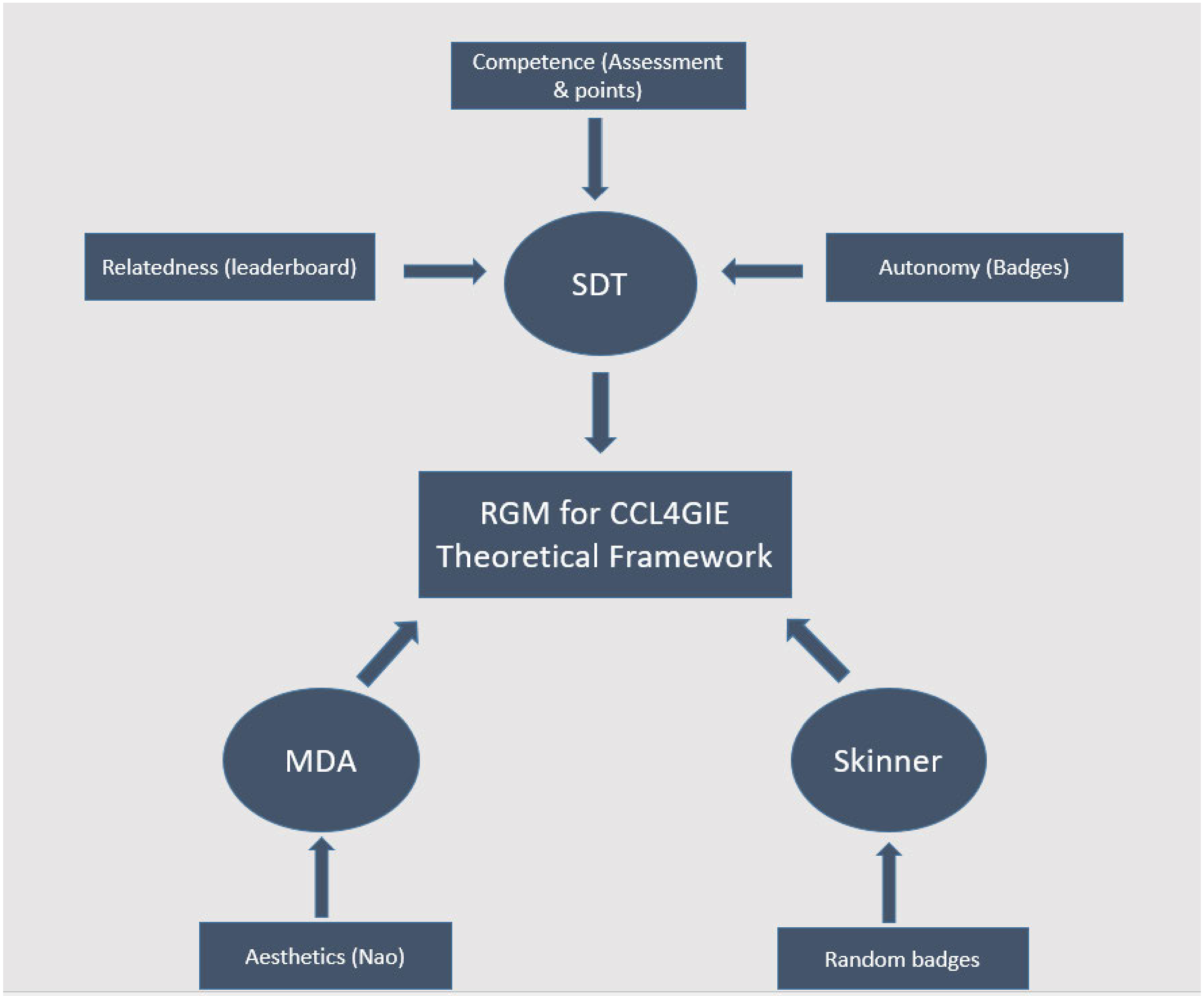

Figure 4.1 RGM-4-CCL4GIE Education Theoretical Framework

4.3 Methodological Framework

The methodological approach underpinning this research is the Design Science Research Methodology (DSR), an iterative framework suited for the creation and evaluation of innovative artefacts within the field of information technology. The DSR emphasizes a structured approach to problem-solving, focusing on the design, development, and assessment of technology solutions to address real-world challenges. In the context of this research, DSR provides a robust framework for the development and validation of the RGM-4-CCL4GIE (Kory-Westlund & Breazeal, 2019; Robinson, 2019). The DSR employed herein is articulated across six distinct, yet interconnected phases: problem identification, defining objectives, model design, prototyping, evaluation, and communication as summarized in

Figure 4.2.

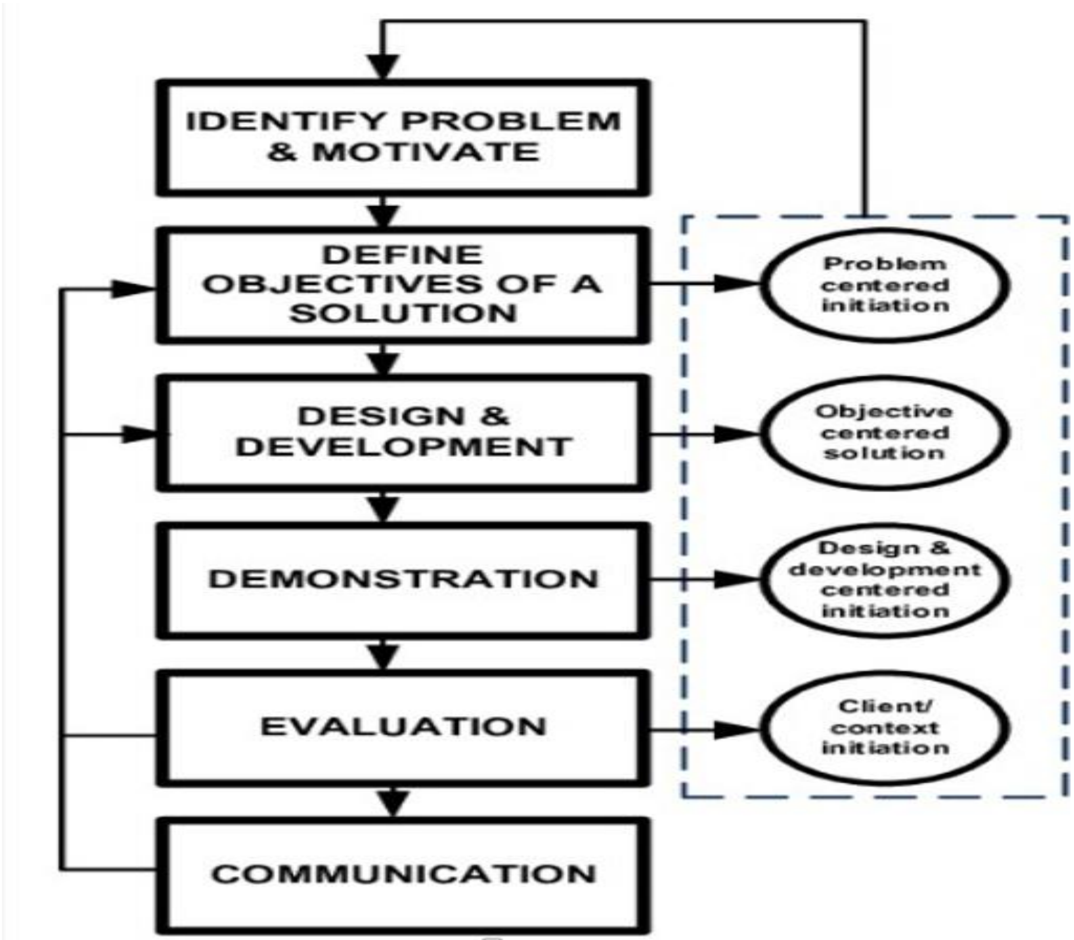

Figure 4.2 Design Science Research Methodology summary

The initial phase, problem identification, establishes the critical need for a robotic gamification model within the specific context of SSA. This phase employs a systematic literature review, incorporating techniques of research synthesis and meta-analysis. This approach is crucial for identifying existing gaps and limitations in current gamification models, particularly their efficacy in sustaining long-term learner motivation and engagement within complex and evolving subjects such as climate change (Morschheuser et al., 2018). The literature review encompasses a broad spectrum of scholarly works, including studies on gamification in education, climate-change education pedagogies, the application of robotics in educational settings, and the specific socio-economic and cultural context of SSA. This comprehensive review culminates in three key deliverables: a comprehensive state-of-the-art survey paper synthesizing the existing literature and pinpointing key research gaps, a research problem statement, and a thesis statement.

Building upon the identified problem, the second phase, defining objectives, establishes research questions and objectives that the RGM-4-CCL4GIE aims to address. These research questions serve as guiding principles for the design and subsequent evaluation of the model, with a core focus on its capacity to enhance sustained intrinsic motivation and long-term engagement. This phase involves further refinement of the literature review and research synthesis, ensuring alignment of the research objectives with the current state of knowledge and the identified gaps.

The third phase, model design, is dedicated to the development of the theoretical underpinnings and the detailed architectural design of the RGM-4-CCL4GIE. The design process is firmly grounded in three key theoretical frameworks. The Self-Determination Theory (SDT) provides a robust framework for understanding the nuances of intrinsic and extrinsic motivation, emphasizing the critical role of autonomy, competence, and relatedness in fostering sustained engagement. In addition to this theoretical grounding, this phase incorporates mathematical modelling to define the complex interplay of gamification elements and their projected impact on learner motivation and engagement. Such involves the development of quantitative models to assess the effects of varying reward schedules and interactive elements. Furthermore, a detailed architectural framework is designed to define the structural components of the RGM-4-CCL4GIE for both desktop-based and robot-enhanced learning environments. This includes detailed specifications of the interactions between the software platform, the social robot Nao, and the learners. The deliverables of this phase are comprehensive documentation of the theoretical framework, the mathematical models developed, and the detailed architectural design of both the desktop and robot-enhanced models.

The fourth phase, prototyping, involves the tangible implementation of the RGM-4-CCL4GIE as a functional prototype. This involves the development of both desktop and robot-based modules. The gamified learning environment is implemented on the Moodle e-learning platform, integrating core gamification components such as points, badges, and the dynamic reward system. The robot-based module is specifically designed to facilitate rich and interactive learning experiences with the social robot Nao. This involves programming the robot to deliver educational content, respond dynamically to learner interactions, and provide personalized feedback. A custom plugin is developed using industry-standard web technologies such as HTML, CSS, and JavaScript to implement the random-badge award scheme

(Balogun et al., 2022; McHucha et al., 2017). This plugin is seamlessly integrated into the Moodle platform to provide dynamic and unpredictable rewards, enhancing learner engagement. The resulting prototype serves as the operational foundation for the subsequent testing and validation phases.

The fifth phase, evaluation, focuses on the evaluation of the RGM-4-CCL4GIE prototype's effectiveness. This involves a carefully designed process of participant recruitment and training, ensuring that participants from the target population (students in SSA) are adequately prepared to interact with the prototype system. A pilot study is conducted to gather rich data on learner experiences, engagement levels, and learning outcomes. Participants interact with both the desktop and robot-enhanced versions of the system, allowing for a comparative analysis of their effectiveness. Data collection is conducted through validated surveys based on the Technology Acceptance Model (TAM), which assesses user acceptance and perceived usefulness of the technology. Data on learner engagement, motivation levels, and learning outcomes is also collected through a combination of quantitative and qualitative methods. The collected data is then subjected to rigorous statistical analysis, employing both descriptive and inferential statistics to evaluate the effectiveness of the RGM-4-CCL4GIE. This includes analysing mean scores, correlations, and p-values to determine the statistically significant impact of the model on learner motivation and engagement. Expert evaluations are also conducted to gather valuable feedback on the model's design, usability, and overall effectiveness. The deliverables of this phase include a comprehensive pilot study report, detailed analysed statistical data, and comprehensive expert evaluation reports.

The final phase, communication, focuses on the dissemination of the research findings to both the academic and practical communities. This involves the preparation of manuscripts for publication in reputable peer-reviewed academic journals and presentation of the research at relevant national and international conferences. This ensures that the research contributes meaningfully to the existing body of knowledge in the fields of robotic gamification, climate-change education, and green innovation and entrepreneurship within the specific context of SSA. This detailed methodological approach certifies a rigorous and systematic process throughout the design, development, and evaluation of the RGM-4-CCL4GIE, ultimately contributing to a more effective and engaging learning experience in climate-change education.

4.4 Chapter Summary

This chapter outlines the theoretical and methodological framework underpinning the RGM-4-CCL4GIE. The first section details the theoretical framework, explaining how the OCT, SDT and MDA framework are integrated to foster intrinsic motivation and sustained engagement in climate-change education. This section describes the ways in which SDT principles of autonomy, competence, and relatedness are implemented through gamification elements such as badges, assessments, points, and leaderboards. The chapter then discusses the role of random rewards, guided by the Behavioural Reinforcement Theory, in maintaining learner curiosity and engagement. Finally, Chapter Four explains how the MDA framework informs the model's design, particularly the integration of the Nao robot to enhance the learning experience aesthetics. The second section of the chapter outlines the research methodology, detailing the application of the Design Science Research Methodology (DSR). This section describes the six iterative phases of the research process, from problem identification and objective definition to model design, prototyping, evaluation, and communication. This section also emphasizes the systematic and rigorous approach taken to develop and validate the RGM-4-CCL4GIE within the sub-Saharan African context.

CHAPTER FIVE: THE ROBOTIC GAMIFICATION MODEL FOR CCL4GIE EDUCATION

5.1 Introduction

This chapter introduces and details the prototype of the proposed (RGM-4-CCL4GIE. Building upon the theoretical foundations and contextual requirements discussed in previous chapters, this chapter presents a comprehensive framework that integrates robotic technology with gamification principles. The chapter is structured into two main sections. Section 5.2 focuses on the mathematical modelling of the gamification elements that constitute the RGM-4-CCL4GIE. Section 5.2 presents formal mathematical representations for random badges, competence points, assessment-based badges, leaderboard rankings, and aesthetic elements. These models translate theoretical concepts from the OCT, SDT and MDA framework into quantifiable parameters that can be systematically implemented in educational settings. Section 5.3 details the RGM-4-CCL4GIE education architecture, illustrating how the theoretical and mathematical components are integrated into a functional system. This section describes the roles and interactions between key architectural components including learners, tutors, the gamified desktop module, the Nao robot module, learning content database, gamification database, and the evaluation process. The architecture demonstrates ways in which these elements work together to deliver climate-change literacy education while enhancing learner motivation, engagement, and outcomes through principles of intrinsic motivation and behavioural reinforcement. By presenting both the mathematical foundations and architectural design of the RGM-4-CCL4GIE, this chapter provides a blueprint for implementing robotic gamification in climate-change education that is theoretically grounded, technically feasible, and specifically contextualized for sub-Saharan African educational environments; such gamification would address the unique challenges and opportunities in the region's climate-change education landscape.

5.2 Mathematical Modelling of Gamification Elements

The RGM-4-CCL4GIE model is built upon an integration of OCT, SDT and MDA framework, as illustrated in Figure 4.1, with the goal of maximizing learner motivation, engagement, and outcomes. This section will present the mathematical formulations of the gamification elements that together form the model.

5.2.1 Modelling random badges

Consistent with Skinner's principles, this model employs a random badge awarding system, mathematically described using probability theory. This approach creates a variable reward schedule that aligns with the random nature of OCT (Castillo et al., 2022). In explaining badges, let $B = b_1, b_2 \ldots b_{|B|}$ denote badges and $P = b_i$ illustrate change of badge b_i being awarded. The design features three tiers of badges – bronze, silver, or gold – with the specific type awarded depending on the settings and the achievement. Within this model, users can randomly receive badges simply for logging into the class. Additional badges are earned upon successful completion of lessons and projects. The formula for the probability distribution of the badges is:

$$\sum_{i=1}^{|B|} P(b_i) = 1 \qquad (1)$$

The sum (∑) of probabilities for all badges is set to 1, consistent with probability theory. Here, b start is the initial badge index, and $|B|$ represents all badges to be won. Equation number 1 gives the likelihood of awarding a particular badge b_i. A pseudo-random number r in the interval $(0,1)$, introduces the unpredictability of operant conditioning.

The linear congruential generator (LCG) is a method for producing a sequence of pseudo-random numbers. This model employs LCG due to its simplicity and widespread use as a pseudo-random number generator (PRNG) algorithm, which generates numbers based on a recursive formula:

$$d + 1 = (a * d + c) \; mod \; m \qquad (2)$$

where:

- d – present random number
- $d + 1$ - subsequent random number
- a - multiplier
- c - increment
- m - modulus

The RGM model utilizes a cumulative distribution function to make conclusions on badge awards.

$$F(i) = \sum_{j=1}^{i} P(b_j) \quad (3)$$

Badge allocation depends on determining the smallest i such that $F(i) \geq r$, where b_j is the badge awarded.

$$r \leq F(1) \longrightarrow Award\ b_1$$

$$F(1) < r \leq F(2) \longrightarrow Award\ b_2$$

$$F(|B| - 1) < r \leq F(|B|) \longrightarrow Award\ b_{|B|} \quad (4)$$

The values $P(b_1)$ represent probabilities, serving as parameters that indicate how likely each badge is to be awarded.

5.2.2 Modelling competence

RGM-4-CCL4GIE design implements the feeling of competence through the awarding of points as supported by SDT. Let C be points obtained after test. Every learner wins particular points following results of evaluation. The competence points $c_i \in C$ *where* i denotes the user.

$$C = c_1, c_2 \ldots c_{|B|} \quad (5)$$

The design considers that competence points illustrate one's performance. Let P_i represent the performance of user i, and $f(Pi)$ be a function that plots performance to competence points,

therefore $$Ci = f(Pi) \quad (6)$$

Tailored to the particular assessment criteria established in Moodle, the function f is utilized. Points are accumulated over time to illustrate the student's growing proficiency. If $Ci(t)$ signifies the points achieved by user i at time t, this can be calculated by summing all competence points awarded until that time:

$$Ci(t) = \sum_{j=1}^{t} C^j \quad (7)$$

where C^j is the competence points awarded to user i at time j. Competence points are visually represented on a user profile to provide feedback on the user's mastery and progress.

5.2.3 Modelling badges based on assessments

Badge allocation in the model is mathematically modelled using assessment grades, with a system that assigns specific badges to certain grade ranges. Consider G as the grade received by a student in the assignments, and B a as the corresponding badge. Grades are expressed in percentage format, with predefined intervals like 0-59%, 60-79%, and 80-100%. Each of these percentage bands will be linked to a particular badge in the following manner.

$$\text{A: } 70\% \leq \text{G} \leq 100\% \rightarrow \text{B} = \text{“Gold Badge”}$$

$$\text{B: } 60\% \leq \text{G} < 70\% \rightarrow \text{B} = \text{"Silver Badge"}$$

$$\text{C: } 50\% \leq \text{G} < 60\% \rightarrow \text{B} = \text{"Bronze Badge"}$$

$$\text{D: } 40\% \leq \text{G} < 50\% \rightarrow \text{B} = \text{"Green Badge"}$$

$$\text{F: G} < 40\% \rightarrow \text{B} = \text{"Red Badge"} \quad (8)$$

The badge assignment process based on performance levels is mathematically captured by this representation.

5.2.4 Modelling leaderboard

The leaderboard's mathematical framework utilizes a scoring paradigm whereby points are awarded to students as a function of their assessment points.

Let

- S represent student
- Ps represent total points
- l represent the leaderboard

Correct answers in assessments earn points according to this scoring system. This scoring system awards points per correct assessment answer. Correct Answer: $+X$points

Incorrect Answer: 0 points

The worth of X is accustomed following the distribution of points. The aggregate points P_s is a user considered by the points obtained in the assessment.

$$Ps = \sum_{i=1}^{N} Xi \tag{8}$$

N signifies the number of correct responses and X_i is the points earned. Moreover, the learners are graded based on the cumulated P_s whereby the learner with the most points holds the top position on the leaderboard.

$$Rank\ (S)\ =\ Rank\ of\ Ps\ in\ L \tag{9}$$

Students on the leaderboard can be ranked in ascending or descending order. Furthermore, the representation provides a list of students showing their individual ranks and total points.

$$L\ =\ \{(S_1, Rank_1, P_1, (S_2, Rank_2, P_2), \ldots, S_n, Rank_n, P_n) \tag{10}$$

In Equation 10, $S_i$is the ith student, $Rank_i$ is their rank, and P_i is their total points. The fundamental principle of a leaderboard, where students are ranked by total assessment points, is captured by this mathematical model.

5.2.5 Modelling aesthetics

The subjective nature of aesthetics is evident in its encompassing of various sensory and emotional aspects. Presenting variables for emotional impact *(EI)*, visual appeal *(VA)*, and auditory pleasure (AP) allows quantification. *EI* varieties from *0* to *1*, with *0* representing low and *1* high emotional impact. Equally, *VA* and *AP* vary from *0* to *1*, signifying low to high visual appeal and auditory pleasure, correspondingly. The amalgamation of these factors creates the overarching aesthetic experience, involving the synthesis of individual elements for a thorough evaluation

$$Aesthetics = W_{EI}.\text{EI}\ +\ W_{VA}.\text{VA}\ +\ W_{AP}.\text{AP} \tag{11}$$

where W_{EI},W_{VA} , W_{AP} are weights that represent the significance of each factor, and the model seeks to measure and synthesize the various components that affect aesthetics.

5.3 RGM-4-CCL4GIE Education Model Architecture

The RGM-4-CCL4GIE with Nao robot was conceived drawing from SDT, OCT and MDA framework, as already noted. The elements of the model, as shown in Figure 5.1, are two databases, two modules, learners, a tutor, arrows, and evaluation sections.

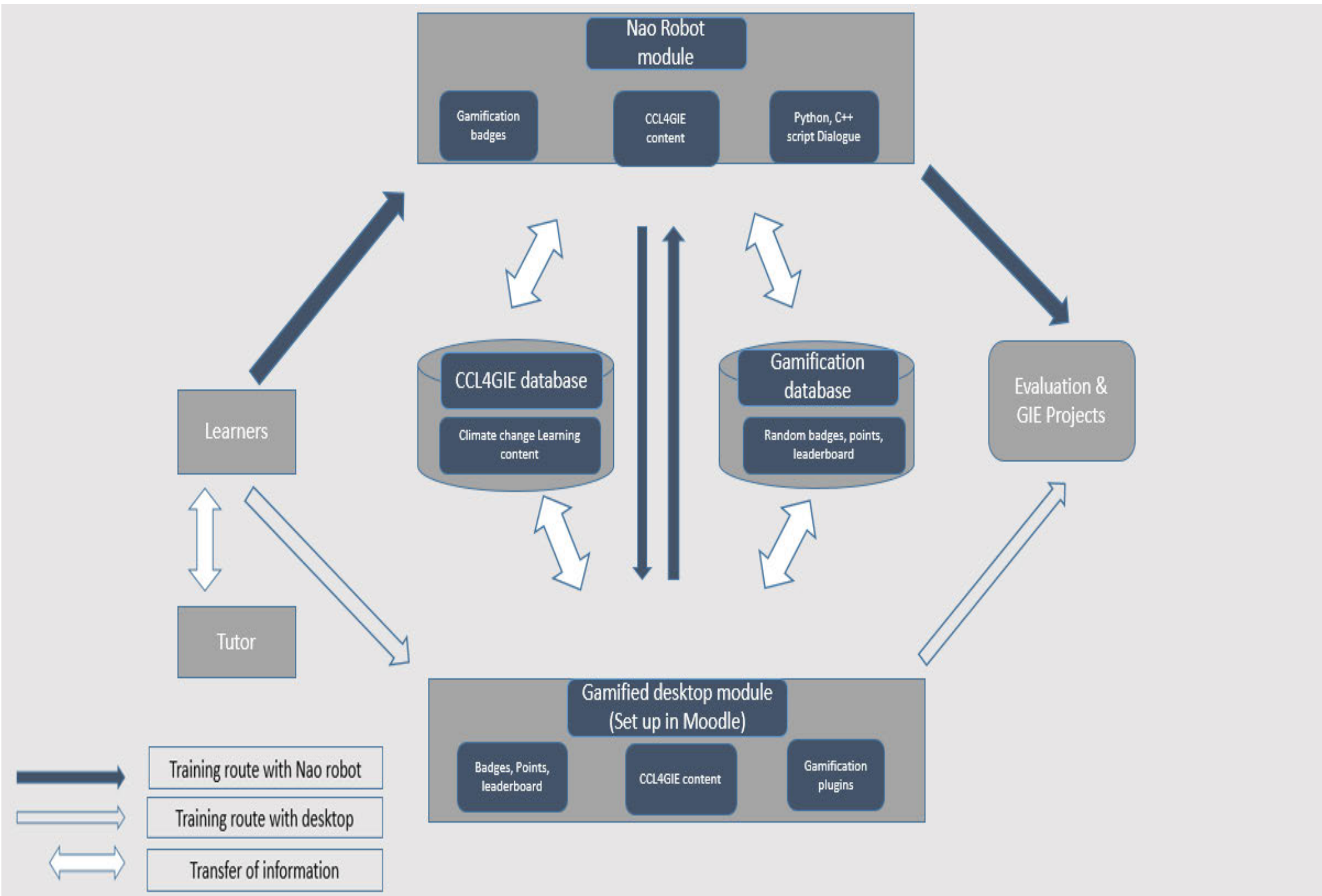

Figure 5.1 RGM-4-CCL4GIE education model architecture

5.3.1 Learner and tutor

The learner section of the model refers to the volunteer students in the climate-change training. The tutor section defines the instructor who assists learners with system configuration and orients them towards desktop or robot-based tasks.

5.3.2 Arrows

Arrows track learner advancement where the white arrows indicate communication between model components, starting with tutor-learner coordination. The robot connects to databases for training information and gamification instructions before delivering the climate change training. The desktop module also links to these databases for training delivery. The grey arrow shows the path of desktop training, while green arrows show the path of Nao robot module users.

5.3.3 Gamified desktop module

Utilizing gamification principles, the gamified training module delivers instruction to students. This model's desktop module is realized within the Moodle e-learning system, the digital space for the Carbon Literacy course. A custom plugin designed to introduce random badge awards is installed on the Moodle platform. Furthermore, plugins that support gamified learning are fitted and configured to create unpredictable awards. In accordance with Skinner's theory, a random consistency badge is incorporated. Assessments are gamified by presenting questions Cryptex and crossword modes. Further, the system is designed to grant a reward to students upon completion of the training, prior to the assessments. Following assessment completion, learners receive a badge corresponding to their achieved marks. A leaderboard displays position of learners once the assignments are finalized. Final phase of the involves a collaborative task where each student is required to join with two peers to brainstorm and develop ideas for Green Innovation and Entrepreneurship (GIE) projects (Rutledge, 2018). This group activity encourages teamwork, critical thinking, and practical application of the knowledge gained during the course. Students are given a 48-hour window to complete the task and present their proposed project concepts to the tutor for evaluation and feedback.

5.3.4 Nao robot module

The model incorporates the Nao robot as an integral component to enhance user engagement and motivation throughout the learning experience. As depicted in Figure 3.6, Nao was selected for this implementation due to its ongoing commercial availability and continued production, ensuring accessibility and long-term support. Equipped with dual body cameras and a variety of sensors (also shown in Figure 3.6), Nao can interact dynamically with learners. It can be programmed to participate in dialogues, perform limb movements, and alternate its head while conveying training content in an interactive manner. In addition to its instructional role, Nao also contributes to the gamified environment by awarding digital badges to students upon involvement in the training. While Nao is the primary robot used in this model, alternative robots may be employed in different contexts, depending on their availability and compatibility with the system.

5.3.5 CCL4GIE learning content database

The CCL4GIE training content database contains CCL and GIE information for students, feeding both desktop and robot modules. This includes basic definitions, carbon footprints, greenhouse gases, causes and remedies of climate change, and assessments with answers.

5.3.6 Gamification database

The central objective of this design is to establish a CCL and GIE training system that fosters sustained learner engagement and motivation. Consequently, a gamification database is a crucial element. The model's design includes badges, points, leaderboards, and GIE projects to drive learner motivation. Self-Determination Theory (SDT) posits that intrinsic motivation grows when participants' desires for autonomy, relatedness and competence are satisfied (Donnermann, 2021; Riedmann et al., 2022). Badges cater to users' competence needs. The leaderboard fosters relatedness, and the GIE project achieves relatedness through teamwork (Rajanen, 2019; Robinson, 2019; Yaşar, 2020). Autonomy is also achieved through points learners gain after assessments. The robot enhances aesthetics in the model to keep learner emotions high, increasing training engagement as per the MDA framework (Fernández Galeote & Hamari, 2021). Lastly, the model employs Skinner's behavior reinforcement theory by using a random, not systematic, reward system. Learners receive random badges upon training login to encourage continued participation and boost engagement, motivation, and learner outcomes.

5.3.7 Evaluation and GIE projects

The final evaluation phase involves a TAM-based survey for student feedback analysis. We prioritize the Technology Acceptance Model (TAM) for its proven ability to measure user acceptance via perceived usefulness and ease of use, making it ideal for our gamified-robot learning model. SDT and other frameworks offer additional insights into learner motivation and experience for a comprehensive analysis. This last stage gathers post-training learner information, followed by result communication, and includes an expert survey. In computing, the Technology Acceptance Model (TAM), derived from the Theory of Reasoned Action (TRA), is a pivotal tool for assessing computer system user acceptance (Davis, 1989; Durodolu, 2016). This model evaluates external variables like perceived usefulness (PU), perceived ease of use (PEOU), attitude (A), skills engagement (SE), and interaction engagement (IE) (Veiga & de Andrade, 2021). TAM, based on TRA, offers a comprehensive way to examine user acceptance of information systems (Durodolu, 2016), and user feedback on these areas will evaluate the system. This research will use TAM and also SDT, Flow Theory, Cognitive Load Theory, and Human-

Computer Interaction (HCI) frameworks to empirically compare the designed model (Davis, 1989). Survey prompts, developed using TAM, captured user experience with robotic and gamification elements: random badges, points, leaderboards, and Nao robot aesthetics. These elements were based on SDT, OCT, and MDA frameworks. The RGM-4-CCL4GIE with social robot Nao aims to create sustained learner engagement and motivation for long-term learning outcomes.

5.4 Chapter Summary

This chapter details the mathematical modelling of the gamification elements within the RGM-4-CCL4GIE, grounded in the OCT, SDT and MDA framework. This integrated theory mathematically represents the random badge award system using the probability theory and a pseudo-random number generator, aligning with Skinner's principles of intermittent reinforcement. The chapter then models competence through points awarded based on user performance, and badges earned according to assessment grades. Chapter Five further formulates the leaderboard ranking system based on accumulated points. A mathematical model for aesthetics is also presented, incorporating emotional impact, visual appeal, and auditory pleasure. Finally, the chapter describes the RGM-4-CCL4GIE education architecture, outlining its components: learners, tutor, and gamified desktop module, Nao robot module, learning content database, gamification database, and evaluation section, explaining how each component interacts to deliver and enhance climate-change education.

CHAPTER SIX: PROTOTYPE IMPLEMENTATION

6.1 Introduction

Chapter Six documents the implementation of the RGM-4-CCL4GIE prototype, demonstrating the systematic integration of gamification mechanics and robotic elements within a Moodle-based learning management system. The implementation architecture transforms the theoretical framework into a functional system comprising interconnected modules for climate-change literacy and green innovation entrepreneurship education. The chapter's structure follows the system's technical architecture, beginning with an overview of the core components and their integration points. The chapter then examines the desktop module implementation, detailing the XAMPP server configuration, Moodle platform deployment, and the development of custom plugins for random badge distribution and game-based assessments. The final section documents the robotic training module implementation, focusing on the NAO robot programming through Choregraphe, including behaviour scripting, speech interaction protocols, and the integration of these robotic elements with the core learning platform. Each section includes technical specifications, implementation procedures, and the underlying mathematical models that drive the system's gamification mechanics.

6.2 The Key Components and Implementation

The prototype leverages the Moodle e-learning management system as its primary platform, seamlessly integrating gamified content and crossword game-based assessment mechanisms. This choice ensures a familiar and robust foundation for delivering interactive educational experiences. A standout feature of the prototype is the implementation of a random badge awarding plugin, which introduces an element of chance to the learning journey. Each time users access their dashboard, the system generates a random number between 0 and 10, determining whether they earn a badge. This dynamic and unpredictable system fosters excitement, encouraging more frequent engagement with the platform. To further enhance the user experience, the prototype incorporates the Nao robot. This integration enriches the aesthetic and interactive dimensions of the learning process by providing embodied interaction. The presence of the robot helps create a more engaging and emotionally resonant environment, appealing to learners on both cognitive and affective levels. Additionally, the prototype includes various gamification elements, such as points, badges, and leaderboards. These features are thoughtfully designed to support key motivational drivers—autonomy, competence, and relatedness—encouraging sustained learner engagement and fostering a sense of achievement and community within the platform.

By synergizing advanced gamification principles with robotics technology and innovative random reward mechanisms, this RGM prototype represents a significant contribution to climate-change education. The RGM-4-CCL4GIE theoretical framework explains how the gamification elements are determined and the aspect of motivation that the elements inclusion produces, as summarized in Figure 4.1, Table 4.1 and Table 6.1. A new framework is thus offered for addressing the pressing need for effective climate-change literacy and green entrepreneurship education in the contemporary global context, while potentially increasing sustained learner engagement through its unique approach to gamification and reward distribution.

6.3 Desktop Module

The desktop training module is set up in the Moodle e-learning platform because it already has background settings that can be optimized to deliver a gamified training. The default Moodle platform, however, lacks plugins needed to achieve random badge award and block game and level-up plugins that are required to gamify the assessments in the RGM-4-CCL4GI. The plugins are downloaded and installed to create provision for course gamification in line with the proposed framework. The random badge award plugin is also designed and implemented in this prototype section.

6.3.1 Setting up the Moodle platform

XAMPP is a freely available, open-source, cross-platform package that provides a web server solution stack, bundling Apache, the MySQL database, PHP, and Perl. Downloading XAMPP provides a local server environment, essential for hosting Moodle without the reliance on external web hosting services. This RGM-4-CCL4GIE training system is set up in a local host computer because gamification configurations must be tested first before they are launched in the general university e-learning platform.

The installation process is initiated by launching the downloaded XAMPP installer as shown in Figure 6.1. Following the on-screen instructions, users install XAMPP, which includes Apache (web server) and MySQL (database server). Apache serves to host Moodle web pages, while MySQL stores Moodle data. After installation the XAMPP control panel is accessed to start the Apache and MySQL servers (Converse et al., 2004). These actions initialize the Apache web server and MySQL database server, allowing them to run locally on the computer.

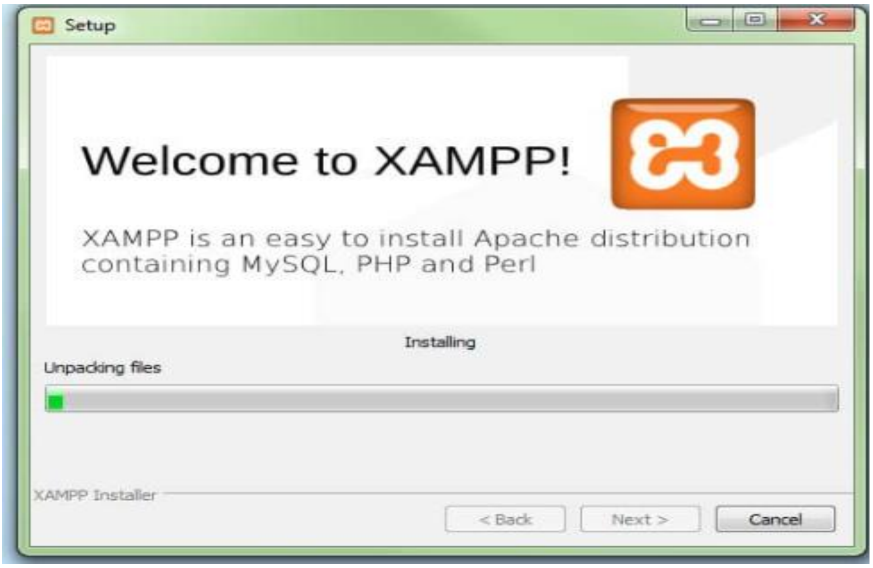

Figure 6.1 Installing XAMPP

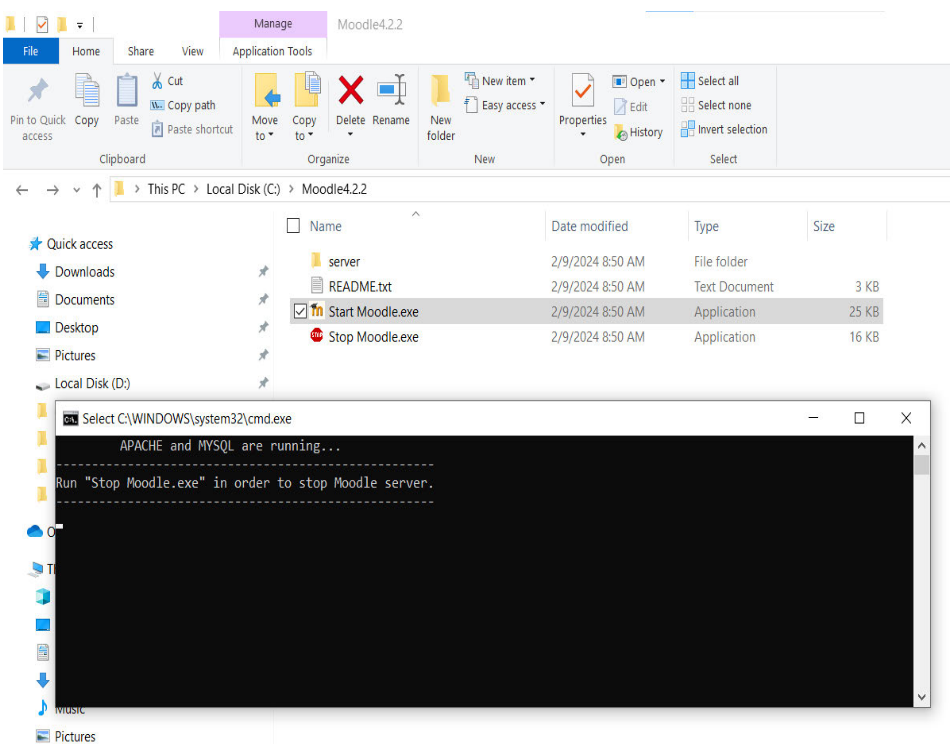

Figure 6.2 Starting Moodle

Moodle, an open-source learning management system (LMS), is necessary for creating and managing online courses. This system was configured with gamification features to support points, leaderboards and badges. The Moodle installation process is initiated by accessing “localhost” in their web browser, leading to the XAMPP welcome page. Following on-screen instructions, users configure Moodle settings, including database details. The Moodle system must be started anytime a user needs to launch it in a local computer, as shown in Figure 6.2.

6.3.2 Setting up the training in Moodle

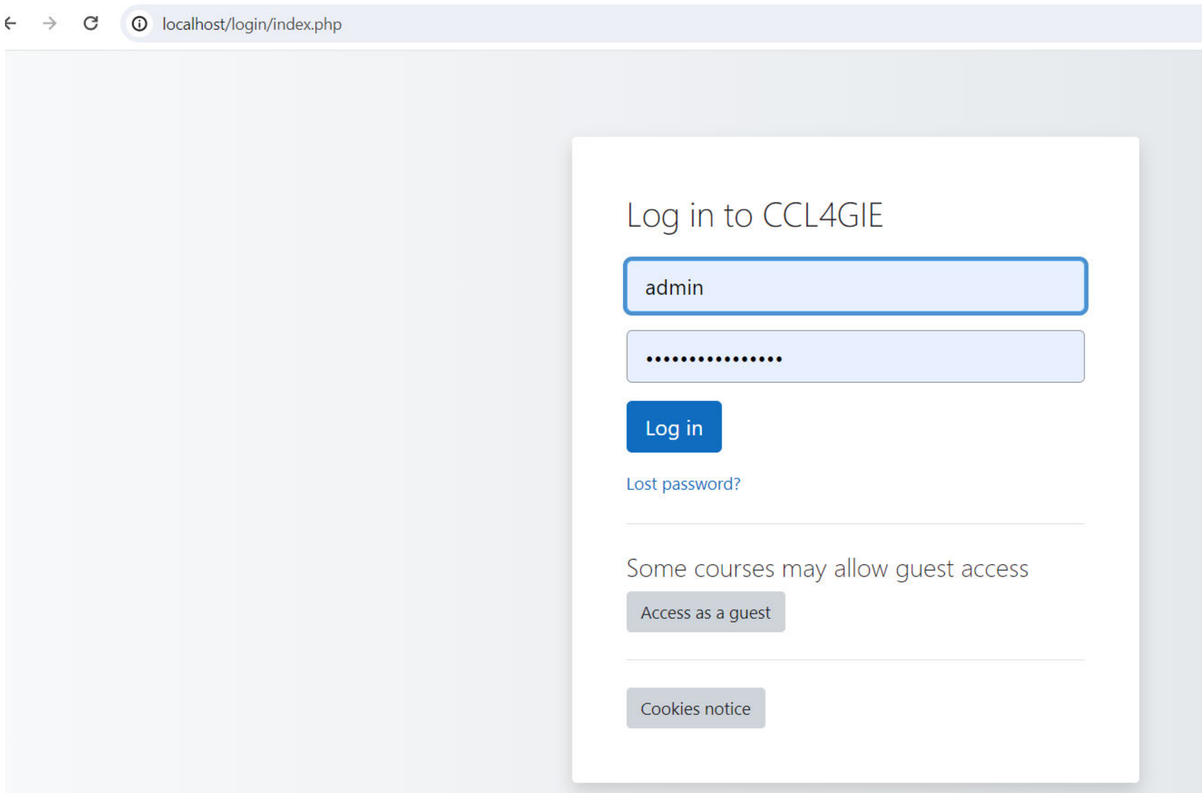

Figure 6.3 Admin setting in Moodle

After installing Moodle in a local host computer, the admin accounts are created as shown in Figure 6.3. The course details such as name and code are then configured, as shown in Figure 6.4, and users added to the course.

The course overview page also has a short video that introduces learners to the climate-change literacy course as shown in Figure 6.5. The inclusion of this video is also a gamification technique in line with MDA.

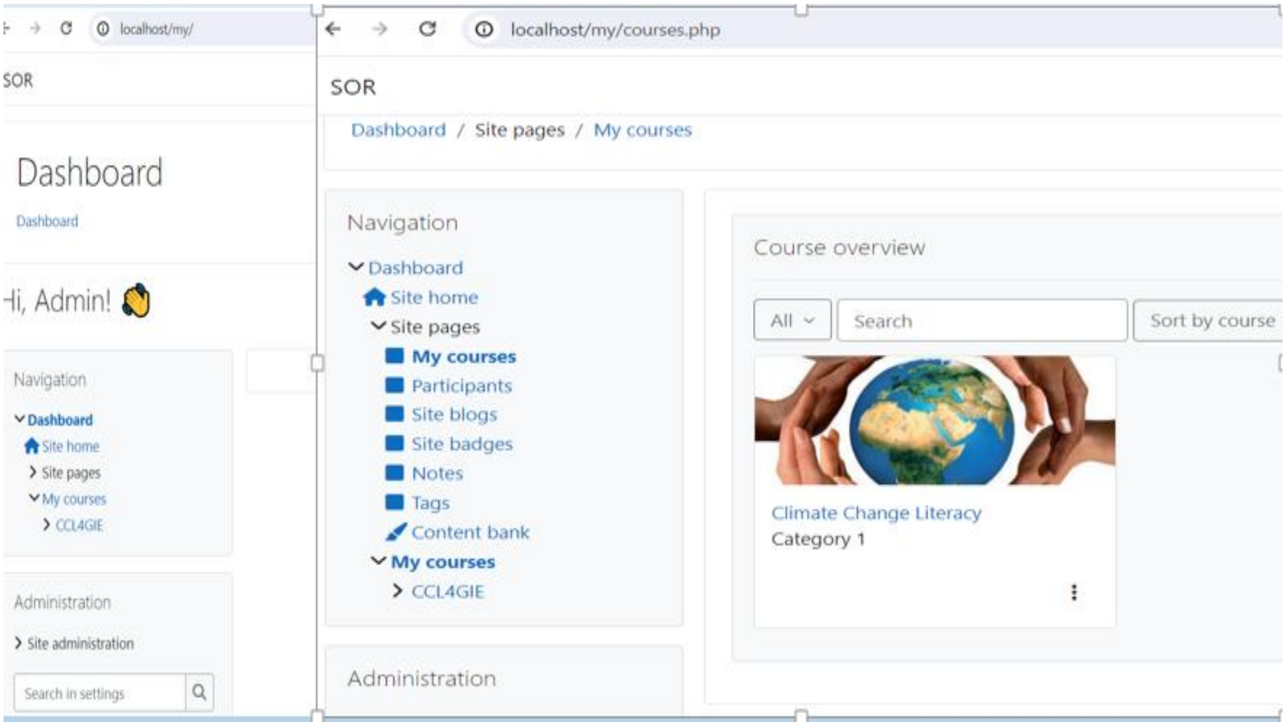

Figure 6.4 Course configuration

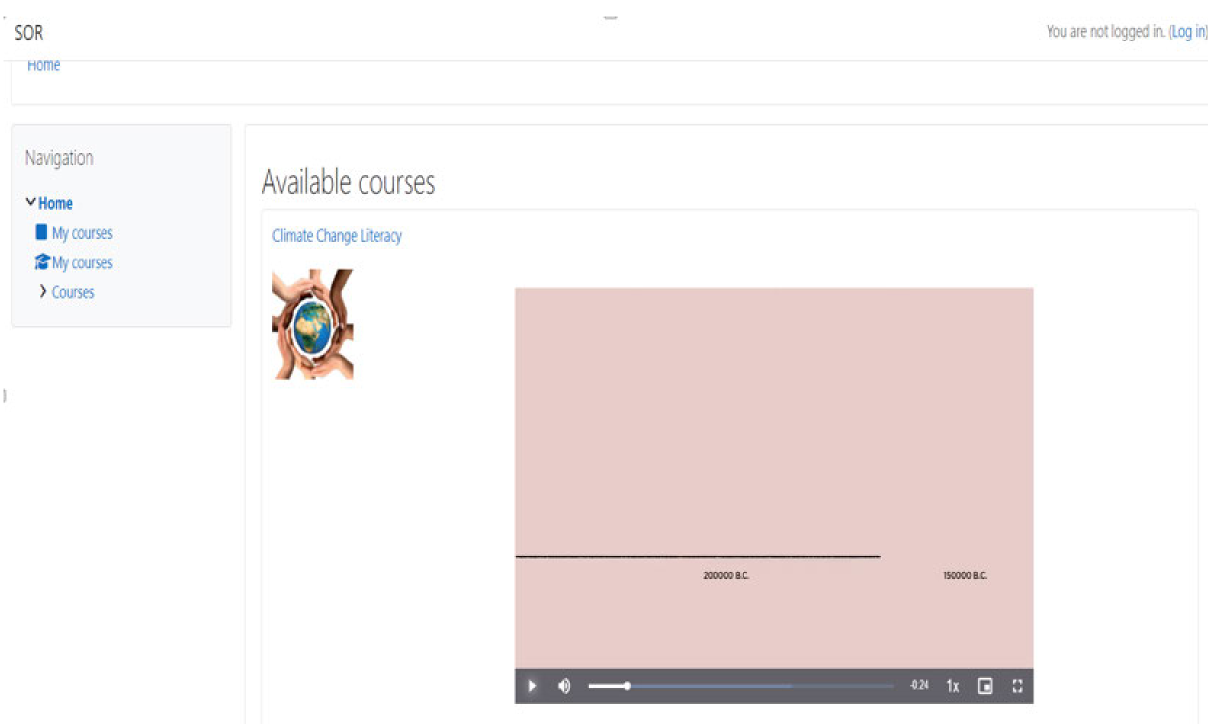

Figure 6.5 Course introduction video

The climate-change literacy course outline is as shown in Figure 6.6. The first item is announcement. A welcome note is placed here together with an image shown in Figure 6.7. The student then takes the Topic One lesson which is a 1-minute video of the climate-change basic training. The video is made from the slides to increase visual appeal while going through the training.

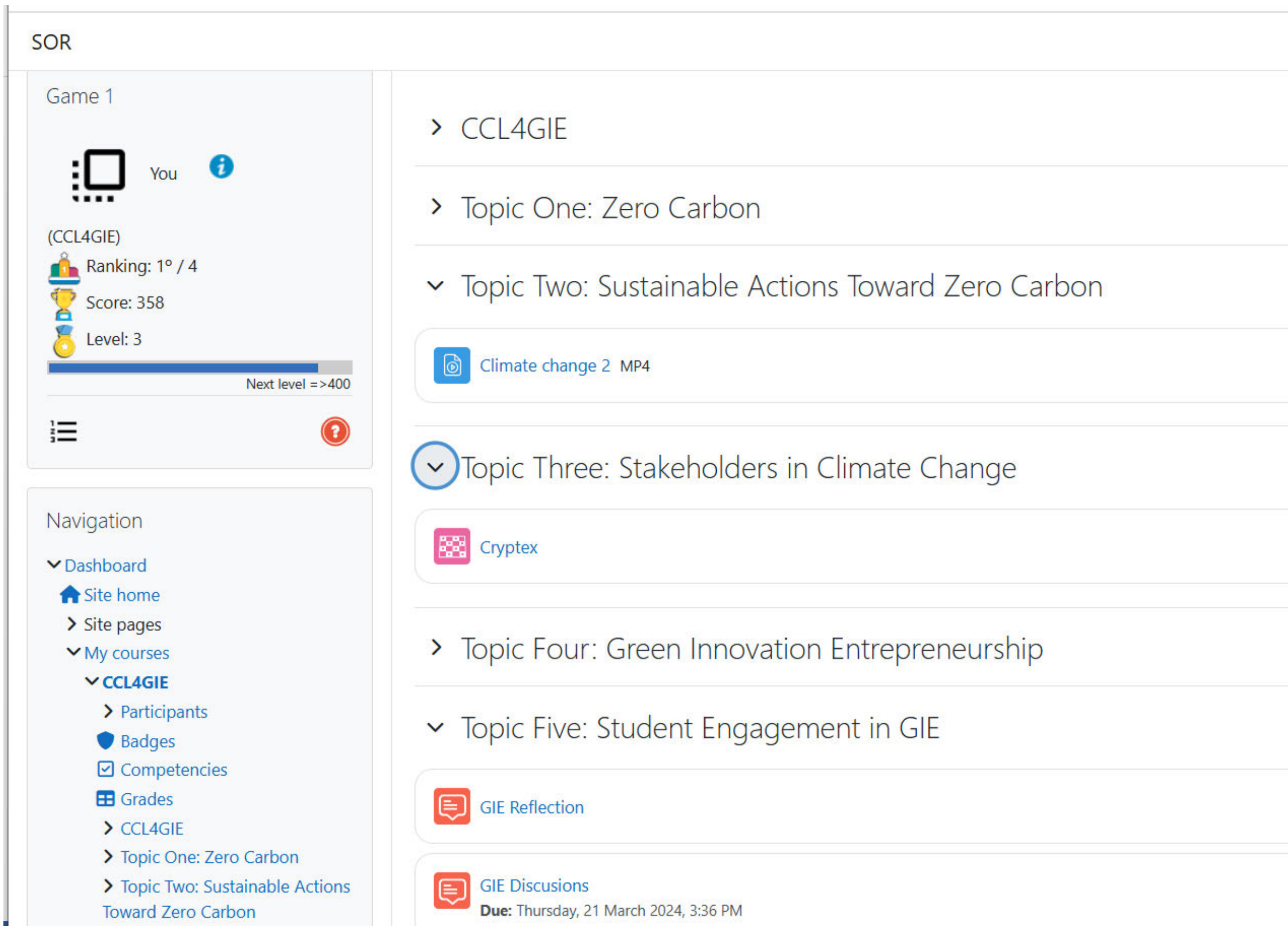

Figure 6.6 Course outline

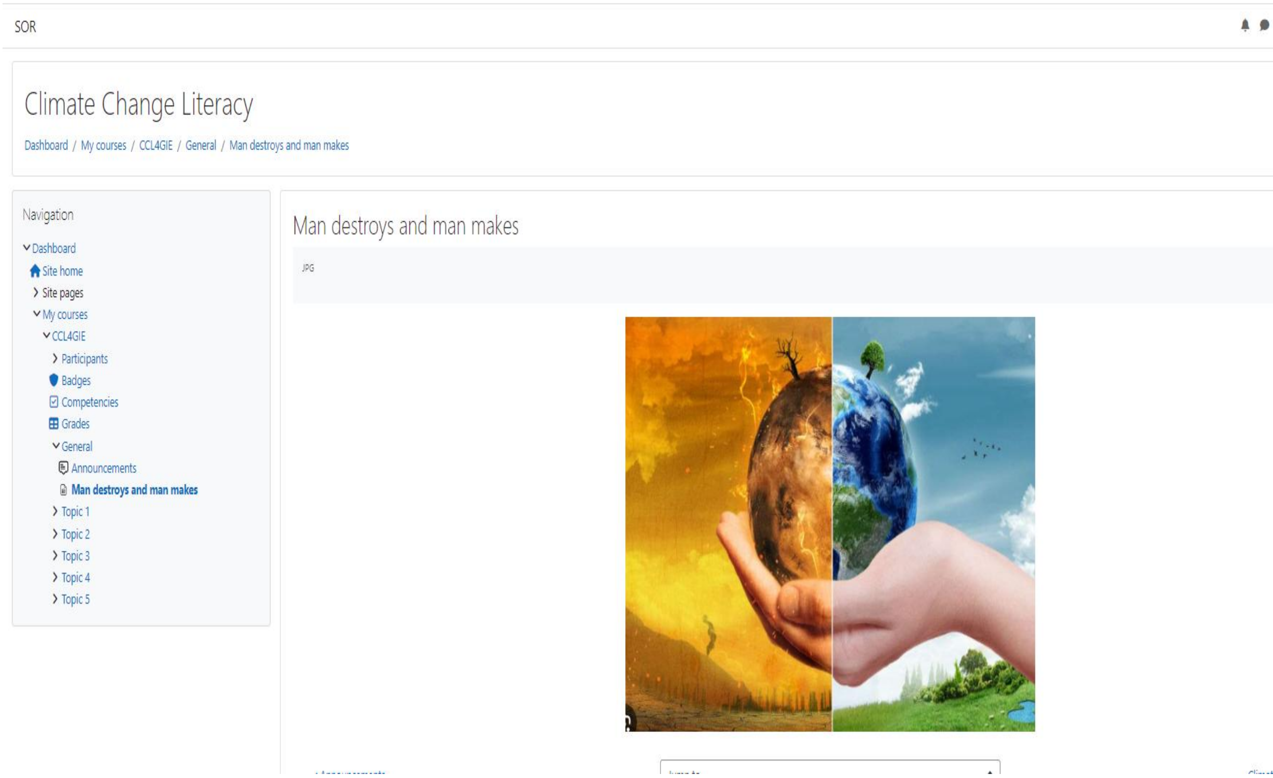

Figure 6.7 Course introduction image

Figure 6.8 Topic One lesson

6.3.3 Operationalizing the SDT-OCT-MDA into gamification components in the prototype

This prototype is an implementation of the RGM-4-CCL4GIE designed in Chapter Four. During the prototyping phase, the Self-Determination Theory aspects are used to set up gamification elements as summarized in Table 6.1

Table 6.1 Mapping of Gamification Elements and Theories

THEORY	GAMIFICATION ELEMENTS
SDT	
Competence	Assessment and points
Autonomy	Grade badges
Relatedness	Leaderboard and group project
Operant Conditioning Theory	Random badge award for class progress
MDA	Nao robot inclusion

These are three gamification components that contribute to competence, autonomy, and relatedness aspects of the SDT.

6.3.3.1 *Competence*

Competence, in the context of SDT, signifies the yearning to feel adept and influential in one's pursuits. In the RGM-4-CCL4GIE, competence was set to be achieved through inclusion of assessments. The mathematical modelling of competence utilizes the formula shown in Equation 7. From the equation, C^j represents the points awarded to user i at time j, and $Ci(t)$ represents the cumulative competences of user i at time t. The users in this case refer to students enrolled in the course. The competence points are the grades attained per time as the user progresses with the course and completes the assessments. The prototype has two assessments after each of the two lessons, as shown in Figure 6.9.

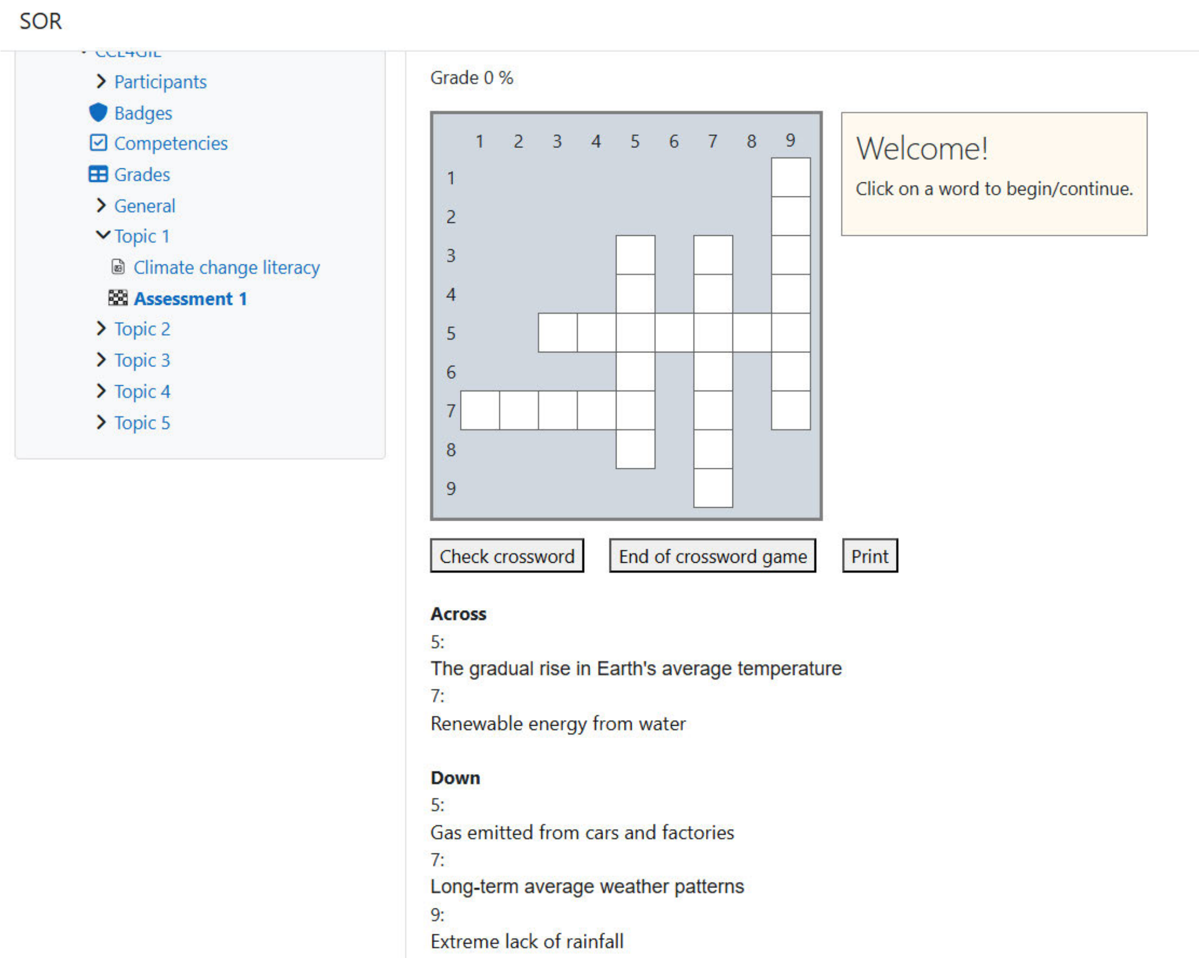

Figure 6.9 Assessment

Each of the assessments is made in the form of a game. Assessment One is a crossword game, while Assessment Two is a Cryptex game. The crossword game is played by reading questions and entering responses in the spaces provided. The responses must be synchronized with other words entered in the intersecting spaces. The Cryptex game, on the other hand, requires students to identify responses to the jumbled set of words. In order to configure the game mode of the assessments, the block game plugin was used to support this scenario. Furthermore, a glossary was set up from which the crossword and the Cryptex games would fetch the questions for display. The glossaries are hidden from learners, only visible from the admin side, as shown in Figure 6.10.

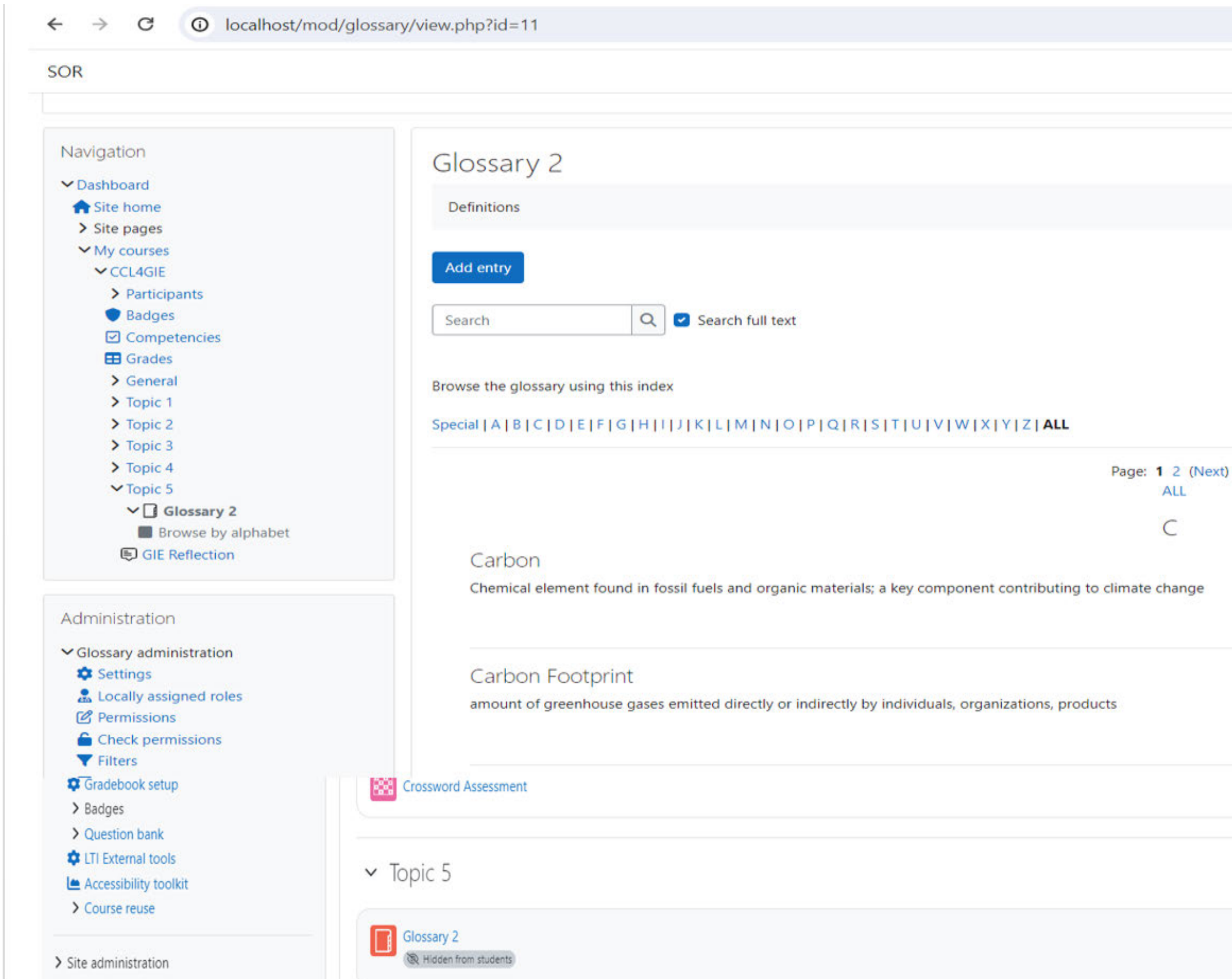

Figure 6.10 Glossary

From the SDT theory, the points shown in Figure 6.11 achieved from the assessments appeal to the competence aspect of the learners, and consequently increase their intrinsic motivation.

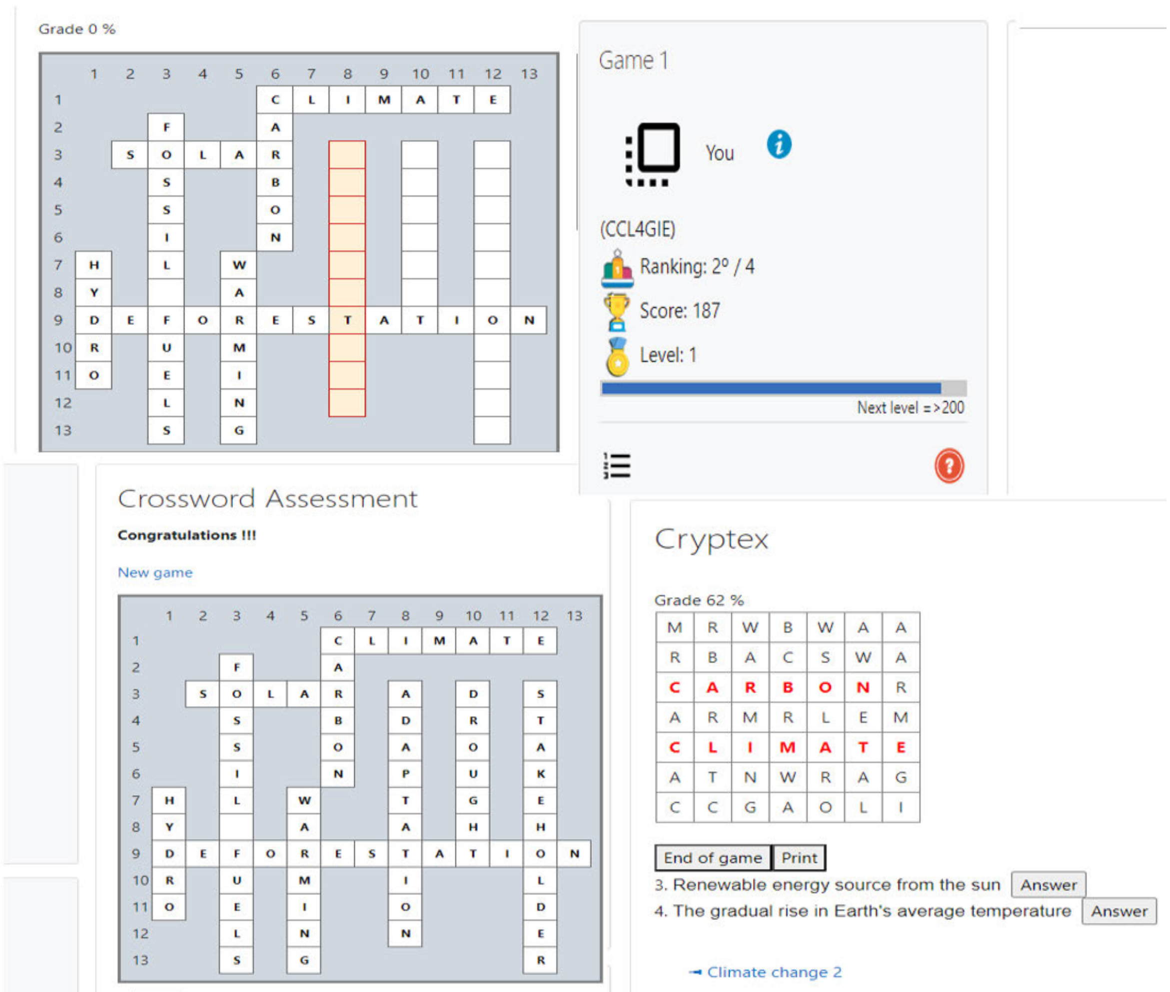

Figure 6.11 Points awarded from assessments

6.3.3.2 *Relatedness*

Relatedness is achieved through the leaderboard, as shown in Figure 6.12, and the GIE project that is delivered through teamwork in a group discussion, as shown in Figure 6.13. From the mathematical approach, the leaderboard is arrived at from a compilation of performance points that ultimately maps the student marks to the ranking list, as illustrated in the Equations 8, 9 and 10.

The prototype of the RGM-4-CCL4GIE has assessments as illustrated in Figure 6.11. As the student progresses with the assessments, the leaderboard ranking changes in line with the performance, as shown in Figure 6.12. During the testing phase, the highest-ranking student had 329 points, followed by two students with 200 points each out of a maximum of 500 points, as shown in Figure 6.12. Figure 6.14 also shows the progress of group discussions. Students give suggestions in their group and so feel connected as they contribute to the GIE project discussion.

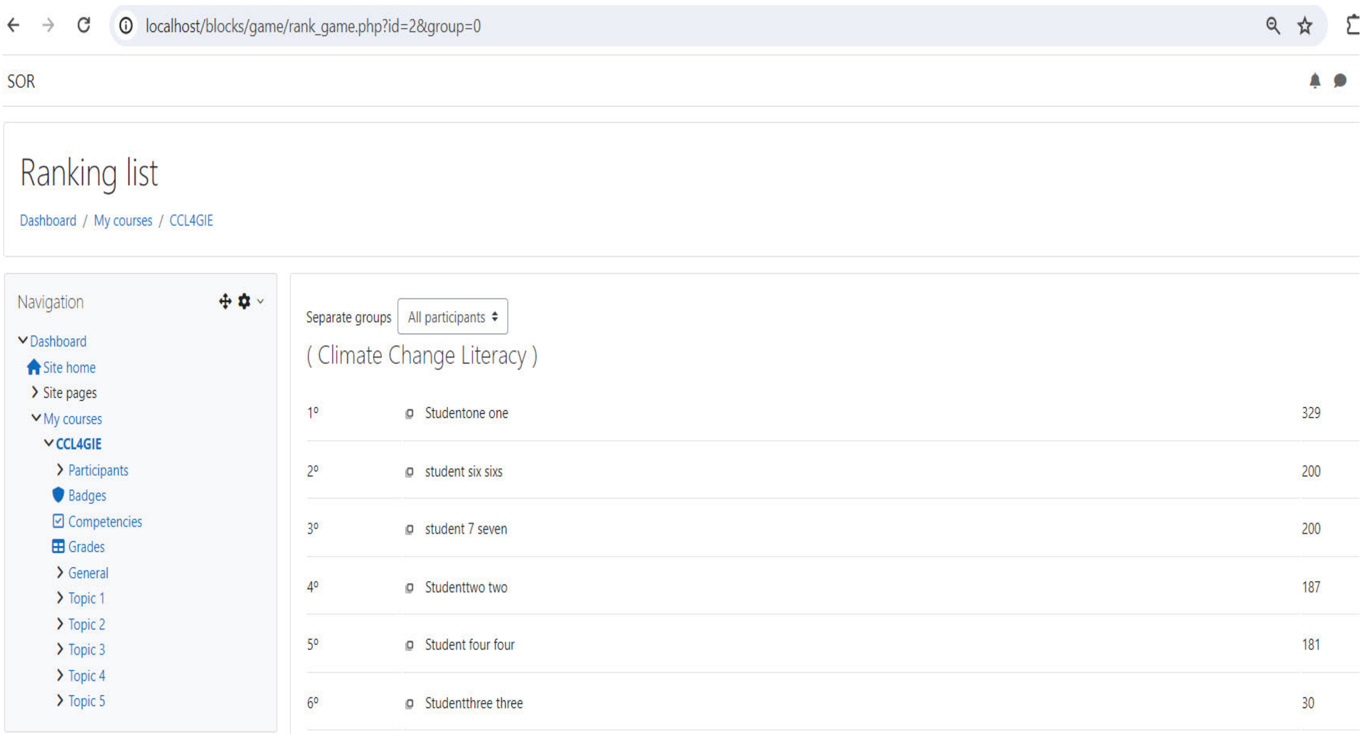

Figure 6.12 Leaderboard

6.3.3.3 *Autonomy*

The prototype of the RGM-4-CCL4GIE implements autonomy through awarding of badges. The badges are set to be awarded intermittently as the students sign in. The badges in the prototype include a starter badge and climate champion and completion badges, as shown in Figures 6.14 and 6.15. In this model, badges are awarded for class logins, lesson completion, and assignment completion. The probability distribution of these badges follows the formula in equation number 3 Equation number 1 gives the likelihood of awarding a particular badge b_i. A pseudo-random number r in the interval $(0,1)$, introduces the unpredictability of operant conditioning.

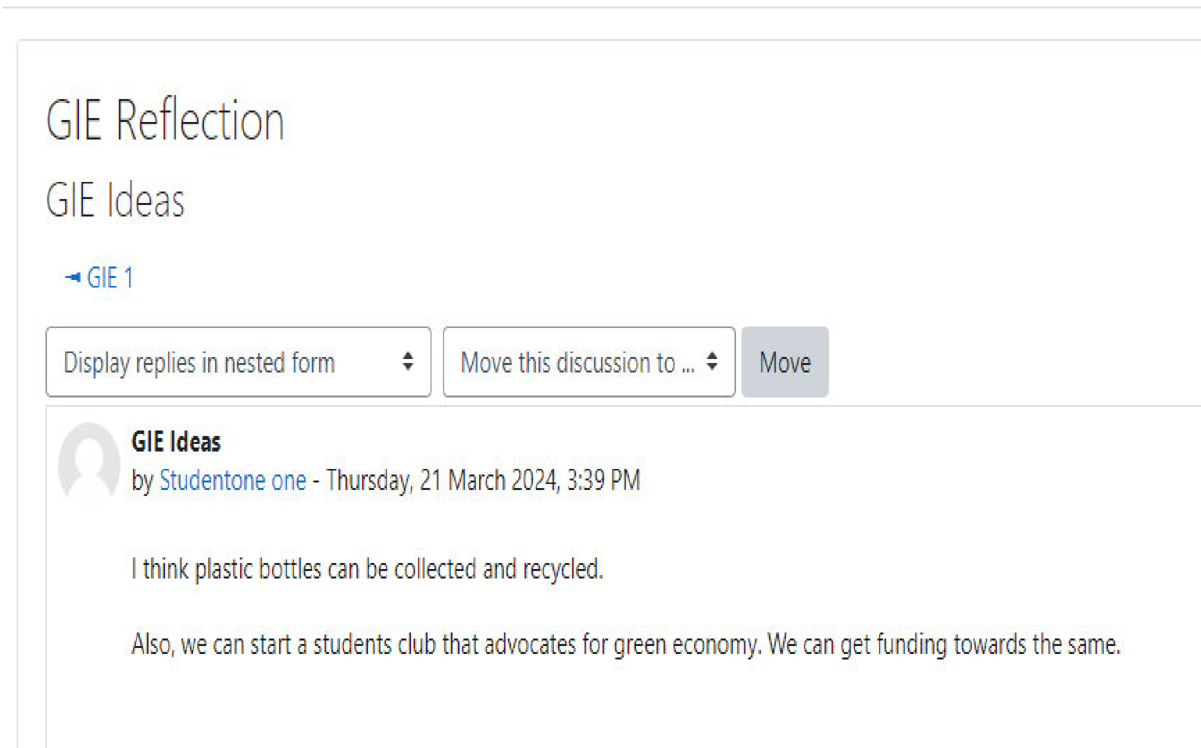

Figure 6.13 GIE project groups

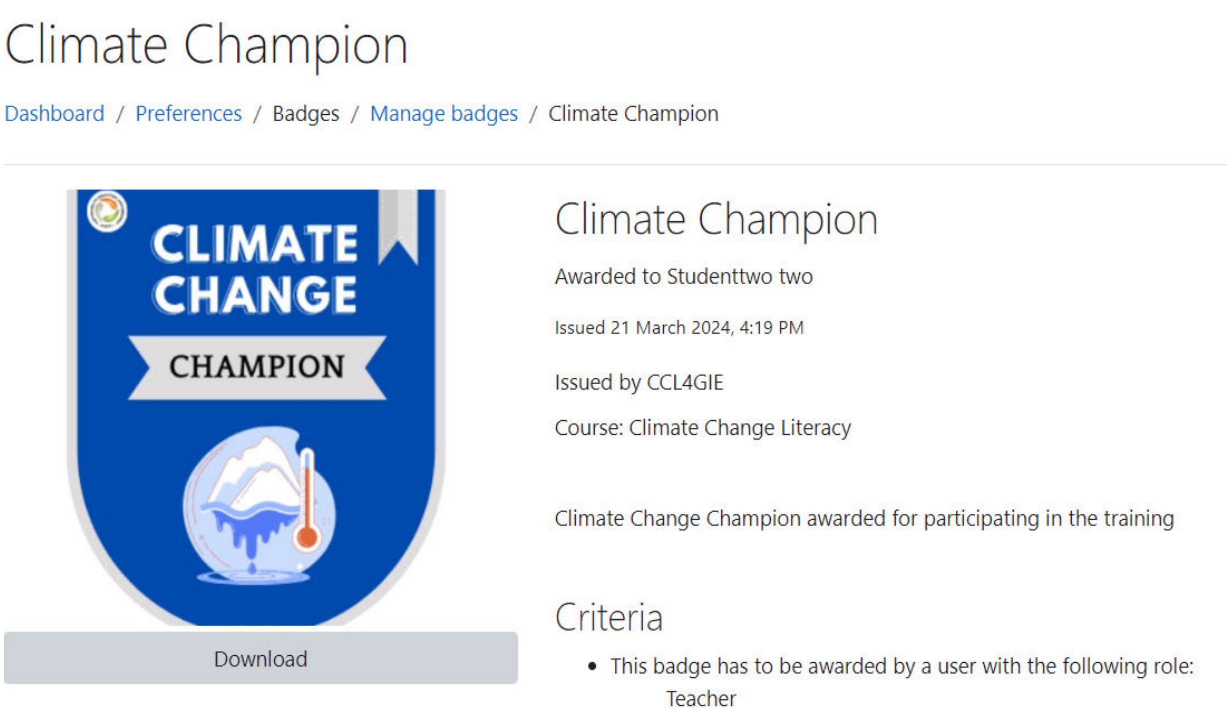

Figure 6.14 Climate Champion badge

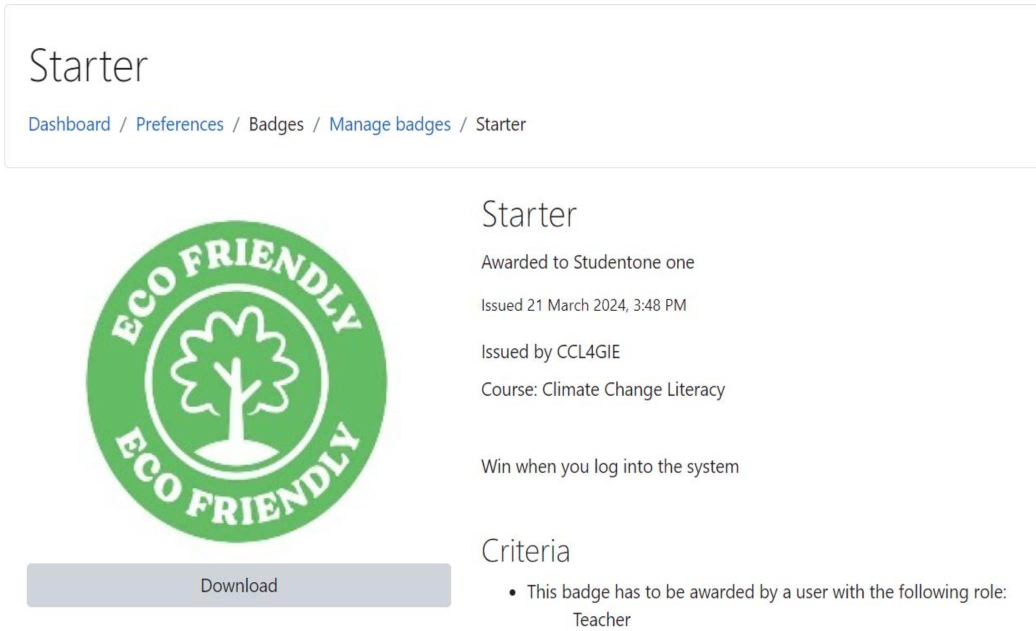

Figure 6.15 Starter badge

6.3.4 Random plugin

This section focuses on the development and implementation of a dynamic and interactive plugin artefact for the Moodle user dashboard. The primary objective is to introduce an element of surprise and gamification to the user's routine interactions with the platform, specifically targeting the moment when users access their dashboard. By leveraging a random number-generator coupled with conditional content display, created is a subtle yet impactful game-like interaction that aims to captivate users' attention and potentially increase their frequency of platform visits.

6.3.4.1 *Algorithm and implementation*

The core of our plugin relies on a simple yet effective algorithm that generates random outcomes and displays appropriate content based on those outcomes. We utilize PHP's built-in rand () function to generate a random integer between 0 and 10 (inclusive). This range is chosen to provide a balanced mix of outcomes, while keeping the logic straightforward, as shown in the probability analysis.

Given our range of 0 to 10, we have a total of 11 possible outcomes:

Even numbers: 0, 2, 4, 6, 8, 10 (6 numbers) and odd numbers: 1, 3, 5, 7, 9 (5 numbers). This leads to the following probabilities:

Probability of an even number: 6/11 ≈ 54.55%

Probability of an odd number: 5/11 ≈ 45.45%

The slight bias towards even numbers is due to the inclusion of 0 in our range. This small imbalance can be seen as a feature rather than a bug, as it slightly favours the 'winning' outcome, potentially boosting user satisfaction. The generated number is then evaluated to determine whether it is odd or even. This is achieved using the modulo operator, which returns the remainder after division by 2, as shown in the scripts (Figure 6.16).

```
$randomNumber = rand(0, 10);
$is Even = ($random Number % 2 == 0)
```

Figure 6.16 Number generation

The generated number determines whether or not a student wins a badge. The conditional badge display is based on the odd/even status of the number. We generate the content for the badge, as shown in the scripts in Figure 6.17. This includes different headings, messages, and images.

```
echo '
<div id="welcomeModal" class="modal">
    <div class="modal-content">
        <h2>' . ($isEven ? 'Congratulations' : 'Welcome to Moodle') . '</h2>
        <p>Your random number is: <strong>' . $randomNumber . '</strong></p>
        <div class="badge-container">
            <img src="' . ($isEven ? $CFG->wwwroot . '/badges/badge.png' : $CFG-
>wwwroot . '/badges/odd_badge.png') . '"
                 alt="' . ($isEven ? 'Even Badge' : 'Odd Badge') . '"
                 class="centered-badge">
        </div>
        <p>' . ($isEven ? 'You have won a badge for logging in!' : 'Continue
learning') . '</p>
        <button id="closeModal">Close</button>
    </div>
</div>
';
```

Figure 6.17 Random badge scripting

Figures 6.18 and 6.19 show the badge display when a student signs into the module. The random number generator determines whether a student wins a badge. Figure 6.18 is an example of a won badge. The plugin is integrated directly into Moodle's index.php file for the dashboard. This ensures that the random number generation and modal display occur each time the dashboard is loaded, as shown in Figures 6.18 and 6.19.

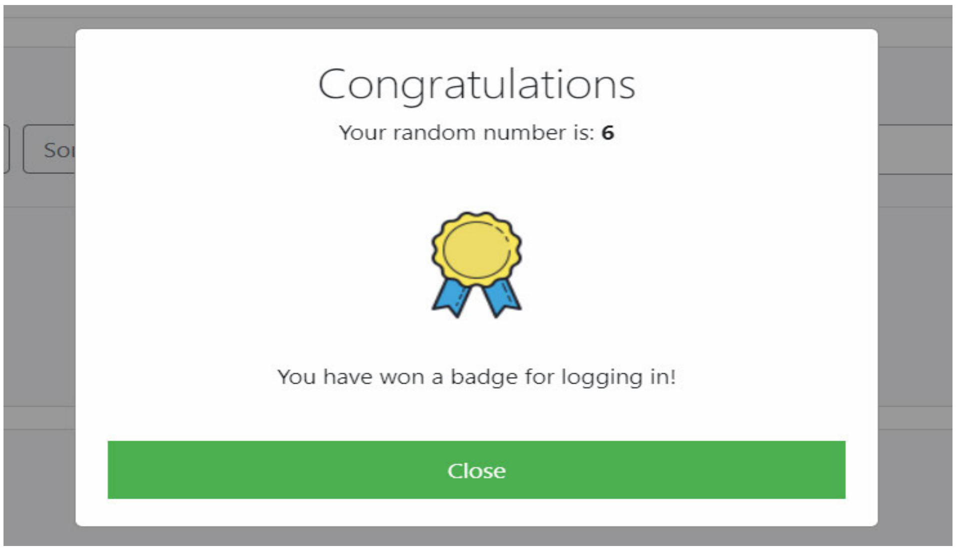

Figure 6.18 Random badge won

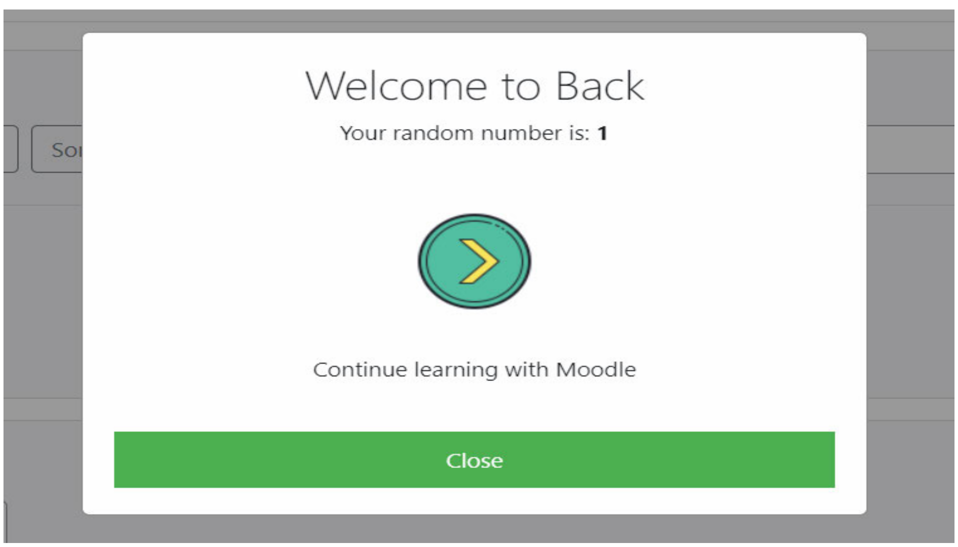

Figure 6.19 Random badge missed

We carefully analysed the index.php file, determining the most appropriate location to insert our code. The chosen spot ensures that our feature loads after all necessary Moodle components have been initialized, but before the page content is rendered.

6.3.4.2 *User interface design*

The modal interface is implemented using a combination of HTML, CSS, and JavaScript, ensuring a smooth and responsive user experience. The structure of the modal is designed to be semantic and accessible, as shown in Figures 6.20-6.22:

```
<div id="welcomeModal" class="modal" role="dialog" aria-labelledby="modalTitle">
    <div class="modal-content">
        <h2 id="modalTitle">[Dynamic Title]</h2>
        <p>Your random number is: <strong>[Random Number]</strong></p>
        <div class="badge-container">
            <img src="[Dynamic Badge Source]" alt="[Dynamic Badge Description]"
class="centered-badge">
        </div>
        <p>[Dynamic Message]</p>
        <button id="closeModal">Close</button>
    </div>
</div>
```

Figure 6.20 HTML structure

The modal's visually appealing and responsive CSS, informed by the MDA framework's emphasis on aesthetics, contributes to sustained engagement. A positive first impression and reduced cognitive load, achieved through clear design, encourages continued use. This enhanced user experience across devices fosters satisfaction and return visits. Ultimately, aesthetics drive intrinsic motivation, supporting long-term engagement and learning outcomes. JavaScript handles the display logic, showing the modal when the page loads, and allowing users to close it.

```css
.modal {
    display: none;
    position: fixed;
    z-index: 1000;
    left: 0;
    top: 0;
    width: 100%;
    height: 100%;
    Background-color: rgba (0, 0, 0, 0.4);
}

.modal-content {
    Background-color: #fefefe;
    margin: 15% auto;
    padding: 20px;
    border: 1px solid #888;
    width: 80%;
    max-width: 500px;
    border-radius: 5px;
    text-align: center;
}

.centered-badge {
    display: block;
    margin: 20px auto;
    max-width: 100px;
}

#closeModal {
    background-color: #4CAF50;
    color: white;
    padding: 10px 20px;
    border: none;
    border-radius: 4px;
    cursor: pointer;
    font-size: 16px;
}

#closeModal:hover {
    background-color: #45a049;
}
```

Figure 6.21 CSS structure

```javascript
document.addEventListener('DOMContentLoaded', function() {
    var modal = document.getElementById('welcomeModal');
    var closeButton = document.getElementById('closeModal');

    // Show the modal when the page loads
    modal.style.display = "block";

    // Close the modal when the close button is clicked
    closeButton.onclick = function() {
        modal.style.display = "none";
    }

    // Close the modal if the user clicks outside of it
    window.onclick = function(event) {
        if (event.target == modal) {
            modal.style.display = "none";
        }
    }
});
```

Figure 6.22 JavaScript structure

To optimize performance, we have implemented efficient code execution, server-side rendering, resource optimization, and caching mechanisms, minimizing impact on Moodle. The plugin is modular, scalable, and designed for easy maintenance, with configurable parameters, extensible content, and localization readiness. Whenever students log into the Moodle e-learning system, the random plugin is activated, awarding badges whenever the random number-generator returns is even. The student is encouraged to continue with training even when they do not win a badge. Such a setting fulfils the OCT of interment rewards scheme.

6.4 Robotic Training Module

In the RGM-4-CCL4GIE, the MDA informs the need to increase aesthetics in a gamified system and supports the inclusion of the Nao robot as an aspect of aesthetics. To set up the Nao robot in Choregraphe, and to programme it to teach CCL4GIE, various steps were followed. The first step is to install Choregraphe, the official software provided by Softbank Robotics for programming Nao robots. The next step is to connect the Nao robot to Choregraphe, either via a USB cable or Wi-Fi, and wait for it to be detected within the software interface. The Choregraphe panel is as shown in Figure 6.23.

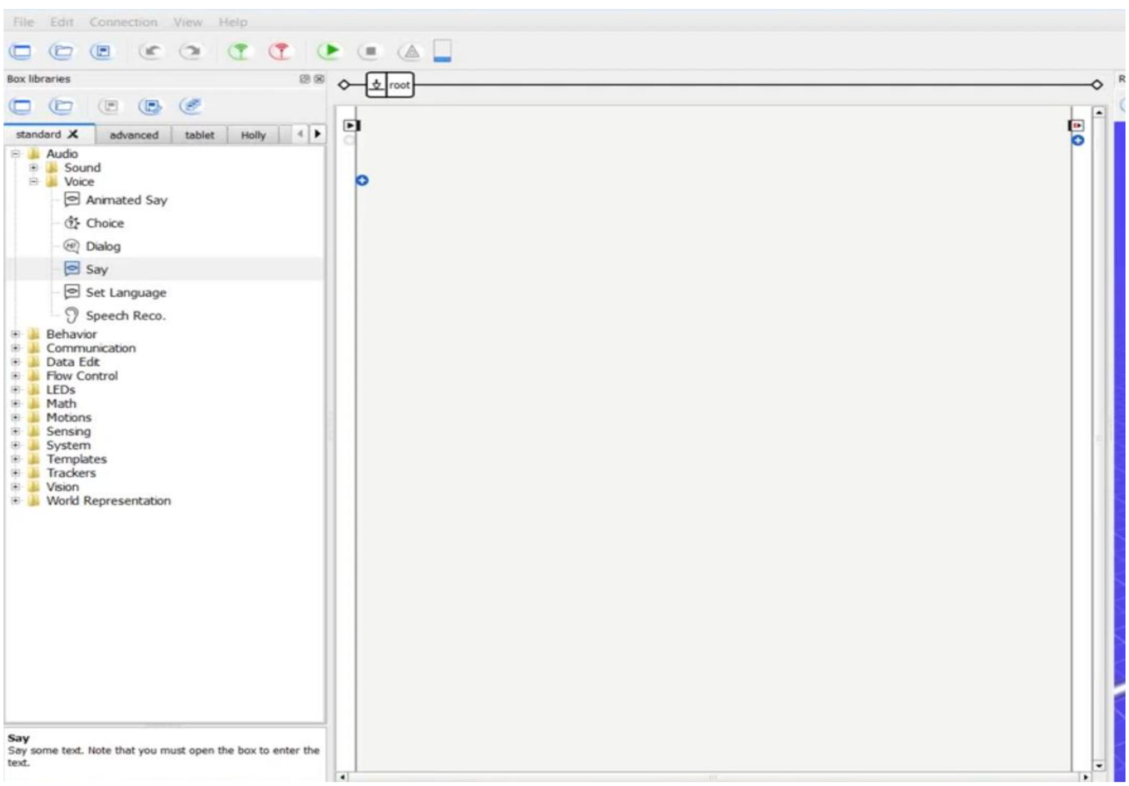

Figure 6.23 Choregraphe panel

Using Choregraphe's drag-and-drop interface, the Nao robot behaviours were created by programming Nao to speak predefined phrases, move its arms or head, display emotions through facial expressions, and interact with objects in its environment. Figure 6.24 illustrates the initial Nao robot programming step.

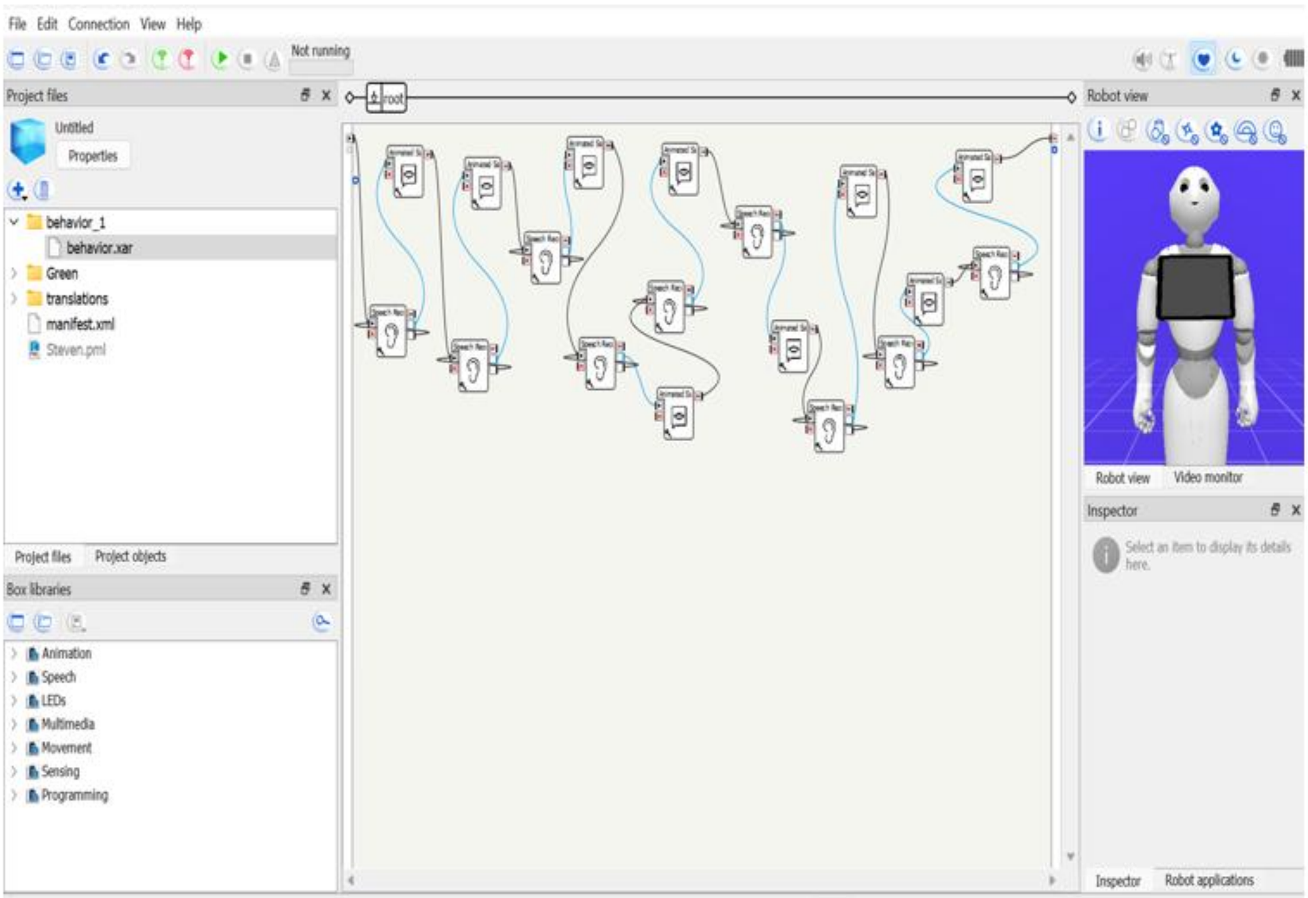

Figure 6.24 Choregraphe process

Figure 6.24 illustrates the project control panel, flow-diagram panel and the robot-view panel. The Choregraphe process shows several boxes and connections. The first connection is known as global start; the last connection is the global stop. The chain of boxes illustrates the proceedings in the training session. Figure 6.25 illustrates the Choregraphe training script in which the first input to the robot is set as the speech-record box to receive a greeting from the users, followed by subsequent training progresses.

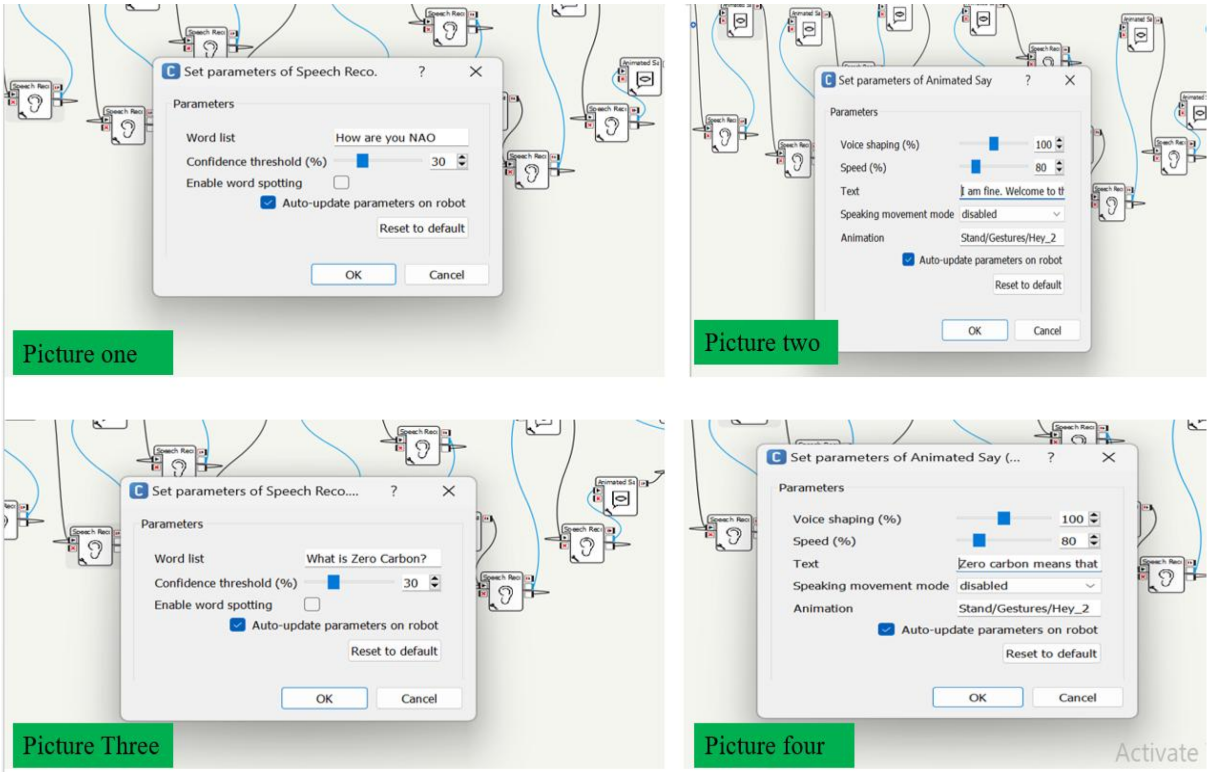

Figure 6.25 Choregraphe training script

Picture One shows a greeting from a user. The Nao robot is programmed to respond to this greeting as illustrated in Picture Two in Figure 6.25. The Nao robot replies and prompts the student to ask the first question related to climate change. Social robot Nao had been programmed to deliver climate-change literacy training. The students asked questions and the robot answered in line with the prompts. This section illustrates the prototype of robotic gamification with social robot Nao, with the aim of sustaining motivation, engagement, and learning outcomes in climate-change literacy.

6.5 Chapter Summary

In summary, the prototype section implements the RGM-4-CCL4GIE.The Moodle e-learning platform is integrated with a random badge plugin, and the Nao humanoid robot. The system is grounded in the OCT, SDT and MDA framework. Key features include gamified assessments, leaderboards, and randomized badge awards to enhance engagement. The Nao robot delivers climate-change lessons, adding an aesthetic dimension to the learning experience. This system aims to rise continued student motivation and engagement in CCL and GIE education through i gamification techniques and robotic integration.

CHAPTER SEVEN: EVALUATION, RESULTS AND DISCUSSION

7.1 Introduction

This chapter presents the evaluation of the RGM-4-CCL4GIE. Chapter Seven details the research design, including participant recruitment, training procedures, and data-collection instruments. The chapter then presents the results of the student survey, analysing user motivation, engagement, perceived usefulness, ease of use, and aesthetics. A comprehensive statistical analysis follows, employing descriptive statistics, reliability tests, and inferential statistics to assess the system's effectiveness. Furthermore, the chapter incorporates expert feedback on the gamification elements, Carbon Literacy content, and human-computer interaction aspects of the RGM-4-CCL4GIE. Finally, the findings are discussed in relation to existing literature, highlighting the contributions and implications of this research in the field of robotic gamification for climate-change education. The research design followed a single-group post-test survey based on modified TAM model prompts, which allowed for an in-depth exploration of participants' experiences and perceptions of the RGM-4-CCL4GIE (Yan et al., 2022).

7.2 Training Procedure

Participants were recruited from the Durban University of Technology using a stratified random sampling technique to ensure representation across various academic disciplines in the faculty and levels of study. The experiment consisted of a one-hour training session utilizing the RGM-4-CCL4GIE system. Participants engaged in two primary components:

1. Robotic Module: An initial interaction with the Nao social robot, programmed to deliver climate-change content and to facilitate a question-and-answer session.
2. Desktop Module: Engagement with a Moodle-based e-learning platform, featuring gamified content and assessments related to climate-change literacy and green innovation as explained in the prototype section.

7.2.1 Data-collection instruments

Data was collected using a survey instrument developed based on the Technology Acceptance Model (TAM) (Davis, 1989) and adapted to include dimensions specific to gamification and robotic interaction. The survey comprised six sections:

1. Biographical information
2. Motivation
3. User engagement
4. Perceived usefulness
5. Perceived ease of use
6. Aesthetics

Each section utilized a 5-point Likert scale (1 = Strongly Disagree, 5 = Strongly Agree) to measure participant responses.

7.2.2 Ethical considerations

The study was conducted in compliance with the ethical guidelines of Durban University of Technology. Informed consent was obtained from all participants, and data anonymity and confidentiality were ensured throughout the research process.

7.3 Results

7.3.1 Participant characteristics

A total of 20 students participated in the study. Their demographic characteristics are summarized in Table 7.1.

Table 7.1 Demographic Characteristics of Participants

Characteristic	Category	Frequency	Percentage
Gender	Female	9	45%
	Male	11	55%
Age	17-20 years	5	25%
	21-24 years	13	65%
	25-28 years	1	5%
	29-32 years	1	5%
Department	Information Technology	9	45%
	Information Systems	7	35%

	Chemical Engineering	2	10%
	Auditing and Taxation	2	10%
Academic Year	Year 2	4	20%
	Year 3	9	45%
	Year 4	6	30%
	Adv Diploma	1	5%

The sample demographics reflect a diverse representation across gender, age groups, academic disciplines, and levels of study, enhancing the generalizability of the findings within the university context.

7.3.2 Student survey feedback

Tables 7.2-7.6 displays survey results from users providing a review on various aspects of the RGM-4-CCL4GIE.

Table 7.2 Data on User Motivation Prompts

UM 1 Using the RGM-4-CCL4GIE system inspires me to continue the training.	**Frequency**	**Percent**
Agree	5	25
Strongly agree	15	75
UM 2 Having points in the RGM-4-CCL4GIE system adds to my motivation.	**Frequency**	**Percent**
Agree	7	35
Strongly agree	13	65
UM 3 Having leaderboards in the RGM-4-CCL4GIE system adds to my motivation.	**Frequency**	**Percent**
Agree	6	30
Strongly agree	14	70

UM 4 Having random badges in the RGM-4-CCL4GIE system adds to my motivation.	**Frequency**	**Percent**
Neither agree nor disagree	2	10
Agree	5	25
Strongly agree	13	65

Table 7.3 Data on User Engagement Prompts

UE 1 Using the CCL4GIE training system increases ease of conducting assessments.	**Frequency**	**Percent**
Disagree	1	5
Agree	5	25
Strongly agree	14	70
UE 2 Using the CCL4GIE training system increases my participation in class.	**Frequency**	**Percent**
Neither agree nor disagree	1	5
Agree	5	25
Strongly agree	14	70
UE 3 Using the CCL4GIE training system increases my understanding ability in class.	**Frequency**	**Percent**
Neither agree nor disagree	2	10
Agree	4	20
Strongly agree	14	70

UE 4 Having random badges in the RGM-4-CCL4GIE system increases my engagement in the training.	**Frequency**	**Percent**
Neither agree nor disagree	1	5
Agree	9	45
Strongly agree	10	50

Table 7.4 Data on Perceived Usefulness

PU 1 Using the RGM-4-CCL4GIE training system enables me to understand climate change matters.	**Frequency**	**Percent**
Disagree	1	5
Agree	4	20
Strongly agree	15	75
PU 2 Using the RGM-4-CCL4GIE training system increases my understanding of GIEs.	**Frequency**	**Percent**
Disagree	1	5
Neither agree nor disagree	2	10
Agree	7	35
Strongly agree	10	50
PU 3 I will always attend training where the gamified CL4GIE training system is used.	**Frequency**	**Percent**
Neither agree nor disagree	2	10
Agree	8	40
Strongly Agree	10	50

Table 7.5 Data on Perceived ease of Use

PUOE 1 My interaction with the RGM-4-CCL4GIE training system is clear and understandable.	**Frequency**	**Percent**
Agree	9	45
Strongly agree	11	55
PUOE 2 Overall, I find the RGM-4-CCL4GIE training system easy to use.	**Frequency**	**Percent**
Agree	7	35
Strongly agree	13	65
PUOE 3 Using the RGM-4-CCL4GIE training system is frustrating.	**Frequency**	**Percent**
Strongly disagree	13	65
Disagree	6	30
Neither agree nor disagree	1	5
PUOE 4 Conducting assessments is easy using the RGM-4-CCL4GIE training system.	**Frequency**	**Percent**
Strongly disagree	1	5
Disagree	1	5
Neither agree nor disagree	2	10
Agree	7	35
Strongly agree	9	45

Table 7.6 Data on Aesthetics

AA 1 The Nao robot inclusion increases my motivation to continue attending training.	**Frequency**	**Percent**
Neither agree nor disagree	1	5
Agree	9	45
Strongly agree	10	50
AA 2 The Nao robot appearance increases the emotional appeal of the training.	**Frequency**	**Percent**
Neither agree nor disagree	2	10
Agree	7	35
Strongly agree	10	55
AA 3 Nao robot speech increases the emotional appeal of the training.	**Frequency**	**Percent**
Neither agree nor disagree	2	10
Agree	8	40
Strongly agree	10	50
AA 4 I have attended robotic gamification training before.	**Frequency**	**Percent**
Strongly disagree	9	45
Disagree	7	35
Neither agree nor disagree	1	5
Agree	2	10
Strongly agree	1	5

7.4 Statistical Analysis

7.4.1 Statistical methods

The data analysis employed a multi-faceted approach to ensure a comprehensive evaluation of the RGM-4-CCL4GIE. All analyses were conducted using IBM SPSS Statistics 27.0, with the significance level set at $\alpha = 0.05$ for all statistical tests.

1. Descriptive Statistics: Measures of central tendency (mean, median) and dispersion (standard deviation, interquartile range) were calculated for each Likert-scale item. These statistics provide an overview of the participants' responses and help identify general trends in the data.
2. Internal Consistency: Cronbach's alpha was computed to assess the reliability of each subscale. This measure is crucial in determining whether the items within each subscale consistently measure the same construct.
3. Inferential Statistics: One-sample t-tests were used to determine whether the mean responses significantly differed from the neutral point. These tests help to establish whether participants' perceptions were significantly positive or negative, providing insights into the ways in which the various aspects of the RGM-4-CCL4GIE interact.

7.4.2 Scale reliability

Table 7.7 presents the Cronbach's alpha coefficients for each subscale.

Table 7.7 Internal Consistency of Subscales

Subscale	Cronbach's α	Number of Items
Motivation	0.86	4
User Engagement	0.82	4
Perceived Usefulness	0.89	3
Perceived Ease of Use	0.84	4
Aesthetics	0.88	4

The Cronbach's alpha values for all subscales shown in Table 7.7 exceeded the commonly accepted threshold of 0.80, indicating good internal consistency. This suggests that the items within each subscale are reliably measuring the same construct. The high reliability of the motivation ($\alpha = 0.86$) and perceived usefulness (α = 0.89) subscales is particularly noteworthy, these items being central to evaluating the effectiveness of the RGM-4-CCL4GIE in achieving its primary objectives of enhancing motivation and perceived learning outcomes.

7.4.3 Descriptive and inferential statistics

Table 7.8 presents the descriptive statistics and one-sample t-test results for each subscale.

Table 7.8 Descriptive Statistics and One-Sample t-test Results

Subscale	Mean (SD)	Median	t-statistic	p-value	Cohen's d
Motivation	4.58 (0.51)	5.00	13.87	<.001	3.10
User Engagement	4.49 (0.63)	4.75	10.57	<.001	2.36
Perceived Usefulness	4.40 (0.75)	4.67	8.32	<.001	1.86
Perceived Ease of Use	4.33 (0.68)	4.50	8.71	<.001	1.95
Aesthetics	4.26 (0.71)	4.25	7.93	<.001	1.77

The results shown in Table 7.8 reveal consistently high mean scores across all subscales, with all means exceeding 4 on the 5-point Likert scale. This indicates strong positive perceptions of the RGM-4-CCL4GIE across all measured dimensions. The motivation subscale received the highest mean score ($M = 4.58$, $SD = 0.51$), suggesting that the RGM-4-CCL4GIE was particularly effective in enhancing learner motivation. This aligns with the primary objective of the model to address the challenge of sustaining motivation in climate-change education. One-sample t-tests were conducted to determine whether these mean scores were significantly different from the neutral point (3 on the 5-point Likert scale). All subscales showed statistically significant differences ($p < .001$) from the neutral point, with large effect sizes (Cohen's $d > 0.8$). The largest effect size was observed for the motivation subscale ($d = 3.10$), further emphasizing the model's success in enhancing motivation.

These results provide strong statistical evidence for the effectiveness of the RGM-4-CCL4GIE across all measured aspects, with particularly strong effects on motivation and user engagement.

7.4.4 Analysis of individual items

7.4.4.1 *User motivation*

The RGM-4-CCL4GIE system demonstrates remarkable success in fostering user motivation, with all motivation-related items receiving overwhelmingly positive responses. The item "Using the RGM-4-CCL4GIE system inspires me to continue the training" received the highest rating (M = 4.75, SD = 0.44). Some 75% of participants strongly agreed that the system inspires them to continue training, indicating its effectiveness in cultivating intrinsic motivation. The points system and leaderboards also proved highly motivating, with 65% and 70% of participants strongly agreeing to their motivational impact, respectively. The random badge system showed significant motivational power (M = 4.55, SD = 0.69). Some 65% of participants strongly agreed that random badges added motivation, with an additional 25% agreeing. This strong positive response to random badges underscores the effectiveness of the operant conditioning principles incorporated into the system design. By providing unpredictable rewards, the random badge plugin taps into the psychological mechanisms that drive sustained engagement, encouraging students to continually interact with the system in anticipation of earning new badges. This supports the incorporation of the Behavioural Reinforcement Theory in the model, specifically the use of variable reward schedules to maintain engagement.

7.4.4.2 *User engagement*

The survey results indicate that the RGM-4-CCL4GIE system is highly effective in promoting user engagement across various dimensions of the learning experience. Some 70% of participants strongly agreed that the system increased ease of conducting assessments (M = 4.60, SD = 0.75). This suggests that the gamified assessment formats (e.g., crossword puzzles, Cryptex) effectively lowered perceived barriers to participation, potentially increasing self-efficacy (Lester et al., 2023). Furthermore, 70% of respondents strongly agreed that the system enhances their understanding ability in class (M = 4.65, SD = 0.59). The random badge feature emerges as a driver of engagement, with 95% of participants agreeing or strongly agreeing that it increases their engagement in training. This high level of engagement attributed to random badges further validates the operant conditioning approach employed in the system design. The unpredictable nature of badge rewards creates a variable reinforcement schedule, which, according to Operant Conditioning Theory, is effective in maintaining behaviour over time. This finding supports the thesis focus on random badges as a key mechanism for sustaining long-term user engagement in educational technology.

7.4.4.3 *Perceived usefulness*

The RGM-4-CCL4GIE system demonstrates high perceived usefulness among users (M = 4.65, SD = 0.75). Some 75% of participants strongly agreed that the system enables them to understand matters of climate change, indicating its effectiveness. The system's impact on understanding green innovation and entrepreneurship (GIE) was also positive, with 50% strongly agreeing and 35% agreeing (M = 4.30, SD = 0.86). Some 90% of participants either agreed or strongly agreed that they would always attend training where this gamified system is used, suggesting a strong preference for this learning approach. The high perceived usefulness, especially in conjunction with the random badge system, underscores the effectiveness of the operant conditioning principles employed.

7.4.4.4 *Perceived ease of use*

The survey results indicate that the RGM-4-CCL4GIE system is user-friendly and accessible. For instance, the average score for PUOE 2 ("I find the RGM-4-CCL4GIE system easy to use") was M = 4.65 (SD = 0.477), with 65% of participants strongly agreeing and 35% agreeing. This high perceived ease of use is essential for minimizing cognitive load and enabling learners to focus more on the content rather than on the system's navigation. Additionally, 55% of respondents strongly agreed, and 45% agreed that their interaction with the system was clear and understandable, yielding an M = 4.55 (SD ≈ 0.50), indicating that the user interface is designed to be intuitive. The frustration level was very low: 65% strongly disagreed, and 30% disagreed with the statement that the system was frustrating to use, with M = 1.40 (SD ≈ 0.60). This underscores the system's effectiveness in providing a seamless user experience. In terms of assessment ease, 45% strongly agreed and 35% agreed that conducting assessments was straightforward (M ≈ 4.25, SD ≈ 0.75). However, 10% were neutral, and 10% disagreed, suggesting some room for improvement in this feature. Overall, the system's intuitive design and low frustration levels play a crucial role in fostering user engagement and learning.

7.4.4.5 *Aesthetics*

The inclusion of the Nao robot within the RGM-4-CCL4GIE system has been a notable enhancement, particularly in terms of user motivation and emotional engagement. A significant 95% of participants either agreed or strongly agreed that the NAO robot increased their motivation to continue attending training, with a mean score of 4.45 (SD = 0.60). This underscores the effectiveness of the robot in maintaining sustained engagement over time. Additionally, 90% of participants believed that both the robot's appearance and speech increased the emotional appeal of the training experience. Specifically, 55% strongly agreed that the robot's appearance made the training more emotionally engaging (M = 4.45, SD = 0.69), highlighting the robot's visual and auditory contributions to the learning environment. This emotional engagement is critical for creating memorable and immersive learning experiences, which are essential for long-term retention. The innovation of this robotic inclusion is also evident, most participants not having encountered robotic gamification before, making this a fresh and engaging element. When combined with the random badge system, the Nao robot's contribution helps create a multi-faceted approach to learner engagement. By blending visual, auditory, and reward-based stimuli, the system aligns with operant conditioning principles. The survey results indicate that the Nao robot not only enhances the aesthetic and emotional aspects of the learning experience but also effectively sustains user interest, in line with the MDA framework's emphasis on aesthetics as a key driver in gamified environments.

7.5 Expert Analysis Section

Tables 7.9-7.12, 13 to 16 illustrate the results of expert survey. The expert evaluation involved 11 volunteers recruited from diverse academic backgrounds. Participants included professionals from information technology (4), entrepreneurship (3), and environmental studies (4) departments. The experts' qualifications were high, with 7 holding master's degrees and 4 having attained PhD degrees. Participants' teaching experience ranged from 4 to 9 years, ensuring a mix of fresh perspectives and seasoned insights. The gender distribution was balanced, with 6 males and 5 females, promoting diverse viewpoints in the evaluation process. The experts were requested to provide feedback. The experts' reflections on gamification elements, the Carbon Literacy content and the HCI were captured. The grading used is a 5-point Likert scale ranging from 1 (strongly disagree), to 2 (disagree), 3 (neutral), 4 (agree), and 5 (strongly agree).

Table 7.9 Biographical Information

Category	Subcategory	Count
Department	Information Technology	7
	Entrepreneurship	2
	Environmental Studies	2
Academic Qualification	Master's	7
	PhD	4

Gender	Male	6
	Female	5
Years of Experience	0–5 years	4
	6–10 years	4
	Above 10 years	3

7.5.1 Scales Reliability Test

Table 7.10 Internal Consistency Measurement

Subscale	Cronbach's α	Number of Items	Interpretation
Gamification Elements	0.87	5	Highly reliable
Carbon Literacy	0.90	3	Excellent reliability
Human-Computer Interaction	0.88	4	High reliability
Overall Scale	0.89	12	Strong internal consistency

The reliability of measurement items in this study was assessed using Cronbach's alpha coefficient. Across three primary subscales: gamification elements, Carbon Literacy, and human-computer interaction, the research demonstrated high measurement reliability. The gamification elements subscale achieved a Cronbach's alpha of 0.87, indicating strong internal consistency among its five measurement items. Carbon Literacy showed excellent reliability with a Cronbach's alpha of 0.90, suggesting that the three items measuring this construct consistently capture the intended concept. The human-computer interaction subscale also displayed high reliability with a Cronbach's alpha of 0.88. The overall scale reliability of 0.89 provides robust evidence that the measurement items consistently and accurately represent their respective constructs. This high internal consistency validates the expert survey's methodological rigour, ensuring that the collected data reliably reflects the intended research dimensions of the robotic gamification training system. Statistically, Cronbach's alpha values above 0.70 are considered reliable, with values approaching 0.90 indicating excellent measurement precision. These results meet the benchmarks, offering substantial confidence in the measurement's validity and the subsequent research findings.

Table 7.11 Gamification Elements

GE 1 The rewards and incentives provided by the robotic gamification training system are designed to sustain user motivation over extended periods.	**Frequency**	**Percent**
Agree	5	45
Strongly Agree	6	55
GE 2 The crossword and Cryptex game assessments mode engaged can keep learners consistently engaged over long periods.	**Frequency**	**Percent**
Neither agree nor disagree	2	18
Agree	4	36
Strongly agree	5	46
GE 3 The point system in the robotic gamification training model is structured to maintain user interest and motivation beyond initial interactions.	**Frequency**	**Percent**
Neither agree nor disagree	1	8
Agree	5	46
Strongly agree	5	46
GE 4 The random badge system is designed to promote continuous engagement and long-term progress in climate literacy.	**Frequency**	**Percent**
Agree	5	45
Strongly agree	6	55
GE 5 The leaderboard element is implemented to foster ongoing competition and sustained user engagement over time.		
Agree	6	55
Strongly agree	5	45

Table 7.12 Carbon Literacy and GIE

CL 1 The robotic gamification training system presents information on carbon causes in a manner that promotes long-	**Frequency**	**Percent**

term retention and understanding.		
Agree	4	36
Strongly agree	7	64
CL 2 The system's approach to teaching carbon reduction strategies is designed to encourage ongoing application in users' daily lives.	**Frequency**	**Percent**
Agree	6	55
Strongly agree	5	45
CL 3 The real-world scenarios provided by the system are diverse and evolving, promoting continuous learning and application of Carbon Literacy knowledge.		
Agree	5	45
Strongly agree	6	55

Table 7.13 Human Computer Interaction

HCI 1 The user interface is designed to remain intuitive and engaging over repeated, long-term use.	**Frequency**	**Percent**
Neither agree nor disagree	1	8
Agree	5	46
Strongly agree	5	46
HCI 2 The system's navigation is structured to support progressive learning and sustained engagement with climate-change topics.	**Frequency**	**Per cent**
Neither agree nor disagree	2	18
Agree	4	36
Strongly agree	5	46
GE 3 The visual appeal of the system incorporates elements that maintain user interest over extended periods of use.	**Frequency**	**Per cent**
Agree	4	36

Strongly agree	7	64
HCI 4 The learning objectives for climate-change education are structured to support ongoing, incremental learning and long-term engagement.	**Frequency**	**Per cent**
Agree	6	55
Strongly agree	5	45

7.5.2 Breakdown and analysis of data

This analysis is based on expert responses regarding the biographic profile of the participants, the effectiveness of gamification elements, the promotion of Carbon Literacy, and the human-computer interaction (HCI) aspects of the robotic gamification training system. The survey collects feedback on various system elements, rated on a scale from 1 (strongly disagree) to 5 (strongly agree), with the goal of evaluating the system's ability to sustain user engagement, learning, and motivation.

7.5.2.1 *Biographic information*

The participants surveyed come from diverse backgrounds, spanning three main departments, varying academic qualifications, and a balanced gender distribution, which provides a rich foundation of perspectives. A total of 11 respondents come from three departments: Information Technology (7), Entrepreneurship (2), and Environmental Studies (2). The dominance of respondents from Information Technology aligns with the technical focus of the robotic gamification system, providing feedback rooted in both educational and technical expertise. The majority of the respondents hold a master's degree (7), while 4 have a PhD. This suggests that the feedback gathered is well-informed and provided by experts with significant academic backgrounds, contributing valuable insights into the system's educational and technological design. The gender distribution is nearly balanced, with 6 male and 5 female participants, ensuring that a diverse range of perspectives is captured, reducing potential gender-related bias in the feedback. The respondents have varying levels of experience: 4 have 0-5 years of experience, 4 have 6-10 years, and 3 have over 10 years of experience. This mix of early-career and seasoned professionals provides feedback that takes into account both fresh perspectives and long-term industry insights.

7.5.2.2 *Gamification elements*

This section focuses on the feedback provided regarding the key gamification elements incorporated into the RGM-4-CCL4GIE system. These include rewards, points, badges, and leaderboards, as well as engagement tools such as crosswords and Cryptex games.

GE 1: Rewards and Incentives: The rewards and incentives are seen as a strong motivator, with 45% of respondents agreeing, and 55% strongly agreeing that these elements help sustain user motivation over extended periods (M = 4.55, SD = 0.52). This suggests that the reward system is perceived as highly effective in encouraging long-term engagement with the platform.

GE 2: Crossword and Cryptex Games: The effectiveness of these game-based assessment modes received mostly positive feedback, with 18% of respondents neutral, 36% agreeing, and 46% strongly agreeing that these tools engage learners over extended periods (M = 4.27, SD = 0.78). The mix of responses indicates a generally positive reception, although some experts may feel that the engagement features could be further refined to eliminate distraction.

GE 3: Points System: The points system is viewed as another crucial factor in maintaining user interest, with 8% neutral response, 46% agreeing, and 46% strongly agreeing with this (M = 4.45, SD = 0.52). This feedback suggests that the points mechanism plays an important role in motivating users beyond their initial interactions, fostering continued engagement.

GE 4: Random Badge System: Feedback on the random badge system, which is designed to promote continuous engagement, was unanimously positive, with 45% of respondents agreeing and 55% strongly agreeing with this aspect (M = 4.55, SD = 0.52). The random plugin designed and implemented in the Moodle platform randomly awarded students badges whenever they logged in. The high level of agreement underscores the effectiveness of badges in encouraging users to strive for long-term progress.

GE 5: Leaderboard Element: The leaderboard, implemented to foster competition and sustained engagement, also received strong positive feedback (55% agree, 45% strongly agree), with a mean score indicating that competition is seen as a key driver of user motivation (M = 4.45, SD = 0.52). This highlights that competition among users through the leaderboard is a well-received aspect of the gamification model.

Overall, the feedback on the gamification elements is largely positive, with most respondents either agreeing or strongly agreeing that the system's rewards, game mechanics, and competition features are effective in promoting user motivation and engagement.

7.5.2.3 *Carbon Literacy and GIE*

This section captures feedback on the RGM-4-CCL4GIE system's ability to educate users on carbon causes, reduction strategies, and its use of real-world scenarios to reinforce learning and practical application.

CL 1: Carbon Causes: The system's presentation of information on carbon causes received high marks, with 36% of respondents agreeing and 64% strongly agreeing that the system promotes long-term retention and understanding (M = 4.64, SD = 0.50). This suggests that the system is effective in delivering content that fosters a deep understanding of climate issues.

CL 2: Carbon Reduction Strategies: Similarly, feedback on the system's approach to teaching carbon reduction strategies indicates strong positive sentiment (55% agree, 45% strongly agree), with an overall mean suggesting that the system encourages the practical application of these strategies in daily life (M = 4.45, SD = 0.52). Experts believe that the system's educational content is actionable and effective in promoting sustainable behaviours.

CL 3: Real-World Scenarios: The use of diverse real-world scenarios to reinforce Carbon Literacy also received highly favourable feedback, with 45% of respondents agreeing and 55% strongly agreeing (M = 4.55, SD = 0.52). The high level of agreement suggests that the system's approach to presenting real-world challenges effectively promotes continuous learning and application of climate literacy. The feedback on the Carbon Literacy component indicates that the system successfully educates users on climate issues, provides practical strategies for carbon reduction, and reinforces learning through relevant, real-world applications.

7.5.2.4 *Human-computer interaction (HCI)*

The HCI component of the feedback focuses on the system's interface design, navigation, visual appeal, and learning objectives, particularly in terms of their ability to support long-term engagement with climate education.

HCI 1: User Interface: Feedback on the intuitiveness and engagement of the system's user interface shows positive sentiment, with 8% neutral response, 46% agreeing, and 46% strongly agreeing (M = 4.36, SD = 0.50). While most respondents believe that the interface is effective, the neutral response suggests that there may be room for minor improvements in terms of user-friendliness or ease of use.

HCI 2: System Navigation: The system's navigation structure, designed to support progressive learning, received slightly mixed feedback, with 18% respondents neutral, 36% agreeing, and 46% strongly agreeing (M = 4.27, SD = 0.78). While most experts see the navigation as conducive to learning, the higher standard deviation indicates some variability in how well it supports sustained engagement. This variation suggests that, although the majority found the navigation effective, a subset of users may have encountered challenges with the system's ease of use, hence the need for simpler designs.

HCI 3: Visual Appeal: The system's visual appeal was highly rated, with 36% agreeing and 64% strongly agreeing that it helps maintain user interest over extended periods (M = 4.64, SD = 0.50). This strong consensus reflects the importance of visual design in sustaining long-term user engagement.

HCI 4: Learning Objectives: Feedback on the learning objectives, which are structured to support ongoing, incremental learning, was positive (55% agree, 45% strongly agree), with the mean indicating strong overall support for the system's educational goals (M = 4.45, SD = 0.52). This suggests that the system's learning objectives are well-designed to promote continuous climate education and engagement. The responses to the HCI prompts show that the system's design is largely successful in maintaining user interest and supporting long-term educational engagement, although slight refinements in navigation and interface design may further enhance the user experience.

7.6 Comparative Analysis

This research contributes to the field of robotic gamification in education by introducing the RGM-4-CCL4GIE. Unlike the works in (Hilario et al., 2022; Manining et al., 2022), that only developed a conceptual framework for robots assisting underperforming geography students the RGM-4-CCL4GIE has been empirically evaluated with strong statistical evidence demonstrating its effectiveness in sustaining intrinsic motivation and student engagement.

The statistical analysis revealed consistently high mean scores across all evaluation dimensions, with the motivation subscale receiving the highest rating (M = 4.58, SD = 0.51). One-sample t-tests confirmed that all subscales showed statistically significant differences ($p < .001$) from the neutral point, with the largest effect size observed for the motivation subscale ($d = 3.10$). This empirical validation addresses a critical gap in the literature, moving beyond theoretical frameworks to demonstrate measurable outcomes.

While (Madariaga et al., 2022) established that offline robots increase motivation more than online robots, these researchers recommended random participant selection to avoid peer influence. The RGM-4-CCL4GIE study implemented this recommendation and achieved similar positive results, as detailed in the statistical analysis. (Chen et al., 2023)'s STEM education study showed that educational robots could improve learning motivation and creativity, but recommended experiments in more diverse settings than just Taiwan. The RGM-4-CCL4GIE directly addresses this gap by conducting research in sub-Saharan Africa, providing valuable insights from a different geographical and cultural context.

Some other works revealed that gamified artificial intelligence educational robots systems increased engagement but proposed using diverse types of robots to compare results (Xefteris & Palaigeorgiou, 2019; Yang et al., 2023). Our study specifically utilized the Nao robot, which proved highly effective in motivating users, with 95% of participants either agreeing or strongly agreeing that the robot increased their motivation to continue attending training (M = 4.45, SD = 0.60). The expert evaluation further validated the system's effectiveness, with strong positive feedback on gamification elements such as the random badge system (M = 4.55, SD = 0.52) and the leaderboard (M = 4.45, SD = 0.52).

Contrary to the results of our study, other studies indicated that incorporating gamification with robotics does not lead to a substantial increase in learner engagement and motivation. (M. de Graaf, 2017; Riedmann et al., 2022). Likewise, other studies indicated that the separate addition of gamification elements or social robots did not significantly enhance engagement and motivation (Donnermann et al., 2021; Riedmann et al., 2022). However, our comprehensive evaluation of the RGM-4-CCL4GIE, which incorporates both elements synergistically, demonstrates statistically significant improvements in motivation and engagement. The high perceived usefulness scores (M = 4.40, SD = 0.75) and user engagement ratings (M = 4.49, SD = 0.63) directly contradict these earlier findings, suggesting that the integration of robotic elements with carefully designed gamification features can indeed produce significant positive outcomes.

The RGM-4-CCL4GIE's unique contribution lies in its empirically validated approach to sustaining intrinsic motivation through operant conditioning principles, particularly through the random badge system which received overwhelmingly positive feedback from both users and experts. This innovative integration of the Behavioural Reinforcement Theory with educational robotics addresses the critical challenge of maintaining long-term engagement in climate-change education, an area in which sustained motivation is essential for meaningful learning outcomes.

7.7 Chapter Summary

The chapter evaluates the Robotic Gamification Model for Climate Change Literacy (RGM-4-CCL4GIE), a novel educational approach combining robotic interaction and gamification techniques. The study involved 20 students from the Durban University of Technology, utilizing a Nao social robot and Moodle-based platform to enhance climate-change education. Statistical analysis revealed overwhelmingly positive results, with high mean scores across motivation, engagement, perceived usefulness, and ease of use dimensions. The random badge system and robotic interaction were particularly effective in maintaining student motivation, with 75% of participants reporting inspiration to continue training. Expert analysis from 11 professionals further validated the model's effectiveness, highlighting its potential to create engaging, interactive learning experiences about climate change and green innovation.

CHAPTER EIGHT: SUMMARY, CONCLUSION AND FUTURE WORKS

8.1 Introduction

This chapter provides a summary of the study's key objectives, findings, and contributions. Chapter Eight is structured into three subsections. Summary reviews the study's objectives, model development, and validation. The conclusion discusses the significance of the RGM-4-CCL4GIE model and finally, the future work section outlines recommendations for further research and potential enhancements.

8.2 Summary

This study addressed four key objectives. First, it critically assessed the requirements for a robotic gamification model for CCL4GIE education in a sub-Saharan African context (Chapters Two and Three). This assessment revealed contextual challenges, including limitations in existing climate-change education (only 32% of countries offering a stand-alone subject), low climate-change awareness (28% of the population), technological constraints (28% internet penetration, 64% adult literacy), and pedagogical gaps (only 23% of science teachers feeling competent to teach climate change). Furthermore, this research established that current gamification designs in educational settings lack ability to instil learner motivation and engagement towards sustained achieving learning outcomes, relying predominantly as they do on predictable extrinsic reward schemes. These findings underscored the need for an innovative and sustainable approach tailored to SSA.

The second objective was to develop a robotic gamification model based on a combination of an SDT, OCT and MDA framework with mathematical modelling of gamification elements, to meet the SSA-contextualized CCL4GIE education requirements. This resulted in the development of the RGM-4-CCL4GIE model as recorded in Chapters Four and Five, drawing upon the integrated principles of the Self-Determination Theory (SDT), the Operant Conditioning Theory (OCT), and the Mechanics-Dynamics-Aesthetics (MDA) framework, as well as mathematical models of gamification elements in section 5.2. These chapters detail the mathematical modelling of key gamification elements. For example, the random badge award system is modelled probabilistically using a pseudo-random number generator and a cumulative distribution function. Competence is quantified through points awarded based on performance; and the accumulation of these points is mathematically defined. The chapters also detail the mathematical relationship between assessment grades and awarded badges, the leaderboard ranking system, and a model for quantifying aesthetics based on emotional impact, visual appeal, and auditory pleasure. The chapter concludes with a description of the RGM-4-CCL4GIE's architecture, outlining its key components (learners, tutor, and desktop module, Nao robot module, learning content database, gamification database, and evaluation section) and their interactions.

The third objective was to implement a prototype of the robotic gamification model, as shown in Chapter six, utilizing the Moodle e-learning platform enhanced with a custom-designed random badge plugin, and incorporating the Nao humanoid robot. The desktop module in Moodle was configured with gamified assessments (crosswords and Cryptex games), points, leaderboards, and grade-based badges. The random badge plugin, implemented in PHP, generates a random number upon user login to determine badge awards. The Nao robot was programmed using Choregraphe to deliver climate-change lessons and to interact with students, adding an aesthetic and interactive element. The chapter explicitly maps the theoretical underpinnings (SDT, OCT, and MDA) to specific gamification elements within the prototype, explaining their contribution to learner competence, relatedness, and autonomy.

Finally, the model's effectiveness in fostering sustained motivation and long-term engagement to achieve learning outcomes was empirically validated by 20 university students from the Durban University of Technology and 11 expert evaluators, as recorded in Chapter Seven. Students interacted with both the Nao robot and the Moodle-based desktop module, then completed a modified TAM survey. User survey data revealed strong positive perceptions, with all subscales (motivation, user engagement, perceived usefulness, perceived ease of use, aesthetics) scoring above 4 (on a 5-point scale), showing significant differences from the neutral point ($p<.001$) and large effect sizes (Cohen's $d > 1.77$). Motivation had the highest mean (4.58, $SD=0.51$) and largest effect size ($d=3.10$). Individual items reflected high agreement on motivation (e.g., "inspires me to continue training", $M=4.75$, 75% strongly agreed), engagement (e.g., random badges, 95% agreed or strongly agreed, $p < 0.001$), usefulness (e.g., understanding climate change, 75% strongly agreed), ease of use ($M=4.65$, 65% strongly agreed, 35% agreed), and aesthetics (Nao robot, 95% agreed or strongly agreed). Expert evaluation, involving 11 volunteers with master's or PhD degrees and 4-9 years of teaching experience, further validated the system. Cronbach's alpha values for all subscales (gamification elements, Carbon Literacy, and human-computer interaction) were above 0.80, indicating high internal consistency. Expert feedback highlighted the effectiveness of the rewards and incentives ($M=4.55$), game-based assessments ($M=4.27$), and the random badge system ($M=4.55$) in sustaining motivation and engagement, as well as the clarity and relevance of the Carbon Literacy content (carbon causes M=4.64, reduction strategies M=4.45, real-world scenarios M=4.55) and the intuitiveness of the user interface (M=4.36). These results demonstrate the RGM-4-CCL4GIE's potential to address critical needs in climate-change education within the sub-Saharan African context.

8.3 Conclusion

This research centred on the development and validation of the RGM-4-CCL4GIE to address a critical problem in gamification systems design: the lack of long-term intrinsic motivation and engagement towards learning outcomes, primarily due to an overreliance on predictable extrinsic rewards. The study highlighted that traditional educational methodologies often depend on these predictable reward systems, which creates a significant gap in maintaining learner motivation and effective engagement. This issue is particularly concerning in the realm of climate-change education, in which ongoing engagement is essential for fostering awareness and driving actionable outcomes.

To address these challenges, the RGM-4-CCL4GIE integrates gamification principles with robotics, particularly through the use of the Nao humanoid robot and a dynamic random badge award system designed and implemented in the Moodle e-learning platform. This innovative model seeks to redefine climate-change education by promoting knowledge acquisition and intrinsic motivation among learners. Through the RGM-4-CCL4GIE system, students can sustainably learn about climate-change issues and act towards environmental conservation. The study employed a Design Science Research Methodology (DSR) approach, which guided the systematic identification of gaps in current educational gamification systems, followed by design and validation of the RGM.

The model's theoretical underpinnings, grounded in the Self-Determination Theory and the Behavioral Reinforcement Theory, contributed to its effectiveness in promoting learner autonomy, competence, and relatedness. The random badge award system, designed using principles of variable reward schedules, successfully maintained learner curiosity and sustained engagement over time. The MDA framework informed the inclusion of the social robot Nao in the model.

Results from the analysis of student experiences demonstrated that the RGM-4-CCL4GIE effectively enhanced learner motivation and engagement. Descriptive statistics indicated a mean motivation score of 4.58, with a t-statistic of 13.87 and a p-value of less than .001, highlighting a strong positive response from participants**.** Furthermore, expert evaluations corroborated these findings, with gamification elements receiving high approval ratings, particularly the random badge system, which scored a mean of

4.55. Participants expressed high satisfaction with the overall user experience, as evidenced by a perceived ease of use mean score of 4.33. Furthermore, experts recognized the model's capacity to foster motivation and engagement, and to enhance understanding of climate-change issues.

In summary, this research fills a significant gap in the existing literature by demonstrating the ways in which the integration of robotic gamification can effectively address the limitations of traditional climate-change education methodologies in SSA. By providing a framework that combines gamification elements, interactive robotics, and practical application of climate literacy, the RGM-4-CCL4GIE positions itself as a transformative educational tool. The findings underscore the importance of innovative approaches in fostering learner engagement and improving educational outcomes, ultimately contributing to a more informed and proactive response to climate-change challenges in sub-Saharan Africa.

8.4 Future Works

A key limitation of this study lies in the relatively small number of participants involved in the usability evaluation and prototype validation—specifically, 20 university students and 11 subject-matter experts. This limited sample size was primarily due to the use of a local host deployment of the RGM-4-CCL4GIE system, which constrained participation to individuals physically present at the test site. As a result, broader involvement from a more diverse and distributed population was not possible. Although the local deployment enabled close observation and focused feedback, it limited the external validity of the findings and the generalizability of the results to large-scale educational settings.

To address this, future research should prioritize the deployment of the RGM-4-CCL4GIE system on an online or cloud-based platform. Such an approach would remove geographic and technical access barriers, allowing for participation from a larger and more demographically diverse audience. Large-scale experiments could involve hundreds or thousands of learners across different institutions, cultures, and educational levels. This would not only improve statistical validity but also enhance the model's relevance across varied contexts.

Beyond scaling participation, longitudinal studies should be conducted to assess the sustainability of learner motivation and engagement over extended periods. While the current study focused on short-term interactions, future research should investigate how the model supports retention, behavioral change, and continued interest in climate-change learning over weeks or months. This would provide stronger evidence for the model's long-term impact and pedagogical value.

Future work should also explore the integration of adaptive and intelligent technologies into the RGM-4-CCL4GIE framework. This includes incorporating artificial intelligence (AI) for personalized learning paths, real-time feedback, and adaptive game difficulty levels. Furthermore, the use of augmented reality (AR) and virtual reality (VR) could be explored to enhance interactivity, immersion, and learner presence in climate-change scenarios. These technologies could offer highly engaging learning experiences that simulate real-world environmental challenges and decision-making.

Another promising area for exploration is the refinement of the reward system within the gamified model. While the current study employed both intrinsic and extrinsic motivational elements, future research could investigate alternative reward mechanisms—such as narrative-driven achievements, community recognition, or project-based incentives—that go beyond point-based systems. These may offer more meaningful and sustained engagement, especially in educational settings that emphasize critical thinking and behavioural change. Cross-cultural studies also present a valuable opportunity for future research. The current evaluation was limited to a single institutional and cultural context. Comparative studies involving learners from diverse cultural and geographic backgrounds would help determine how motivation strategies and gamification dynamics function across educational systems. Such research could inform the design of culturally sensitive gamification tools for global use.

Finally, future research may focus on applying the RGM-4-CCL4GIE framework to other subject areas beyond climate-change education. Its theoretical foundation—integrating Self-Determination Theory, Operant Conditioning, and the Mechanics-Dynamics-Aesthetics framework—is generalizable and could be adapted for use in fields such as health education, entrepreneurship, digital literacy, and STEM disciplines. This would validate the model's versatility and contribute to broader innovations in gamified learning. In conclusion, while this study provides a robust foundation for understanding and applying robotic gamification in climate-change education, it also opens numerous avenues for further investigation. Expanding the scale of validation, incorporating intelligent and immersive technologies, refining motivation strategies, and exploring diverse applications will contribute to the continuous evolution of effective gamified learning environments. These efforts will not only enhance climate-change literacy but also support the development of more adaptive, engaging, and inclusive educational technologies for the future.

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Appendix A

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Dear Mr Oguta

A Carbon Literacy for Green Innovation and Entrepreneurship Gamification model using Pepper social robot.

The FAI-Research Ethics Committee acknowledges receipt of your gatekeeper permission letters.

Please note that FULL APPROVAL is granted to your research proposal. You may proceed with data collection.

Any adverse events [serious or minor] which occur in connection with this study and/or which may alter its ethical consideration must be reported to the FAI-FREC.

Please note that any deviations from the approved proposal require the approval of the FAI-FREC before data can be collected.

It is compulsory for a student or researcher to apply for recertification on an annual basis. The failure to do so will result in withdrawal of ethics clearance. It is the responsibility of the researcher and the supervisor to apply for recertification.

Please note that you are required to submit a Notification of Completion of Study form together with an abstract to the DUT-FREC office on completion of your study.

Yours Sincerely,

Dr. M. Rajkoomar
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