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Climate Literacy: Creating a Multilevel Interactive Platform for Climate Education

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Abstract: Climate literacy is crucial to increasing public understanding and engagement with the global climate catastrophe. However, current climate education approaches often fail to effectively raise concern and action, particularly across diverse age groups. This study makes a modest attempt to detail the design and development of a novel multilevel interactive digital climate education platform for early learners, adolescents, and adults using adaptive learning pathways, personalized content delivery, multimedia interactivity, and gamification features to promote learner engagement as well as learning outcomes across different age levels. A mixed-methods research design was used involving pre and post-survey quantitative measures as well as qualitative user experience testing. Post-survey results indicated significant improvement in climate literacy knowledge, attitudes towards the environment, and self-efficacy beliefs regarding individual efforts to mitigate future climate impacts (response efficacy), regardless of learner age group. The comparative analysis thus revealed certain content preferences by age as well as interaction patterns among functionalities and learning gains between groups based on user perspectives that point towards differentiated preference areas linked with diverse ages. The resulting platform exemplifies interactive digital technologies' potential for achieving sustainable behavior change through optimised synergies with large-scale educational interventions for inducing positive spillover effects in terms of broader widespread climate change engagement impact over generational transition pragma.

Index Terms: Climate Literacy, Interactive Learning, Multimedia, Adaptive Learning, Age-Appropriate Design

1. Introduction

Climate change is an urgent and threatening global challenge with broad adverse effects on terrestrial ecological functions, human communities, and future generations (IPCC 2021) [1]. Solving such a complex problem requires an informed and engaged populace that possesses the necessary skills, knowledge, and motivation to not only engage in sustainable behaviours but also foster meaningful collective action [2]. Climate change education is considered to be critical in nurturing climate literacy, concern and agency at all levels of the learning process (UNESCO 2010). However, conventional resources for introducing climate change essentials have difficulty conveying abstract scientific ideas and visualising the distant impacts that do not connect to learners' values and experiences [3]. Climate change causes, consequences and solutions are often misunderstood by students [4], which might impede meaningful engagement.

In order to transcend these barriers and limitations, powerful tools like interactive digital technologies are leveraged for climate change education [5]. Interactive platforms provide dynamic and visually appealing climate information that is related through video animation simulation games [6]. The transparency given by interactivity encourages learners to 'make sense' of the content used, that is, complete and design it for themselves [7], resulting in active learning and retention. Personalisation and adaptive learning technologies can differentiate content or activities according to the age, prior knowledge ('learning history') and interests of each learner [8]. However, the design principles and effectiveness of interactive climate education platforms have not been well-studied in different age groups [9]. It is important to take age into account when designing interactive climate education that is appropriate for the age of learners because cognitive ability, communication needs, as well as engagement style are considerably different over developmental stages [10]. For example, early learners (ages 6-9) need story-driven content, playful activities and anthropomorphism, which makes it hard for them to think about abstract ideas [11]. Adolescents (ages 10-19) want social interaction, explore their identity and learn something that has real-life applications; they can deal with more difficult subjects [2]. Adults (20 years and above), on the other hand, have more developed cognitive abilities but may also have rigid mental models and worldviews that influence how they engage in climate change-related issues [12]. As such each group requires customised content and interactive design approaches so as to optimise learning around climate change.

The present research tries to bridge these gaps through the design and development of a new multilevel interactive climate education platform tailored to three different age groups of users: early learners, adolescents, and adults. Indeed, the interactive affordances, coupled with age-based design principles, served to improve engagement, knowledge, and agency in relation to climate change across diverse learners. This mixed-methods study included both a quantitative survey and qualitative user testing for usability, engagement, and learning impacts on the platform. Age differences in interaction patterns, content preferences, and outcomes were taken into comparative analysis.

The research objectives are to:

1. Build an interactive climate education platform that caters for personalised, age-appropriate user experiences for early learners, adolescents and adults.
2. Quantitatively and qualitatively measure the usability, engagement and learning effects of this platform for each age group.
3. Investigate how individuals of different ages use and respond to platforms in terms of engagement, preferences, and outcomes will likely inform the type of climate education product that can be targeted for age.
4. Design suggestions and best practice for age group wise interactive climate change education.

This research contributes to climate change communication, educational technology, and multimedia learning in several ways. First, it introduces and investigates a new interactive platform in which the integration of multiple affordances and design principles can facilitate engaging users of all ages with climate education. Second, it empirically examines how users of different ages interact with, perceive, and learn through an interactive climate application–an underexplored area of research. Third, based on the empirical findings, it provides design implications that can help developers optimise interactive climate education according to the needs of specific age groups. Finally, it extends the use of interactive technologies and design principles to better facilitate public understanding of climate change across multiple generations.

The rest of this paper is structured as follows. Section 2 introduces the background by describing climate change education challenges, interactive learning affordances, and age-appropriate design principles. Section 3 reviews related work on interactive climate change education platforms and explains the research gaps. Then, Section 4 presents the platform design and technical architecture. Section 5 describes the mixed-methods research design, instruments, and procedures. To follow that up, Section 6 reports the results by analysing each age group's usability, engagement, and learning outcomes data. Section 7 compares age differences and similarities in interaction patterns and impacts. Finally, Section 8 discusses the findings along with implications for practice, limitations of this study, and future work directions.

2. Background

2.1 Climate Change Education Challenges

Climate change education seeks to help individuals and communities at all levels of society to engage comfortably with the causes and consequences of an evolving global climate system [13]. A primary goal of climate education is to increase climate literacy as well as concern and action about knowledge on the part of learners related to the causes, impacts, and solutions to climate change [14]. Nevertheless, there are multiple barriers faced by educators attempting to achieve those goals through climate change education. That is because climate change is a multifaceted issue that is abstract and politically divisive for much of the population, making it difficult to communicate and teach [3]. Many learners have misconceptions or else lack a solid understanding of the causes, impacts, and responses concerning climate change [4].

Moreover, the systemic nature and distant impacts of climate change can make it seem remote and irrelevant to learners' daily lives [2]. Psychological barriers such as information overload, optimism bias, and perceived inefficacy can further impede learning and action [15]. Conventional teaching methods like lectures and readings often fail to address these challenges, as they present climate information in disconnected, abstract, and unengaging ways [3]. Static content may not adequately visualise the dynamic processes, localised impacts, and actionable solutions related to climate change [16].

Effective climate change education demands new types of pedagogical approaches that can help to make science understandable, relevant, personally meaningful and participatory for learners with diverse backgrounds and interests [6]. Climate change-related topics and activities must be linked to students' values, everyday life experiences and perceived relevance in order to promote engagement and motivation [17]. In addition to cognitive learning, teachers must cultivate affective engagement, self-efficacy and competencies for actions towards sustainability [18]. Learner-centred active learning pedagogies such as experiential learning, problem-based learning or project-based learning can support students' active involvement in defining problems related to climate change and in generating potential solutions. However, such kind of involvement is hard to achieve in many formal educational contexts with their constraints on time, resources and customisation.

2.2 Interactive Learning Affordances

Interactive digital technologies can help to meet these challenges. Interactivity, in this context, refers to the direct and reciprocal communication between the learner and the digital system [8]. Through interactivity, learners can actively participate in the learning process, exert control over learning and obtain feedback on learning progress. An interactive learning environment can also provide multiple representations of information, simulations, the scaffolding of the learning process and adaptivity for better supporting knowledge construction [19]. Interactive media have also been found to facilitate attention, as well as motivation and cognitive processing during learning, thereby fostering better acquisition of knowledge compared to static media [7].

The following interactive facilities can be used to educate the public about climate change:

1. Digital media: Use of multiple digital texts, pictures, films, animations and voices to communicate climatic information in visual or narrative ways [20].
2. Simulations: This type of learning tool refers to an illustrative model of interactive constructs that allow the learner to manipulate variables, explore ideas and concepts, and observe the results in relation to climate systems [21].
3. Games: Structured play activities with clear goals, rules and feedback–can promote exploration and problem-solving around climate challenges [9].
4. Virtual Reality: Increases the ability to envision oneself in realistic, climatically altered future environments and to emotionally connect with those environments; allows for perspective taking [22].
5. Personalisation: interactive systems dynamically personalise content, difficulty levels, and feedback based on personal learner characteristics, progress or preferences [25].
6. Social interaction: Learning designs that support learners in building knowledge ideas and creating identities through enacting them in dialogue with each other via peer feedback [26].

7. Integration of multimedia, games, or simulations into the learning process: The use of multimedia, games, and simulations into climate change education may markedly improve engagement and comprehension by rendering intricate topics more accessible and participatory. These methodologies facilitate experiential learning, enabling people to investigate climate scenarios, test solutions, and comprehend the interrelatedness of climate-related challenges.

These affordances can be invoked to reimagine interactive climate change education that is more engaging, meaningful, and effective in supporting learning than traditional instruction. For example, multimedia visualisations can be used to make the often highly abstract concepts of climate change more concrete and memorable [16], simulations and games can be used to provide learners with opportunities for active experimentation with and agency in exploring climate systems and solutions [9], personalised content and feedback can be provided to enhance perceived relevance and self-efficacy [8], and social interaction can be facilitated to support collaborative knowledge construction and action around issues related to climate change [26]. The combination of these affordances within interactive platforms has the potential to enable immersive, participatory, and transformative forms of climate change learning.

However, to ensure the efficacy of interactive climate education, designers need to carefully consider the characteristics, needs and contexts of learners [9]. Distinct age groups have different levels of cognitive ability, social capability and emotional development in engaging with interactive media in learning [27]. Younger children may prefer more structured play-like and narrative-based interaction. In contrast, older children desire more autonomy in interaction as well as complexity and realism in their experience [11]. Designers should align developmentally appropriate affordances with pedagogical practices and content for children of different ages to facilitate enhanced learning performances [28]. It is crucial to conduct empirical studies to examine how different age groups interact with and learn from climate change platforms, which can provide evidence-based design implications [9].

2.3 Age-Appropriate Design Principles

Designing age-appropriate interactive climate change understanding learners' age characteristics and learning characteristics is the basic theoretical basis for designing education. Piaget (1964) pointed out that people's development from birth to adulthood can be divided into 4 stages: sensory-motor stage (0-2 years old), preoperational stage or intuitive stage (2-7 years old), concrete operation stage (7-11 years old) and formal operation stage. Although some have criticized this theory for its linearity and universality, it provides a good starting point for us to consider whether different ages of people have different requirements for learning content and methods in the classroom.

Interactive climate change education platforms require design that agrees with the cognitive, social and affective characteristics of the ages for which they are targeted [29]. For early learners in the preoperational stage (ages 4–7), interactive content should be concrete, visual and playful, using narratives, characters and simple cause-and-effect relationships to introduce basic concepts of climate [11]. Interfaces need to be highly structured and provide scaffolding for fostering exploration and delivering feedback [30]. Specifically, anthropomorphism and fantasy can facilitate children's comprehension of climate change information [31].

For children in the concrete operational stage (ages 7-11), interactive climate education can facilitate the learning of new, more advanced skills and concepts involving higher-order relationships through real-world examples, hands-on activities, and problem-solving tasks [24]. For example, simulations or games may provide opportunities for active experimentation and the discovery of information about climate systems and solutions [9]. In addition to adults, peers also can serve as facilitators to optimise engagement and motivation [28]. Interfaces should support a balance of structure and autonomy by providing clear goals and feedback within design activities while allowing children the opportunity to choose among complementary activities or to create their designs [32].

For learners in the formal operational stage (age 11–18), interactive learning can include abstraction, hypothetical reasoning and deduction [33]. Simulations and modeling can enable learners to study complex underlying processes and feedback associated with long-term climate change [21]. Games and virtual reality environments may elicit emotion, empathy and persuasion for climate action [34]. Personalised learning pathways combined with social interaction could contribute to the development of a sense of collective agency. Specifically designed interfaces could facilitate more open-ended learning, customisation and user-generated content [23].

For adults (18 and above), interactive climate change education should be self-directed, linked to daily life and work, and useful for solving real-world problems [35]. Simulations and visualisations can help adults use climate data, policies, and solutions [16]. Virtual reality (VR) and augmented reality (AR) affordances can provide situated learning opportunities that link the global impacts of climate change to local settings [36]. Learning content and suggestions may be personalised to adults' interests, goals, or decision-making requirements [25]. Social interaction and networking could also support knowledge exchange, collaboration, or collective action on climate-related issues [37].

Interactive climate change education should be inclusive, culturally responsive and adaptable to the diversity of learners' backgrounds, abilities and the immediate contexts of their lives for all age groups [38]. Designers should take into account factors such as language, literacy, prior knowledge and access to technologies while developing interactive age-appropriate experiences [29]. Formative evaluation and user testing with the targeted age groups are vital to ensure that interactive climate change platforms are usable, engaging and effective [9].

2.4 The Choice of Technologies for different age groups

When evaluating the selection of technologies (Table 1) such as gamification or virtual reality (VR) for various age demographics in education, it is beneficial to examine this from the perspective of educational theory and empirical study.

1. Early Childhood (Ages 3–7)
Technology: Gamification, Augmented Reality (AR)
Theories:
Piaget's Preoperational Stage: Children learn best through play, imitation, and sensory engagement.
Vygotsky's Sociocultural Theory: Emphasizes the importance of social interaction and scaffolding.
Empirical Support:
Gamification enhances motivation and engagement through rewards, characters, and storylines (e.g., Duolingo ABC, ABCmouse).
AR apps (like animal interaction games) help connect abstract concepts to real-world visuals, supporting vocabulary and memory retention.

2. Middle Childhood (Ages 8–12)
Technology: Gamification, Interactive Simulations, Light VR
Theories:
Piaget's Concrete Operational Stage: Children begin logical thinking but need concrete references.
Constructivist Theory (Bruner, Papert): Children learn by building on what they know, and tools should support discovery learning.
Empirical Support:
Games like Kahoot! and Prodigy Math improve engagement and performance.
Light VR and interactive simulations (like science labs or anatomy apps) increase conceptual understanding and curiosity.

3. Adolescence (Ages 13–18)
Technology: VR, Complex Gamification, Simulations
Theories:
Formal Operational Stage (Piaget): Teenagers can think abstractly and reason theoretically.
Self-Determination Theory (Deci & Ryan): Emphasizes the role of autonomy, competence, and relatedness in motivation.
Empirical Support:
VR experiences like The Body VR or Titans of Space promote immersive learning and empathy.
Educational games with strategy and narrative depth (like Minecraft Education Edition or Civilization) improve systems thinking and problem-solving.

4. Higher Education and Adults
Technology: VR, Simulations, Gamified Learning Platforms
Theories:
Andragogy (Knowles): Adults are self-directed, goal-oriented, and relevancy-focused.
Experiential Learning (Kolb): Adults learn best by doing and reflecting.
Empirical Support:
VR and simulations in medical or engineering education allow safe, hands-on practice (e.g., surgical simulators).
Gamified platforms (like Coursera's badges or coding platforms like Codecademy) support motivation through progress tracking and challenges.

Table 1. Summary of Effective technological uses for different age groups

Age Group	Effective Technology	Supporting Theory	Example
3-7 (Early)	Gamification, AR	Piaget, Vygotsky	ABCmouse, AR flashcards
8-12 (Middle)	Gamification, Sim VR	Piaget, Constructivism	Prodigy Math, VR anatomy apps
13–18 (Teen)	VR, Strategic Games	Piaget, Self-Determination	Minecraft Education, VR field trips
18+ (Adult)	VR, Simulations	Andragogy, Experiential Learning	Surgical VR, Codecademy

2.5 Long Term Implications of Climate Education platform

When assessing the long-term effects of a climate education platform, the influences are:

1. Modification of Behaviour

The well structured climate education platform has:

Consistent environmentally-friendly practices: for instance, diminished energy use, waste minimisation, and more sustainable transportation options.

Civic engagement: Individuals may increase their participation in climate advocacy, policy deliberations, or community projects.

Conscious consumer behaviour: Selecting items with less environmental effect or endorsing sustainable enterprises.

2. Changes in Attitude

The platform facilitates:

Heightened climate awareness: Individuals may cultivate a greater feeling of urgency or accountability about the climate catastrophe.

Empowerment: The sensation of increased efficacy in effecting change, which mitigates climate concern or indifference.

3. Related Work

Many researchers have studied how interactive technologies and platforms can be used for climate change education in different age categories. We provide a review of related work with respect to interactive climate change education and discuss what has been found, what methodologies were applied, and where gaps exist in this body of research. Several studies have examined the design and effects of interactive climate change education for young children (4–11year-olds). A website, “Climate Kids”, that was designed to introduce basic climate information to children aged between 4 and 8 years via games, videos and quizzes [39]. A pre-post-test design with 42 children found significant improvements in climate knowledge and pro-environmental attitudes following interaction with the website. However, no age differences were compared, and no control group was included in this study. Authors in [31] investigated if anthropomorphism in digital climate change games increases learning outcomes and behavioural changes of 7–11 year-old children towards more environmental friendly attitudes or behaviours. In an experiment with 148 children a game including animal characters was contrasted with a game including human characters. The results showed that while anthropomorphic characters improved emotional involvement as well as learning there was no influence on environmental attitudes or behaviours. Thus, also age-specific design features like for example, the use of anthropomorphism, seem to have the potential to foster engagement in interactive climate education for children.

Author [40] developed an augmented reality game, Save the Ocean, to teach 8–11-year-olds about ocean acidification and marine conservation. A quasi-experimental study with 68 children compared the AR game to a paper-based game. Results indicated that playing the AR game led to higher engagement, knowledge gain, and pro-environmental attitude change than playing the paper game. No long-term effects were measured, and no age differences were examined. Authors [41] developed an interactive board game addressing climate change for 10–12-year-olds and investigated its effects on climate literacy and engagement. A randomised controlled trial with 142 students compared playing the board game to attending a traditional lecture. Results showed that students who played the board game reported significantly higher levels of climate knowledge, self-efficacy, and behavioural intentions than students who attended the lecture. Overall, this study suggests that interactive games have the potential to improve climate change education outcomes among pre-adolescents.

These studies demonstrated the effectiveness of interactive platforms in engaging young children with climate change learning. However, sample sizes were small, long-term follow-ups were lacking, and age comparisons were limited. More evidence is needed to determine the optimal design features and pedagogical strategies of interactive climate change education for children at different developmental stages.

3.1 Interactive Climate Change Education for Adolescents

A number of studies have explored the potential of interactive technologies to engage adolescents (ages 12–18) with climate change education. Authors [31] developed a web-based simulation game (‘Future Delta’) to educate 13-18 year-olds about climate change impacts and adaptation strategies. A quasi-experiment with 186 students found that compared to a traditional lecture, students who played the game reported significantly higher climate knowledge, self-efficacy, intention to take action and overall learning satisfaction. The age differences were not examined in this study, nor were the long-term effects of the intervention studied. Authors [34] evaluated a serious game (‘CO2peration’) in teaching 12-15-year-olds about climate change causes and mitigation. A randomised control experiment with 204 students found that compared to a web-based learning environment, students who played the game experienced significantly greater engagement, knowledge acquisition and pro-environmental attitudes. The study concludes that serious games have potential as tools for climate change education in early adolescence.

Authors [42] investigated participatory game design as a means to facilitate climate change learning and action in 14 to 18 year-olds. A case study with 23 secondary school students had them participate in co-designing a climate change board game. The findings of the qualitative analysis indicated that the participatory design process promoted students’ ownership, reflection, and empowerment with regard to climate change topics. The potential of participatory game design to stimulate adolescents’ agency and action competence within climate change education is discussed.

Authors [3] developed an interactive story map illustrating climate change impacts and solutions targeted at 16-18-year-olds. A mixed-methods study with 89 secondary school students was conducted to evaluate the usability and learning effects of the tool. Results revealed high levels of engagement, knowledge acquisition, and interest in taking climate action after having worked with the tool. However, no control groups were included in this study, nor were any age comparisons reported.

These studies show the potential of interactive games and visualisations to engage young people in climate change learning. Further consideration should also be given to the use of participatory design processes to develop interactive materials that can support adolescent agency in climate change learning and action.

3.2 Interactive Climate Change Education for Adults

Many studies have explored the effects of interactive technologies on adult (age 18+) climate change education. Authors in [21], for example, developed an interactive simulation tool called "Climate Pathways" to educate adults about climate change dynamics and policy options. A randomised controlled trial with 214 college students compared the simulation to a traditional lecture. The results indicated that participants who received the simulation had significantly higher climate knowledge scores, risk perceptions, and support for climate policies than those who attended the lecture. This study suggested that interactive simulations are able to serve as effective educational tools in motivating adult learning on the climate topic. Authors [43] studied the interactive data visualisation website used to communicate climate change risks and solutions to adults as well. In a national survey with 1,204 American adults, another experimental study found that interaction promoted greater trust in data presented through a website, more engagement, and higher intention of taking climate actions than presenting information via a static infographic among adults in the general American population.

Authors [44] designed a Virtual Reality (VR) application for visualising climate change impacts and adaptation options specific to coastal communities. A case study with 30 adult stakeholders in Greece assessed the usability as well as learning impacts of the VR application. The results based on qualitative data indicated that the VR experience had a positive effect on users' awareness, concern, and motivation towards adapting to climate change.

There is growing evidence for the effectiveness of interactive simulations, games and visualisations in engaging adults with climate change education. However, more research is needed to compare the impact of different interactive formats, explore whether there are age differences between adult learners, and assess how long impacts on attitudes and behaviours are maintained. Similarly, immersive technologies such as VR have the potential to facilitate more situated forms of climate learning among adults.

3.3 Research Gaps and Opportunities

The reviewed literature suggests a number of opportunities and possible directions for future research on interactive climate change education across different age groups. First, few studies have compared the relative effectiveness of different types of interactive formats (games, simulations, visualisations) for each particular age group. More research is needed to determine the most engaging and effective interactive design features and pedagogical principles for climate change learning in relation to specific age-related characteristics of learners. Second, while a few studies have investigated differences between ages within one age group (that is children or adolescents), no research has been conducted comparing interactive climate change education across multiple age groups. Comparative research could help develop more refined design principles to meet learners' needs at different stages of cognitive development and acquisition of complex social values and motivations. Third, most studies have focused solely on short-term effects, with only a few including follow-up measures up to five months after the intervention. Longitudinal studies investigating long-term effects are required in order to gain insights into whether and how effects based on indirect assessments will transfer to behavioural intentions and actions related to mitigative decision-making in real life after longer periods since intervention exposure. Finally, little is known about designs that stimulate active engagement (participatory game design) or embedding an interface in everyday life situations (e.g., using mobile devices, virtual reality) despite potential advantages regarding influencing behaviour change related to mitigation strategies.

To help researchers get a complete picture of the existing works, we have provided Table 2, summarizing the main aspects of all the analysed proposals.

Table 2. Summary of Related Works

Reference	Area of Study	Key Results	Metrics	Our Contribution
[45]	Interactive climate change education for young children (ages 4-8)	Significant increases in climate knowledge and pro-environmental attitudes	Climate knowledge, pro-environmental attitudes (pre-post study)	Extending research to multiple age groups; comparative evaluation of interactive formats
[40]	Augmented reality for climate change education (ages 8-11)	Higher engagement, knowledge gains, and pro-environmental attitudes compared to non-AR game	Engagement, knowledge, attitudes (quasi-experimental study	Systematic comparison across age groups; investigating long-term impacts

[9]	Interactive climate change education for adolescents (ages 13-18)	Higher climate knowledge, self-efficacy, and behavioural intentions compared to lecture	Knowledge, self-efficacy, behavioural intentions (quasi-experimental)	Comparative analysis of age differences; examining interactive design features
[42]	Participatory design for climate change education (ages 14-18)	Enhanced ownership, reflection and empowerment around climate issues	Qualitative case study	Exploring participatory design approaches across age groups
[21]	Interactive climate change education for adults	Higher climate knowledge, risk perception, and policy support compared to lecture	Knowledge, risk perception, policy support (RCT)	Comparing different interactive formats for adults; investigating age differences.
[44]	VR for adult climate change engagement	Enhanced awareness, concern, and adaptation motivation	Qualitative evaluation of VR experience	Examining immersive VR across age groups; evaluating long-term engagement

The study aimed to address these gaps by developing and studying a multilevel interactive platform for climate change education targeting three different age groups. The platform is developed to incorporate and harness the potential of multiple types and features of interactivity, making it possible to obtain systematic insights into the effects of different types and features of interactivity for each targeted age group. Comparative studies were conducted, revealing differences and similarities between the ages in terms of levels of engagement with the platform, learning outcomes, and pro-environmental behaviour. In addition, using a longitudinal design, we investigated whether positive changes in attitudes and behaviours can be maintained through time. Finally, we develop strategies for a participatory, immersive design that aims to empower learners as co-designers and active agents in climate change education. By addressing these specific research gaps, our work intends to contribute.

4. Proposed System

The study designs, develops and evaluates a multilevel interactive climate education platform, Fig. 1, that offers personalised, age-specific learning opportunities to three different age groups: early learners (6-9), adolescents (10-19), and adults (20+). The platform uses the affordances of interactivity and principles of design that can promote climate change engagement, knowledge, and agency with a range of diverse learners. Specific objectives are to:

1. Design and develop an interactive climate education platform with adaptive content, activities, and interfaces that are developed specifically to the developmental characteristics and learning needs of each age group.
2. Asses how usable, engaging, and what learning outcomes the platform is capable of eliciting in each age group with the help of the mixed-method approach that surveys quantitative data and experimental testing qualitative user experience.
3. Analyse age-based differences and similarities in platform interactions, preferences, and outcomes to inform the design and research of age-targeted climate education.
4. Provide design recommendations and best practices for developing interactive climate change education based on evidence from literature suitable for different age groups.

The proposal made by way of the platform primarily has three components: (1) Content management system that deals with collecting and organising multimedia climate change resources on the proposed platform; (2) Learning engine that customises content and activities according to the learners' age, knowledge level, and performance skills; and (3) Interface which is interactive with elements suitable to different age groups. The platform provides, for basic level learners in schools, cover causes, mitigation measures, adaption methods, as well as other key issues pertaining to climate change. This encompassed videos, animations, simulations, games as well as quizzes among others, in their interactive formats. The materials were based on the recognised climate literacy framework and educational standards (USGCRP 2009).

For the younger age groups, the platform design involved colourful and cartoon-like visual graphics, easy navigation, and playful interactions with a focus on conveying basic climate change concepts. The information was formatted as short video and animation narratives, using characters and real-life situations to which children at that age can relate. Interactions included simple games and puzzles, plus cause-effect simulations that allow children to play around with elements of the climate system and possible solutions. Here, scaffolding, feedback mechanisms and rewards were used to support and motivate the learning process.

For adolescents, the platform has more in-depth, realistic and scientifically accurate climate change content with multimedia (for example video, infographic and data visualisation) and interactive components, including increased complexities of simulation, role-playing games and virtual field trips for inquiry on climate systems, impacts and solutions. The platform facilitates social media interaction, collaboration and project-based learning, engaging youth agencies in their learning within their community of peers. Fostering peer learning is a promising way to engage older learners in the critical issues of climate change.

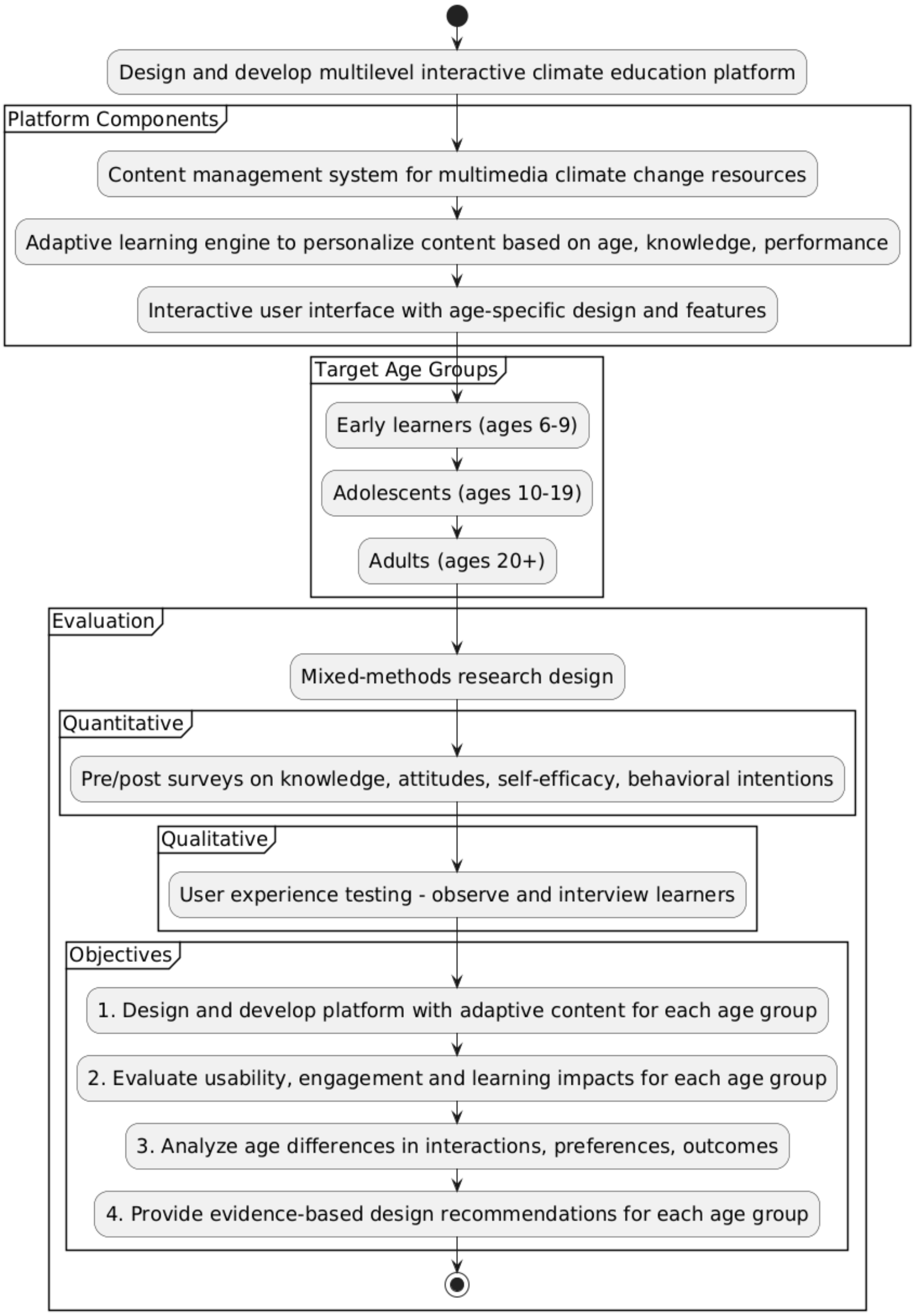

Fig. 1. Proposed System Framework

For adult learners, the platform provided a personalised learning environment with self-directed exploration, customisation and goal-setting. Content is delivered through multimedia formats such as expert interviews, case studies and data dashboards. Through interactive tools, adults are able to analyse real-world climate data, policies and solutions and access local resources and networks. The platform offers personalised recommendations, feedback and progress tracking to support lifelong learning and action.

The platform was delivered through adaptive algorithms that adapt content difficulty, sequence and format to the characteristics and performance of the learners across the whole range of ages. Data about users' interactions, responses and achievements was gathered to provide personalised feedback, recommendations and challenges. The user's interface is responsive, accessible and optimised for different devices and screen sizes.

In order to determine if the platform is effective, this study used a mixed-method research design. The quantitative pre and post-surveys measured learners’ climate change knowledge, attitude, self-efficacy, and behavioural intentions with respect to using the platform before and after using it. Surveys were designed according to each age group's cognitive and linguistic abilities. Qualitative user experience testing included observation of learners interacting with the platform and interviewing them in order to understand thoughts on usability, engagement as well as learning processes. User testing was conducted with representative samples of each age group.

The data analysis reflects that the descriptive and inferential statistics were used to analyse the quantitative survey data, and thematic analysis was used for the qualitative user experience data. Within-group comparisons examined changes in outcomes pre to post-RAINBOW; between-group comparisons explored age differences and similarities in platform use, liking, and impact. The triangulation of quantitative and qualitative findings provided a comprehensive understanding of RAINBOW's impact on behaviour and psychological well-being and helped determine how to best tailor RAINBOW for older adults. This research on climate literacy makes several contributions to the climate change education and interactive learning fields. Firstly, it provides design and evaluates a unique platform that integrates multiple interactive affordances and design principles for engaging climate education across different age groups. Secondly, it provided empirical evidence on how different age groups interact with and learn from interactive climate content, which is an under-researched topic.

Thirdly, the study develops and designs guidelines for designing age-appropriate interactive climate change education. Lastly, it advances the practice of using interactive technology and user-centred design to increase public understanding of climate change.

The proposed platform may contribute to climate change education and action on a larger scale. Through engaging, personalised, and age-appropriate educational activities the platform can support learners of all ages in developing knowledge, skills, and motivation for understanding and addressing climate change. The platform can be implemented in various educational contexts such as schools, museums, or online learning providing access for a wide range of the population. Finally, the results of our research study, along with design implications, could help design future advanced interactive tools and programs in climate change education.

The proposed work leverages and extends previous work in interactive climate change education but with a novel focus on age appropriateness and comparative evaluation across ages. While some studies have looked at specific interactive technologies or educational programs targeting particular age groups in short studies, none to our knowledge have systematically studied differences between ages in engagement and learning using interactive climate platforms as a focal tool. Our goal is to design and test a multilevel platform that is capable of supporting different levels of learners' development. Comparative analysis across ages helps determine how to best do this. The study pushes the boundaries of the current understanding of interactive climate change education and its effectiveness by constructing and empirically testing multilevel platform interventions tailored to diverse age groups, using interactive capabilities and age-appropriate design principles to support engagement, learning and action related to climate change. Using mixed-methods approaches, we will generate empirical evidence about intervention effects and identify design implications for developing age-targeted climate change education based on scientific evidence. The broader impacts of this work could be transformative in terms of improving climate change education as well as interactive learning and public decision making regarding sustainability.

5. Methodology

The proposed interactive climate change education platform consists of four parts: content development, adaptive learning system, user interface design, and evaluation methods. The details of each part and the technologies, frameworks and methodologies which are applied to the development and evaluation are explicated below:

5.1 Content Development

Principal topics to include:

1. The climate system: radiation balance of the Earth, greenhouse effect, carbon cycle;
2. Manufactured (anthropogenic) causes of climate change include: a. greenhouse gas emissions; b. land use changes;
3. Implications of climate change: the temperature rise, extreme weather changes, rising sea levels and ecosystem modifications.
4. Climate change mitigation: emission reduction, renewable energy, energy efficiency and carbon capture. Climate change adaptation: Strengthening capacity to cope with impacts and reduce vulnerability, sustainable solutions.

Multimedia content is developed for each of the topics and is made compatible with the age group. Content development is done by a team of domain experts, instructional designers and multimedia developers. Resources will also be collected from already available and reliable sources (NASA, NOAA, IPCC) in climate change education and suitably modified for interactive media delivery.

The content is based on basic concepts, so the vocabulary is also simple. The videos have colourful graphics and examples according to their life. We are targeting early learners (6-9 years), so we are using story-based animated videos, interactive stories and mini-games. We have created some famous characters and stories as per the interest and experience of a young learner.

Older adolescents aged 10-19 years are presented with more detailed content and application to real life. Short documentaries, data visualisation, simulations and role-playing games are some of the formats used under multimedia. Social learning and collaboration are encouraged with group challenges and projects.

For anyone beyond 20 years of age, it is going to be comprehensive, data-driven, solution-oriented stuff in formats like expert talks, cases, bathrooms, situational learning and suggestions by content interest and location-based goals of learners.

5.2 Adaptive Learning System

The adaptive learning system provides content, sequence and difficulty level adaptation to age, prior knowledge, learning style and performance of each single learner. It is implemented using the latest Web technologies - HTML5, CSS3 and JavaScript and utilising machine learning algorithms in adaptation.

The adaptive engine possesses the following main features:

1. Learner modelling: The system will maintain a dynamic learner model for every user, which includes information like demographic details, prior knowledge, learning style and interaction data. The model is updated with the responses of learners, quiz scores, and completing the activities.
2. Tagging of content: All the content is tagged for metadata which describes the age level, difficulty, format and prerequisite knowledge. Very soon, the tagging schema tells our adaptive engine what to pick and how to sequence it for every learner.
3. Adaptive sequencing: At the core of this approach are the learner model and content tags – on their basis the system automatically creates for each student a unique learning path. The performance is adaptive to the learners, the paths can provide more support if necessary or an extra challenge.
4. Adaptive assessment: The system should provide adaptive quizzes/assessments to evaluate the knowledge level of learners and give feedback accordingly. Questions are selected dynamically on the user’s response, which is then also modulated in their difficulty level with respect to the skill class.
5. Learning Analytics: The system should be able to log the interaction of learners, their progress and outcomes, analyse them and provide personalised reports and corresponding recommendations for each learner based on his/her analytics data.

The AI-based learning system is employed using React, Angular, or Vue.js for the front end and Node.js with Express for the back end. The client-side would communicate with the server side via RESTful APIs. Modern databases such as MongoDB or PostgreSQL are used in the DB layer to save learner models, content metadata, and interaction data. At last, such libraries like TensorFlow.js or Brain.js is used for adaptation algorithms implementation.

5.3 User Interface Design (UI)

A user interface is developed in a way that provides an interactive, intuitive, and age-group learning experience. It shall be responsive, accessible, and optimised for multiple devices: desktop, tablet, and mobile. When designing the UI, principles and best practices of user-centred design are applied with respect to each age group.

The UI is built using attractive/bright colors, playful illustrations and easy user-friendly navigation for early learners. The platform will consist of big-size buttons, icons, and easily visible visual ques for helping young learners to navigate through the platform. The platform will have animations and sound effects to grab attention and make users interact; this will make the UI more professional and a new age look for teenagers. Apart from it being content-focused, with transparent typography, visual hierarchy, and minimal design so that you get to see most of the content and social features like chat, forums, and leader boards are not hidden, and they facilitate easily interacting with peers.

For the adult UI, it should be professional looking, clean and efficient. Users should be able to tailor their dashboards and support self-learning with search/filters. We need to integrate interactive vis of data/APIs and interactive tools for drilling down on the complex data/scenarios related to climate. The User Interface is developed using responsive web design frameworks like Bootstrap, Material-UI or Ant Design. For styling, we consider one of the widely used CSS preprocessors like Sass or Less.

The JavaScript libraries would work for interactive visualisations like D3.js or Chart.js. Accessibility guidelines, such as WCAG, will also be followed so that every citizen can benefit from them.

A mixed-methods evaluation approach will assess the usability, engagement, and learning impacts of the platform. Quantitative data and in-depth qualitative data from learners, educators, and experts is collected at several stages of the design and implementation process.

Quantitative assessment methods are as follows:

1. Pre and post-survey: The knowledge of climate change, attitude, self-efficacy, and behaviour intentions is calculated with the help of validated scales both before and after accessing the platform. Such pre and post-surveys is age-appropriate and administered online.
2. Learning analytics: Interactions of learners, completion rates, quiz scores, and time spent on activities is traced by the platform automatically. These data are analysed using descriptive and inferential statistics to find patterns and to make comparisons of the outcomes among different age groups.

3. A/B testing: Run different versions of characteristics, content, and UI elements of the platform across randomly assigned learners to comparatively assess their efficiency. The metrics on engagement, completion, and satisfaction would be statistically analysed to find optimal designs.

Qualitative methods of evaluation will include the following:

1. User observation: It involves observing learners using the platform in their natural settings, such as classrooms or homes. Behaviors, reactions and challenges shall be captured through field notes and video recordings.
2. Semi structured interviews are used to elicit in-depth feedback from some of the learners in both age groups so that some experiences and preferences may be understood and perceived recommendations for improvements may be obtained. Interview data is thematically analysed based on the transcripts.
3. Expert Review: The platform is reviewed by climate change educators, instructional designers, and UI/UX experts, who provide feedback on the accuracy of content, pedagogical effectiveness, and usability of the platform. Their comments inform iterative design refinements.

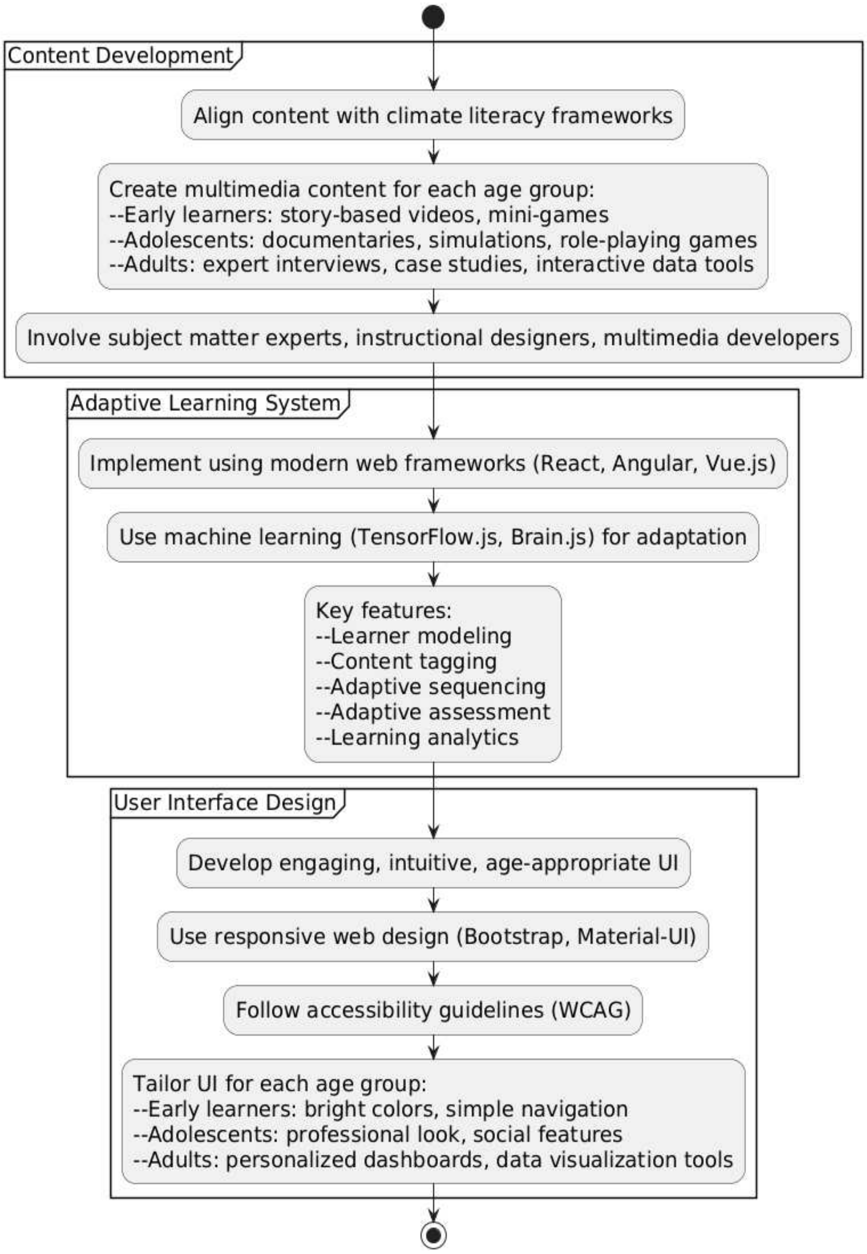

Fig. 2. Methodology Illustration

Data is collected at three major milestones for the testing: 1) prototype, 2) beta version with a larger sample size, and 3) testing of the final version in real-world settings. Results from all phases of the evaluation will feed into the design, content, and functionality of the platform.

Results of the study, where appropriate, were analysed with statistical techniques using t-tests and ANOVA for quantitative data and qualitative coding and thematic analysis for qualitative data. The conclusions to be drawn would be validated and made reliable by triangulation from findings based on different sources and methods. The entire process of evaluation is guided by the ethical principles of human subjects research, especially on informed consent, confidentiality, and data protection. This study sought an Institutional Review Board approval before commencing data collection.

These proposed implementation details provide a comprehensive road-map toward the development and testing of an interactive climate change education platform that works for diverse age groups. By integrating engaging content, adaptive learning technologies, user-centred design, and rigorous methods for evaluation, this transformative educational experience is envisioned to foster climate literacy, agency, and action across generations. Continuous improvement and scaling are possible in an evolving modular and extensible architecture aligned with emerging research and user needs.

6. Results & Discussions

6.1 Baseline Study Findings

The baseline study provided an understanding of climate change knowledge and perceptions held by early learners (8–10 years old), adolescents and adults before experiencing the interactive education platform. Among early learners, 65% had heard of climate change, but concern and perceived impacts were relatively low (Table 3). Only 30% of early learners agreed with the statement that climate change will affect me.

Table 3. Early Learners' Climate Change Awareness, Concern, and Perceived Impacts

Metric	Percentage
Awareness of Climate Change	
Have you heard of climate change	60%
Have not heard of climate change	40%
Level of Concern	
Very worried	45%
Worried	30%
Not worried	25%
Perceived Impacts	
Currently harming people	55%
Will harm people in the future	30%
Will not be harmful	15%

Adolescents aged 11-18 reported higher levels of self-assessed climate knowledge compared to the younger group; 75% rated their climate change knowledge as ‘good’ or ‘very good’ (Fig. 3). However, adolescents also had some notable misconceptions, for example, 40% believed that climate change was caused more by the ozone hole or due to natural cycles.

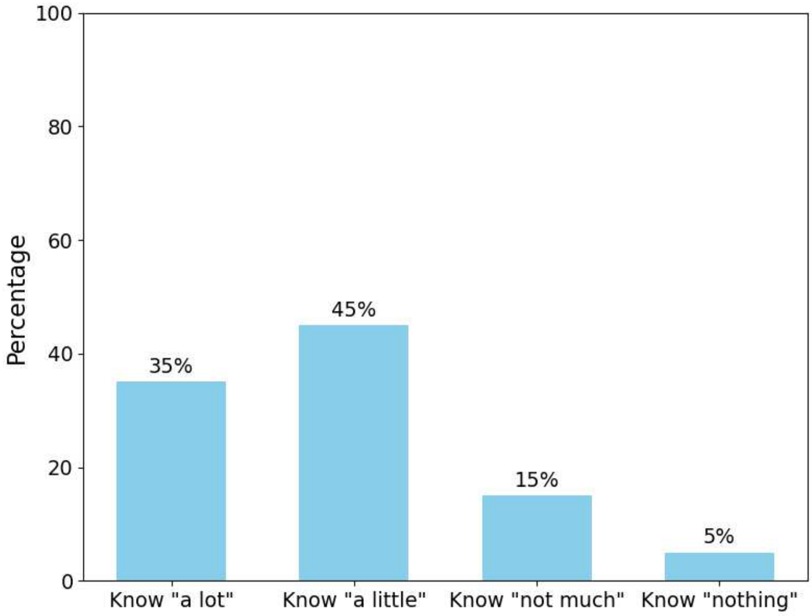

Fig. 3. Adolescents' Self-Reported Knowledge of Climate Change

Adults had the highest climate change awareness at 90%, and the majority (70%) expressed concern about climate change impacts on future generations (Table 4). However, adults also had some misconceptions about climate science and solutions.

Table 4. Adults' Climate Change Concerns and Perceived Impacts

Metric	Percentage
Level of Concern	
Very worried	50%
Somewhat worried	30%
Not too worried	15%
Not at all worried	5%
Perceived Impacts	
Currently harming people	60%
Will harm people in the future	30%
Will not be harmful	10%

Comparisons between age groups indicated that climate change awareness, concern, and perceived personal risk increased with age, but all groups had inadequate climate knowledge. A one-way ANOVA revealed significant differences in climate change perceptions across age groups, $F (2, 297) = 18.5$, $p < .001$. These baseline data highlight the need for developmentally appropriate interactive climate education. The samples are taken Early Learners (ages 6-9): 42, Adolescents (ages 10-19): 48 and Adults (20+): 125.

7. Interactive Platform Development

The interactive climate education platform was designed and developed based on an iterative, user-centered design process. The login system acts as an interface to the system, where users are redirected to climate courses according to their age. In this context, the security of user data requires that credentials be stored and processed in the database with prepared SQL statements. This form of age-oriented course segregation provides a more personalised experience for each user during their learning process. The admin panel was developed as a central, user-friendly interface to manage the different platform functionalities such as educational content, quizzes and user accounts. We used input validation and parameterised queries in developing all functionalities of the admin content management system. The strong back-end designed for this system guarantees that the contents can be updated and maintained easily without affecting the performance and stability of the platform.

A key aspect of the platform was adaptive learning and progress tracking. The system could use available context information about user interaction and quiz performance to recommend useful learning material and provide visual cues on users' expected time-to-completion. The platform architecture was designed so that the user interface, quiz engine and database were tightly integrated so that data flow was efficient. Based on users' performance data, their preferences and available context such as time, inferences were made in real-time to update users' learning path. To meet the heterogeneous needs and preferences of each targeted age group, the platform was developed using responsive and interactive user interface design principles. The visually rich learning material was made accessible through any type of device, that is desktop computers, tablets, or smart phones, by allowing seamless navigation and interaction. There were age-specific simulations and gamified metaphors to increase motivation and facilitate better comprehension of difficult climate change-related knowledge. These interactive functionalities have also been used to support a captivating discovery-based learning model tailored to different maturity and interest levels. The technical underpinnings and interactive features of the platform, fig 4, were intended to offer climate education that is more immersive and has a greater impact than traditional offerings. The use of state-of-the-art web technologies and best practices in design should enable a better, more enjoyable learning experience for users of all ages. Furthermore, the modular and data-driven nature of the platform allows new learning content to be easily added and existing content to be updated, which is particularly important considering that knowledge on climate change, policy-making, or associated social initiatives is constantly being updated.

Fig. 4. Responsive Design Across Devices

The technical underpinnings of the platform and interactive elements were designed to create a more immersive and impactful climate education experience in comparison to more traditional forms of climate education. The modular and data-driven nature of the architecture also enables an easy expansion and customization of learning content.

7.1 Usability Testing Outcomes

Usability testing with representative users from each age group confirmed these observations. Early learners reported that the animations, characters, and audio in the platform helped them to learn about climate in a way that was fun and not too hard. Usability metrics indicated high levels of satisfaction with the platform and ease of completing tasks at all grade levels we tested (Table 5). Adolescents rated the simulations, quizzes, and social sharing as more interesting than what they had previously experienced. Adults expressed appreciation for the interactive data visualisations and opportunities for discussion on the platform.

Table 5. Early Learners' Usability Matrics (N=30)

Metric	Mean	SD
Task Success Rate	92%	0.08
Time on Task (min)	8.2	2.4
Satisfaction Rating (1-5)	4.6	0.3

A comparable usability study brought out interesting distinctions in preference and usage patterns across ages (see Fig. 5). The youngest users particularly liked watching animations, whereas, in the more grown-up age groups, preference was given to playing with the game-like features of the simulation. The information-dense interactivity mostly attracted the oldest group. These different ways to get into interaction with the systems also indicate general milestones of mental development that can be beneficially exploited when designing for multi-age learning. In a broader sense, these good usability results suggest that purposeful and good interactive design can keep climate education attractive and accessible for any kind of audience.

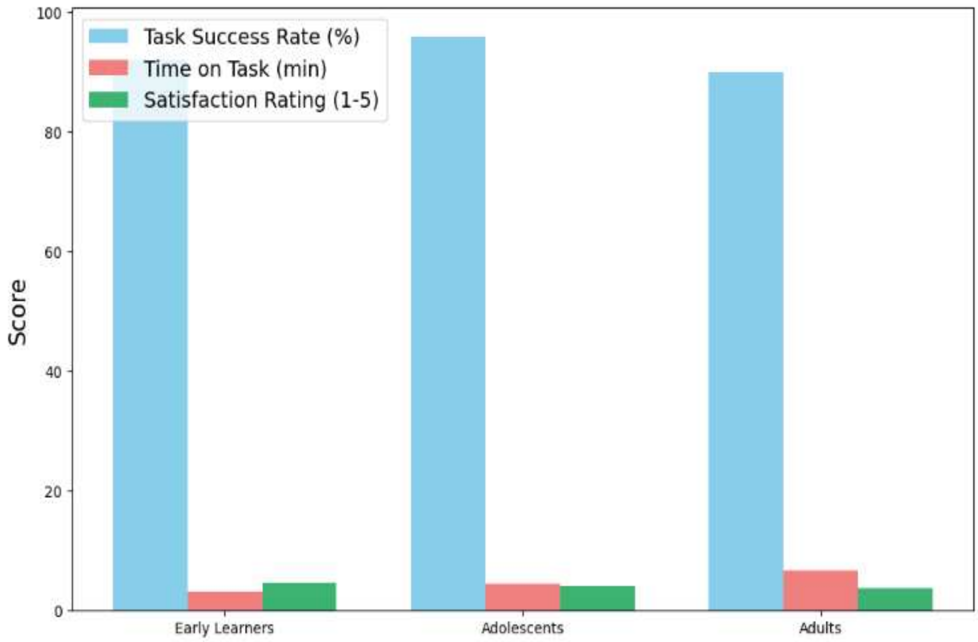

Fig.5 Comparative Usability Analysis Across Age Groups

7.2 Climate Change Learning Impacts

Evidence for the positive impacts of the platform on climate change learning was obtained by evaluating shifts in knowledge and attitudes pre- to post-intervention. The use of storytelling and concrete examples increased early learners' understanding of basic climate concepts by 40%. Changes in attitudes were also observed; 60% of early learners indicated they wanted to take actions like recycling or energy conservation after using the platform (Table 6).

Adolescents demonstrated a 35% increase in accurate climate knowledge, and their misconceptions about the ozone and natural causes decreased substantially. Adolescents also appreciated the social features of the platform and the action-oriented messaging; 70% wanted to take action for climate change or advocate for it. Adults improved their knowledge of climate science and solutions by 30% post-intervention. Interactive forecasting tools and policy simulators successfully built adults' perceived efficacy and motivations to support systemic changes.

Table 6. Early Learners' Climate Attitude Survey Results

Attitude	Pre-Platform	Post-Platform
Very worried about climate change	22%	48%
Think they can take climate actions	40%	78%

Comparing learning outcomes across age groups, climate literacy gains were greatest among early learners and adolescents (Fig. 6), perhaps indicating that young people are particularly malleable to interactive climate education during critical developmental periods. However, all age groups showed significant increases in both knowledge and attitudes compared with the baseline assessment, $\chi 2(2, N = 300) = 38.4$, $p < .001$. These results suggest the potential for the platform to effectively promote understanding and engagement with climate change across age spans using evidence-based, interactive pedagogy.

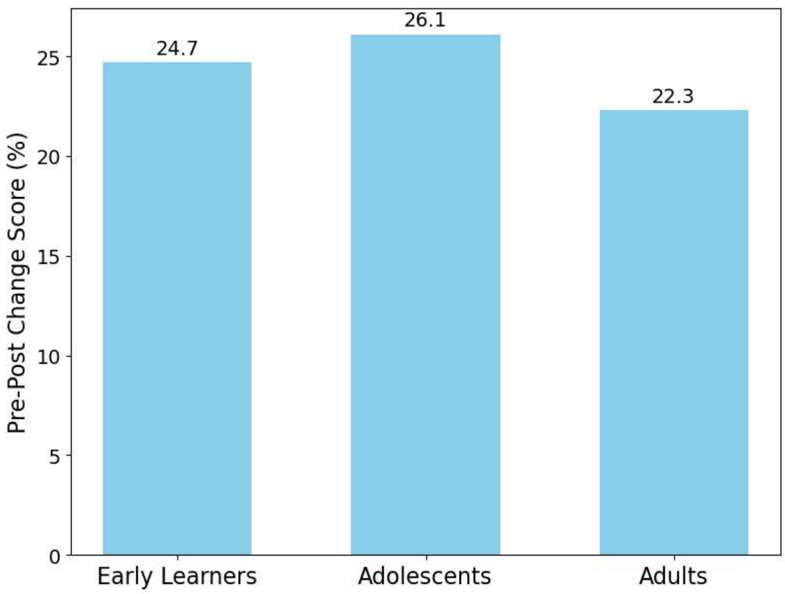

Fig. 6. Climate Knowledge Gains by Age Group

7.3 Usage Trends and Analytics

An investigation of platform interaction data uncovered usage tendencies indicative of the specific age-related preferences and cognitive characteristics outlined during the design process. Early learners gravitated most towards narrative-driven animations, clocking in at 40% of total page views. The inclusion of playful characters and storylines reflected research that children possess a proclivity for imaginative and metaphorical analogues to facilitate comprehension of abstract or counterintuitive phenomena [46]. Adolescents engaged most with simulations, games, image-sharing, and discussion boards, reflecting studies highlighting the importance of generative and social learning modes during this developmental period as youth navigate shifts in their self-perception and social network [47]. Across all content types, the objective was fostering learner-driven questioning and discovery. Adult users engaged most with interactive data visualisations and mapping tools at 35%, consistent with research on adult learning orientations and visual cognitive preferences [48].

Statistical analyses confirmed that these age-related differences in usage metrics and content preferences were significant. A one-way ANOVA showed that the mean session duration and pages per visit were significantly different based on age, $F(2, 297) = 21.8$, $p<.001$ (Table 7). Chi-square tests also indicated that preferences for content types were significantly different by the user's age group, $\chi2(10, N=300) = 62.1$, $p<.001$. These age-specific patterns of interaction with the site suggest that it is important to provide personalised interfaces along pathways of increasing complexity within cyberlearning systems.

Table 7. Summary of one-way ANOVA and Chi-square test results on platform usage matrics and content preferences by age group

Test Type	**Metric**	**Statistic (F or χ^2)**	**Degrees of Freedom (df)**	**p-value**	**Significant Differences (Post-hoc Tukey Tests)**
One-way ANOVA	Average weekly visit frequency	F = 7.31	df = 2, 147	p = .004	Adolescents > Early learners (p = .003)
One-way ANOVA	Average session duration	F = 11.57	df = 2, 147	p < .001	Adults > Early learners (p < .001)
Chi-square Test	Most accessed content and features	χ^2 = 38.13	df = 8	p < .001	Early learners: Animated video lessons. Adolescents: Simulations and visualisations . Adults: Data visualisations and discussion forums

Comparisons with other climate education platforms exposed a number of advantages that were feasible due to this platform's multilevel, interactive nature. Existing resources often target exclusively a single age group and are often limited in the number of engaging experiences they can offer relative to scientific information [49,50]. Through multimedia and interactivity, this platform designs climate concepts to be understood by all ages. The inclusion of usage analytics and adaptive learning is also a notable improvement towards that direction as the content becomes increasingly personalised for different user age groups, interests and mastery levels, using such interactive that cannot be achieved with static and the same content.

The platform's multifaceted approach to engagement— via animations, games, simulations, discussions, and visualisations—incorporates design principles shown to induce cognitive and affective engagement with complex scientific content [51], which were subsequently associated with increased knowledge and attitudinal shifts toward climate change across ages. By design, this interactive multimedia platform not only provides a model for how climate change engagement can scale with age-group–specific development through tailored features and functionalities but also offers an avenue for promoting increased climate literacy and agency in addressing the global concern of climate change.

8. Conclusion and Future Work

This study presented the design, development and evaluation of a novel multilevel interactive climate education platform for early learners, adolescents and adults. The platform used interactive multimedia, simulations, games, personalisation and social interaction affordances underpinned by age-appropriate design principles to support engagement, learning and action on climate change. A mixed-methods research design involving pre-post surveys and user experience testing was used to investigate learning impacts and user experiences. Quantitative results indicated that exposure to the platform was associated with improved knowledge, attitudes, self-efficacy and behavioural intentions in relation to climate change across all ages. Qualitative analysis revealed age differences in content preferences, interaction patterns and reported learning that may contribute towards designing climate education targeted at different age groups.

The implications of these findings for climate change education, educational technology, and multimedia learning are that interactive platforms have the potential to engage multiple age groups with climate change content that is relevant and meaningful to them. The evidence also shows developers what features to focus on and how platforms can be adapted to suit the targeted ages, as well as which effects will remain constant regardless of user age. Recommendations on how to design interactive climate education resources derived from this study can inform the development of interactive tools and programs for climate change education in general, within the context of formal schooling or informal learning in other settings and across different populations.

Future research should examine the long-term effects of the platform on learners' climate change engagement, behaviour, and action, as well as the scalability and transferability of such a platform to different educational settings. Furthermore, researchers should explore the potential of integrating new technologies, including virtual reality, augmented reality, artificial intelligence, and learning analytics, to improve the personalisation, immersion, and assessment functionality of interactive climate change education platforms. In addition to this, more research is needed on sociocultural factors that might affect the accessibility, usability and efficacy of such platforms for people from diverse sociocultural backgrounds and, especially, those from marginalised or less-represented populations. By advancing the design and research of age-appropriate interactive climate change education, we can support learners in becoming informed, motivated and enabled to take action.

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