"Angry Penguin": A gamified carbon emission education game design and study

Xiyu Zheng[1,*,†], Yuze Song[1,†], Xuerong Cai[1], An Chen[1] and Jie Zhang[1]

[1]Tongji University, No.100 Zhangwu Road, Yangpu District, 200092, Shanghai

Abstract

Environmental education for the public aims to inspire a broader range of people to engage in the practice of achieving sustainable development goals. This study introduces *Angry Penguin*, a gamified experience designed to prompt young people to reflect on unsustainable behaviors in daily life by vividly illustrating the hidden impacts of carbon emissions. Set within a dynamic sandbox world, players step into the quirky role of a wind-up penguin on a mission to challenge carbon-intensive behaviors woven into the fabric of everyday life. Central to the experience is the innovative "Penguin's Eye," a feature that reveals the invisible presence of carbon emissions, immersing players in a tangible exploration of the unseen forces driving climate change.

What makes *Angry Penguin* unique is its ability to blend humor, empathy, and purposeful interactivity to provoke meaningful reflection on human behaviors and their environmental consequences. By engaging players through anthropomorphism and interactive gameplay, the game bridges the gap between knowledge acquisition and the transformation of daily actions, offering fresh perspectives on sustainability. This study contributes to the evolving dialogue at the intersection of gamification and climate advocacy. Through experimental investigations and the integration of player feedback, we explored how narrative - driven mechanisms and empathetic design can enhance players' awareness of carbon emissions in gamified environmental education. This research provides valuable insights for more effective environmental education targeted at the general public.

Keywords

Gamification, Climate-change engagement, Carbon Emission Awareness, Environmental Education, Interactive Learning, Anthropomorphic Characters

1. Background

Global carbon emissions are a driving force behind climate change, underscoring the urgent need for widespread public awareness and behavioral shifts [1, 2, 3]. Everyday choices—ranging from transportation methods to the use of electronic devices—contribute to greenhouse gas emissions, with profound and far-reaching environmental consequences [4, 5]. However, according to the 2023 China Low - Carbon Awareness and Behavior Survey Report, there is a discrepancy between the public's low - carbon awareness and the degree of implementation of low - carbon behaviors . People have a relatively low awareness of their personal contributions and responsibilities in five major areas: catering, housing, travel and office, and shopping[6]. To bridge this gap, game-based learning has emerged as a compelling solution, offering interactive and immersive experiences to tackle abstract and complex issues in an engaging manner.

This study introduces *Angry Penguin*, a game designed to re-imagine climate education through interactivity and storytelling. The background of this project is derived from the adaptation of the documentary *The Year Earth Changed*, which elaborates on the relationship between urban carbon emissions and glacier melting, as shown in Figure 1. In this project, climate issues are integrated with familiar daily urban scenarios, placing players in situations where they encounter and need to address carbon - emitting behaviors. By combining narrative-driven mechanics with actionable learning, *Angry Penguin* empowers players to identify emission sources and reflect on sustainable practices, fostering both awareness and meaningful behavior change [7, 8, 9].

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*Corresponding author.

†Xiyu Zheng and Yuze Song contributed equally to this work as first authors.

zhengxiyu1019@gmail.com (X. Zheng); 283742240@qq.com (Y. Song)

0009-0001-2370-1200 (X. Zheng); 0000-0001-7116-9338 (Y. Song)

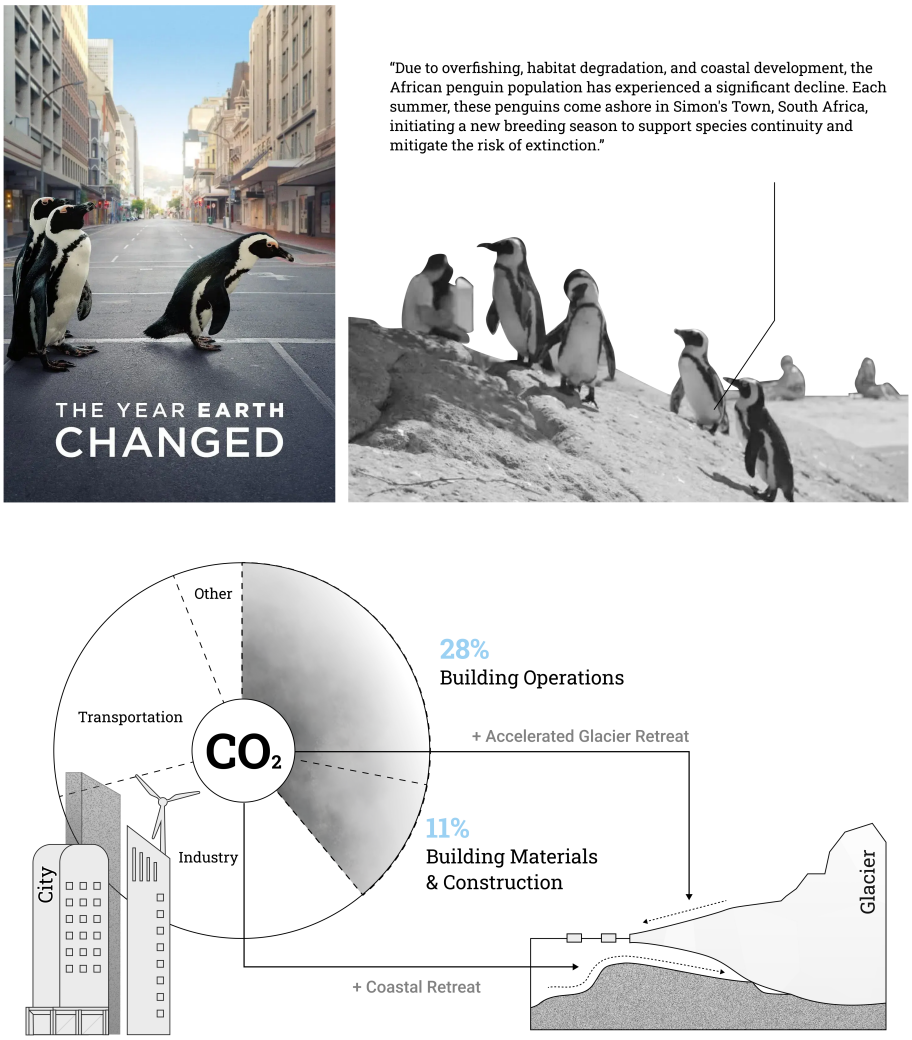


Figure 1: Excerpts from *The Year Earth Changed* (2021) and the impact of urban greenhouse gas emissions on glaciers, based on 2018 global annual average CO_2 emissions data.

1.1. Research objectives

The primary objective of this study is to assess how a gamified, character-centric approach can enhance players' awareness of carbon emissions in routine contexts. By embodying an anthropomorphized character, *Angry Penguin* seeks to foster empathy and critical reflection through interactive, exploratory scenes [10, 8]. A key feature, the "Penguin's Eye," visualizes hidden carbon emissions, allowing players to identify sources of emissions within familiar settings and destroy them through interaction. This combination of immersive gameplay, humor, and environmental education aims to prompt players to reflect on the sustainability of their behaviors [11, 12].

This study explores how narrative elements, anthropomorphic characters, and educational mechanics can jointly enhance environmental understanding and inspire responsible actions. Through *Angry Penguin*, players gain insights into the carbon footprint associated with daily objects and activities, encouraging them to consider more sustainable practices in their real lives.

1.2. Contributions

This study is firmly rooted in an extensive review of literature on gamified environmental education and the anthropomorphic empathy mechanism. Drawing upon the prototype project *Angry Penguin*, it comprehensively utilizes research methodologies such as behavior tracking and questionnaire surveys. A total of 100 subjects, with ages ranging from 18 to 25 years old, were recruited for data collection, followed by both qualitative and quantitative analyses. This research offers several significant contributions to the fields of gamification, environmental education, and interaction design:

- **Visualizing carbon emissions in gameplay**: *Angry Penguin* leverages the "Penguin's Eye" to render invisible carbon emissions visible within the game environment, making environmental impact both measurable and perceptible to players.
- **Empathy-driven learning through anthropomorphic characters**: The game's central character—a wind-up penguin—serves as a unique medium for empathy and engagement, helping players experience the effects of environmental degradation from the perspective of a creature impacted by climate change.
- **Behavioral reflection through interactive destruction**: Players engage in disruptive interactions with high-emission objects across familiar settings, fostering reflection on habitual behaviors and highlighting the cumulative effects of individual actions on global carbon emissions.

These contributions demonstrate the potential of gamified experiences to advance environmental education by employing interactive storytelling and character-centered mechanics to engage players in sustainability awareness and promote meaningful behavior change.

2. Related work

2.1. Gamification in education and sustainability

Gamification is defined as "use of game design elements in non-game contexts"[13]. As an innovative strategy, gamification has been applied to multiple fields. In educational contexts, it is used as an interdisciplinary approach to encourage learner participation, enhance motivation, and facilitate behavioral change[14]. Research demonstrates that gamification significantly improves learning motivation, increases engagement, and promotes long-term behavioral changes [7]. Moreover, interactive and game-based experiences are particularly effective in making abstract or complex topics more comprehensible by embedding them within scenarios that encourage active participation [7, 9].

In the field of environmental sustainability education, gamification has emerged as a powerful tool to enhance engagement and understanding within educational settings. It is particularly useful in helping learners grasp abstract environmental issues, such as carbon emissions, climate change, and resource management. For example, *Keep Cool* employs climate change strategy simulations to improve players' understanding of low-carbon decision-making. Similarly, the educational game *EcoChains: Arctic Crisis* leverages strategic simulations and role-playing to enhance awareness of climate change and ecosystem conservation. Additionally, gamification has been shown to encourage positive behavioral changes toward sustainability, with players frequently reporting a heightened interest in sustainable practices after gameplay [15].

Despite its potential, gamification in sustainability education faces significant challenges. A systematic review highlights a key issue: how to enhance learning outcomes by integrating dynamic feedback and immersive learning experiences into educational games [16]. Furthermore, researchers emphasize the need for personalized gamification designs that cater to the diverse needs of different player types [17]. Future research should focus on the integration of dynamic feedback and visualization tools into environmental education games to better facilitate behavioral change and strengthen players' understanding of environmental issues.

2.2. Anthropomorphic characters and empathy in learning

Anthropomorphism describes the tendency to imbue the real or imagined behavior of nonhuman agents with humanlike characteristics, motivations, intentions, or emotions [18]. Studies show that anthropomorphic design fosters empathy and emotional engagement, helping players better understand abstract or complex concepts while forming deeper connections with learning content [19, 10]. Epley et al. proposed the three-factor theory of anthropomorphism, explaining how humans connect with non-human entities through emotional projection, which enhances emotional resonance and promotes higher levels of cognitive engagement [20]. Furthermore, Batson's research highlights that empathy, driven by the mechanism of "self-other merging," can inspire behavioral reflection and change, offering theoretical support for behavior-focused interventions in educational games [21].

In environmental education, anthropomorphic characters provide players with unique perspectives on ecological issues. Emotional resonance has also been shown to boost engagement and positively influence player behavior [22, 23]. For instance, simulation games like *Zoo Tycoon* recreate animal behaviors and ecological dynamics, evoking emotional connections with animals and encouraging players to reflect on their ethical responsibilities and the relationship between humans and nature [12]. Similarly, virtual ocean games allow players to experience the fragility of marine ecosystems, helping them better understand the impact of human activities on the environment [24]. These studies demonstrate that emotional engagement through anthropomorphic design is a powerful tool for raising environmental awareness and promoting sustainable behaviors. Moreover, unlike the previous cases, *Angry Penguin* enables users to step into the shoes of and manipulate non-human characters themselves, so as to further enhance the empathy driven by the "self-other merging" mechanism.

Empathy-driven character design not only fosters emotional connections between players and game characters but also integrates dynamic feedback and reflective mechanisms, deepening learning and encouraging behavioral changes [22, 24]. Future research should explore how real-time feedback and immersive learning can bridge the gap between emotional resonance and critical reflection, enhancing the effectiveness of anthropomorphic design in addressing complex social and ecological challenges.

3. Game design

3.1. Overview of game concept

Angry Penguin is a role-playing game set in a vast sandbox world. Sandbox games are a genre that prioritizes player freedom and creativity, offering open virtual environments where players can explore, interact, and create without being constrained by rigid story lines or predefined tasks. This flexibility allows players to shape their own experiences and experiment with different approaches to challenges within the game.

The overarching goal of *Angry Penguin* is to raise awareness about the environmental impact of carbon emissions by immersing players in a dynamic, interactive world. Through exploration and active engagement, the game encourages players to critically examine high-carbon behaviors and discover practical ways to reduce environmental harm. By taking on the role of a wind-up penguin, players navigate diverse urban environments, uncovering and disrupting carbon-emitting activities to reduce their impact on the virtual world.

The interaction system centers around the concept of disruption, where players actively engage with carbon-emitting objects to reduce their effects. The journey begins in a small town, serving as a tutorial area, and gradually progresses to a skyscraper with peak carbon concentrations. Along the way, players explore everyday locations such as hospitals, gas stations, gyms, schools, apartments, and offices—spaces that often hide significant sources of carbon emissions. These settings and tasks are designed to reflect real-world environmental challenges, with the ultimate aim of inspiring players to think critically about their own behaviors and their potential for change.

By combining creative freedom with educational objectives, *Angry Penguin* seeks to balance entertainment with impactful learning, empowering players to reflect on their actions and consider sustainable

practices both within and beyond the game.

Table 1
Design Goals and Implementation Strategies

Goal	Design Element	Implementation
Enhance sustainability awareness	Character design	Lovable design, emotional interaction.
Strengthen environmental knowledge	Information visualization	Simulate scenarios, highlight emissions with "Penguin's Eye."
Promote knowledge retention	Task and feedback	Contextual tasks, reinforce with knowledge cards.
Encourage behavior change	Interaction mechanism	Dynamic tasks, personalized goals.
Sustain engagement	Reward system	Points, badges, achievements.

A defining feature of the game is the "Penguin's Eye," which visually highlights carbon concentrations around objects and locations. Emission hotspots are marked with bright colors and expanding heat rings, making invisible environmental impacts tangible and easier to identify. The gameplay revolves around disrupting high-emission objects and activities, with difficulty levels corresponding to the carbon footprint of each item. For instance, in Level 3, as shown in Figure 2, the game narrows the perspective to an office environment, challenging players to identify and disrupt workplace-related high-carbon-emission activities in an engaging and impactful way.

By immersing players in the perspective of an anthropomorphized penguin, the game offers a fresh and empathetic lens on human behaviors and their environmental consequences. Through its unique blend of humor, absurdity, and educational storytelling, *Angry Penguin* transforms climate awareness into an engaging and thought-provoking experience, encouraging players to reflect on the hidden environmental costs of their daily choices.

3.2. Characters and skills

In Angry Penguin, players assume the role of an anthropomorphized wind-up penguin, designed to engage players in a humorous yet thought-provoking manner. This character, known as "Angry Penguin," serves as both the protagonist and the player's avatar for exploring human-driven environmental challenges. The penguin's unique design incorporates a clockwork mechanism, metaphorically representing the ticking clock of climate change, while its exaggerated and endearing animations foster empathy and encourage players to engage with environmental themes from a non-human perspective.

The penguin character is equipped with several skills that aid players in navigating the game world and achieving objectives related to carbon awareness. As shown in Figure 3, the primary skill, the "Penguin's Eye," allows players to view otherwise invisible carbon emissions around objects and locations, visually enhancing the penguin's perception of the world. Areas with high carbon concentration are marked by color-coded heat rings, with brighter colors signifying higher emissions. This skill not only makes emissions visible, but also highlights specific environmental impacts associated with different objects, providing an educational layer to the mechanics of the game.

In addition to the "Penguin's Eye," Angry Penguin features a range of interactive abilities, as shown in Figure 4, enabling players to creatively engage with the environment. These abilities include basic actions such as pecking to attack objects, jumping to navigate obstacles, and shouting to interact with NPCs(Non-player characters). In more dynamic scenarios, players can guide the penguin to disrupt high-emission settings like party environments or crowded spaces by utilizing these actions strategically. For instance, the penguin can peck at decorations, jump to reach higher platforms, or interact with other characters to create distractions. These mechanics reflect the game's emphasis on engaging with carbon-emission sources through increasingly creative and complex problem-solving approaches.

Event	**Toppling an unattended computer**	**Snatching a phone used during a meeting**	**Knocking over an overflowing trash bin**	**Dismantling a holiday Christmas tree**
Object				
Background	The computer is connected to a high-energy data center. Data centers continuously store and process data, generating large amounts of greenhouse gases. It's estimated that they contribute approximately **100 trillion kg of CO_2 emissions annually**.	The production and usage of smartphones have significant carbon footprints: manufacturing a smartphone produces around **70 kg of CO_2**, while using 1 GB of data generates **3 kg of CO_2**. A typical user emits approximately **315 kg of CO_2 annually** through phone usage and charging.	Waste management plants emit CO_2 during operation and power usage. Based on the 2019 urban population of **520 million**, the CO_2 emissions from waste treatment account for approximately 0.2% of China's total carbon emissions.	Holiday-related consumer goods lead to high carbon emissions. A single artificial Christmas tree sent to a landfill can emit **around 16 kg of CO_2 during decomposition**, which releases substantial greenhouse gases. Artificial trees **emit greenhouse gases 10 times more than real trees**.

Figure 2: Carbon emission scenario narrative demonstrated through the office level, showcasing the identification and disruption of high-emission activities in a workplace environment.

3.3. Levels and environments

Angry Penguin features diverse urban environments, from small towns to high-rise office buildings, each representing common carbon-emission scenarios. As shown in Figure 5, players start from the tutorial in a small town and progress through levels of increasing complexity, such as hospitals, gas stations, gyms, and schools. In these scenarios, players identify and disrupt high-emission sources using the “Penguin’s Eye” tool, ultimately reaching the skyscraper challenge with the highest carbon concentration.

Dynamic elements, such as heat rings indicating emission intensity, guide players to key areas. Challenges require creative problem-solving, such as disabling HVAC(Heating, Ventilation, and Air Conditioning) systems in offices or addressing energy-intensive equipment in hospitals. Levels blend core tasks with optional objectives, allowing players to explore hidden carbon stories while progressing through the game.

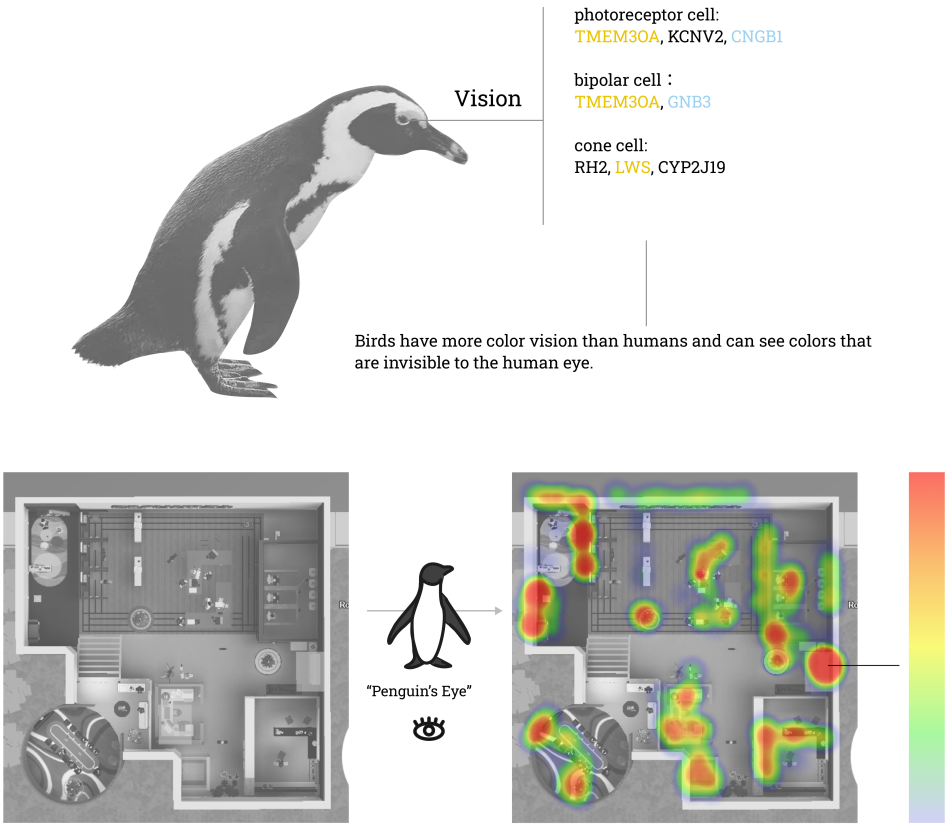


Figure 3: The "Penguin's Eye" mechanic highlights carbon emission hotspots, using a heatmap to guide players from high (red) to low (blue) emission areas.

3.4. Core mechanics and interaction

The core mechanics of Angry Penguin are built around exploration, interaction, and environmental disruption, all of which aim to educate players about carbon emissions in an engaging way. Players navigate a variety of urban settings, searching for and targeting high-emission items while using the "Penguin's Eye" skill to identify hidden emissions hotspots. This mechanic visually highlights objects based on their carbon output, with brighter, more intense colors representing higher emissions. This enables players to prioritize their interactions based on environmental impact, reinforcing the educational aspect of the gameplay.

Central to the interaction system is the concept of "disruption," where players actively engage with carbon-emitting objects to reduce their impact. As shown in Figure 6, basic interactions include locating high-carbon-emission items using the "Penguin's Eye," followed by actions such as knocking over objects or dismantling them. For instance, players might disrupt a holiday tree display in an office setting by attacking decorations or triggering chain reactions to break it down. Successful interactions lead to the elimination of the emission source, allowing players to proceed to the next challenge. Each interaction reflects the challenges of mitigating emissions, with higher-impact items requiring more strategic or multi-step problem-solving.

Angry Penguin also integrates a reward system to encourage exploration and learning. Upon successfully disrupting carbon-heavy objects or completing specific tasks, players earn "carbon knowledge" cards that reveal real-world facts about the environmental impact of everyday items. These cards are stored in the player's collection and can be reviewed anytime, providing an ongoing reference for real-world carbon emission data. Additionally, completing primary objectives within each level unlocks

Figure 4: Character and action design, showcasing player-controlled interactions with the environment during gameplay

hidden content, including bonus areas and "easter egg" interactions inspired by classic games, blending entertainment with environmental messaging.

4. Development and evaluation methods

4.1. Development process

The development of *Angry Penguin* followed a structured, iterative process beginning with conceptualization, progressing through prototyping, and incorporating user testing and feedback-driven refinement.

Conceptualization: The initial phase focused on defining the game's core objectives—raising awareness about carbon emissions through an engaging, character-driven experience. During this stage, key mechanics like the "Penguin's Eye" and various disruptive actions were designed to integrate educational elements seamlessly within gameplay. Additionally, the levels were conceptualized to represent a range of everyday environments where carbon emissions are prevalent, making the educational content relevant and intuitive for players.

Prototyping: With the core concepts in place, a functional prototype was created to test the main gameplay mechanics. The prototype included a basic version of the "Penguin's Eye" tool, initial character animations, and preliminary level designs for testing. This prototype allowed developers to explore and evaluate early user interactions, focusing on ease of navigation, clarity of objectives, and the effectiveness of carbon visualization in enhancing environmental awareness.

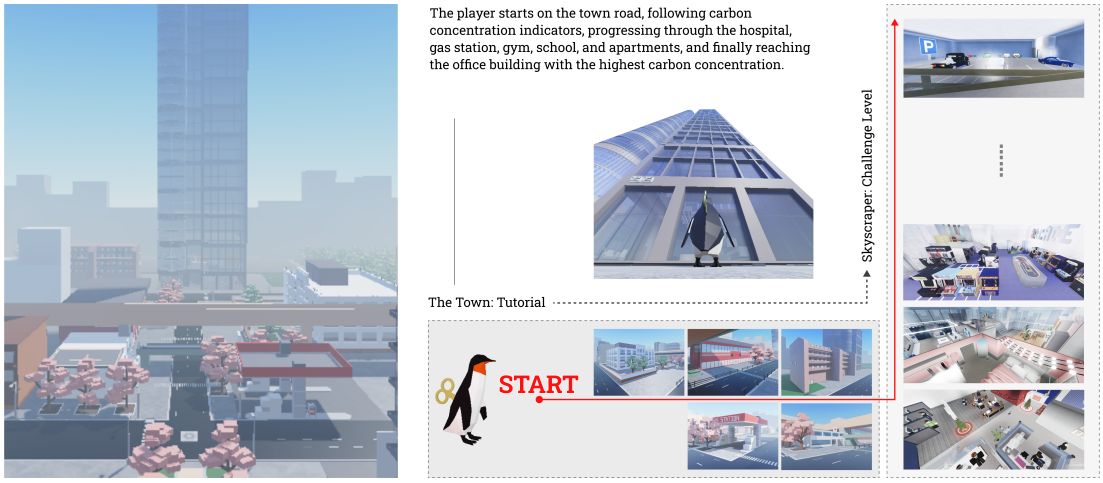


Figure 5: Game map design showcasing progression from the town tutorial to the skyscraper challenge, highlighting increasing carbon concentration and gameplay complexity

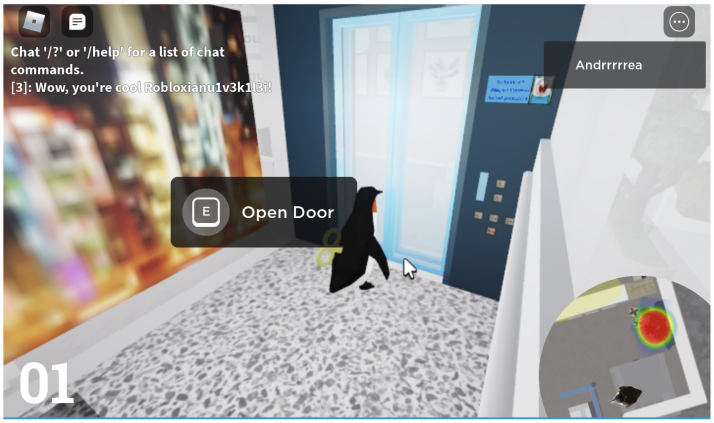
User testing and iteration: User testing was conducted in multiple stages to collect initial feedback and refine the gameplay experience. Early playtesting sessions involved a small group of users who provided insights on game controls, character design, and the educational impact of the "Penguin's Eye." Feedback on these elements guided adjustments to improve usability, visual clarity, and engagement. Each testing phase concluded with a round of refinements, including adjustments to the visual interface, enhancements to interactive elements, and modifications to difficulty levels based on user interactions and comprehension.

Initial user feedback was collected primarily through direct observation and post-session interviews, where players were encouraged to share their thoughts on gameplay experience and learning outcomes. Iterations were conducted using an agile development approach, allowing developers to address specific feedback in each cycle. This iterative process ensured that the game's mechanics aligned with its educational goals, enhancing both playability and the depth of its carbon emission awareness messaging.

4.2. Data collection and analysis

To evaluate *Angry Penguin*'s educational impact and gameplay efficacy, a combination of qualitative and quantitative data collection methods was used.

- **Behavior Tracking**: The system records participants' interaction behaviors. This includes time spent on tasks or scenarios, frequency of tool usage, and the proportion of core tasks completed compared to optional tasks. These data are used to analyze participants' navigation strategies, task engagement, and responses to the learning content.
- **Questionnaire Survey**: After completing tasks or activities, participants fill out questionnaires. The surveys collect quantitative data on their understanding of the content and changes in perception. Questions focus on knowledge retention, emotional feedback, and willingness to adopt sustainable behaviors, using Likert scales and multiple-choice questions to evaluate their engagement and comprehension.
- **Interviews**: In-depth interviews were conducted with some participants to gather qualitative insights. The interviews explored their understanding of key features, emotional connections, and views on the effectiveness of design mechanisms. This helped identify which educational and experiential elements resonated most with participants.



Use the Penguin's Eye to locate high carbon-emission events or items

Find the corresponding item and attack it to interrupt carbon emissions

Object successfully destroyed, proceed to the next location

Figure 6: Gameplay mechanics demonstration: Using the "Penguin's Eye" to locate high-carbon-emission items, interacting with objects to disrupt emissions, and progressing to the next challenge after successful actions

Analytical Approach: The analysis combined descriptive statistics and thematic analysis to evaluate the impact of *Angry Penguin*. Quantitative methods included:

- **Paired-sample t-test**: This statistical method was used to compare pre- and post-game survey scores. The null hypothesis (H_0) assumed no significant difference between the scores, while the alternative hypothesis (H_1) posited a positive impact. The t-test evaluated whether the mean

difference between two related samples was statistically significant.

- **Correlation analysis**: This was used to examine the relationship between engagement metrics (e.g., tool usage frequency, task completion rates) and knowledge retention or behavioral changes. Correlation coefficients (r) and p-values were calculated to quantify the strength and significance of these relationships.

By integrating these data sources, the study captured the educational impact of Angry Penguin, exploring both players' cognitive understanding of carbon emissions and their emotional responses to environmental themes. [25]

5. Experiment design and user testing

5.1. Target audience and testing approach

The target audience for Angry Penguin includes environmentally conscious individuals, students, and casual gamers. Young adults aged 18-25 were chosen because they are familiar with computers and gaming. This familiarity helps control variables and allows for a clear evaluation of the game's educational impact.

Participants were recruited through social media, university mailing lists, and environmental forums. A total of 100 participants with balanced demographics were selected. A subset with diverse backgrounds and levels of sustainability knowledge provided insights into the core research questions. Future studies could include a wider age range to confirm these findings.

Table 2
Participant Information with Areas of Expertise and Sustainability Knowledge Level

Abbr.	Age	Gender	Areas of Expertise	Sustainability Knowledge Level
P1	18	Woman	Education	Low
P2	20	Man	Data Analysis	Medium
P3	22	Man	UX Design	High
P4	24	Woman	Environmental Science	High
P5	21	Man	Game Development	Medium
P6	23	Woman	Psychology	Low
P7	19	Woman	Social Media	Medium
P8	22	Man	Marketing	High
P9	25	Man	AI Research	Low
P10	24	Woman	Sustainability Advocacy	High

Testing methods: A mixed-methods approach was employed, combining pre- and post-game surveys, in-game behavior tracking, and semi-structured interviews.

- **Pre-game survey**: Participants completed a survey assessing their baseline understanding of carbon emissions and environmental impact. This survey included multiple-choice and open-ended questions to capture both factual knowledge and subjective attitudes toward sustainability.[26]
- **Gameplay session**: Participants were instructed to play *Angry Penguin* for 60 minutes, completing at least two levels while engaging with core and optional objectives. In-game tracking recorded their interactions, including time spent using the "Penguin's Eye," number of completed tasks, and exploration of optional objectives.[27]
- **Post-game survey**: After gameplay, participants answered questions measuring knowledge acquisition, emotional engagement, and perceived impact of the game. The survey included Likert-scale questions to quantify changes in understanding and attitudes, as well as open-ended responses to capture qualitative feedback.[28] [29]

- **Follow-up interview**: A subset of 20 participants was selected for in-depth interviews, focusing on their reflections on gameplay experience, emotional connection to the game's message, and perceived relevance of the educational content.[30]

5.2. Evaluating educational impact

Quantitative analysis:

- **Knowledge absorption**: Changes in participants' knowledge were measured by comparing pre- and post-game survey scores. A paired t-test was conducted to evaluate statistically significant differences in knowledge levels, focusing on players' ability to identify carbon-heavy activities and understand emission sources.[31]
- **Engagement metrics**: In-game data, such as the frequency of "Penguin's Eye" usage, task completion rates, and time spent on optional objectives, were analyzed to quantify player engagement. Correlations between engagement levels and post-game survey scores were examined to determine whether more interactive gameplay led to greater knowledge retention.[32]

Qualitative analysis:

- **Behavioral reflection**: Open-ended survey responses and interview transcripts were analyzed using thematic coding to identify recurring themes in players' reflections on their behavior. Key themes included the emotional impact of the penguin character, the clarity of the "Penguin's Eye" visualization, and the perceived relevance of the carbon knowledge cards.[33]
- **Long-term impact**: Interviewees were asked about potential changes in their daily habits inspired by the game. Responses were coded to assess the extent to which the game influenced players' willingness to adopt sustainable practices, such as reducing energy consumption or seeking alternative transportation.[34]

Results integration: Quantitative findings were triangulated with qualitative insights to present a robust evaluation of the game's impact. For instance, players who exhibited high engagement (frequent use of the "Penguin's Eye" and completion of optional objectives) often demonstrated more nuanced reflections in interviews, indicating a deeper absorption of the game's educational content. Conversely, participants with lower engagement tended to show minimal changes in survey scores, highlighting the importance of interaction depth in fostering meaningful learning experiences.

Control measures: To ensure the validity of the findings, participants were grouped by prior environmental knowledge (low, medium, high) based on pre-game survey scores. This stratification allowed for an analysis of how *Angry Penguin* influenced players with varying levels of familiarity with carbon emissions. Control questions unrelated to the game's content were included in the surveys to account for potential biases.

Conclusion: The combination of quantitative performance metrics and qualitative reflections provided a comprehensive understanding of how *Angry Penguin* educates players about carbon emissions. By evaluating both immediate knowledge absorption and potential long-term behavioral shifts, the study demonstrates the game's effectiveness as a tool for environmental education and advocacy.

6. Results and analysis

6.1. User feedback on game experience

Participants provided valuable feedback on the design and mechanics of *Angry Penguin*, highlighting strengths and areas for potential improvement. Key findings are summarized below, with additional context and definitions for clarity:

- **Character design**: The protagonist's design received high praise for its humor and relatability ($M = 4.7$, $SD = 0.5$). Participants highlighted how the penguin's animations and character traits

made them more emotionally connected to the game's themes. One participant noted, "The penguin's animations were adorable but also made me care about the issues it faced." This emotional connection aligns with the intended goal of using character-driven storytelling to enhance engagement and learning outcomes.

- **Level structure**: Levels scored an average of 4.5 (SD = 0.6), with users appreciating realistic settings such as hospitals and office environments. These settings were described as relatable and reflective of real-life decisions, such as turning off appliances or reducing unnecessary energy use. A participant remarked, "The tasks reminded me of real-life decisions, like turning off appliances." This feedback supports the game's educational intent to connect virtual scenarios with real-world behaviors.
- **Core gameplay mechanics**: The gameplay was rated highly at 4.6 (SD = 0.4) for its balance of fun and education. Participants particularly enjoyed solving puzzles integrated with environmental challenges, with tasks like disabling HVAC systems standing out as highlights. This suggests that embedding educational goals within engaging gameplay can effectively foster interest while delivering meaningful content.
- **"Penguin's Eye" feature**: This mechanic was valued by 92% of participants for its ability to visualize otherwise invisible carbon emissions, described as insightful and impactful. One participant reflected, "It's like seeing the hidden damage around us—we ignore so much every day." This feature aligns with the game's objective to make abstract environmental impacts tangible and actionable.
- **Engagement with optional objectives**: Optional tasks were completed by 88% of participants, who described these elements as adding depth and flexibility to the gameplay. Optional objectives, such as exploring additional tasks and collecting carbon knowledge cards, were noted as effective in emphasizing the broader implications of player choices. As one participant stated, "The carbon knowledge cards made me realize the broader impact of my choices."
- **Task completion rates**: On average, 85% of in-game tasks were successfully completed, demonstrating strong user involvement throughout the experience. This high completion rate suggests that the game design was accessible yet challenging enough to maintain player engagement.

Discussion: While the results indicate strong positive feedback across all dimensions, the findings also highlight areas for further refinement. For example, while most participants engaged with optional tasks, feedback suggests additional guidance or incentives could further enhance engagement. Similarly, while the "Penguin's Eye" was highly effective, future iterations could explore expanding its functionality to cover more nuanced environmental scenarios.

6.2. Educational outcomes and behavioral insights

The results demonstrate that *Angry Penguin* had a significant impact on participants' knowledge retention, reflective behaviors, and engagement:

1. **Knowledge retention**: Across all groups, knowledge scores increased by an average of 31%. Low-awareness participants improved from 40% (SD = 5.2) to 75% (SD = 4.8), moderate-awareness participants improved from 50% (SD = 6.1) to 88% (SD = 5.3), and high-awareness participants increased from 70% (SD = 4.5) to 90% (SD = 3.7). Statistical analysis using paired-sample t-tests confirmed the significance of these improvements ($t(45) = 8.27$, $p < 0.01$).
   Figure 8 provides a visual representation of these knowledge retention trends before and after gameplay across the three participant groups. Notably, low-awareness participants demonstrated the most substantial improvement, suggesting the game's potential to bridge knowledge gaps for individuals with less prior understanding of environmental issues. This aligns with the goal of engaging a broad audience and fostering awareness in diverse groups.
2. **Behavioral reflection**: Reflection scores improved significantly across all groups, with an average score of 4.7 (SD = 0.4) post-game. Participants noted a heightened awareness of hidden

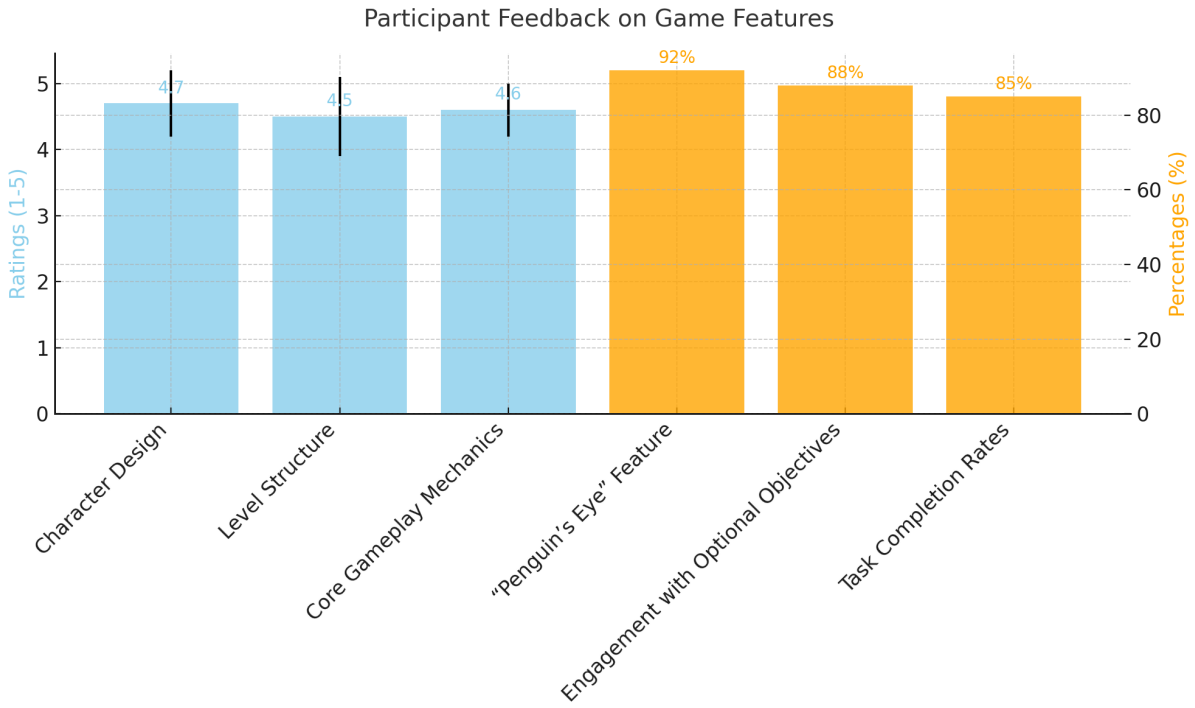


Figure 7: Participant feedback on game features

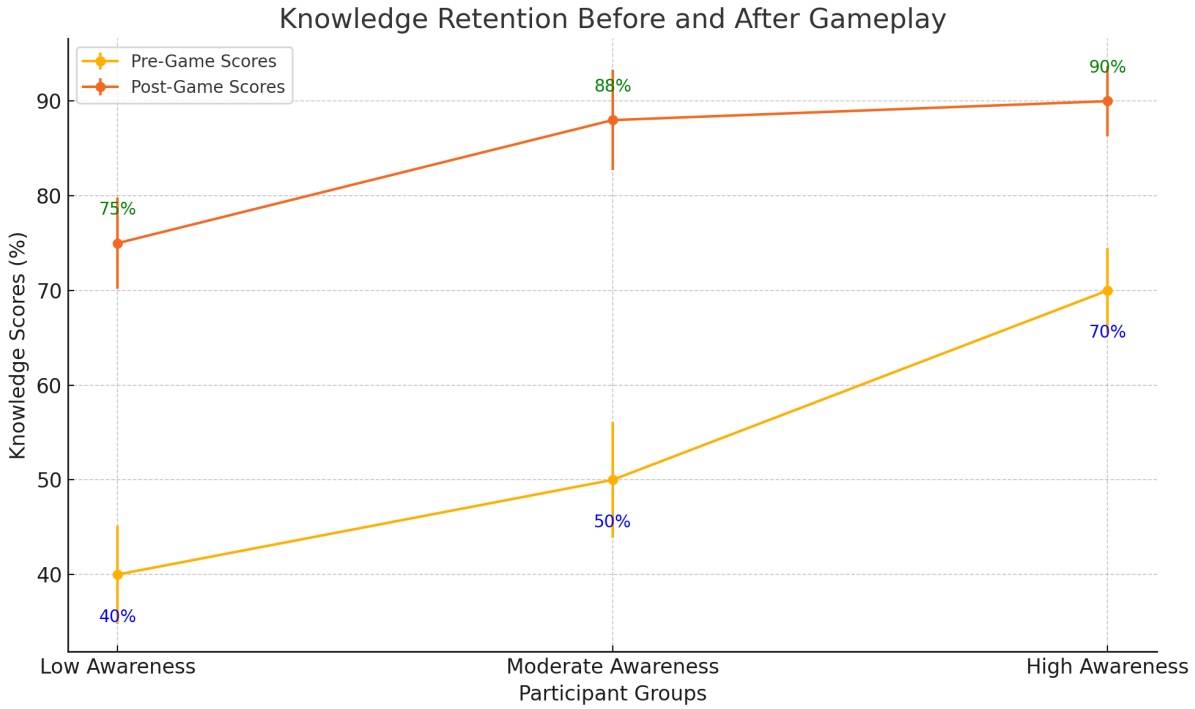


Figure 8: Knowledge Retention Before And After Gameplay

environmental impacts. One player remarked, "I didn't realize how much electricity things like treadmills use—it's a wake-up call." The paired-sample t-test confirmed a statistically significant improvement in reflection scores ($t(45) = 7.89$, $p < 0.01$).

3. **Engagement insights**: Players who engaged more with optional objectives exhibited better knowledge retention and provided richer reflections. Correlation analysis showed a strong positive relationship between engagement metrics (e.g., optional task completion rates, tool usage frequency) and post-game knowledge retention ($r = 0.65$, $p < 0.01$). This suggests that deeper interaction with game elements enhances the educational impact.
4. **Real-world behavioral intentions**: 65% of participants indicated intentions to adopt more sustainable behaviors, such as reducing energy consumption. One participant shared, "I'm more conscious of leaving devices on unnecessarily—small changes matter." Although qualitative in nature, these responses highlight the potential for the game to influence real-world actions.

Statistical Analysis Details: The paired-sample t-tests evaluated significant changes in pre- and post-game knowledge retention and reflection scores. The null hypothesis (H_0) assumed no significant difference between pre- and post-game scores, while the alternative hypothesis (H_1) posited a positive impact. Cohen's d was calculated to measure effect size, with medium-to-large values indicating practical significance. Confidence intervals (95%) provided additional validation of the results.

Correlation analysis assessed the relationship between gameplay engagement (e.g., optional task completion rates) and educational outcomes. The observed strong correlation ($r = 0.65$) highlights the importance of engagement in enhancing learning outcomes and reflective behaviors. These findings underline the effectiveness of *Angry Penguin* in fostering environmental awareness and inspiring behavior change.

6.3. Discussion of findings

The findings underscore the effectiveness of gamified approaches, like *Angry Penguin*, in blending education with entertainment to enhance user engagement and knowledge retention. Participants responded positively to features such as the Penguin's Eye, which effectively visualized carbon emissions and guided gameplay. This highlights the significant potential of visual tools in raising awareness and making abstract concepts tangible.

Moreover, the game's layered design—combining core tasks with optional objectives—proved successful in fostering exploration and deeper interaction, particularly among players with lower baseline environmental awareness. The strong knowledge absorption rates across all participant groups demonstrate the ability of interactive mechanics to address diverse learning needs. These results align with existing research on gamified learning, further validating the role of immersive environments in knowledge dissemination.

However, challenges remain in translating in-game awareness into sustained real-world behavioral changes. While a majority of participants expressed intent to adopt sustainable practices, maintaining long-term motivation requires deeper integration of behavioral reinforcement mechanisms. Future research could explore adaptive feedback systems, longitudinal interventions, or multiplayer collaborations to enhance the impact of such games beyond the immediate gameplay experience.

Additionally, the findings reveal opportunities to refine the game's design to cater to different demographics. For example, younger participants found the humorous and empathetic aspects of the protagonist particularly engaging, while older participants were more focused on the cognitive elements of the gameplay. These insights suggest the need for customizable features that align with diverse user preferences and motivations.

7. Conclusion

This study explores the design and evaluation of *Angry Penguin*, a gamified approach to raising awareness about carbon emissions. By integrating interactive mechanisms such as the "Penguin's Eye" and diverse

urban scenarios, the game provides players with an engaging way to understand the environmental impact of everyday activities. Its progressively challenging design and dynamic tasks encourage critical thinking, achieving a balance between entertainment and education.

Empirical evaluations revealed that the game significantly improved participants' knowledge retention and reflective behaviors, enhancing their understanding of carbon footprints. Engagement with optional tasks and game challenges further demonstrated the game's ability to sustain interest while delivering educational value. Feedback also highlighted players' emotional connection to the protagonist, emphasizing the potential of character-driven storytelling to enhance learning outcomes.

The findings suggest that *Angry Penguin* is not only an effective environmental education tool but also demonstrates the broader potential of gamification in addressing real-world issues. Future research could explore expanding game mechanics to include cooperative gameplay or real-world action tracking, further bridging the gap between virtual experiences and behavioral change.

From the perspective of interaction design, this study contributes to the growing field of gamified education by showcasing the power of immersive storytelling and meaningful gameplay in fostering environmental awareness.

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A. Appendix: Survey questionnaire

The following pages contain the survey questionnaire.

The following pages contain the survey questionnaire.

01 Pre-Testing Survey: Baseline Knowledge and Attitudes

Section 1: Demographic Information

1. Age: _____
2. Gender: _____
3. Occupation/Student Status: _____
4. Have you played any educational or sustainability-themed games before? (Yes/No)
5. On a scale of 1–5, how familiar are you with the concept of carbon emissions?
   1: Not familiar
   5: Very familiar

Section 2: Knowledge Assessment

1. Which of the following is the largest contributor to global carbon emissions? (Select one)
   A) Transportation B) Agriculture C) Industry D) Residential energy use

2. What is the average carbon footprint (in metric tons) per person per year in developed countries?
   A) 2-4 tons B) 5-10 tons C) 10-20 tons D) Over 20 tons

3. Which of these activities has the smallest carbon footprint? (Select one)
   A) Driving a car for 10 miles B) Charging a smartphone overnight
   C) Eating a beef burger D) Taking a 1-hour flight

Section 3: Attitudes Toward Sustainability

1. On a scale of 1–5, how important do you think reducing carbon emissions is?
   1: Not important at all 5: Extremely important

2. How often do you consider carbon emissions when making daily choices (e.g., transportation, food)?
   A) Never B) Rarely C) Sometimes D) Often E) Always

3. What do you believe is the most effective way to reduce carbon emissions? (Open-ended)

Section 4: Familiarity with Gamified Learning

1. Have you previously played games designed for educational purposes? (Yes/No)

2. On a scale of 1–5, how effective do you think games can be for learning about complex topics like climate change?
   1: Not effective 5: Very effective

Section 5: Expectations for Angry Penguin

1. What do you expect to learn or experience from playing this game? (Open-ended)

02 Post-Test Questionnaire

Section 1: Overall Gameplay Experience

1. What is your overall rating of the game on a scale of 1 to 5?
   1: Poor,
   5: Excellent

2. Which aspects of the game did you enjoy the most? (Open-ended)

3. Were there any moments in the game that felt confusing or frustrating? Please explain.

4. Would you recommend Angry Penguin to others interested in learning about carbon emissions? (Yes/No) Why?

Section 2: Educational Impact

1. Did the game help you understand carbon emissions better? (Yes/No) Please explain.

2. Which feature or mechanic of the game contributed the most to your learning? (e.g., "Penguin's Eye," level designs, hidden objectives)

3. On a scale of 1 to 5, how likely are you to consider the knowledge you gained from the game in your daily life?
   1: Very unlikely,
   5: Very likely

4. Did the game inspire you to reflect on your own carbon footprint or behaviors? (Yes/No) If yes, in what way?

Section 3: Engagement and Motivation

1. On a scale of 1 to 5, how engaging did you find the gameplay?
   1: Not engaging at all,
   5: Extremely engaging

2. Did you feel motivated to complete optional tasks or explore hidden objectives? Why or why not?

3. Which level or scenario did you find the most impactful or memorable? Why?

Section 4: Feedback and Suggestions

1. What aspects of the game would you like to see improved?

2. Are there any additional features or content you think would enhance the game?

3. How could the game better connect its educational content to real-world applications?

Closing Thank you for sharing your feedback! Your responses are invaluable in improving Angry Penguin and making it an effective tool for environmental education.

03 Knowledge-based Questionaire

The following pages contain the knowledge-based Questionaire.

Knowledge-Based Questionnaire
- Common Carbon Emission Sources in Offices

1. Which of the following behaviors will significantly increase office energy consumption and lead to high carbon emissions?
   a) Keeping air conditioning on for long periods when no one is using the office
   b) Setting computers to “sleep mode” instead of fully shutting them down
   c) Keeping lights on even when natural light is sufficient
   d) Turning off all office equipment after work hours

2. Which behavior is the least beneficial for reducing office carbon emissions?
   a) Turning off air conditioning and some lights during lunch breaks
   b) Keeping high-power devices (e.g., ovens or water heaters) running unnecessarily for long periods
   c) Consolidating printing tasks to specific times
   d) Using email to share documents instead of printing

3. Which devices are the highest sources of carbon emissions in an office?
   a) Long-unused and poorly maintained air conditioning systems
   b) Electrical outlets and devices with leakage issues
   c) Multifunction printers left in standby mode for extended periods
   d) Unused but running projectors in meeting rooms

4. Recognizing Behaviors That Affect Carbon Emissions Which behavior significantly increases energy consumption in the office?
   a) Providing employees with rechargeable devices
   b) Turning off monitors when leaving desks
   c) Running air conditioning while windows are open
   d) Using natural light for meetings instead of turning on all lights

5. Which of the following actions reduce office carbon emissions the most? (Select all that apply)

a) Moving meetings to smaller spaces to reduce air conditioning needs
b) Installing motion-sensor lighting to reduce energy use
c) Using electric heaters for extended periods instead of central heating
d) Replacing outdated high-energy-consuming devices with energy-efficient ones

6. Which printing practice helps reduce carbon emissions the most?
   a) Using double-sided printing to reduce paper usage
   b) Increasing printer resolution for higher-quality outputs
   c) Printing once and photocopying instead of printing multiple copies
   d) Sharing files in PDF format instead of printing

7. What is the most environmentally friendly action when a meeting room is unoccupied?
   a) Turning off all lights and projectors
   b) Keeping devices running to save restart time
   c) Setting air conditioning to maintain room temperature
   d) Keeping curtains open to enhance natural lighting

Identifying Carbon Emission Sources and Taking Action

1. Which office devices require regular maintenance to reduce energy consumption? (Select all that apply)
   a) Air conditioning filters
   b) Meeting room projectors
   c) Old fluorescent lamps used for lighting
   d) Desktop computers on office desks

2. Which actions indicate high-carbon-emission activities? (Select all that apply)
   a) Printing small batches of documents multiple times daily
   b) Sharing a single monitor for group presentations when many users are present
   c) Equipping each employee with individual heating devices
   d) Consolidating infrequently used documents for weekly printing

3. Which behavior most improves office energy-saving performance?
   a) Regularly checking electrical circuits to reduce leakage issues
   b) Increasing the use of disposable cups
   c) Setting all devices to run continuously throughout the day
   d) Keeping equipment in standby mode during lunch breaks to save restart time