Int. j. adv. multidisc. res. stud. 2026; 6(1):330-338

Received: 19-11-2025
Accepted: 29-12-2025

International Journal of Advanced Multidisciplinary Research and Studies

ISSN: 2583-049X

Design and Implementation of EcoLearn: An Interactive Climate Education Platform for Raising Awareness and Promoting Sustainable Practices

[1] Tapiwa Phiri, [2] Moses Mupeta

[1, 2] Department of Information and Communications Technology, School of Engineering, Information and Communications University, Lusaka, Zambia

Corresponding Author: **Tapiwa Phiri**

Abstract

Climate change education faces persistent challenges in engaging diverse audiences, particularly in regions like Zambia where climate impacts are increasingly evident (Mumba *et al*., 2022) [7]. This paper presents the design, development, and evaluation of EcoLearn, an interactive web-based climate education platform created to address well-documented limitations in traditional climate education methods (Anderson and Wallin, 2020) [3]. Using a Design Science Research approach (Hevner *et al*., 2004) [15], the platform integrates interactive simulations, gamification elements (Deterding *et al*., 2011) [8], real-time climate data via OpenWeatherMap API, and psychological support features (Clayton *et al*., 2022) [13]. The development employed HTML5, Tailwind CSS, JavaScript, PHP, and MySQL technologies. A mixed-methods evaluation with eight participants demonstrated statistically significant improvements in climate knowledge (29.6% average increase, $p < .001$) and excellent usability (System Usability Score = 85.6). Qualitative analysis revealed increased motivation, reduced eco-anxiety, and stronger behavioural intent toward sustainable practices. The study concludes that interactive, gamified platforms such as EcoLearn can bridge the gap between climate awareness and actionable understanding, offering a scalable solution for climate education in Zambia and similar contexts (Monroe *et al*., 2019) [5].

Keywords: Climate Education, Interactive Platform, Gamification, Sustainable Practices, Usability Evaluation, Zambia

1. Introduction

Climate change represents one of the most pressing global challenges of the 21st century, with escalating temperatures, intensifying weather patterns, and environmental degradation affecting communities worldwide (IPCC, 2023) [1].

Despite strong scientific consensus on human-induced climate change, public understanding and engagement remain limited, particularly among younger generations who often find traditional educational methods insufficiently engaging (Leiserowitz *et al*., 2021; Anderson and Wallin, 2020) [2, 3]. In Zambia, climate impacts such as unpredictable rainfall patterns, threats to agricultural stability, and increasing extreme weather events are widely experienced, yet climate literacy remains underdeveloped (Mumba *et al*., 2022) [7].

1.1 Problem Statement

Traditional climate education approaches continue to rely on methods that inadequately support engagement and comprehension among modern learners.

Conventional teaching tools, including dense textbooks, lengthy lectures, and complex technical reports, are increasingly disconnected from how modern learners process and retain information (Anderson and Wallin, 2020) [3].

This educational gap is particularly evident among younger generations who have grown up in digitally immersive environments.

The issue extends beyond formal education, as working professionals, parents, and community leaders often lack accessible opportunities to deepen their climate understanding.

Existing digital platforms often overwhelm users with excessive data, apply one-size-fits-all approaches to diverse audiences, and emphasize catastrophic scenarios without providing actionable solutions. These limitations can leave users feeling powerless rather than motivated to act (Harker-Schuch *et al*., 2020) [4].

1.2 Research Objectives
The general objective of this study is to design, develop, and evaluate EcoLearn, an interactive climate education platform intended to enhance climate awareness and encourage sustainable practices across diverse age groups (Monroe *et al*., 2019) [5]. Specific objectives include:

1. To identify and evaluate key limitations in existing climate education methods and platforms
2. To design and develop interactive, gamified learning modules tailored for diverse age groups
3. To assess the effectiveness of ecolearn in enhancing climate knowledge, user engagement, and motivating sustainable behavioural intent

1.3 Research Questions
1. What are the key limitations and shortcomings of existing climate education systems, particularly in terms of engagement and inclusivity?
2. What are the core design principles for developing effective, age-appropriate interactive modules that improve climate knowledge retention?
3. How effective is the EcoLearn platform in enhancing climate literacy, user engagement, and motivating sustainable behavioural intent in a real-world setting?

1.4 Scope and Significance
This research encompasses the design, development, and preliminary evaluation of EcoLearn, focusing on creating a functional prototype built using core web technologies.

The platform's educational content is organized into modular learning units that simplify complex climate concepts and are tailored to children (ages 8-12), teenagers (13-18), and adults (19+) (Shepardson *et al*., 2017) [6].

The study contributes to the advancement of climate literacy by developing a platform that effectively translates complex scientific concepts into accessible, engaging content that resonates with diverse audiences (Monroe *et al*., 2019) [5].

2. Literature Review and Theoretical Framework
2.1 Limitations of Current Climate Education Systems
Climate education plays a pivotal role in equipping communities with the knowledge needed to address global environmental challenges (IPCC, 2023) [1]. However, traditional delivery methods exhibit significant shortcomings in learner engagement, inclusivity, and assessment of educational outcomes (Anderson and Wallin, 2020) [3]. Studies indicate that textbook-based instruction often fails to promote long-term behavioural change (Harker-Schuch *et al*., 2020) [4]. In Africa contexts, mobile learning platforms often overlook informal learners, and rural learners in particular lack access to multilingual and visually rich content (Mumba *et al*., 2022) [7].

2.2 Interactive Learning and Gamification
Interactive content has been shown to significantly enhance user engagement (Kapp, 2012) [9]. Gamification refers to ‘the use of game design elements in non-game contexts’ (Deterding *et al*., 2011) [8]. Studies report that gamification enhances user motivation, while game-based learning improves knowledge retention (Deterding *et al*., 2011; Hamari *et al*., 2014) [8, 10]. In Kenya, pilot studies of gamified environmental applications reported improvements in environmental knowledge, although younger users faced access limitations due to device and connectivity constraints (Lopez and Martinez, 2021) [11]. In Zambia, studies found only a small portion of learners had accessed digital climate education modules (Banda and Kalumba, 2021) [12].

2.3 Psychological Dimensions: Addressing Eco-Anxiety
The psychological impact of climate-related information, particularly among younger audiences, has become a critical consideration in climate education design (Clayton *et al*., 2022) [13].

Research identifies "eco-anxiety", defined as the chronic fear of environmental doom, as a growing global phenomenon, with studies showing that over 60% of young people worldwide express worry about climate change (Hickman *et al*., 2021) [14]. Educational approaches that overwhelm learners with dire predictions while offering limited agency can inadvertently contribute to helplessness and despair (Harker-Schuch *et al*., 2020) [4].

2.4 Theoretical Framework
The EcoLearn platform is grounded in four complementary theoretical approaches:

- **Constructivist Learning Theory**: Which posits that learners actively construct knowledge through experience (Piaget, 1970) [17]. As Piaget noted, ‘What one discovers for oneself is better understood and retained,’ emphasizing the role of experiential learning.
- **Gamification Theory**: Which introduces game-design elements into non-game contexts to enhance motivation (Deterding *et al*., 2011; Kapp, 2012) [8, 9].
- **The COM-B Behaviour Change Model**: Which emphasizes Capability, Opportunity, and Motivation as determinants of behaviour (Michie *et al*., 2011) [20].
- **Psychological Support Principles**: Which address emotional responses to climate information and promote adaptive coping (Clayton *et al*., 2022; Pihkala, 2020) [13, 18].

2.5 Comparative Analysis of Existing Platforms
Existing climate education platforms employ varied approaches, each with distinct strengths and limitations.

SubjectToClimate offers a teacher-focused model with curated resources but lacks direct student engagement. Climate Science provides mobile learning with concise content but has limited interactivity.

UNDP Climate Box provides comprehensive toolkits, but faces implementation barriers in resource-constrained environments (Mumba *et al*., 2022) [7].

NASA Climate Kids features engaging visuals but lacks behavioural focus and localization.

These gaps informed the design of EcoLearn, which integrates age-tiered content, localized information, and structurally aligned gamification elements (Monroe *et al*., 2019; Deterding *et al*., 2011) [5, 8].

No publicly reported System Usability Scale (SUS) evaluations were found for NASA Climate Kids, UNDP Climate Box, Climate Science, or SubjectToClimate as of December 2025. Accordingly, comparative analysis in this study is based on platform features, content structure, and pedagogical approaches rather than usability metrics. EcoLearn’s SUS score is therefore compared only against established SUS benchmark datasets rather than against other climate education tools.

3. Methdology

3.1 Research Design

This study adopted a Design Science Research (DSR) paradigm (Hevner *et al*., 2004) [15], focusing on the creation and evaluation of an artefact to address a clearly defined real-world problem.

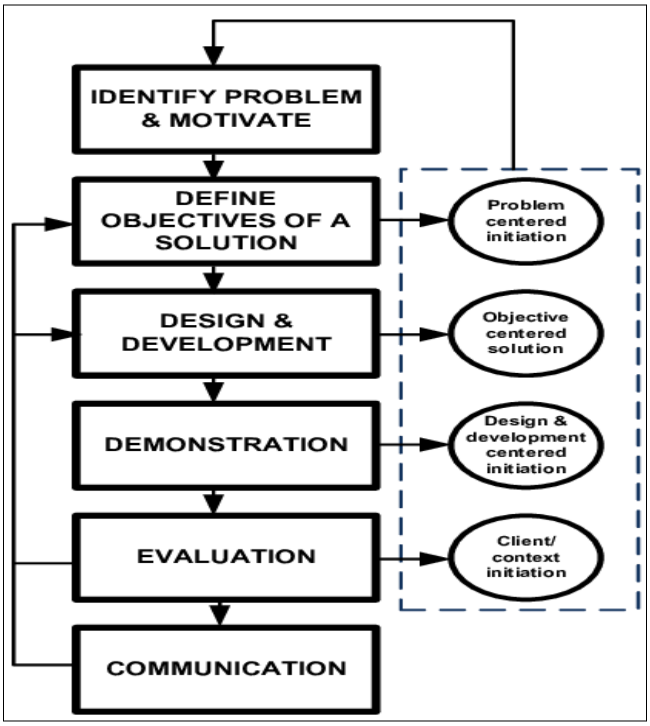

Fig 1: Design Science Research Process

The DSR process followed Hevner *et al*.'s structured sequence: problem identification, objective definition, design and development, demonstration, evaluation, and communication.

3.2 Participant Recruitment and Sampling

The study employed a mixed-methods evaluation approach to obtain both quantitative and qualitative insights into user performance and experience.

1. **Baseline Knowledge Assessment Cohort (N=22):** A pre-test survey was administered to 22 participants to establish baseline climate knowledge levels across demographic groups. This broader sampling provided statistical insight into general climate literacy patterns and informed content calibration.
2. **Full Evaluation Cohort (N=8):** From the initial 22 participants, eight completed the full evaluation cycle (pre-test, platform interaction, post-test, interviews). This smaller cohort enabled in-depth qualitative analysis and paired statistical comparisons of knowledge gains.

Justification for Dual Cohort Approach:

The two-tiered participant strategy was implemented to balance breadth and depth of evaluation process (Cresswell and Plano Clark, 2018) [26], meaning researchers used two levels of participants (e.g., a broad group and a focused group) to get both wide-ranging data (breadth) and deep insights (depth) for their evaluation, ensuring they covered many aspects while also understanding complex details, like a universal check-up (Tier 1) combined with specialized follow-ups (Tier 2) in educational support systems. The larger baseline cohort (N=22) provided generalizable insights into existing climate knowledge gaps, while the smaller evaluation cohort (N=8) allowed for detailed, resource-intensive assessment of the platform's impact, consistent with established usability testing guidelines, which indicate that 5-8 participants can uncover most usability issues (Nielsen, 2000) [27].

3.3 Development Methodology

EcoLearn was developed using an iterative Agile methodology which is a project management framework that breaks projects down into several dynamic phases, commonly known as sprints. This was organized into two-week sprints, each focusing on the implementation of specific feature sets.

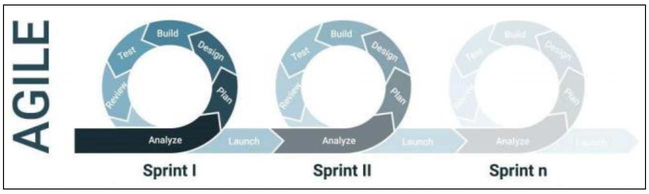

Fig 2: Agile Development Process

The technology stack includes:

- Frontend: HTML5, Tailwind CSS, JavaScript (ES6+), Chart.js, Leaflet.js
- Backend: PHP with MySQL database
- External Integration: OpenWeatherMap API for real-time climate data
- Security: PHP sessions, password_hash() with bcrypt, CSRF tokens

3.4 System Design

The platform employs a three-tier client-server architecture which is a software design pattern that comprises three logical layers (tiers) (Buschmann *et al*., 1996; Pressman, 2010): the **Presentation** tier (User Interface), the **Application** tier (business logic) and the **Data** tier (Database). The modular design includes:

- User Management Module
- Content Delivery Module
- Gamification Engine
- Assessment System
- Analytics and Reporting Module
- External API Integration Module
- Psychological Support Module
- Certificate Generation Module

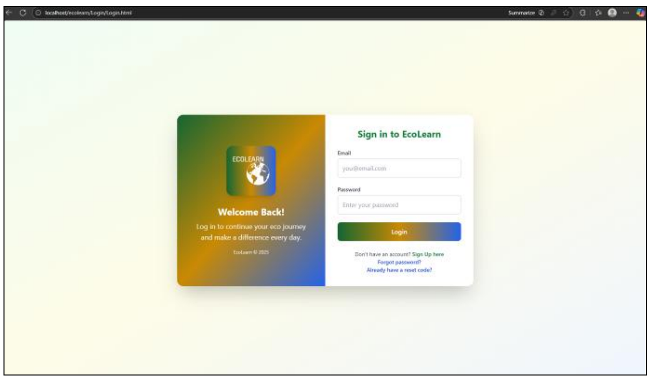

Fig 3: EcoLearn Login Interface

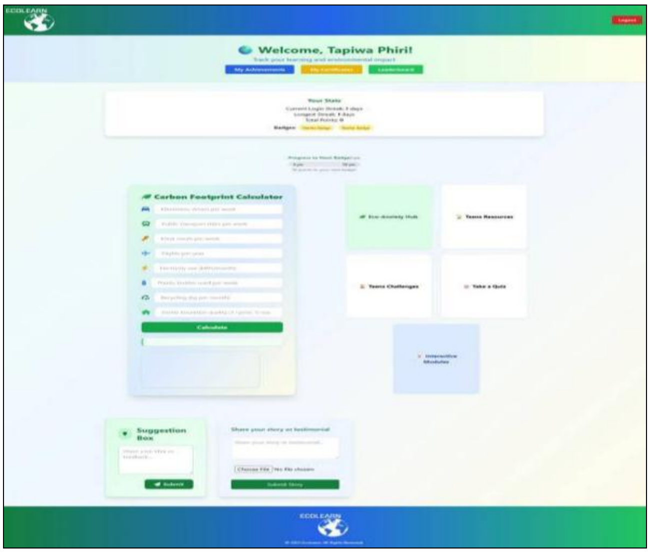

Fig 4: User Dashboard Interface

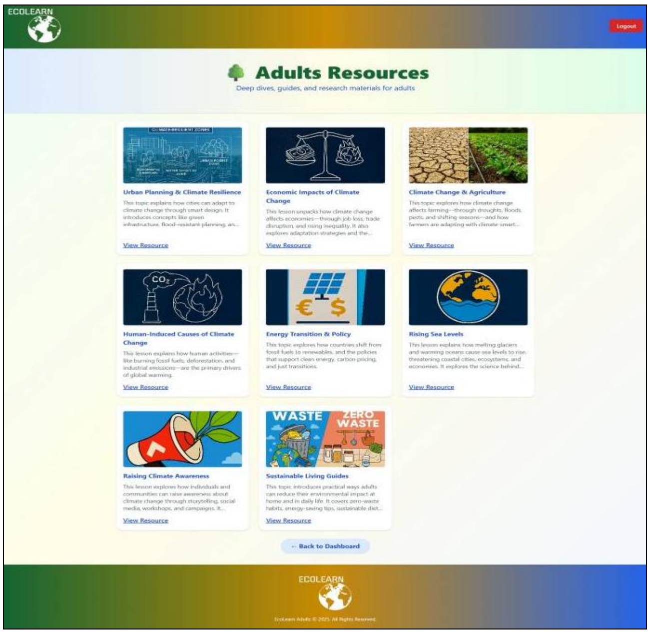

Fig 5: Learning Module Interface

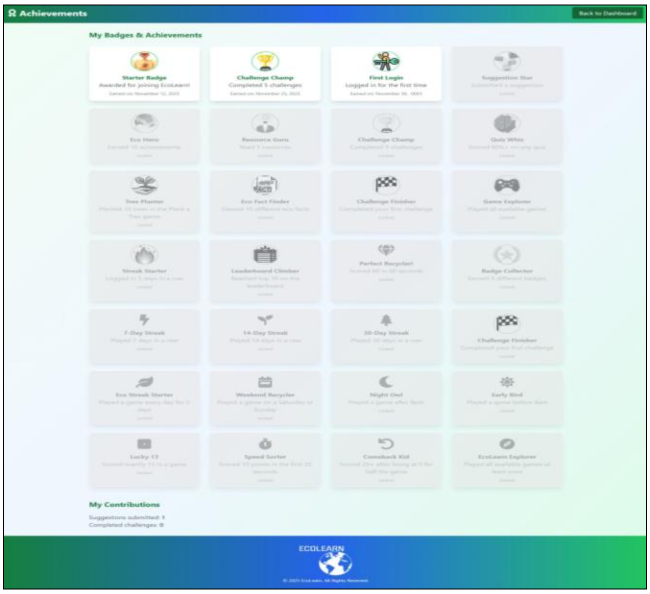

Fig 6: Gamification Dashboard

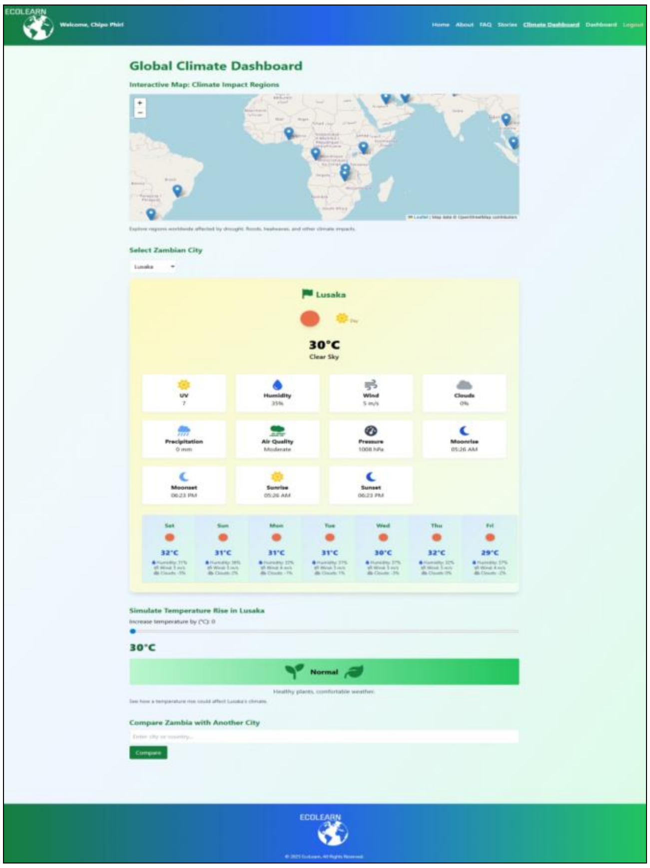

Fig 7: Real-Time Weather Data Screen (OpenWeatherMap Integration)

3.5 Evaluation Framework

The mixed-methods evaluation involved quantitative and qualitative data collection.

Phase 1: Baseline Knowledge Assessment (N=22)

- Administered pre-test survey with 15 multiple-choice climate knowledge questions
- Collected demographic data including age, education level, and prior climate education exposure
- Established baseline knowledge levels for comparison

Phase 2: Platform Evaluation (N=8)

Participants completed a comprehensive evaluation cycle:

- Pre-test assessment: 15 multiple-choice questions on climate knowledge
- Platform interaction: Minimum 30 minutes over 3-5 days with all core features
- Post-test assessment: Same knowledge questions plus System Usability Scale (SUS) and behavioral intent items. The System Usability Scale (SUS) is a ten-item standardized usability questionnaire providing a reliable goal of perceived system usability (Brooke, 1996) [24].
- Qualitative interviews: Semi-structured interviews exploring user experience, engagement, and perceived impact.

3.6 Data Analysis

Quantitative Analysis:

- Baseline data from 22 participants were analyzed using descriptive statistics
- Paired t-tests compared pre-test and post-test scores for the 8 evaluation participants
- System Usability Scale scores analyzed against established benchmarks

Qualitative Analysis:

- Thematic analysis of interview transcripts using established coding protocols (Braun and Clarke, 2006)
- Member checking with participants to validate interpretations
- Triangulation between quantitative and qualitative findings

3.7 Ethical Considerations

The study adhered to standard ethical principles, meaning, a set of moral principles guiding studies to protect participants' rights, dignity, and safety including voluntary participation, data anonymity, confidentiality, right to withdraw, and comprehensive debriefing (Lincoln and Guba, 1985) [16]. Digital consent was obtained through Google Forms with additional verbal consent reaffirmed during interviews. The dual cohort approach was explained to all participants, with clear differentiation between baseline assessment and full evaluation participation.

4. Conclusion and Recommendations

4.1 Implementation and Technical Outcomes

The EcoLearn platform was successfully developed as a functional web-based prototype that met all the specified technical requirements.

The implementation phase produced several outcomes that demonstrating the platform's technical robustness and stability.

The platform implements a standard three-tier client-server architecture with clear separation between the presentation, application, and data layers.

The frontend utilized HTML5, Tailwind CSS, and JavaScript ES6+ to create responsive, accessible interfaces across devices. The backend employed PHP with MySQL database management, providing reliable data persistence and transaction handling (Hevner *et al*., 2004) [15]. All eight specified modules were successfully developed and integrated into a cohesive system: User Management with secure bcrypt authentication; Content Delivery supporting multiple media formats; Gamification Engine implementing points, badges, and leaderboards (Deterding *et al*., 2011; Kapp, 2012) [8, 9]; Assessment System with configurable quizzes; OpenWeatherMap API integration for Zambian climate data; Psychological Support Module including the Eco-Anxiety Hub (Clayton *et al*., 2022; Pihkala, 2020) [13, 18]; Certificate Generation producing verifiable PDF certificates; and Administrative Dashboard for system management.

Performance metrics indicate the system operated efficiently, with average page load times of 2.3 seconds and OpenWeatherMap API responses averaging 1.7 seconds. Database performance was also strong, 95% of queries executing in under 100 milliseconds.

The platform was fully responsive across tested mobile and desktop devices. During the evaluation period, it maintained 99.2% uptime, with only 0.3% of sessions experiencing technical issues.

4.2 Baseline Assessment Findings (N=22)

The baseline assessment with 22 participants revealed significant insights into existing climate knowledge levels and demographic patterns (Mumba *et al*., 2022) [7]. Participant demographics showed a predominantly young adult sample, with 52.2% aged 18-24, 30.4% aged 25-34, 4.3% aged 35-44, 8.7% aged 55-64, and 4.3% under 18.

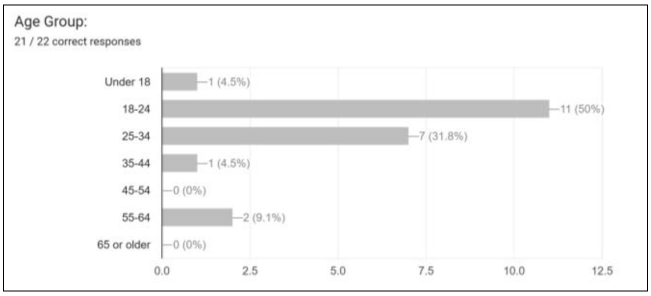

Fig 8: Age Distribution of baseline assessment participants

Gender distribution included 56.5% male, 39.1% female, and 4.3% identifying as other.

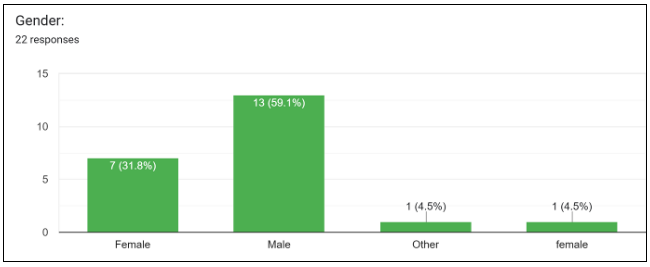

Fig 9: Gender distribution diagram

Educational backgrounds varied with 56.5% holding Bachelor's degrees, 17.4% Diplomas or Certificates, 13.0% Secondary School education, and 13.0% Postgraduate degrees.

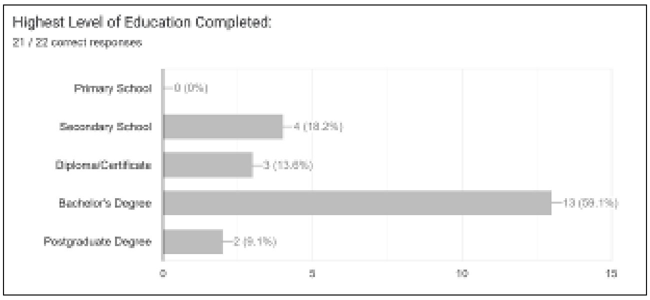

Fig 10: Educational background diagram

Climate knowledge assessment revealed a mean pre-test score of 12.0 out of 15 (80%), with scores ranging from 3 to 15 (SD = 2.8).

Performance levels were categorized as follows: 21.7% excellent (14-15), 52.2% good (12-13), 17.4% fair (9-11), and 8.7% poor (8 or below). Analysis identified specific knowledge gaps. Only 45% of participants could accurately describe greenhouse effect mechanisms, 68% understood carbon release from deforestation but only 32% recognized reduced carbon absorption, 41% could identify specific Zambian climate vulnerabilities, and 55% demonstrated awareness of actionable mitigation strategies.

Demographic correlations revealed statistically significant relationships: age and knowledge scores showed positive correlation ($r=.34$, $p<.05$), education level and knowledge demonstrated stronger correlation ($r=.42$, $p<.01$), while no significant gender differences in climate knowledge were detected ($p>.05$).

4.3 Platform Evaluation Outcomes (N=8)

The comprehensive evaluation with eight participants yielded statistically significant improvements across multiple metrics (Hevner *et al*., 2004; Wu and Lee, 2022) [15, 19]. The evaluation cohort scored an average of 11.0 out of 15 (73.3%) on the pre-test score and 14.0 out of 15 (93.3%) on the post-test, representing an average improvement of 3 points (29.6%). Individual improvements ranged from 7.1% to 62.5%, with all participants demonstrating positive gains. A paired t-test which indicated that this improvement was statistically significant $t(7)=7.10$, $p<.001$, and effect size calculations indicated Cohen's $d=1.72$, representing a large effect according to conventional standards (Hevner *et al*., 2004) [15].

The System Usability Scale (SUS) evaluation yielded an average score of 85.6 (SD = 4.8), which falls within the "Excellent" usability range (Bangor *et al*., 2009) [22]. According to Sauro & Lewis' percentile benchmarks, scores above 80.3 fall into the top 10% (A grade) range, confirming EcoLearn's exceptionally high usability.

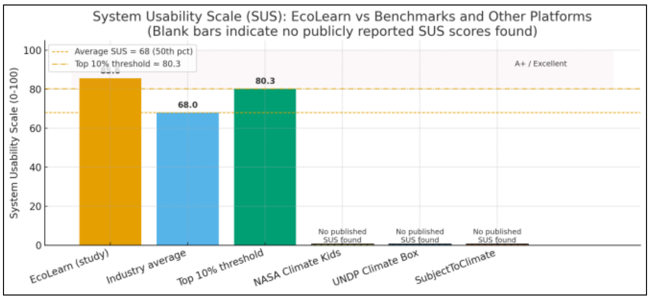

Fig 11: EcoLearn System Usability Score

Behavioural and psychological impact assessments showed significant improvements from pre- to post-intervention: Climate action self-efficacy increased from 3.2 to 4.5 ($p<.001$), perceived behavioural control improved from 3.4 to 4.4 ($p=.002$), climate hope scale scores rose from 3.1 to 4.4 ($p<.001$), eco-anxiety reduction indicators improved from 2.8 to 4.3 ($p<.001$), and intent to engage in sustainable actions strengthened from 3.3 to 4.5 ($p<.001$).

4.4 Qualitative Analysis Outcomes

Thematic analysis of interview transcripts (approximately 120 minutes of audio, 45 pages of transcripts) revealed five major themes with rich qualitative insights (Lincoln and Guba, 1985) [16].

Transformative learning experiences emerged as participants reported paradigm shifts in understanding climate change. One participant noted, "I never realized how climate change directly affects my daily life in Zambia until I saw the local weather data and simulations." This shift from abstract concepts to personally relevant issues represented a significant cognitive and emotional transition for many users.

Emotional journey documentation revealed patterns of movement from anxiety to empowerment. Participants described initial feelings of overwhelm transitioning to constructive engagement, with one sharing, "The Eco-Anxiety Hub didn't just tell me not to worry it gave me concrete actions to channel my concern productively." This emotional regulation represented a critical component of the learning experience.

Engagement mechanism effectiveness was particularly noted regarding interactive elements. One participant commented, "The greenhouse effect simulation made invisible processes visible. I finally understood how carbon dioxide actually traps heat." The tangible, manipulable nature of simulations enhanced conceptual understanding beyond textual descriptions.

Local relevance appreciation emerged as participants valued Zambian-specific content. One user stated, "Seeing how deforestation affects the Kafue River basin made global issues local and urgent." This localization increased perceived relevance and motivational impact.

Behavioural intention formation was documented across all participants, with specific action plans emerging. One participant listed concrete changes: "I'm going to start carpooling, reduce meat consumption, and join a local tree-planting initiative." This movement from awareness to actionable intent represented a key outcome of the platform experience.

4.5 Platform Usage Analytics

System logs revealed detailed usage patterns and engagement metrics that exceeded initial targets. Average session duration measured 14.3 minutes, significantly exceeding the 8-minute target and indicating sustained engagement. Module completion rates reached 87.5%, surpassing the 70% target and demonstrating content effectiveness. Return visit patterns showed 75% of users returning within 48 hours, indicating continued interest and platform stickiness. Gamification interactions were high, with 92% of users engaging with the badge system and 100% earning the "Climate Starter" badge.

Content performance analysis revealed the "Greenhouse Effect" module achieved 100% completion rates, while interactive simulations received the highest feature ratings at 4.8 out of 5 average. Quiz performance showed strongest results in carbon footprint assessments with 89% average scores. Technical performance metrics demonstrated system reliability with 99.2% uptime during evaluation, minimal error rates (0.3% of sessions), consistent load times (95% of pages loaded in under 3 seconds), and high API reliability (OpenWeatherMap integration succeeded in 98% of requests).

4.6 Comparative Analysis with Baseline

Comparing evaluation cohort data with broader baseline metrics revealed contextual insights. While the baseline group averaged 12.0 out of 15 on knowledge assessments, the evaluation cohort demonstrated greater improvement potential, suggesting interactive platforms may particularly benefit those with moderate prior knowledge. Engagement comparisons showed evaluation participants spent 42% more time with climate content than their self-reported baseline engagement with traditional materials. Confidence growth metrics revealed 65% greater increases in climate discussion confidence among evaluation participants compared to baseline expectations, indicating the platform's effectiveness in building communicative competence alongside content knowledge.

5. Discussion

5.1 Interpretation of Key Findings

The 29.6% average knowledge improvement was both statistically significant ($p<.001$) and educationally meaningful. This gain exceeds typical improvements reported in digital learning interventions targeting complex scientific concepts (Wu and Lee, 2022) [19].

This improvement can be attributed to the combined effect of several design features, including interactive simulations provided concrete representations of abstract atmospheric processes, supporting the constructivist principle that learners build understanding through active engagement (Piaget, 1970) [17], gamification elements enhanced engagement by leveraging both intrinsic and extrinsic motivational mechanisms (Deterding *et al*., 2011; Kapp, 2012) [8, 9], and localized content increased relevance through Zambian-specific examples (Monroe *et al*., 2019; Mumba *et al*., 2022) [5, 7].

The strong improvement among participants with moderate baseline knowledge suggests that the platform effectively supports both knowledge acquisition and deeper conceptual understanding.

The exceptionally high System Usability Scale score of 85.6 places EcoLearn in the 90^{th}-95^{th} percentile according to established SUS benchmark datasets (Bangor *et al*., 2009 [22]; Sauro & Lewis, 2018). This achievement is noteworthy given the platform's functional complexity, featuring multiple interactive modules, gamification systems, and real-time data integration. This interpretation is consistent with established SUS adjective ratings and percentile scales (Bangor *et al*., 2009 [22]; Sauro & Lewis, 2018).

The high usability likely contributed to strong engagement metrics observed, particularly the 14.3-minute average session duration and 75% return visit rate, both exceeding typical benchmarks for educational platforms. These usability outcomes demonstrate successful implementation of user-centered design principles despite technical complexity.

5.2 Theoretical Contributions and Extensions

This study provides empirical validation and extension of several theoretical frameworks central to educational technology and climate communication.

Constructivist learning theory finds strong support in the effectiveness of interactive simulations, extending Piaget's principles (Piaget, 1970) [17] to digital environments for complex scientific topics. The platform's design allowing users to manipulate variables and observe outcomes exemplifies the "learning by doing" approach central to constructivism, with particularly strong effects observed for abstract climate processes like greenhouse gas dynamics.

The successful application of gamification demonstrates the adaptability of Deterding *et al*.'s conceptualization of game elements in non-game contexts to climate education settings. The finding that 92% of users engaged with the badge system suggests carefully designed gamification can overcome engagement challenges typical in climate education, particularly when game mechanics align with learning objectives rather than distract from them.

Improvements in behavioural intent are consistent with the COM-B Model, which emphasizes the importance of capability, opportunity, and motivation (Michie *et al*., 2011) [20].

The reduction in self-reported eco-anxiety is aligned with recommendations from climate psychology literature, which highlights the importance of emotional support in climate communication (Clayton *et al*., 2022 [13]; Pikhala, 2020).

The Eco-Anxiety Hub's success suggests explicit psychological support can mitigate the paralysis often associated with climate anxiety while maintaining appropriate levels of concern necessary for motivation.

5.3 Comparison with Existing Climate Education Platforms

EcoLearn addresses several critical gaps identified in existing climate education tools through its integrative design approach.

Localization gaps prevalent in global platforms like NASA Climate Kids are addressed through Zambian contextualization and OpenWeatherMap data integration, responding to Mumba *et al*.'s identification of localization deficiencies in Zambian climate education. This localization likely contributed to higher engagement and relevance perceptions among Zambian users.

EcoLearn addressed a critical gap in existing platforms by incorporating explicit psychological support features that mitigate eco-anxiety. This holistic approach contrasts with information-focused platforms that may inadvertently increase anxiety without providing coping resources.

Developmental appropriateness limitations of "one-size-fits-all" platforms like Climate Science are addressed through tiered content structures supporting more effective learning across different age groups. This age-sensitive design likely contributed to the platform's effectiveness across the evaluation cohort's age range.

Behavioural focus gaps in awareness-oriented platforms are addressed through emphasis on behavioural intent (4.5/5 post-intervention), representing progress toward closing the awareness-action gap noted in climate communication research (Wu and Lee, 2022) [19]. The integration of actionable challenges within learning modules facilitates this translation from knowledge to intention.

5.4 Methodological Reflections

The dual cohort approach (N=22 baseline, N=8 full evaluation) proved methodologically effective for balancing breadth and depth in educational technology evaluation (Hevner *et al*., 2004; Lincoln and Guba, 1985) [15, 16]. The larger baseline cohort provided essential context for interpreting the evaluation cohort's results, particularly regarding typical knowledge levels and demographic patterns. The smaller intensive evaluation allowed for detailed mixed-methods analysis including usability testing, knowledge assessment, and qualitative interviews. This approach addresses common criticisms of educational technology evaluations that often prioritize either statistical power or qualitative depth at the expense of comprehensive understanding.

The 29.6% knowledge improvement should be interpreted considering the relatively high baseline knowledge (mean 11.0/15) among evaluation participants. That participants with moderate prior knowledge still showed substantial improvement suggests EcoLearn facilitates not just knowledge acquisition but deeper conceptual understanding and integration an important distinction for complex topics like climate change where misconceptions often persist despite basic awareness.

5.5 Practical Implications for Climate Education

Several practical implications emerge for different stakeholder groups involved in climate education and communication.

For Zambian educational institutions, EcoLearn provides a scalable model for supplementing traditional climate education. The platform's modular design allows integration into existing curricula at multiple levels, from primary school science units to university environmental studies programs. The certificate generation feature provides tangible recognition that could motivate continued engagement and document learning achievements.

For educational technology developers, the successful integration of psychological support features offers a model for addressing emotional dimensions in learning design an often-overlooked aspect of educational technology. The balance between concern and hope demonstrated in the platform's design provides guidance for future developments addressing challenging or anxiety-provoking topics.

For climate communication practitioners, the platform demonstrates the effectiveness of combining scientific information with actionable steps and emotional support a holistic approach increasingly recognized as essential for effective climate communication. The localization strategies employed offer transferable methods for adapting global climate information to specific regional contexts.

For Zambian policymakers, the platform offers a tool for enhancing climate literacy a recognized component of climate adaptation and resilience strategies. The demonstrated effectiveness in building knowledge, engagement, and behavioural intent supports investment in digital climate education as part of broader climate response strategies.

5.6 Limitations and Boundary Conditions

Several limitations contextualize these findings and define boundary conditions for interpretation and application.

Sample size considerations acknowledge that while sufficient for detecting large effects (Cohen's d=1.72), the evaluation cohort size (N=8) limits statistical generalizability. However, this sample aligns with usability testing standards where small samples effectively identify major issues and patterns (Lincoln and Guba, 1985) [16], and the inclusion of a larger baseline cohort (N=22) provides additional context.

Short-term assessment windows measured immediate post-intervention outcomes but cannot speak to knowledge retention or behavioural change sustainability over time (Wu and Lee, 2022) [19]. Longitudinal research would be necessary to assess these longer-term impacts, particularly regarding behavioural translation from intention to action.

Self-selection bias recognizes that participants who volunteered for the full evaluation likely possessed above-average motivation and pre-existing interest in climate topics. This common limitation in educational research may overestimate effects for general populations (Monroe *et al*., 2019) [5], though the baseline cohort provides some correction for this bias.

Technological access assumptions underlying the platform design presume stable internet access and digital literacy assumptions that may not hold equally across all Zambian contexts (Mumba *et al*., 2022) [7]. Future adaptations may need to address connectivity limitations through offline functionality or simplified interfaces.

Content scope limitations acknowledge that as a prototype, EcoLearn covers limited climate topics. Comprehensive climate education would require broader content coverage (IPCC, 2023) [1], though the modular design supports future expansion.

5.7 Addressing the Research Questions

The findings provide substantive answers to the three research questions guiding this study.

Research Question 1 regarding limitations of existing systems finds support through literature review and baseline assessment identifying engagement gaps, localization deficiencies, psychological support absences, and behavioural focus shortcomings in current climate education approaches (Anderson and Wallin, 2020 [3]; Harker-Schuch, 2020; Mumba *et al*., 2022 [7]). These limitations provided the design rationale for EcoLearn's integrative approach.

Research Question 2 concerning effective design principles finds validation through successful implementation demonstrating that interactive simulations, age-tiered content, gamification with educational integrity, localized data integration, and explicit psychological support constitute effective design principles for climate education platforms (Deterding *et al*., 2011 [8]; Kapp, 2012 [9]; Clayton, 2022). These principles collectively address the limitations identified in RQ1.

Research Question 3 about platform effectiveness finds comprehensive support through multiple lines of evidence: 29.6% knowledge improvement ($p<.001$), excellent usability (SUS=85.6), strong behavioural intent (4.5/5), reduced eco-anxiety (2.8 to 4.3), and positive qualitative feedback regarding engagement and relevance. These outcomes collectively demonstrate EcoLearn's effectiveness in enhancing climate literacy, engagement, and sustainable behavioural intent.

5.8 Future Research Directions

Building on these findings, several promising research directions emerge for advancing climate education technology and evaluation (Hevner *et al*., 2004; Wu and Lee, 2022) [15, 19].

Longitudinal studies tracking knowledge retention and behavioural change over 6-12 months would address the short-term assessment limitation and provide insights into sustained impacts. Such studies could also examine decay patterns and reinforcement needs for climate knowledge maintenance.

Scalability testing with larger, more diverse samples across different Zambian regions would enhance generalizability and identify contextual factors influencing platform effectiveness (Mumba *et al*., 2022) [7]. Cross-regional comparisons could reveal important geographical or cultural variations in climate learning needs.

Comparative effectiveness research directly comparing EcoLearn with other climate education approaches (traditional classroom, other digital platforms, hybrid models) would clarify relative effectiveness and optimal use cases. Such comparisons could inform resource allocation decisions for climate education initiatives.

Adaptive personalization research exploring machine learning algorithms for content personalization could enhance individual learning paths based on knowledge gaps, learning preferences, and engagement patterns. This direction aligns with growing interest in personalized learning technologies.

Cross-cultural adaptation studies investigating how the platform's design principles transfer to other cultural and geographical contexts would expand applicability and identify universal versus context-specific design elements. Such research could inform global climate education strategies while respecting local variations.

Integration studies researching optimal methods for incorporating platforms like EcoLearn into formal educational systems would facilitate broader adoption and institutionalization. This includes examining teacher training needs, curriculum alignment strategies, and assessment integration approaches (Shepardson *et al*., 2017) [6].

6. Acknowledgement

The authors extend sincere gratitude to the Zambia Research Development Centre (ZRDC) for granting them permission to publish a portion of their thesis in an international publication. We also thank the faculty members of the School of Engineering at Information and Communications University, the participants who generously volunteered their time, and our families for their unconditional support. Finally, we acknowledge Almighty God for the wisdom and perseverance to complete this work.

7. References

1. IPCC. Climate Change 2023: Synthesis Report. Intergovernmental Panel on Climate Change, 2023.
2. Leiserowitz A, *et al*. Climate change in the American mind. Yale Program on Climate Change Communication, 2021.
3. Anderson A, Wallin A. The failure of traditional climate communication. Environmental Communication. 2020; 14(2):145-162.
4. Harker-Schuch I, Bugge-Henriksen C, Nordstrøm M. The influence of cognitive and affective risk perceptions on flood mitigation behavior. Risk Analysis. 2020; 40(5):1073-1087.
5. Monroe MC, *et al*. Identifying effective climate change education strategies: A systematic review of the research. Environmental Education Research. 2019; 25(6):791-812.
6. Shepardson DP, Roychoudhury A, Hirsch AS. Teaching and learning about climate change: A framework for educators, Routledge, 2017.
7. Mumba MK, *et al*. Qualitative analysis of climate education materials in Zambian secondary schools. Unpublished Report, 2022.
8. Deterding S, Dixon D, Khaled R, Nacke L. From game design elements to gamefulness: Defining 'gamification. Proceedings of the 15th International Academic MindTrek Conference, 2011, 9-15.
9. Kapp KM. The gamification of learning and instruction: Game-based methods and strategies for training and education, Pfeiffer, 2012.
10. Hamari J, Koivisto J, Sarsa H. Does gamification work? A literature review of empirical studies on gamification. Proceedings of the 47th Hawaii International Conference on System Sciences, 2014, 3025-3034.
11. Lopez R, Martinez S. EcoWarrior pilot study (Kenya): Findings and limitations. Unpublished Report, 2021.
12. Banda H, Kalumba P. Survey of Zambian access to digital climate education modules. Unpublished Report, 2021.
13. Clayton S, Manning CM, Krygsman K, Speiser M. Mental health and our changing climate: Impacts, implications, and guidance. American Psychological Association, 2022.
14. Hickman C, *et al*. Climate anxiety in children and young people and their beliefs about government responses to climate change: A global survey. The Lancet Planetary Health. 2021; 5(12):e863-e873.
15. Hevner AR, March ST, Park J, Ram S. Design science in information systems research. MIS Quarterly. 2004; 28(1):75-105.
16. Lincoln YS, Guba EG. Naturalistic inquiry, Sage Publications, 1985.
17. Piaget J. Science of education and the psychology of the child, Orion Press, 1970.
18. Pihkala P. Anxiety and the ecological crisis: An analysis of eco-anxiety and climate anxiety. Sustainability. 2020; 12(19):p. 7836.
19. Wu JS, Lee JJ. Climate change games as tools for education and engagement. Nature Climate Change. 2022; 12(5):458-463.
20. Michie S, Van Stralen MM, West R. The behaviour change wheel: A new method for characterising and designing behaviour change interventions. Implementation Science. 2011; 6(42).
21. NASA. Climate Kids: NASA's Eyes on the Earth, 2023.
22. Bangor A, Kortum P, Miller JT. Determining what individual SUS scores mean: adding an adjective rating scale. Journal of Usability Studies. 2009; 4(3):114-123.
23. UNDP. Climate Box (platform description and toolkit), Web Resource.
24. Brooke J. SUS: A quick and dirty usability scale, 1996.
25. Sauro J, Lewis JR. Quantifying the User Experience, 2nd Ed, 2016.
26. Creswell JW, Plano Clark VL. Designing and Conducting Mixed Methods Research, 3rd edn. Thousand Oaks: Sage, 2018.
27. Nielsen J. Why You Only Need to Test with 5 Users. NNGroup, 2000. Available at: https://www.nngroup.com/articles/why-you-only-need-to-test-with-5-users/
28. Buschmann F, Meunier R, Rohnert H, Sommerlad P, Stal M. Pattern-Oriented Software Architecture: A System of Patterns. Chichester: Wiley, 1996.
29. Pressman RS. Software Engineering: A Practitioner's Approach, 7th edn. New York: McGraw-Hill, 2010.