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Long Paper

Prototype Implementation of a Robotic Gamification Model for Climate Change Literacy for Green Innovation and Entrepreneurship with Social Robot Nao

Stephen Oguta
Information Technology Department,
Durban University of Technology, Durban, South Africa
22290746@dut4life.ac.za
(corresponding author)

Sunday Ojo
Information Technology Department,
Durban University of Technology, Durban, South Africa
sundayo1@dut.ac.za

Benard Maake
Computing Sciences Department
Kisii University, Kisii, Kenya
bmaake@kisiiuniversity.ac.ke

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Abstract

Purpose – This research introduces the Robotic Gamification Model for Climate Change Literacy for Green Innovation and Entrepreneurship (RGM-CCL4GIE) as an innovative educational solution for Sub-Saharan Africa (SSA), addressing the limitations of current gamification systems that fail to sustain long-term learner motivation and engagement.

Method – The study employs Design Science Methodology (DSM) to develop and validate the model, which integrates Self-Determination Theory, Mechanics-Dynamics-Aesthetics (MDA) framework, and Operant Conditioning Theory. The system is prototyped on the Moodle e-learning platform and Social Robot Nao, with empirical testing conducted among students.

Results – The findings demonstrate high learner motivation (mean score of 4.58) and significant positive correlations between random rewards and increased engagement (p-value < 0.001). The model successfully integrates robotic interaction, dynamic rewards, and gamification elements to enhance climate change literacy education.

Conclusion – The RGM-CCL4GIE effectively addresses the limitations of existing gamification systems by promoting sustained engagement and improved learning outcomes in climate change education, particularly within the SSA context.

Recommendations – Implementation of the model should focus on maintaining the balance between robotic interaction and gamification elements while ensuring accessibility and adaptability across different educational contexts.

Research Implications – This study advances the field of educational gamification by providing an innovative framework that combines robotics and advanced motivational theories, establishing a foundation for future research in sustainable, technology-driven learning models.

Practical Implications – The model offers educational institutions in SSA a practical solution for enhancing climate change literacy and green entrepreneurship education through integrated technological approaches.

Social Implications – The implementation of RGM-CCL4GIE contributes to broader climate change awareness and sustainable development goals in Sub-Saharan Africa, potentially influencing social attitudes toward environmental conservation and green innovation.

Keywords – gamification, robot, prototype, climate change, green innovation entrepreneurship

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INTRODUCTION

Gamification refers to the integration of game elements into real-world non-game tasks with the aim of motivating and captivating users (Hamari, 2020; J. Hamari, 2014; Werbach et al., 2012). Gamification not only increases user interest but also has the potential to make the activity more addictive. Owing to its advantages, gamification has found application in various domains, including education. The application domain focus of this research is the subject of Education in the Climate Change Literacy for Green Innovation and Entrepreneurship (CCL4GIE) knowledge domain. The CCL4GIUE knowledge domain deals with leveraging Climate Change (CC) knowledge and awareness, not only to enhance an individual's capability to contribute to mitigating CC effects, but also to exploit Green Innovation and Entrepreneurship (GIE) opportunities in the green economy. Emission. Climate change is a widely acknowledged global phenomenon with far-reaching consequences, affecting ecosystems, weather patterns, and human societies on a significant scale (MAHAT, 2020; Vázquez-Vílchez, 2021). Addressing these challenges effectively necessitates the promotion of climate change literacy among SSA's diverse population, ranging from policymakers to grassroots communities (Hubert et al., 2022), as a means to opening up vista of GIE opportunities in the green economy for socio-economic well-being of the society (CL4YEJC, 2023).

A significant obstacle in climate change education, not only within SSA but globally, revolves around the challenge of maintaining learners' engagement and motivation over prolonged periods (Chen et al., 2023; Hilario et al., 2022), towards achieving learning outcomes. While traditional educational methods such as classroom lectures remain valuable, they often struggle to sustain students' interest, particularly in complex and evolving subjects like climate change (Chen et al., 2023). Learners may initially demonstrate enthusiasm, but interest tends to wane as the novelty of the subject diminishes (Yang et al., 2023).

Gamification, the integration of gaming elements into non-gaming scenarios, is recognized as an educational strategy addressing engagement and motivation challenges. Although gamification shows promise in boosting short-term engagement, it often struggles to sustain these effects, especially in dynamic fields like climate change education. The designs of most gamification systems used in education focus on predictable rewards which are extrinsic in nature("Dicheva, D., Dichev, C., Agre, G., & Angelova, G. (2015). Gamification in Education: A Systematic Mapping Study. 15,"). This research emphasizes the need for an innovative approach harnessing gamification's motivational benefits while ensuring long-term engagement (Oguta et al., 2023). To achieve this goal, a Robotic Gamification Model is proposed, and this paper presents its prototype implementation and evaluation. The robotic gamification model proposed suggests random badge awards and the incorporation of the social robot Nao in the training pedagogy. Robotics emerges as a potential solution for sustaining engagement and motivation in education. Interactive robots like the Social Robot Nao can captivate learners' attention, adapt to individual needs, and provide personalized feedback, fostering intrinsic motivation (Woo et al., 2021; Xefteris & Palaigeorgiou, 2019; Yapa, 2019). This paper reports on the prototype-implementation of a Robotic Gamification Model and its evaluation for effectiveness in enhancing sustained learner engagement and motivation, towards achieving learning outcomes, using the CCL4GIE training as an application domain.

Research Objectives

1. To prototype-implement a Robotic Gamification Model (RGM) using the Moodle e-Learning Management System as a platform with Nao social robot integrated
2. To evaluate the RDM prototype effectiveness in sustained learner engagement and motivation, towards achieving learning outcomes using CCL4GIE training as an application domain.

LITERATURE REVIEW

Previous studies have explored the intersection of gamification, robotics, and education, albeit with varying emphasis and contexts. Lee proposed a musical theatre model for using robots in climate change education (Lee et al., 2022). While their work showcased the potential of robots to engage learners in environmental topics, it primarily focused on delivering content through text-to-speech capabilities, lacking the robotic gamification approach proposed in this research. Lee et al study underscores the relevance of robotics in educational contexts but highlights the need for further exploration of gamification within this domain (Lee et al., 2023; Lee et al., 2022). Furthermore, Hamari provided insights into gamification's application in education, emphasizing its potential to enhance engagement and motivation. While their study did not specifically address climate change education or robotics, it laid the groundwork for understanding the principles of gamification that underpin this research (Galeote, 2021; Hamari & Koivisto, 2015; Hamari, 2020; J. Hamari, 2014).

Werbach and Hunter offered a comprehensive overview of gamification principles and their application across various domains, including education (Werbach et al., 2012). Their analysis elucidated the fundamental game elements in gamification, such as points, badges, and leaderboards, which are integral components of the proposed robotic gamification model. Although their work did not directly explore the integration of robotics into gamified educational settings, it provided valuable insights into the design and implementation of gamification strategies. Additionally, studies focusing on robotics in education have highlighted the potential of robots to enhance learning experiences through interactive and personalized interactions. For instance, Park et al investigated the use of robots as educational companions for children, demonstrating their ability to foster engagement and motivation. While their study primarily targeted a younger demographic and did not specifically address climate change education, it acknowledged the potential of robots in enhancing learner engagement and motivation in educational contexts(Burns et al., 2018; Spaulding et al., 2021) .

Yang, Li-Wen Lian, and Jia-Hua Zhao developed a gamified artificial intelligence educational robot with the goal of enhancing learning outcomes and behavior in laboratory safety courses for undergraduate students (Yang et al., 2023). In their study, the use of robots without gamification in learning resulted in the loss of learner interest, hence the need to add gamification. Their research revealed that implementing the gamified AIER (Artificial intelligence educational robots) system, guided by the Goal, Access, Feedback, Challenges and Collaboration (GAFCC) model [12], significantly enhanced students' academic performance and bolstered their enthusiasm for learning, as well as enriched their engagement, providing a seamless flow experience, and nurtured problem-solving skills (Xefteris & Palaigeorgiou, 2019; Yang et al., 2023). They proposed further investigations to explore the potential of an iterative GAFCC model coupled with diverse types of robots. Collectively, these studies provide a foundation for understanding the theoretical underpinnings of gamification, the potential of robotics in educational contexts, and innovative approaches to climate change education. However, there remains a gap in the literature regarding the integration of gamification principles with robotics technology for climate change literacy training, which this research aims to address.

The Theoretical Framework for the gamified CCL4GIE training model

A research conducted by Oguta et al. (2024) explains how the gamified CCL4GIE model is underpinned with a theoretical framework that combines Self-Determination Theory (SDT), Behavioral Reinforcement Theory, and the MDA Framework to enhance sustained learner engagement and motivation, as depicted in Figure 1 (Oguta et al., 2024). SDT focuses on intrinsic motivations such as autonomy, competence, and relatedness, which are cultivated through the implementation of points, badges, and leaderboards (Chen et al., 2018; Rowe et al., 2017; Ryan & Deci, 2000). Points and badges empower learners by promoting self-directed learning and a sense of achievement, while leaderboards and collaborative activities foster social connections among participants. Behavioral Reinforcement Theory suggests the use of sporadic rewards, such as badges, to reinforce desired behaviors and sustain interest, thus promoting continued engagement (Aguiar Castillo et al., 2022). Lastly, the MDA Framework, represented by the presence of the Nao robot, emphasizes aesthetics to introduce novelty and excitement, thereby enriching the learning environment and bolstering motivation over time (Li et al., 2023; Liu et al., 2017; Yang et al., 2023). This multifaceted strategy prioritizes internal motivators while strategically integrating external rewards, cultivating positive social interactions, and infusing novelty, all contributing to a profoundly engaging and inherently motivating learning experience in the CCL4GIE learning process.

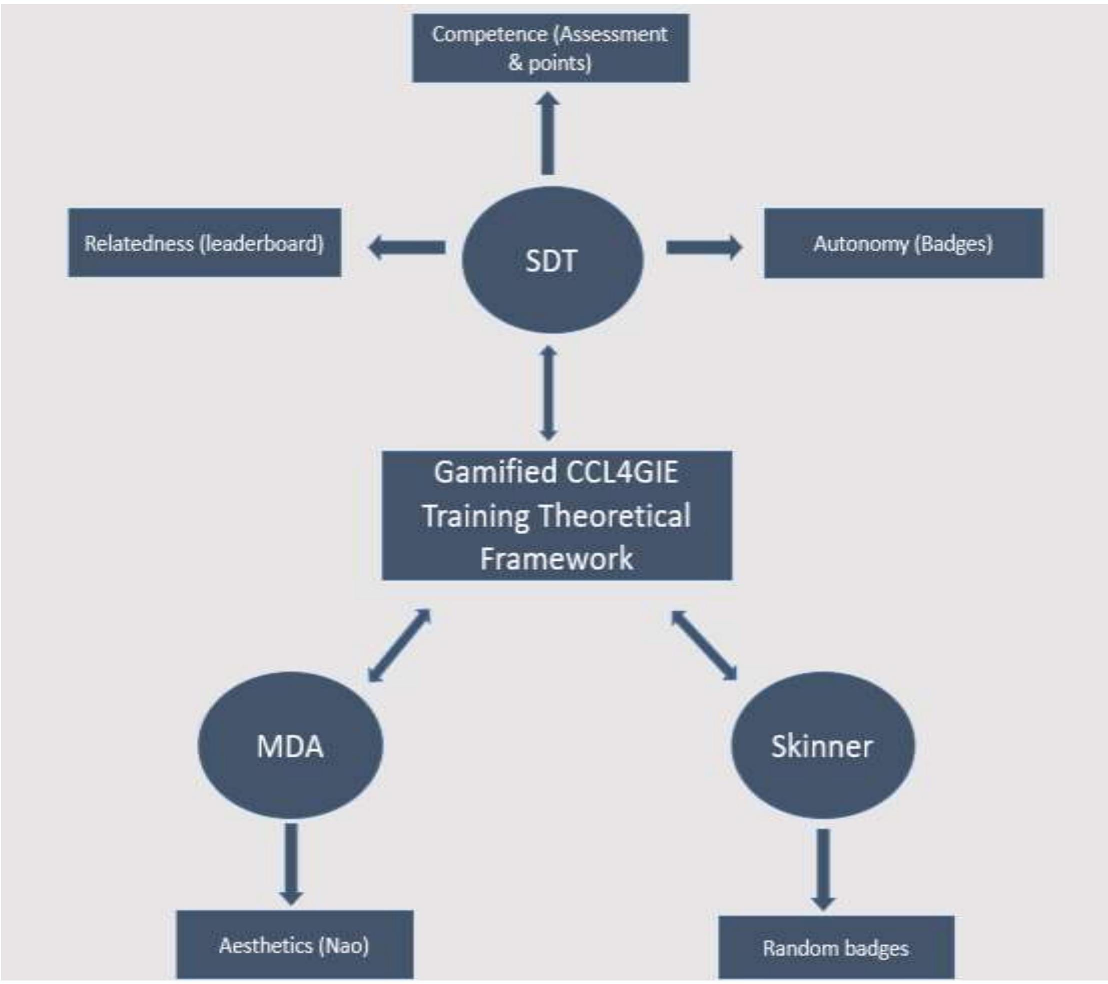

Figure 1. Gamified CCL4GIE Training Theoretical framework

The Architecture of the Gamified CCL4GIE Training System

The gamified CCL4GIE training model, featuring the Nao robot, integrates Self-Determination Theory (SDT) and Skinner's Behavioral Reinforcement Theory. It comprises two databases and modules as detailed in Figure 2, along with components like learners, tutors, arrows, and evaluation sections. Learners, voluntary participants in climate change training, receive instructions from tutors regarding system setup and are directed to either the desktop or robot section. Arrows denote learner progression within the training room, with white arrows indicating communication between system components and grey and green arrows delineating progression through the desktop and Nao robot modules, respectively. The gamified desktop module, hosted on the Moodle E-learning system, employs gamification principles to enhance learner motivation and engagement towards achieving learning outcomes, by incorporating intrinsic motivation elements aligned with SDT theory. Learners receive badges for participation and consistent progress, engage in climate change training and assessments, and participate in team projects, culminating in leaderboard rankings.

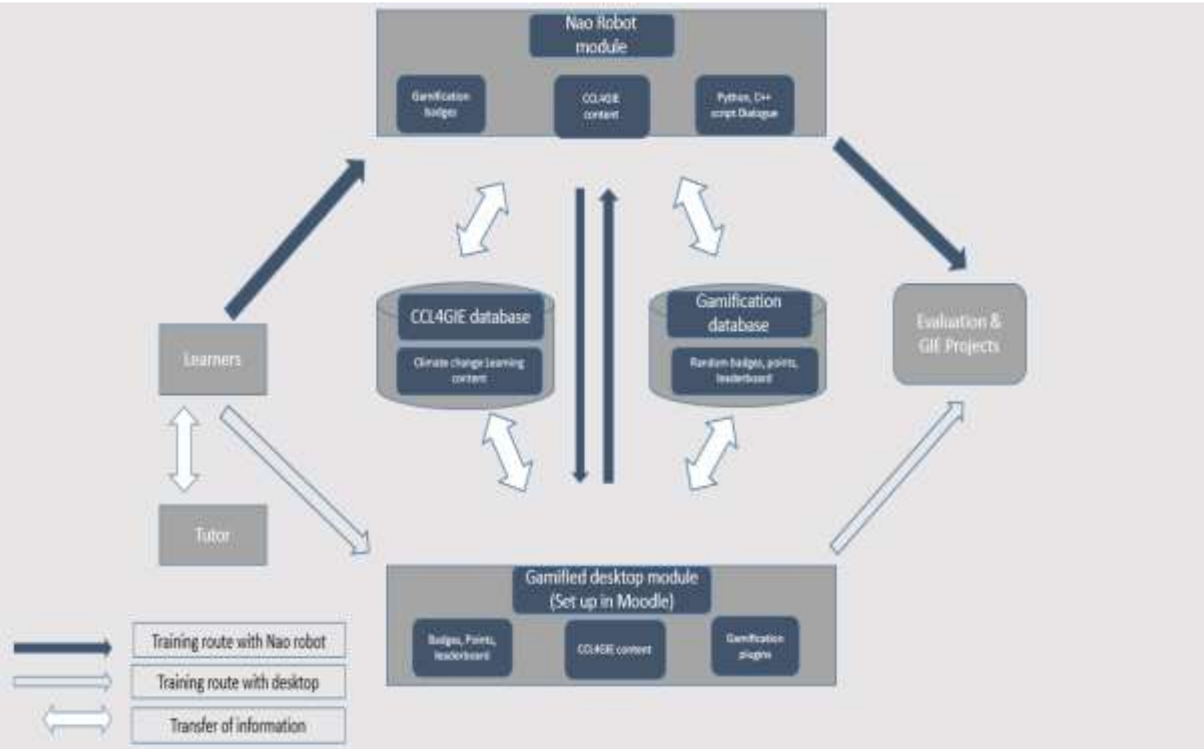

Figure 2. Gamified CCL4GIE training system architecture

METHODOLOGY

Prototyping

The gamified robot-enhanced CCL4GIE training model is implemented using the Design Science Methodology (DSM), chosen for its suitability in developing and validating prototypes (Darmawansah et al., 2023; Rowe et al., 2017; Sitorus, 2017). DSM involves problem identification, objective definition, design and development, followed by demonstration and evaluation, as depicted in Figure 3. In line with DSM, the identified problem is the creation of a gamified robot-enhanced CCL4GIE training model, for a sustained learner engagement and motivation, in CCL4GIE training. (Kory-Westlund & Breazeal, 2019; Robinson, 2019). The design and development phase includes prototyping the gamified robot-enhanced CCL4GIE training model, initially without the Social Robot Nao, then with its inclusion. Plugins from Moodle, such as level up and block game, are employed to integrate gamification elements (Denmeade, 2015; Poondej & Lerdpornkulrat, 2020). The demonstration phase involves testing the developed model and using it to train learners on CCL4GIE. Lastly, the evaluation phase employs a survey based on the Technology Acceptance Model to gather feedback from learners post-training, followed by the dissemination of results. This paper focuses on the prototyping and evaluation phases where the desktop and the Social Robot Nao training systems are set up.

Figure 3. Design science summary

Desktop module

The desktop training module is set up in Moodle e-learning platform because it already has background settings that can be optimized to deliver a gamified training(Sayed et al., 2023). The default Moodle platform lacks block game and level up plugins that are needed to implement the Gamified CCL4GIE Training Model (Alsubhi et al., 2020; Pesek et al., 2020). These are downloaded and installed to create provision for course gamification in line with the proposed framework.

Setting up the Moodle Platform

Setting up Xampp

XAMPP serves as a free and open-source cross-platform web server solution stack package, incorporating Apache, MySQL database, PHP, and Perl(Kew, 2007; Swain et al., 2015). Downloading XAMPP provides a local server environment, essential for hosting Moodle without the reliance on external web hosting services. This gamified CCL4GIE Training system is set up in a local host computer because gamification configurations need to be tested first before they are launched in the general university E-learning platform.

Figure 4. Installing XAMPP

The installation process is initiated by launching the downloaded XAMPP installer. 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.

Downloading and installing Moodle

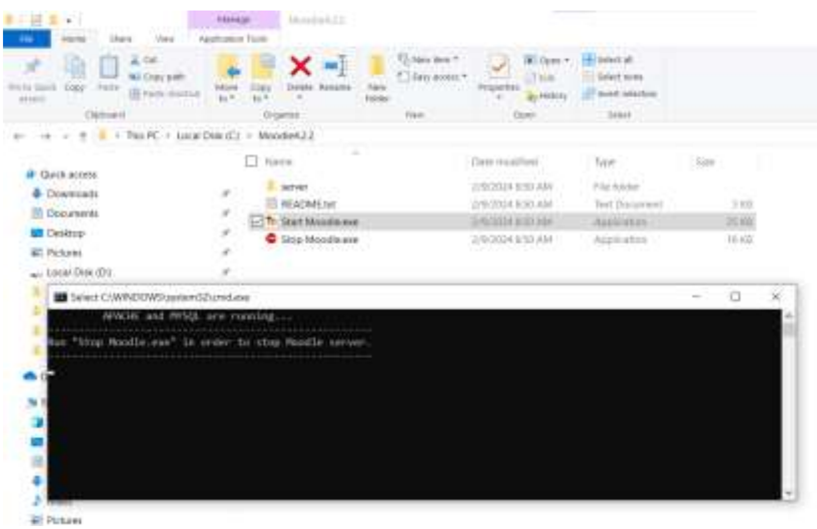

Figure 5. Starting Moodle

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. Downloading Moodle equips users with the requisite files for installing the LMS within the local server environment established by XAMPP. Users locate the downloaded Moodle ZIP file and proceed to extract its contents to a designated destination folder. This step unpacks the Moodle files from the compressed archive, making them accessible for installation. The Moodle installation process is initiated by accessing "localhost" in their web browser, leading to the XAMPP welcome page (Su & Su, 2015). Following on-screen instructions, users configure Moodle settings, including database details. Upon completion of the installation process, one is prompted to create an administrator account for Moodle. Following account creation, users can log in to their Moodle site and commence configuration according to their specific requirements. The Moodle System must be started anytime one needs to launch it in local computer as shown in Figure 5.

Setting up the training in Moodle

After installing Moodle in a local host computer, the admin accounts are created as shown in Figure 6. The course detains such as name and code are then configured as shown in Figure 7 and users added to the course. The name of the course is Climate Change Literacy. An image is set up in the course overview to add the aesthetics appeal to the course in line with MDA framework of gamification (Tamtama et al., 2020). Images increase the visual appeal component which subsequently contribute to student motivation.

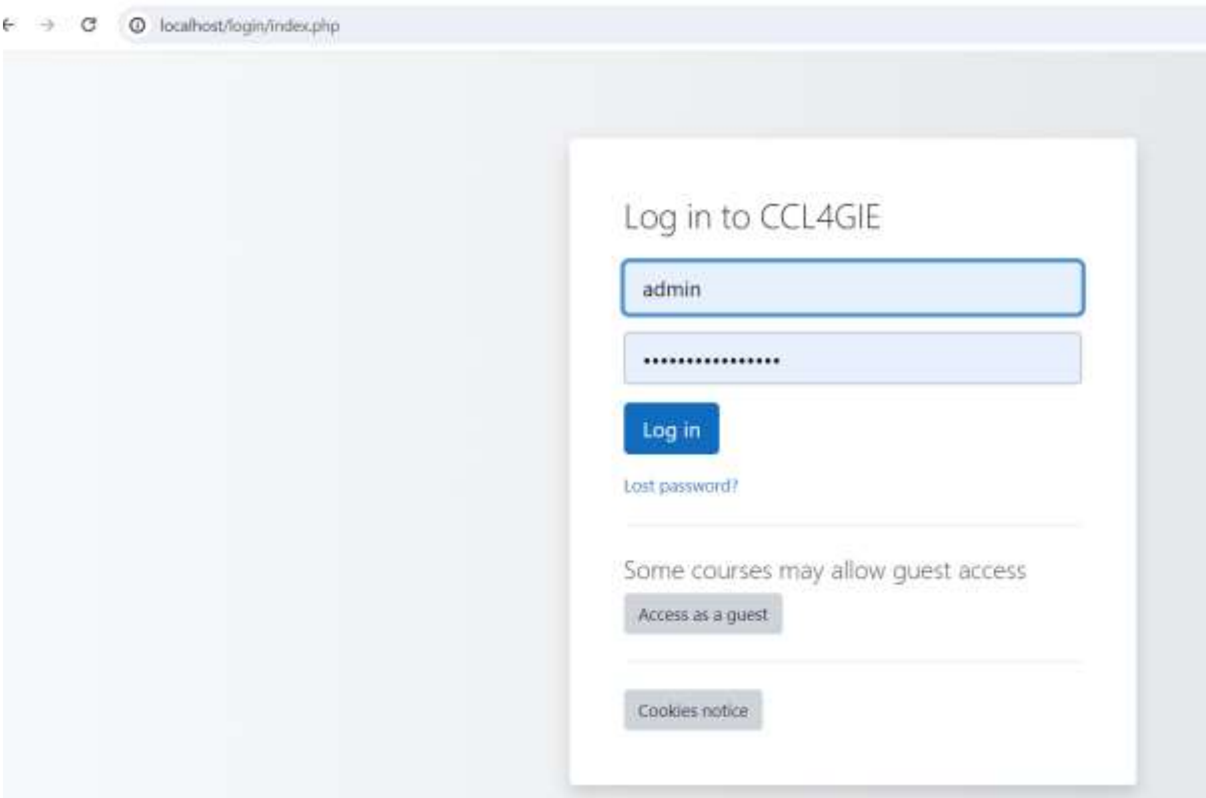

Figure 6. Admin setting in Moodle.

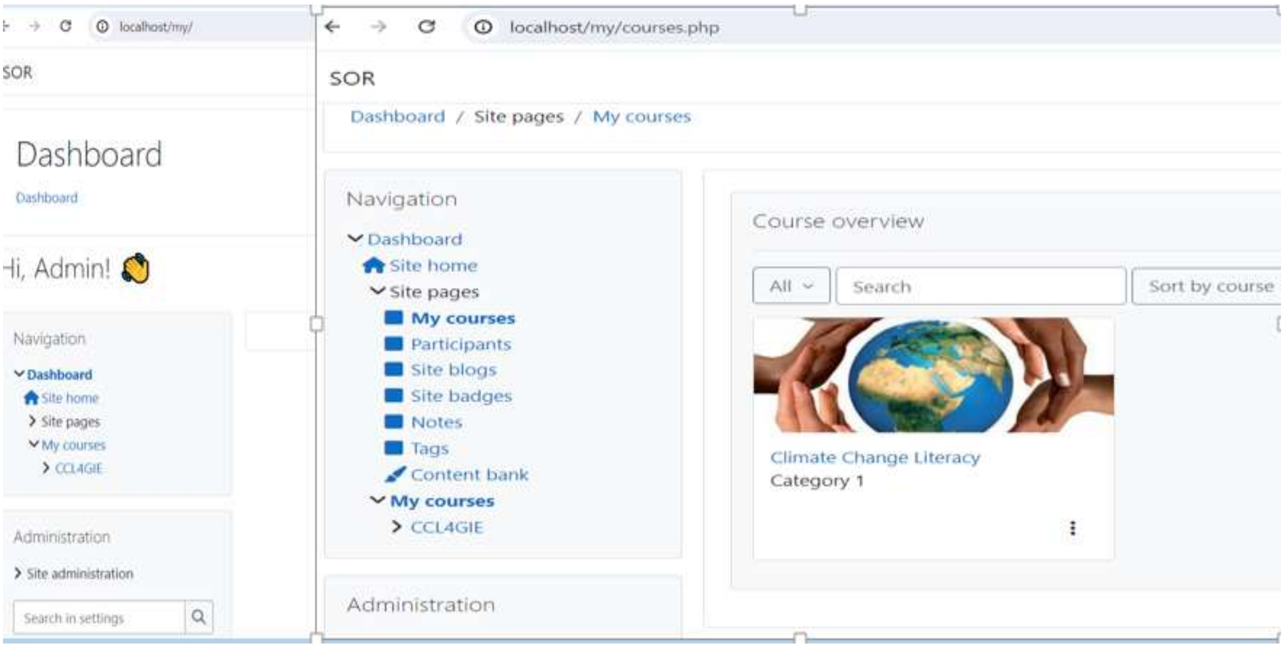

Figure 7. Course configuration

The course overview page also has a short video that introduces learners to the climate change literacy course as shown in Figure 8. The inclusion of this video is also a gamification technique in line with MDA. The video adds to the aesthetics segment of MDA by increasing audio and visual appeal aspects (Hicks et al., 2019; Lu & Ho, 2020; Lu et al., 2023; Ralph & Monu, 2015). The main objective of this prototyping is to avail a gamified robotic gamification training system aimed at increasing motivation, engagement, towards learner outcomes achievement.

Figure 8. Course introduction video

Operationalizing the SDT-OCT-MDA into Gamification components in the prototype

During the prototyping phase, Self-determination theory is referenced to set up points, badges and leaderboards as summarized in table 1.

Table 1. Mapping of gamification elements and theories.

THEORY	**GAMIFICATION ELEMENTS**
SDT Competence Autonomy Relatedness:	 Assessment and points Grade badges 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. According to the self-determination theory, each person has inert desire to appeal to these three components upon which they would achieve intrinsic motivation.

Competence

Competence is an SDT aspect that embodies the aspiration to feel proficient and impactful in one's endeavors. In the gamified CCL4GIE training model, competence was set to be achieved through inclusion of assessments (Oguta et al., 2024). The mathematical modelling of competence utilizes the formula shown in equation 1. From the equation, the sum of competence points awarded per time is given by

$$Ci(t) = \sum_{j=1}^{t} C^j \qquad Equation\ 1$$

Where C^j is the competence points awarded to user i at time j and $Ci(t)$ represents the cumulative competences of user i at time t. Competence points are visually represented on a user profile to provide feedback on the user's mastery and progress. 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 does the assessments. The prototype has two assessments after each of the two lessons as shown in figure 9.

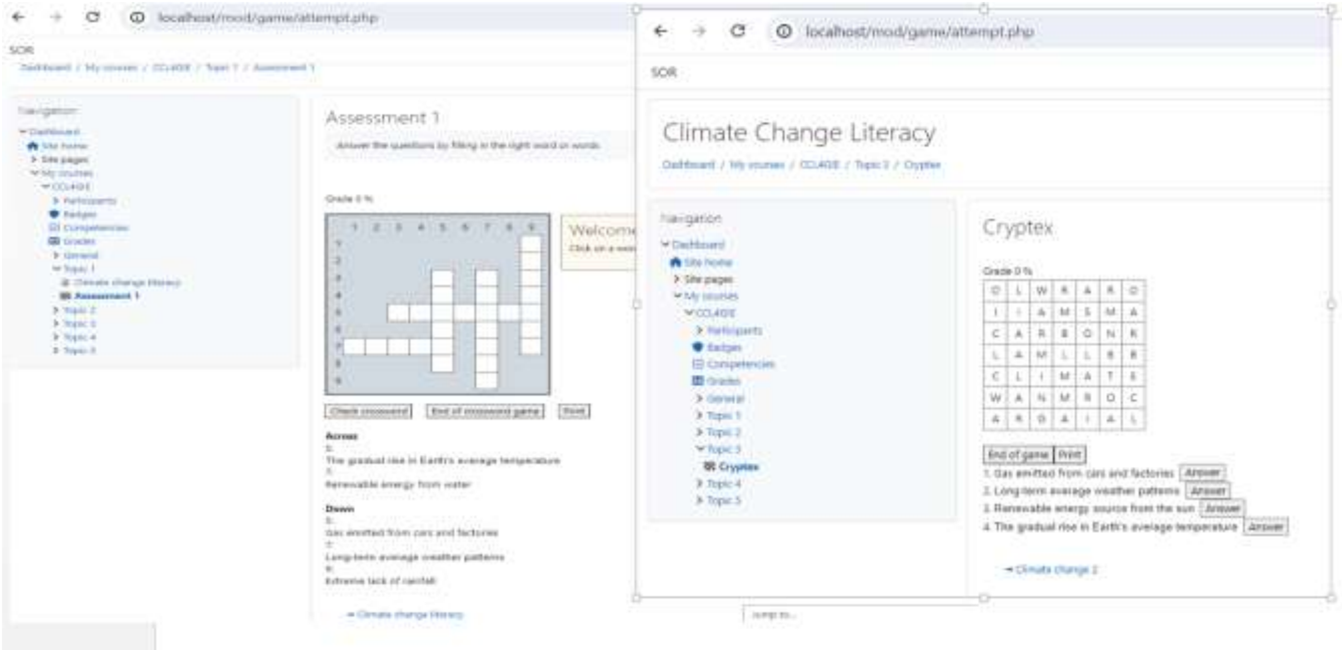

Figure 9. Assessments

Each of the assessments is made in form of a game. Assessment one is a crossword game while assessment two is a cryptex game. Gamifying the assessments is aimed at increasing motivation of learners as they go through the training (Alsawaier, 2018; Buckley & Doyle, 2016; Lumsden et al., 2016; Zainuddin, 2018; Zainuddin et al., 2020). In order to configure the game mode of the assessments, the block game plugin was downloaded to support this scenario. Further, a glossary was set up from where the cross word and the cryptex games would fetch the questions for display.

From SDT theory, the points shown in figure 10 achieved from the assessments appeal to the competence aspect of the learners and consequently increase their intrinsic motivation(Goldman et al., 2017; Ten Cate et al., 2011).

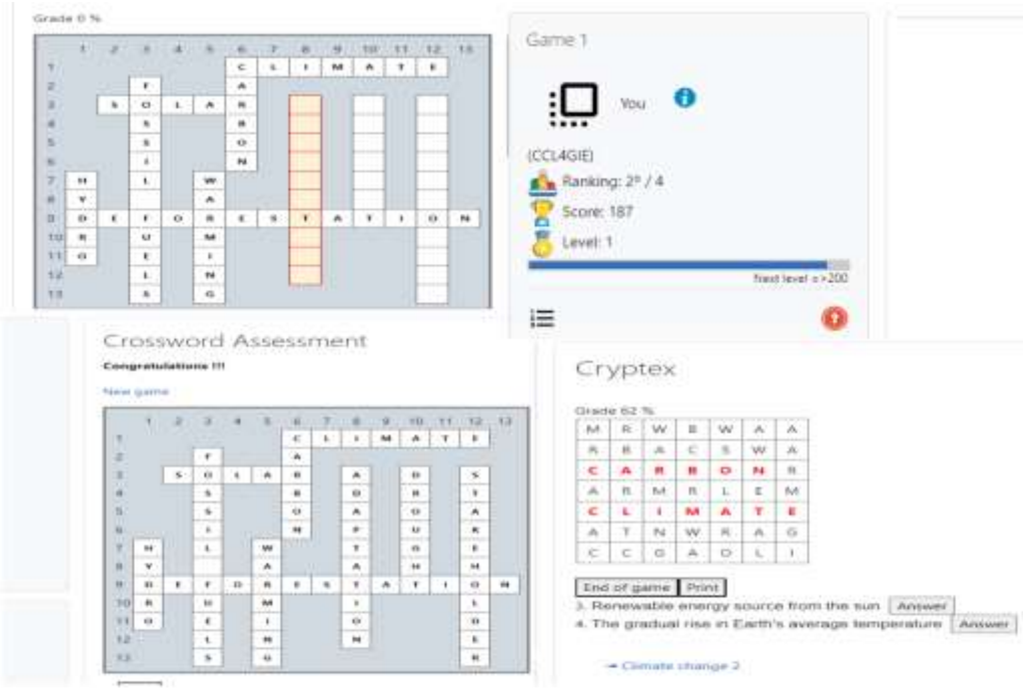

Figure 10. Points awarded from assessments

Relatedness

Relatedness is achieved through leaderboard and the GIE project that is delivered through team work in a group discussion (J. Hamari, 2014; Rajanen, 2019; Robinson, 2019; Yaşar, 2020). Leaderboards show ranks of students per time as they progress with the course and the provided assessments. From mathematical approach, leaderboard is arrived at from a compilation of performance points that ultimately maps the student marks to the ranking list as illustrated in the equation 2, 3 and 4.
The total points P_s for each student is calculated based on their performance in assessments.

$$Ps = \sum_{i=1}^{N} Xi \qquad Equation\ 2$$

In the equation 2, N represents the number of correct answers in the assessments and X_i is the points earned for each correct answer. Further, the students are ranked based on their total points P_s. In such a case, the highest ranking student in the leaderboard is the one with most points.

$$Rank\ (S) = \ Rank\ of\ Ps\ in\ L \qquad Equation\ 3$$

The leaderboard can rank students in ascending or descending order. This representation can list students with their corresponding ranks and total points.

$$L \ = \ \{(S_1, Rank_1, P_1, (S_2, Rank_2, P_2), \dots, i, Rank_i, P_i) \qquad Equation\ 4$$

In equation 4, $S_i$is the ith student, $Rank_i$ is their rank, and P_i is their total points. This mathematical model captures the essence of a leaderboard where students are ranked based on their total points earned from assessments. As the student progresses with the assessments, the leaderboard ranking changes in line with the performance as shown in figure 15. From SDT theory, motivation increases as the students feel connected one to another. This connectedness is as explained by Deci (Ryan & Deci, 2000).The leaderboard implements this relatedness aspect and one gets motivated to rise higher in the leaderboard (Fotaris et al., 2016; Mekler et al., 2013). As a result, engagement and motivation increases (Jang et al., 2016). The highest ranking student has 329 points followed by two students with 200 points each. Each student works towards rising to the top rank and so keep engaged as they continue in the course (Landers et al., 2017; Sailer et al., 2017). Figure 16 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.

Autonomy

The prototype of the gamified CCL4GIE training model implements autonomy through award of badges (Anderson et al., 2014). The badges are set to be awarded intermittently as the course proceeds. From mathematical approach, to define badges and probabilities, let $B = \{b_1, b_2 \dots b_{|B|}\}$ be the set of badges and $P = b_i$ stand for the likelihood of presenting each badge b_i. The badges in the prototype include starter badge and Climate champion and completion badges as shown in figure 17. The probability distribution of the badges takes the formula:

$$\sum_{i=1}^{|B|} P(b_i) = 1 \qquad Equation\ 5$$

Where by $\sum$ represents the summation of all badges to be equal to $\mathbf{1}$ in line with probability theory because the sum of all probabilities must equal to $\mathbf{1}$. Further, $\boldsymbol{i} = \mathbf{1}$ stands for the lower or the beginning point of the badges and $|\boldsymbol{B}|$ which also means the cardinality stands for the total number of badges to be awarded. Equation 5 is the probability of a specific badge $\boldsymbol{b_i}$ from the set (list of badges) $\boldsymbol{B}$ being given.

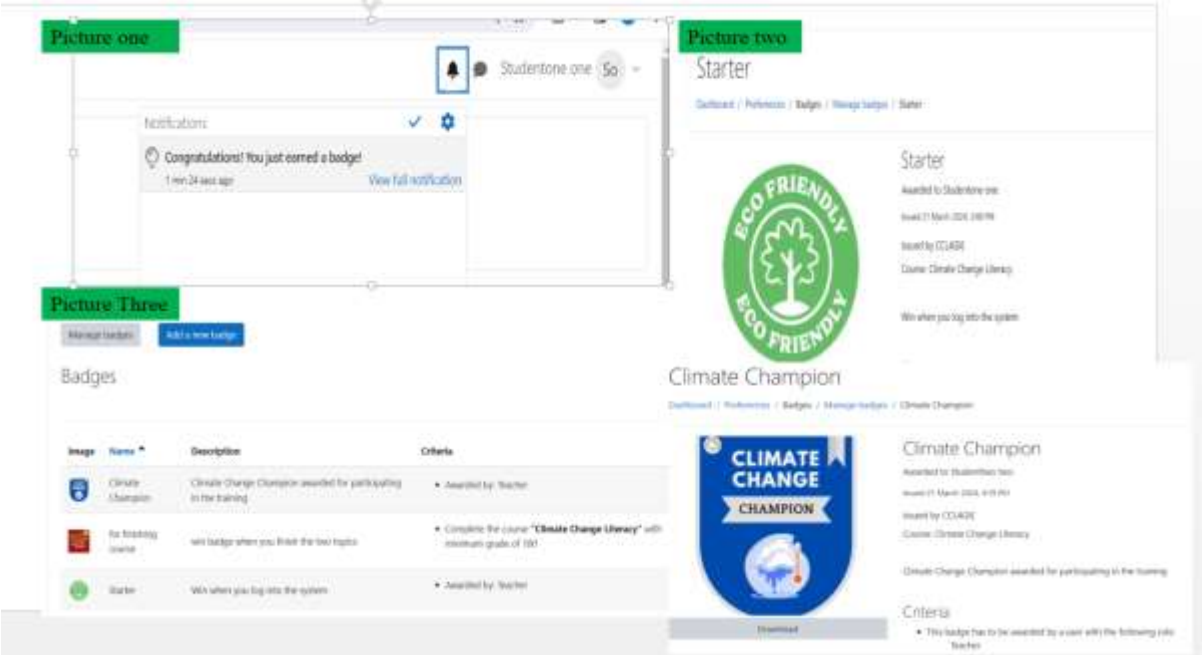

Figure 11. Badge award process and display

Picture one in figure 11 shows a congratulation message to student one for winning a badge while picture two shows the badges awarded to the student and the details of each badge. From the image, the student has won starter and climate champion badge. The users are also able to see the available badges and the criteria for wining them as shown in picture 3 in figure 11.

Random Plugin

This section focuses on the development and implementation of a dynamic and interactive plugin artifact 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, we have created a subtle yet impactful game-like interaction that aims to captivate users' attention and potentially increase their frequency of platform visits.

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 favors the "winning" outcome, potentially boosting user satisfaction. The generated number is then evaluated to determine if it's odd or even. This is achieved using the modulo operator, which returns the remainder after division by 2 as shown in the scripts.

The generated number determined whether a student wins a badge or not. 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 12. 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 12. Random Badge Scripting

Figure 13 and 14 shows the badge display when a student signs into the module. The random number generator determines whether a student wins a badge or not. Figure 13 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 13 and 14.

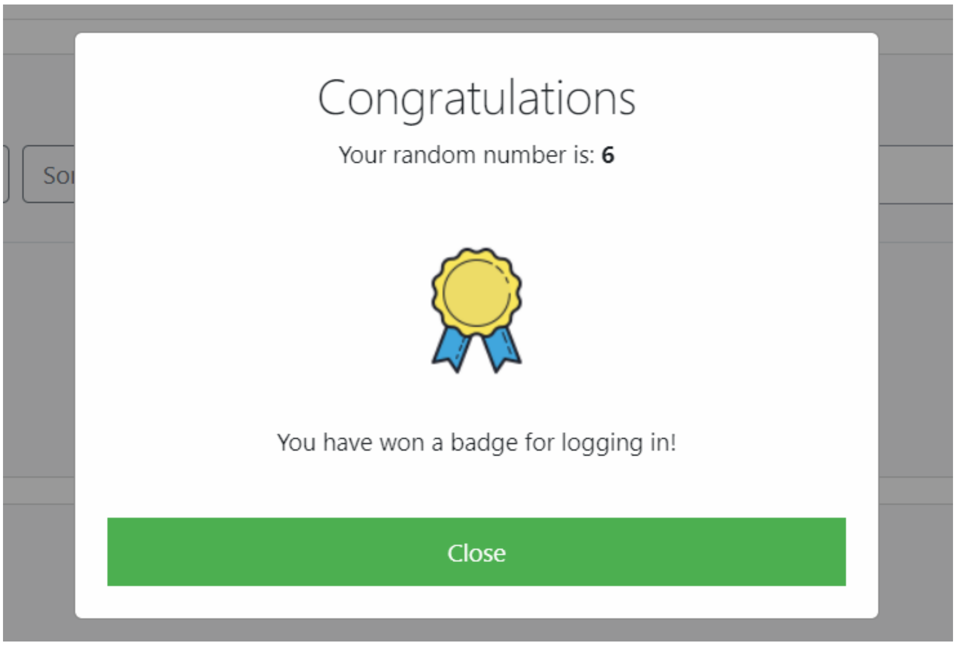

Figure 13. Random badge won

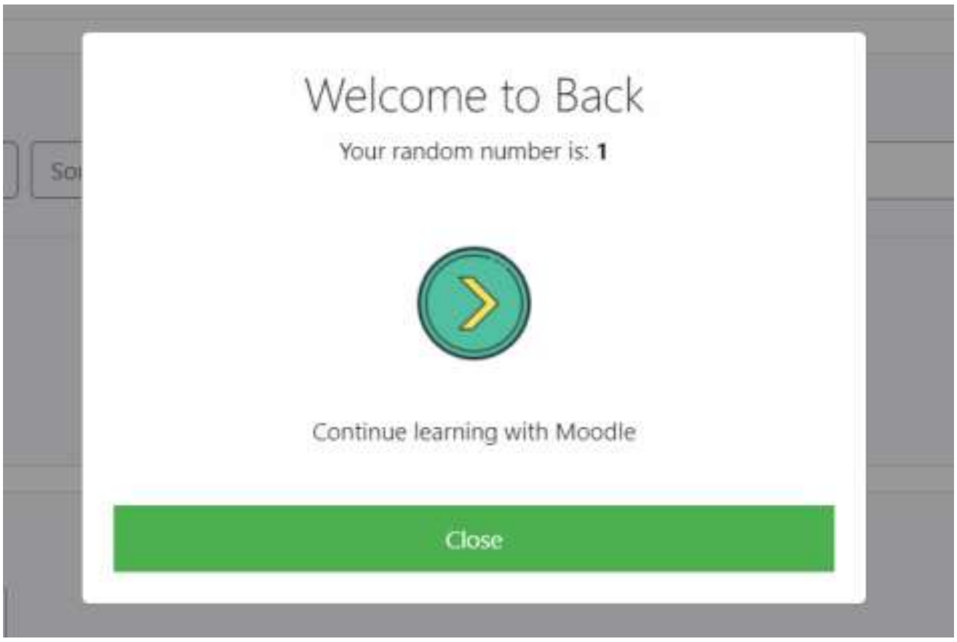

Figure 14. Random Badge missed

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

Robotic Training Module

In the gamified CCL4GIE training model, MDA informs the need to increase aesthetics in a gamified system and supports the inclusion of Nao robot as an aspect of aesthetics. MDA Framework's emphasis on aesthetics, embodied by the Nao robot, injects excitement into the learning environment, further enhancing motivation and prolonging engagement. Very few studies have been done on the use of gamified robots for training climate change. Overall Aesthetic Experience (AE) is a combination of the individual components to derive an overall aesthetic experience. Emotional Impact (*EI*) is defined as the degree of emotional appeal that the robot has on learners ….. Variable *VA* is introduced to represent the *visual appeal* also set in range. Variable *AP* is introduced which represents *auditory pleasure*. Let *EI*, *VA* and *AP*, be in the range *[0, 1]*, where *0* represents low impact, and *1* represents high impact. Therefore,

$$AE = W_{EI}.\mathrm{EI} + W_{VA}.\mathrm{VA} + W_{AP}.\mathrm{AP} \qquad Equation\ 6$$

Where W_{EI},W_{VA} , W_{AP} are weights reflecting the importance of factors EI, VA, and AP, respectively. This model attempts to quantify and combine various factors influencing aesthetics. The Nao Social Robot is a semi-humanoid apparatus featuring electro-mechanical parts, enabling it to engage with humans via speech, facial expressions, and body gestures (Van den Hoven van Genderen, 2018). With its programmable nature, this robot can execute various tasks by loading appropriate scripts, including speech and motion. As a result, it is configured as a tutor or teaching assistant in this CCL4GIE training.

To set up the Nao robot in Choregraphe and program it to teach CCL4GIE, various steps were followed. Choregraphe is a software application developed by Softbank Robotics for programming and controlling their humanoid robots, including the Nao robot (Eguchi & Okada, 2018). First step is to install Choregraphe, the official software provided by Softbank Robotics for programming Nao robots. Next step is to connect the Nao robot to Choregraphe, either via USB cable or Wi-Fi, and wait for it to be detected within the software interface (Brown et al., 2013; Evripidou et al., 2020).

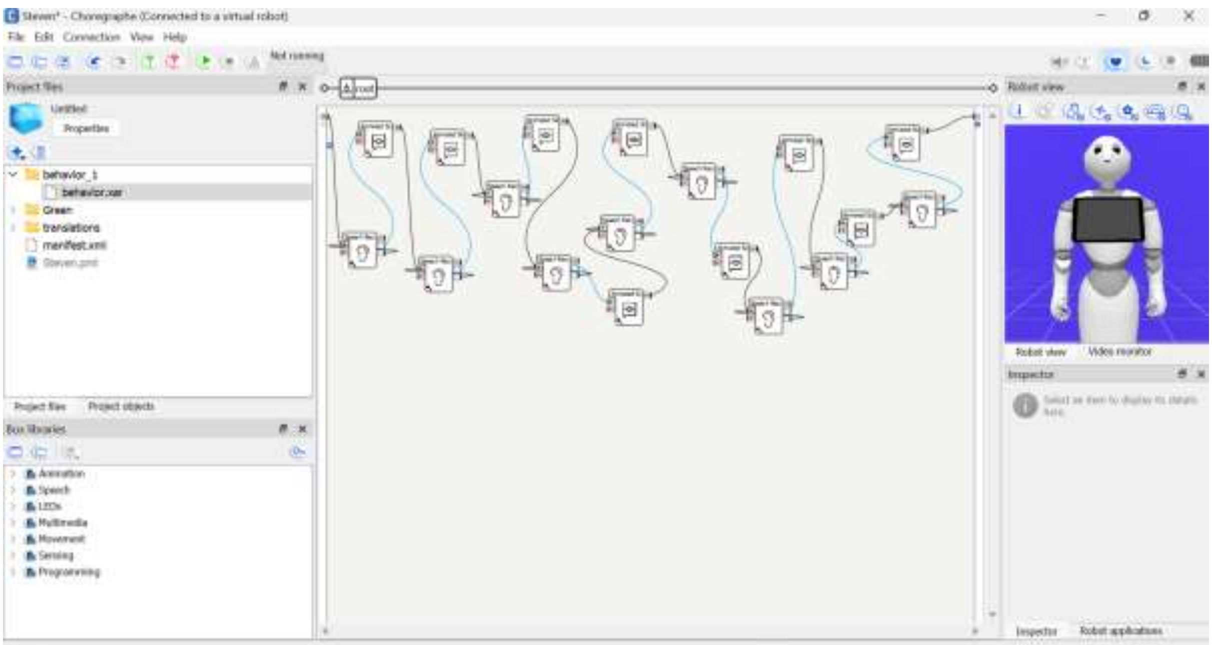

Figure 15. Nao Programming steps

The figure 15 illustrates the project control panel, flow diagram panel and the robot view panel. Programming can be done on a virtual robot then implemented on a physical robot (Garg et al., 2021; Marín et al., 2005; Pan et al., 2012). The first connection is called global start and the very last connection is called global stop. The chain of boxes illustrate the proceedings in the training session. Figure 16 illustrates the training progression 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.

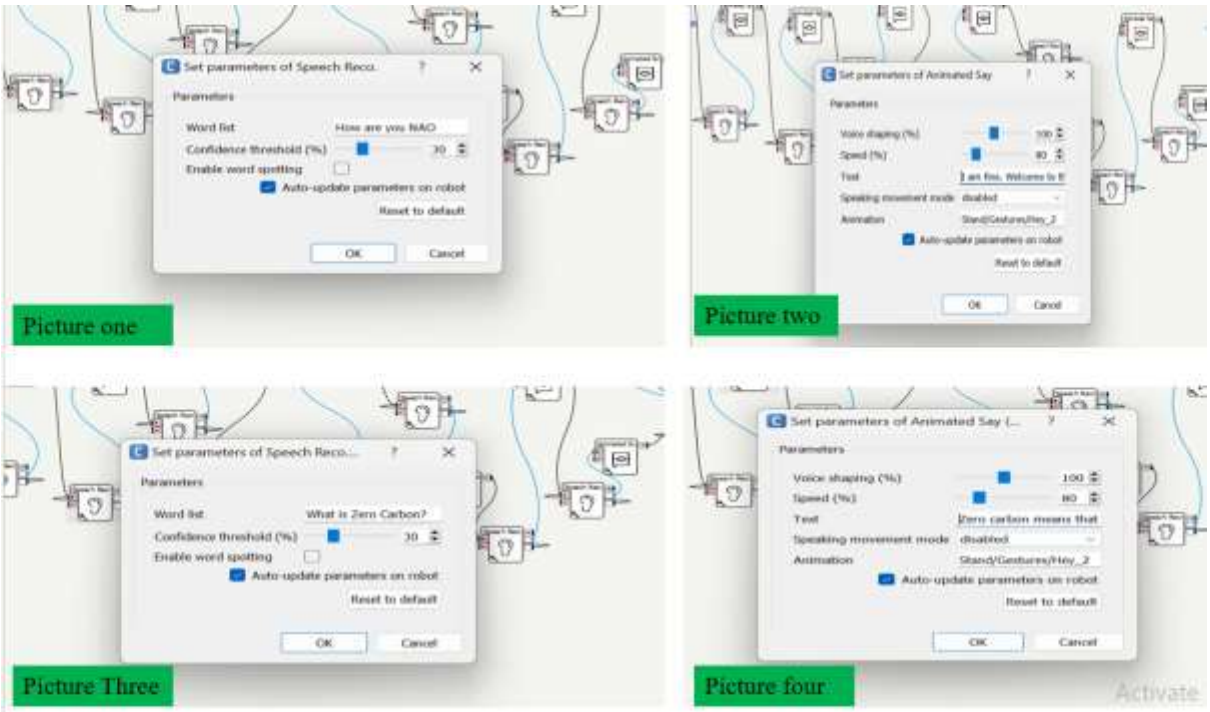

Figure 16. Training progression

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 16. The Nao robot replies and prompts the student to ask the first question related to climate change. In picture three, the student seeks to know what zero carbon means. Picture four has the definition of zero carbon as delivered by the robot to the student.

Once Social Robot Nao had been programmed, it delivered climate change literacy training. The students asked questions and the robot answered in line with the prompts. During the training session the speech, visual appeal, movement and emotional impact of the robot were in display in line with equation 11. During the trials, the students expressed awe and took to their cameras just to record the moment. This research aims at delivering a prototype of robotic gamification with Social robot Nao with the aim of sustaining motivation, engagement and learning outcomes in climate change literacy.

Research Design

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-CCL4GIE (Yan et al., 2022).

Participant Recruitment and Sampling

Participants were recruited from Durban University of Technology using a stratified random sampling technique to ensure representation across various academic disciplines in the faculty and levels of study.

Training Procedure

The experiment consisted of a one-hour training session utilizing the RGM-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 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.

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.

Results

Participant Characteristics

A total of 20 students participated in the study. Their demographic characteristics are summarized in Table 2. 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.

Student Survey Feedback

Tables 3-7 displays survey results from users providing review on different aspects of the RGM-CCL4GIE.

Table 2. 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%

Table 3. Data on User Motivation Prompts

UM 1 using the RGM-CCL4GIE system inspires me to continue the training.	**Frequency**	**Percent**
Agree	5	25
Strongly Agree	15	75
UM 2 Points in the RGM-CCL4GIE system adds me motivation	**Frequency**	**Percent**
Agree	7	35
Strongly Agree	13	65
UM 3 Leaderboards in the RGM-CCL4GIE system adds me motivation	**Frequency**	**Percent**
Agree	6	30
Strongly Agree	14	70

UM 4 Random badges in RGM-CCL4GIE system adds me motivation	Frequency	Percent
Neither agree or disagree	2	10
Agree	5	25
Strongly Agree	13	65

Table 4. Data on User Engagement Prompts

UE 1 Using CCL4GIE training system increases ease of doing assessments	Frequency	Percent
Disagree	1	5
Agree	5	25
Strongly Agree	14	70
UE 2 Using CCL4GIE training system increases my participation in class	Frequency	Percent
Neither agree or disagree	1	5
Agree	5	25
Strongly Agree	14	70
UE 3 Using CCL4GIE training system increases my understanding ability in class	Frequency	Percent
Neither agree or disagree	2	10
Agree	4	20
Strongly Agree	14	70
UE 4 The random badges in the RGM-CCL4GIE system increases my engagement in the training	Frequency	Percent
Neither agree or disagree	1	5
Agree	9	45
Strongly Agree	10	50

Table 5. Data on Perceived Usefulness

PU 1 using the RGM-CCL4GIE training system enables me understand matters of climate change	Frequency	Percent
Disagree	1	5
Agree	4	20
Strongly Agree	15	75
PU 2 Using the RGM-CCL4GIE training system increases my understanding of GIEs	Frequency	Percent
Disagree	1	5
Neither agree or 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 or disagree	2	10
Agree	8	40
Strongly Agree	10	50

Table 6. Data on Perceived ease of Use

PUOE 1 My interaction with the RGM-CCL4GIE training system is clear and understandable	**Frequency**	**Percent**
Agree	9	45
Strongly Agree	11	55
PUOE 2 Summarily, I find the RGM-CCL4GIE training system easy to use	**Frequency**	**Percent**
Agree	7	35
Strongly Agree	13	65
PUOE 3 Using the RGM-CCL4GIE training system is frustrating	**Frequency**	**Percent**
Strongly Disagree	13	65
Disagree	6	30
Neither agree or disagree	1	5
PUOE 4 Doing assessments is easy using the RGM-CCL4GIE training system	**Frequency**	**Percent**
Strongly Disagree	1	5
Disagree	1	5
Neither agree or disagree	2	10
Agree	7	35
Strongly Agree	9	45

Table 7. Data on Aesthetics

AA 1 the NAO robot inclusion increases my motivation continue attending training	**Frequency**	**Percent**
Neither agree or disagree	1	5
Agree	9	45
Strongly Agree	10	50
AA 2 NAO robot appearance increases emotional appeal of the training	**Frequency**	**Percent**
Neither agree or disagree	2	10
Agree	7	35
Strongly Agree	10	55
AA 3 NAO robot speech increases emotional appeal of the training	**Frequency**	**Percent**
Neither agree or 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 or disagree	1	5
Agree	2	10
Strongly Agree	1	5

Data Analysis

Analytical Approach

The data analysis employed a multi-faceted approach to ensure a comprehensive evaluation of the RGM-CCL4GIE. All analyses were conducted using IBM SPSS Statistics 27.0, with the significance level set at α = 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 (Remenyi et al., 2022).
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 if the mean responses significantly differed from the neutral point. These tests help establish whether participants' perceptions were significantly positive or negative providing insights into how different aspects of the RGM-CCL4GIE interact.

Scale Reliability

Table 8 presents the Cronbach's alpha coefficients for each subscale. The Cronbach's alpha values for all subscales shown in table 11 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 (α = 0.86) and Perceived Usefulness (α = 0.89) subscales is particularly noteworthy, as these are central to evaluating the effectiveness of the RGM-CCL4GIE in achieving its primary objectives of enhancing motivation and perceived learning outcomes.

Table 8. 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

Descriptive and Inferential Statistics

Table 9 presents the descriptive statistics and one-sample t-test results for each subscale. The results shown in table 9 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-CCL4GIE across all measured dimensions. The Motivation subscale received the highest mean score (M = 4.58, SD = 0.51), suggesting that the RGM-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 if 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-CCL4GIE across all measured aspects, with particularly strong effects on motivation and user engagement.

Table 9. 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

DISCUSSION

Analysis of Individual Items

User Motivation

The RGM-CCL4GIE system demonstrated exceptional effectiveness in fostering user motivation, with participants showing strong positive responses across all motivation metrics. The system's ability to inspire continued training received the highest rating (M = 4.75, SD = 0.44), with 75% of participants strongly agreeing. The random badge system proved particularly effective (M = 4.55, SD = 0.69), with 65% strongly agreeing and 25% agreeing to its motivational impact. Points and leaderboards also showed significant success, with 65% and 70% of participants strongly agreeing to their motivational value, respectively. The results validate the system's incorporation of operant conditioning principles (Burns et al., 2018).

User Engagement

The survey results indicate that the RGM-CCL4GIE system is highly effective in promoting user engagement across various dimensions of the learning experience. 70% of participants strongly agreed that the system increased ease of doing 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, in particular, 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 behavior over time (Ibisu, 2024). This finding supports the thesis's focus on random badges as a key mechanism for sustaining long-term user engagement in educational technology.

Perceived Usefulness

The RGM-CCL4GIE system demonstrates high perceived usefulness among users (M = 4.65, SD = 0.75). 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). 90% of participants 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.

Perceived Ease of Use

The survey results indicate that the RGM-CCL4GIE system is user-friendly and accessible. For instance, the average score for PUOE 2 ("I find the RGM-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 a 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.

Aesthetics

The integration of the NAO robot into the RGM-CCL4GIE system has notably enhanced user motivation and engagement. A significant 95% of participants agreed that the NAO robot increased their motivation to continue with training, yielding a mean score of 4.45 (SD = 0.60), emphasizing its role in sustaining learner interest. Additionally, 90% felt that both the robot's appearance and speech added emotional appeal, with 55% strongly agreeing that its appearance made the training more engaging (M = 4.45, SD = 0.69). This innovative feature introduced many participants to robotic gamification for the first time, adding a fresh and compelling dimension to the learning environment. Combined with the random badge reward system, the robot's visual, auditory, and interactive contributions align with operant conditioning principles, supporting user engagement. According to the MDA Framework, the system's multi-sensory approach ensures that aesthetics, a critical driver in gamified learning, play a central role in sustaining user interest (Hunicke et al., 2004).

The development and validation of the Robotic Gamification Model for Climate Change Literacy for Green Innovation and Entrepreneurship (RGM-CCL4GIE) marks a significant advancement in educational gamification. This research addressed a fundamental challenge in educational technology: the inability of traditional gamification systems to maintain long-term learner motivation due to their reliance on predictable extrinsic rewards, particularly in climate change education. At the heart of the RGM-CCL4GIE is an innovative integration of gamification principles with robotics, implemented through the Nao humanoid robot and a dynamic random badge award system on the Moodle e-learning platform. The model draws its theoretical strength from a sophisticated blend of Self-Determination Theory, Behavioral Reinforcement Theory, and the MDA framework, creating a comprehensive approach to promote learner autonomy, competence, and relatedness. The model's effectiveness was convincingly demonstrated through rigorous statistical analysis, achieving a remarkable mean motivation score of 4.58 (t-statistic: 13.87, p-value < .001). Notably, the random badge system garnered high approval ratings with a mean of 4.55, while users reported strong satisfaction with the system's ease of use, scoring 4.33. This research contributes significantly to the field through its integration of multiple theoretical perspectives, mathematical modeling of gamification elements, and development of comprehensive architectural and methodological frameworks. The creation and validation of a prototype featuring random plugin design further solidifies its practical applicability.

CONCLUSION AND RECOMMENDATIONS

Looking ahead, it is recommended that future research explore the integration of emerging technologies such as AR and VR within the RGM-CCL4GIE framework to further enhance engagement. Additionally, cross-cultural studies should be conducted to validate the model's effectiveness across different educational contexts, ensuring its adaptability and broader impact in climate change education.

IMPLICATIONS

This study advances the field of educational gamification by providing an innovative framework that combines robotics and advanced motivational theories, establishing a foundation for future research in sustainable, technology-driven learning models. The model offers educational institutions in SSA a practical solution for enhancing climate change literacy and green entrepreneurship education through integrated technological approaches. The implementation of RGM-CCL4GIE contributes to broader climate change awareness and sustainable development goals in Sub-Saharan Africa, potentially influencing social attitudes toward environmental conservation and green innovation.

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DECLARATIONS

Conflict of Interest

The researcher declares no conflict of interest in this study.

Informed Consent

Informed consent was obtained from all participants, and data anonymity and confidentiality were ensured throughout the research process.

Ethics Approval

The study was conducted in compliance with the ethical guidelines of Durban University of Technology.

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Author's Biography

Stephen Oguta is a PhD in Information Technology student at Durban University of Technology. He has a master's degree in Telecommunications Engineering from Jomo Kenyatta University of Technology in Kenya. His research interests are Gamification, Artificial intelligence, Social robots, Big data, Computer security, Cloud computing, and neural networks among others.

Professor Sunday O. Ojo holds a PhD degree in Computing Science from the University of Glasgow in Scotland, UK. His research interest areas include ICT for Development, Computational Linguistics and Natural Language Processing,, Data Science and Machine Learning, Educational Gamification, Green Computing, and Climate Change Literacy for Green Innovation and Entrepreneurship. He is currently an Adjunct Professor (Research) at Durban University of Technology in South Africa.

Dr. Benard Maake is a lecturer in the Department of Computing Sciences at Kisii University, Kenya. He holds a PhD in Computer Systems Engineering from the Tshwane University of Technology in Pretoria, South Africa. His research interests include recommender systems, big data, machine learning, cloud computing, natural language processing, and artificial intelligence.