GreenMate: A Serious Game Educating Children about Energy Efficiency

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***Abstract*—Improving the energy efficiency and reducing the CO_2 emissions are key strategic objectives for governments on an international level. Although children represent the future energy consumers and efforts have been made to enhance their understanding of energy consumption, there is a lack of initiatives focused on assessing children's awareness regarding energy usage at home and school. Serious games present a highly effective approach to educate and raise children's awareness about energy production and consumption; they are widely used to simulate real-world scenarios, inform or raise players' awareness, and stimulate their problem-solving abilities. Moreover, they assist players in visualising their actions and intuitively exploring different events. This paper discusses the development of a serious game, the GreenMate game, which visually portrays the daily activities and experiences of a primary school student. It incorporates progressive levels to enhance comprehension and knowledge of the diverse factors influencing the growing energy crisis, as well as strategies for managing and mitigating them. According to our experimental findings, the GreenMate game can be used as a productive educational tool to effectively foster desired changes in children's behavior regarding energy consumption.**

***Index Terms*—children, energy efficiency, energy sustainability, green energy, serious games**

I. Introduction

DECARBONISING the power sector and delivering cost-effective solutions for boosting the economy are key strategies both on national and international levels. Children, being the future energy consumers and producers (i.e. prosumers) should be aware of how much energy they use from an early age, e.g. which electrical appliances consume the most electricity or how much they are charged for using them in particular time periods [22].

While children can acquire knowledge about energy through dedicated science modules or experiments at school, games serve as a highly effective method to educate and train them on efficient energy consumption. Games usually entail interactions between independent decision-makers striving to achieve their goals within a defined environment. Within the context of a game, specific rules are in place, and players engage in competition against their adversaries to accomplish their respective objectives. However, not all games revolve around competition; some involve players cooperating to achieve a shared objective without individual goals. While games can be played solely for enjoyment, there are specific games, known as serious games [6], which possess a distinct and deliberate educational purpose, prioritising learning over entertainment [28].

The primary objective of serious games is to impart education in diverse forms, with an emphasis on fostering skills such as decision-making, critical thinking, and analytical abilities among players [14], [1], [29]. Regardless of age, serious games prove highly effective in teaching and training players, efficiently communicating various concepts. These games not only facilitate learning but also provide opportunities for players to apply and demonstrate their acquired knowledge throughout the gameplay [35], [16].

Given the pivotal role young minds play in shaping the future of our planet, overlooking their specific needs in serious games is a missed opportunity. For children aged 6-12 years, their cognitive dimension involves understanding basic energy concepts, climate change, and energy-saving behaviors. While knowledge is crucial for informed decision-making, its direct impact on pro-environmental actions can be limited. Emotional responses, encompassing the affective dimension, reveal children's feelings towards energy waste and the consequences of climate change, motivating energy-saving behaviors. This emotional connection is essential for nurturing a sense of responsibility and capability in forming energy-saving habits. From a behavioral perspective, children's abilities to make informed energy decisions and adopt climate-friendly actions are crucial. Developing energy-saving habits early on is key for long-term adherence into adulthood. Lastly, the moral dimension delves into children's developing moral judgments about energy waste and energy saving behavior. Even at a young age, children begin to form morally-based views on environmental harm, considering actions detrimental to nature as morally incorrect. As they mature, concepts of fairness and perspective-taking further develop, laying a foundation for effective energy saving literacy education [22].

Therefore, this paper discusses the development of a serious game, the GreenMate game, which was designed based on the Six Facets of Understanding [18], the Bloom's taxonomy [3] and Kolb's Learning Cycle [31] to increase players' understanding of energy consumption and carbon emissions through simple and daily scenarios. The primary objective of this game is to enhance players' knowledge and comprehension of energy conservation, empowering them to minimise energy wastage effectively.

Our research questions were:

- **RQ1:** How can we design a serious game to effectively raise awareness on energy consumption among children in primary education?
- **RQ2:** How effective can a serious game be in enhancing children's knowledge and awareness of energy consumption across various age groups and geographical locations?

Accordingly, this paper is structured as follows. Section II provides the motivation for our work and focuses on reviewing serious games related to the energy sector. In Section III, we detail the approach taken to design the GreenMate game, integrating appropriate learning methodologies and give an overview of the whole game. The results of our experiments, highlighting positive impacts on various aspects of children's energy-related knowledge and behaviors, are presented in Section IV. Finally, Section V concludes our work with reflections on the effectiveness of the GreenMate game as an educational tool and provides insights for future development.

II. Background & Motivation

Over the years there have been many efforts and attempts on national and international levels to help children understand the concept of energy and how we use it in our everyday life. Developing a solid understanding of energy consumption and conservation can foster a deeper appreciation for the environment and contribute to the well-being of future generations. At school, children can learn about energy through science modules, experiments, books, and even artistic methods like illustrations and sketches. Another highly effective approach to educate and raise children's awareness about energy production and consumption is through serious games citewu2020serious. Throughout the gameplay, players gain new knowledge, hone their social skills, and practice decision-making [5]. Additionally, they have the opportunity to showcase what they have learned during the game, an achievement that might be otherwise impractical in the real world due to safety, cost, or time constraints [30], [25].

Serious games have found extensive use in the energy sector [15], identifying key target areas aimed at fostering environmental awareness and promoting sustainable behaviors. These encompass environmental education, where individuals are educated about relevant environmental topics and provided with knowledge about specific behaviors. Additionally, serious games in the energy sector aim to enhance consumption awareness by increasing understanding of energy usage, spanning both personal consumption and that within specific environments like households or offices. Furthermore, these games seek to stimulate and evaluate energy efficiency behaviors, encouraging the adoption of practices that effectively reduce energy consumption. Through these targeted approaches, serious games contribute to advancing environmental literacy and promoting sustainable actions among individuals [19]. While serious games share similarities with simulation-based learning, their defining characteristic lies in the incorporation of competitive and entertainment elements aimed at engaging players. This emphasis fosters emotional involvement, contrasting with the more impersonal approach often associated with simulations and traditional learning techniques [7].

Social Mpower [4] is a serious game that challenges players to prevent a collective blackout by synchronising and coordinating their actions to reduce individual energy consumption. In this game, players assume the role of consumers confronted with real-world energy issues, and their objective is to avert blackouts by responsibly decreasing energy usage while sustaining the Common-Pool Resource (CPR) [20]. Players must collaborate to prioritise distribution in an economy of scarcity, ensuring a fair allocation and sustaining the community throughout the gameplay. A remarkable 72.4% of all 87 players strongly agreed that *Social Mpower* is highly effective as an educational tool, helping them to proactively avoid potential energy problems in the future.

In the Loop [32] is a serious board game where participants step into the shoes of manufacturing company CEOs, striving to gather seven 'Progress Points' through efficient resource management and product manufacturing. The primary goal of the game is to foster experiential learning regarding material criticality and Circular Economy (CE) principles. Operating on a turn-based mechanism, the game is designed to deepen players' understanding of the advantages of CE methodologies by showcasing the origins, consequences, and potential remedies for material criticality challenge.

EnerCities [8], a European initiative, presents a serious gaming platform where participants are tasked with constructing sustainable cities. Starting with a small village and limited land, players utilize a drag-and-drop interface to construct diverse structures, including residential and industrial zones, renewable and non-renewable energy sources, and green spaces, facilitating city expansion. The primary objective is to harmonize the needs of people, planet, and profit by ensuring adequate electricity supply, implementing energy conservation measures, reducing CO_2 emissions, and minimizing reliance on fossil fuels. Players' decisions have direct consequences on their city's performance in the areas of people, planet, and profit. Successful gameplay unlocks additional city space and strategic options, enabling players to experiment with different approaches and observe the enduring results of their actions. The duration of the game typically ranges from 15 to 45 minutes, determined by the strategies chosen by the player.

The objective of players in the *NRG* game [12] revolves around the management of household energy consumption. This entails responsibilities such as paying gas and electricity bills, acquiring new appliances, generating energy through solar panels or wind turbines, trading appliances for financial returns, enhancing thermal or electric efficiency via investments in insulation or smart meters, among other actions. Players are provided with monetary resources over the course of the game, simulating real-life income, enabling them to make purchases. Following each game round, players can assess their performance, including energy consumption, energy production (if opted for), overall comfort levels, appliance and furniture conditions, electricity and gas expenditure, and annual income.

This data serves as the basis for analyzing player behavior and attitudes towards energy consumption. The primary objective of the serious game *NRG* was to explore rebound effects rather than to specifically target behavior change. This aspect could explain the relatively lower incorporation of Behavior Change Techniques (BCTs) within the game's framework [10].

Spent [26] is a text-based game which places the player in the scenario of a single parent who is unemployed and has recently become homeless. The gameplay commences with the challenge of surviving on $1000 for the next month. Upon securing employment, the player encounters a series of decisions, including finding housing, paying for car insurance, joining a union, and purchasing food. Each decision influences the player's financial status, represented by a money barometer. The challenge of the game lies in making choices akin to those one would typically make in their own life but within the constraints of the limited financial resources available to the player. *The Island* [27] unfolds across five cities, traversing eight seasons, where players navigate distinct decision-making scenarios in each location. Detailed data on weather conditions, such as sunlight and wind intensity, informs the efficacy assessment of various energy stations, including solar panels. Equipped with an initial budget, participant groups collaboratively decide whether to expand housing options, choosing from alternatives with differing energy efficiency profiles. Additionally, they engage in agricultural endeavors, strategically selecting suitable regions for cultivation, and establish diverse industrial ventures. As each season transitions, participants evaluate environmental repercussions, gauging shifts in pollution levels alongside citizen satisfaction following their decisions. The game intricately integrates economic, environmental (climatic, soil conditions), and social (energy infrastructure, housing, transportation, employment) considerations, aligning with a wide array of Sustainable Development Goals (SDGs).

Moreover, the game *We Energy Change* [21] aims to increase awareness of the challenges related to providing cost-effective energy from renewable sources to meet the needs of an entire town. The primary objective is to create an optimal and sustainable energy mix. Players have the responsibility to negotiate, taking on their designated roles, to determine the energy sources to be employed and their suitable locations. The ultimate aim is to convert the town into a self-sufficient and energy-neutral community. The *EVIDENT* project[1] serves as a case study, showcasing the practical implementation of social strategies within serious games [9]. The data analysis emphasises the beneficial outcomes stemming from social strategies such as peer comparison, collaboration, and competition. It further delves into how social components in serious games influence the advancement of energy-related behavioral shifts. Finally, the *power saver game* [11] examines how competition can influence household energy conservation. It considers the attitudes, knowledge levels, and behavioral shifts among participants who engage in the game both with and without the competitive element. The integration of practical energy-saving tasks and real-time feedback within the game enhances its effectiveness. Over an extended period, the findings reveal a noteworthy 8% decrease in energy usage attributed to the presence of competition. Path analysis validates the connection between knowledge alteration, shifts in attitudes, and modifications in behavior.

In our analysis of similar games, as outlined in Table I, a significant gap became evident. Most of these games fail to cater to the specific needs and developmental stages of young children, particularly those aged 6 to 12. To genuinely foster energy awareness in young minds, games must be designed with pedagogical considerations and age-appropriate content. In response to these needs, the GreenMate game was enriched with:

- familiar metaphors and relatable tasks to engage young players effectively,
- timed interactive experiences mirroring real-life situations, fostering a sense of responsibility and empowerment,
- opportunities to witness the direct impact of energy choices in a relatable context.

By incorporating these elements, GreenMate can bridge the comprehension gap and facilitate a deeper understanding of how seemingly simple energy decisions made in everyday life can wield a profound impact on the environment.

III. The GreenMate Game

GreenMate is a serious game designed to educate children aged 6-12 about the growing concerns of energy wastage and carbon emissions. The game serves as a virtual representation of the daily life of a primary school student, integrating various levels to enhance comprehension of the factors contributing to the energy crisis and methods to manage and reduce them. Grounded in established educational theories, the game aims to provide a robust and effective learning experience that goes beyond mere fact-based learning. Specifically, the game design draws upon Piaget's theory [24], emphasizing the active construction of knowledge through interactions with the environment. This theory informs engaging activities that enable children to explore and experiment with energy-saving concepts, fostering a deeper understanding of environmental sustainability. Furthermore, our study was informed by research on children's energy literacy [2], recognizing them as pivotal decision-makers for future sustainability. Despite their significance and contribution, children remain underrepresented in studies targeting household energy literacy enhancement. We prioritized age-appropriate design principles, leveraging children's inherent interest in exploring nature-based themes and engaging activities like sorting out recyclables, to foster energy literacy effectively. As children aged 6 to 12 undergo a significant transition in their social orientation and logical categorization skills [23], our game design integrates real-time monitoring features [34] for energy consumption. This is facilitated through a 'tree buddy,' where the color-changing leaves serve as visual indicators of energy use, along with the monitoring of various appliances. These elements were integrated to provide gameplay scenarios that closely mirror real-life situations, enhancing the relevance and effectiveness of the serious game experience.

[1]https://evident-h2020.eu/

TABLE I: A Comparative Summary of GreenMate and Other Games/Studies

Game/Study	Participants	Prior Knowledge Required	Real-World Energy Issues	Efficient Resource Management	Decision-Making	Real-Time Feedback	Behavioral Change
Social Mpower [4]	Adults	No	Yes	Yes	Yes	Yes	Yes
In the Loop [32]	Adults	Yes	Yes	Yes	Yes	No	Yes
EnerCities [8]	Teenagers	No	Yes	Yes	Yes	No	Yes
NRG [12]	Adults	No	Yes	Yes	Yes	No	Yes
Spent [26]	Teenagers	Yes	No	Yes	Yes	No	Yes
The Island [27]	Adults	Yes	Yes	Yes	Yes	No	Yes
We Energy Change [21]	Adults	No	Yes	Yes	Yes	Yes	Yes
EVIDENT[1]	Adults	No	Yes	No	No	Yes	Yes
Power Saver Game [11]	Teenagers + Adults	Yes	Yes	Yes	Yes	Yes	Yes
GreenMate	Children	No	Yes	Yes	Yes	Yes	Yes

A. Design Process

The design process for GreenMate was a systematic approach that incorporated established educational theories and iterative feedback to ensure the creation of an engaging and effective learning experience. The process unfolded through the following key stages:

- *Identifying Target Audience and Learning Objectives:* We explored relevant literature to better understand the educational needs, preferences, and learning styles of our target audience concerning energy efficiency education [22]. Recognizing the diverse cognitive development and attention spans among children aged 6-12, we tailored the game's content and mechanics to be both engaging and age-appropriate. Guided by the Six Facets of Understanding, Bloom's Taxonomy, and Kolb's Learning Cycle, we laid the foundation for GreenMate's design.
- *Conceptualization and Storyboarding:* A conceptual framework was developed to define the game's theme, tasks, and gameplay mechanics.
- *Iterative Design and Prototyping:* The design involved iterative cycles of prototyping and user testing. Feedback from 8 children, 5 parents, and 3 gaming experts was instrumental in refining game mechanics, user interface, and educational content to optimize the game's effectiveness in imparting educational outcomes.
- Integration of Educational Frameworks: Educational theories and methodologies (i.e., Six Facets of Understanding, Bloom's Taxonomy and Kolb's Learning Cycle) were seamlessly integrated to amplify the learning experience. The Six Facets of Understanding guided the design of interface features and mini-games, enhancing players' comprehension of energy consumption and carbon emissions. Bloom's Taxonomy facilitated the progression from basic to higher-order cognitive learning, promoting a holistic grasp of energy saving practices. Kolb's Learning Cycle addressed diverse learning styles, ensuring an inclusive and engaging learning platform.
- *Evaluation and Validation:* Usability testing was conducted with 5 children using the think-aloud method to assess the game's usability and engagement levels. Insights obtained from these evaluations were crucial in further refining GreenMate's design, ensuring its alignment with educational goals.

B. Learning Methodologies

Integrating different learning methodologies into the interface design of the GreenMate game plays a pivotal role in creating effective educational experiences for our players. These learning methodologies helped us design an interactive and engaging serious game that caters to diverse learning styles and enhances knowledge retention.

1) Six Facets of Understanding: Six Facets of Understanding [33], [17] represents an educational planning approach that prioritises teaching for comprehension. It exemplifies backward design principles, emphasising the examination of outcomes before formulating curriculum units and classroom instructions. Unlike Bloom's taxonomy, which was designed with an emphasis on educators, these six facets [18] were meticulously developed with a keen understanding of children's psychology and thought processes as a whole.

Table II explains the different Facets of Understanding, and how they have been integrated in the GreenMate game. In GreenMate, players are presented with a series of tasks as they progress through various mini-games that depict the daily life of a primary school student. A dialogue box appears at regular intervals to provide guidance on the correct path and the next set of moves. The Six Facets of Understanding are conceived as six equal and suggestive indicators of comprehension. The interface and mini-games of the GreenMate game have been thoughtfully designed based on these Six Facets of Understanding. These facets have been translated into appropriate interface features, creating a simple, daily scenario that enhances players' understanding of energy consumption and carbon emissions. The primary objective of all mini-games is to instill knowledge and understanding of energy preservation, along with strategies to minimise energy wastage.

2) Bloom's Taxonomy: Bloom's Taxonomy [3] goes beyond being a mere measurement tool for assessing the level of

TABLE II: Visualization of Six Facets of Understanding in Teaching & GreenMate Game

Facets	Visualisation in Teaching	Visualisation in GreenMate
Explanation	To ensure students understand why an answer or approach is the right one.	Players are given a message prompt that asks them to consider "why is this energy wastage?"
Interpretation	To ensure students avoid pitfalls and demand answers that are principled. Students are able to encompass as many salient facts and points of view as possible.	Players are provided with a task aimed at reducing energy consumption, based on the earlier explanation. For instance, they are given time to comprehend that turning off the oven after the timer goes off will help decrease energy usage.
Application	To ensure students' key performances are conscious and explicit reflection, self-assessment, and self-adjustment, with reasoning made evident.	The game incorporates decision-based tasks, requiring players to make informed choices aimed at reducing energy consumption. For example, players might be presented with the option to travel from their houses to school either by car or by bicycle.
Perspective	To ensure students know the importance or significance of an idea and to grasp its importance.	Various stages within the game offer players a broader perspective of knowledge. For instance, players receive tasks set in different rooms of their houses and encounter diverse levels, such as the house, school, and farm.
Empathy	To ensure students develop the ability to see the world from different viewpoints in order to understand the diversity of thought and feeling in the world.	Players are assigned tasks with a focus on the welfare of the entire community rather than just individual benefits. For example, they might be asked to decide between using a bicycle or a car to travel from their houses to school, considering that cars produce more pollution, which can have negative effects on the community.
Self-Knowledge	To ensure students are deeply aware of the boundaries of their own and others' understanding.	During the gameplay, certain tasks are repeated across various levels to assess players' self-knowledge. Additionally, at the end of the gameplay, players are presented with a questionnaire.

understanding in learning through instruction. Instead, it serves as a comprehensive method for assessing the alignment of educational objectives, activities, and assessments within a unit, course, or curriculum. This taxonomy categorises learning into three behavioral domains: cognitive, affective, and psychomotor, with particular emphasis on the cognitive domain due to its wide-ranging applicability in primary, secondary, and tertiary education. In GreenMate, these three domains encompass a total of six major categories; knowledge, comprehension, application, analysis, synthesis, and evaluation. Advancement to the next level relies upon successfully completing each preceding level.

By structuring the game's activities and challenges according to Bloom's taxonomy, we aimed to facilitate players' progression through different levels of cognitive learning, ultimately leading to a comprehensive understanding of energy-saving practices and their environmental impact. We believe that this approach enriches the learning experience within GreenMate and reinforces sustainable behaviors, empowering players to make positive changes in their real lives. Table III shows the incorporation of Bloom's taxonomy in GreenMate.

3) Kolb's Experimental Learning Theory and Learning style: Kolb's learning theory [31] emphasises the significance of experience in the process of knowledge creation, as learning is achieved through active engagement and discovery. The theory is comprised of two main components. Firstly, it introduces a four-stage cycle that outlines the learning process. Secondly, it focuses on learning styles, which refer to the cognitive processes involved in acquiring knowledge. Learners integrate new observations with their existing understanding during each encounter, ideally progressing through each of Kolb's four stages of learning. Integrating Kolb's learning theory into GreenMate can create a more positive and effective learning experience for our players.

- *Concrete Experience:* tasks (i.e., turning off lights or appliances, choosing the most energy-efficient mode of transportation) that simulate real-life situations related to energy consumption; managing energy use in the home, school, or community.
- *Reflective Observation:* in-game feedback and visuals such as change in the color of the trees' leaves to help players assess the impact of their choices on energy consumption and carbon emissions.
- *Abstract Conceptualisation:* provides players with information and knowledge about energy-saving practices through pop-up messages and interface cues. Abstract conceptualisation helps players connect energy-saving concepts and understand their interrelationships.
- *Active Experimentation:* encourages players to test and apply their energy-saving knowledge in new situations and challenges within the GreenMate game.

By integrating Kolb's learning theory and addressing different learning styles, GreenMate caters to a diverse audience and offers a more personalised and effective learning experience. Players can develop a deeper understanding of energy conservation and be inspired to adopt sustainable practices in their real lives. Table IV shows the incorporation of Kolb's Learning Theory in GreenMate.

C. Design & Implementation of GreenMate

In GreenMate, players are tasked with navigating various environmental challenges while learning about sustainable energy practices. The primary objective is to educate players about energy conservation principles through engaging gameplay mechanics and narrative-driven tasks. Players must manage resources efficiently, make informed decisions, and adopt sustainable habits to progress through the game. GreenMate's development is organized around the MDA framework [13] which stands for Mechanics, Dynamics, and Aesthetics, and it is used in game design to categorize different aspects of gameplay: Mechanics – The rules and systems governing the game; Dynamics – The interactions and experiences that emerge during gameplay; Aesthetics – The emotional responses and player experiences evoked by the game. The

TABLE III: Visualization of Bloom's Taxonomy in Teaching & GreenMate Game

Facets	Visualisation in Teaching	Visualisation in GreenMate
Knowledge	Foundational cognitive skills, the retention of specific information like facts, definitions or methodologies in a step-by-step process.	Players are provided with factual information regarding energy-saving practices and their environmental impact. They receive immediate feedback regarding the potential outcomes of specific game tasks. For example, the color of their tree buddy changes in real-time based on the amount of energy saved or wasted, offering visual cues to reinforce learning and encourage sustainable behaviour.
Comprehension	One can demonstrate comprehension by rephrasing the content in their own words, categorising items into groups, making comparisons and contrasts with other similar entities, or effectively explaining a principle to others.	Players showcase their understanding by participating in tasks such as classification exercises, where they have to differentiate between different recyclable materials and correctly identify their respective bins.
Application	Use knowledge, skills, or techniques in new situations.	Players use what they have learned to make smart choices that help save energy in different situations throughout the game. For example, they might decide whether to turn off lights when leaving a room or to unplug electronic devices when not in use, all based on what they have learned about energy conservation.
Analysis	The ability to differentiate between fact and opinion.	In GreenMate, players encounter various scenarios where they need to decide how to best conserve energy. For example, they are presented with a choice between using a bicycle or a car to travel to school. By analysing the options and considering factors such as fuel consumption, emissions, and physical activity, players can make informed decisions to minimise energy consumption and contribute to a more sustainable environment.
Synthesis	Generating an original product within a particular context or scenario.	In GreenMate, players engage in tasks that encourage them to generate original solutions within specific scenarios to promote energy efficiency. For example, players are tasked with getting ready for school in the morning. As part of this task, they are challenged to find ways to make their morning routine more energy-efficient. This could involve turning off lights and appliances not in use while getting ready, using energy-efficient appliances to prepare breakfast, and planning their route to school to minimise transportation energy consumption. By creatively addressing energy efficiency within the context of their morning routine, players learn valuable skills and contribute to a more sustainable lifestyle.
Evaluation	To guarantee students have a profound awareness of the limits of their own and others' understanding.	In GreenMate, we aim to assess players' learning progress and understanding of energy-saving concepts through the use of questionnaires. Before starting the gameplay, players are presented with a pre-game questionnaire designed to assess their baseline knowledge and awareness of energy saving practices. After completing the gameplay, players are provided with a post-game questionnaire. This questionnaire is designed to assess how the gameplay experience has influenced their understanding and behavior regarding energy conservation.

TABLE IV: Visualization of Kolb's Learning Theory in Teaching & GreenMate Game

Facets	Visualisation in Teaching	Visualisation in GreenMate
Concrete Experience	Engaging in or having an experience	Players are offered a positive experience while performing specific game tasks. For example, they can witness the water running and overflowing, and they can also see it stopping when they close the tap.
Reflective Observation	Reviewing or reflecting on the experience	Players have to complete a questionnaire consisting of reflective questions and additional decisions based on their reflections from the previous tasks.
Abstract Conceptualization	Concluding or learning from the experience	The questionnaire at the end of the gameplay aids the players in summarising and consolidating their learnings.
Active Experimentation	Implementing or experimenting with what was learned.	New tasks are designed based on the previous conceptualisation. For example, players are given different items to sort into separate waste bins based on the type of waste each item belongs to.

implementation of the MDA framework facilitated the convergence of game design, development, criticism, and technical research of GreenMate. Moreover, we integrated narrative to elevate the overall gaming experience.

The aesthetic features of GreenMate are designed to immerse players in a captivating audio-visual experience. For example, players encounter visually stunning landscapes such as a farm and vibrant environments as they explore the game world. Furthermore, the use of dynamic lighting effects and atmospheric sound design enhances the overall ambiance, eliciting emotional responses that reinforce the game's thematic focus on sustainability and environmental awareness. The game's narrative unfolds as players progress through a series of tasks aimed at reducing energy consumption. For instance, players start their journey by getting ready for school, followed by tasks such as arriving at school and visiting a farm. These tasks are seamlessly integrated into the narrative, guiding players through a story-driven experience that underscores the importance of energy conservation in everyday life.

Drawing upon game-based learning theories such as the Six Facets of Understanding, Bloom's Taxonomy and Kolb's Learning Cycle, GreenMate's mini-games are designed to facilitate understanding of energy conservation principles. For example, tasks within the mini-games are structured to align with theories such as experiential learning, where players actively engage with concepts through hands-on activities. Additionally, feedback mechanisms are implemented to provide players with opportunities for reflection and reinforcement of learning outcomes.

To assess player experiences, GreenMate employed comprehensive questionnaires aimed at capturing feedback and insights. The post-questionnaire included metrics such as player engagement, satisfaction, and perceived learning outcomes. For example, players were asked to rate their level of enjoyment and understanding of energy conservation concepts after completing various tasks within the game. This data was then analyzed to inform iterative improvements and optimizations to enhance the overall gaming experience. GreenMate incorporates dynamic systems that respond to player inputs and interactions in real-time. For instance, players face challenges such as timed supply of water or dialogue prompts for decision-based tasks, which dynamically adjust based on their actions and choices. These dynamic elements create an engaging and interactive experience, where players must adapt to changing circumstances while learning about energy consumption and conservation.

In GreenMate, mechanics encompass the various components that define player interactions within the game world. These include elements such as data representation, algorithms, and control mechanisms. Players navigate through the game environment using specific keyboard inputs, such as arrow keys for movement and the 'E' and 'L' keys for interaction with objects or non-player characters (NPCs). For example, players can use the arrow keys to traverse the environment, while the 'E' key enables interaction with objects like turning off lights or adjusting energy-consuming appliances. Moreover, the mouse pointer facilitates menu navigation and interaction with on-screen elements.

One of the standout features of GreenMate is its integration of real-time feedback from NPCs such as the tree buddy companion. This unique mechanic provides players with immediate insights into their energy consumption habits, allowing for dynamic adjustments and personalized learning experiences. These mechanics are integral to empowering players, enabling them to actively engage with the game's challenges and make informed decisions regarding energy usage and preservation. By providing intuitive controls and responsive gameplay mechanics, GreenMate fosters a sense of agency and immersion, encouraging players to explore and interact with the game world while learning about sustainable energy practices.

D. The mini-games

The development of the mini-games is divided into four main components; mechanics, dynamics, aesthetics, and narrative. Mechanics and narrative remain consistent across all three mini-games, as they govern the player's movements and the game's underlying purpose, respectively. The player's movements are controlled by the mouse pointer and arrow keys, while specific keys are introduced to assist in task completion and enable exiting the game at any given time.

In GreenMate, there are 3 different mini-games:

- 1^{st} mini-game – The house: In this mini-game, the player navigates around their house to prepare for school, and engages in various activities such as brushing their teeth, turning off the bedroom lights and shutting down the computer before leaving the room, having a healthy breakfast, and selecting an energy-efficient mode of transportation to reach their school (see Figure 2). Each activity is presented as a challenge, aimed at teaching the player the significance of energy conservation and imparting knowledge about the carbon emissions associated with specific household items. The key areas within the house – kitchen, bathroom, bedroom and garage – are identified to create engaging tasks for the player. Message prompts are introduced throughout the game interface to provide players with the necessary knowledge for making well-informed decisions as they progress through the tasks.
  The interpretation and application of concepts are woven into the development of motive and decision-based tasks. To create a diverse perspective, different levels of the game were mapped to various rooms or spaces, enabling players to gain a new perspective with each set of tasks. Finally, GreenMate ensures that all tasks are designed to foster personal growth and community involvement, imparting empathy to players. To gauge self-knowledge, some tasks are repeated in the mini-game. The initial set of tasks takes place in the bathroom, encouraging players to minimise water usage for basic hygiene. Timers and energy tokens are used to maintain awareness of their actions. Subsequently, players are presented with tasks in the bedroom and kitchen, such as turning off lights when leaving and checking the oven when timed out. Subsequently, players are required to make a choice between

using a car or a bicycle to commute to school. Each of these tasks is emphasised through various interface cues, such as illuminated screens and lamps, real-time water flow in the bathroom, visual representations of vehicles and laptop, and virtual food to be consumed.
- 2^{nd} mini-game – The school: In this mini-game, the player navigates through a school environment and endeavors to complete an upcoming exam. Afterward, they must exit the school premises while ensuring that electrical appliances such as lights, computers and projector are turned off, the water cooler pump is shut down when not in use and the classroom door is closed before operating the air conditioner to avoid unnecessary usage (see Figure 3). Knowledge is imparted to the players through in-game conversations between an avatar and the player, conveyed through message prompts displayed on the interface.
In this mini-game, our primary focus is on reducing energy consumption by addressing incandescent lights and other electrical appliances, while the water cooler pump and projector exemplify community-based energy consumption reduction tasks, fostering empathy among players. Players gain comprehension of this knowledge through guided task completion, which involves switching off classroom lights while leaving the classroom or when they are not in use. Moreover, the act of switching off computers that are not in use is a recurring task, similar to turning off the computer in the first mini-game, thereby instilling the value of self-knowledge among players. To assess players' understanding of the learned concepts, we introduce new tasks that revisit previous lessons, such as switching off the water cooler when not in use. Finally, we reach the evaluation stage, where players are presented with a comprehensive questionnaire to capture their gaming experience and thoughts.
- 3^{rd} mini-game – The farm: In this mini-game, the player explores a farm setup and undertakes a series of tasks that involve making energy-aware decisions such as closing the water pump to save overflowing water and selecting an appropriate color-coded dustbin for garbage disposal, such as the biodegradable farm waste bin (see Figure 4). To provide players with a genuine experience of working towards reducing the farm's carbon footprint, we emphasise the importance of water conservation. For instance, we present them with an overflowing water tank and give them control to switch off the tap, enabling them to save water. During the gameplay, a clock counts the energy tokens used or wasted, encouraging players to reflect and gain a deeper understanding of the concept. Furthermore, we engage players in a similar yet distinct task where they encounter an overflowing field and must figure out how to close the water turbine to prevent water wastage.

Each interface feature serves a distinct and valuable purpose, focusing on specific aspects of learning during the gameplay. In GreenMate, a range of interface cues is incorporated to help children understand that their individual actions collectively influence the environment. Each of these interface cues is carefully designed with the help of the following components:

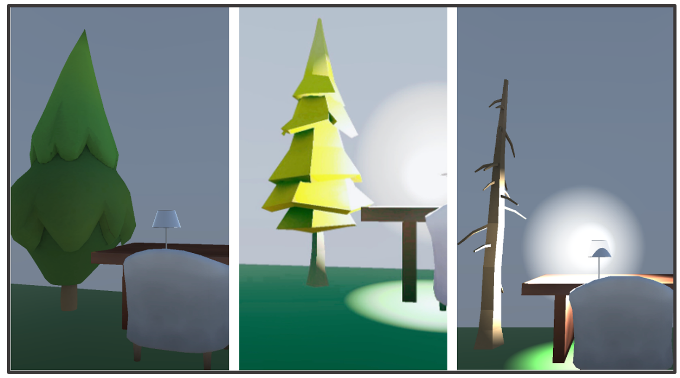

Fig. 1: Players' actions influence the trees' leaves color

- *Visualisation:* plays a pivotal role in conveying important information to the players, enhancing the gaming experience and improving understanding of energy-related concepts. Each task and mini-game is thoughtfully crafted to replicate everyday life scenarios; lights turning on and off, appliances in operation, and water flow in taps. Appliances and vehicles in the game are labeled with energy efficiency ratings, guiding the players to make more environmentally friendly choices. Moreover, the game features a visual representation of a tree that dynamically transforms based on the player's actions. When players make energy-efficient choices, the color of the leaves changes from brown to green.
- *Feedback:* provides valuable information and responses to the player's actions and decisions related to energy conservation. The game provides immediate feedback to players as they make energy-aware choices; feedback comes in the form of visual cues such as the color of the trees' leaves and educational messages, reinforcing positive actions or cautioning against wasteful behavior. At the end of each mini-game, players receive a performance message outlining their energy-saving achievements and areas for improvement. Players are encouraged to fill out two questionnaires – one before starting the game and another after playing it – to reflect on their overall understanding of energy consumption and their experience with the gameplay.
- *Incentives:* are designed to motivate and reward players for adopting energy-saving behaviors and making sustainable choices. GreenMate's incentives enhance player engagement and encourage them to actively participate in the game. Players witness tangible environmental improvements within the game (i.e., change in the color of the trees' leaves (see Figure 1)) as a result of their energy-saving efforts. At the completion of each task and upon reaching the next level, players receive congratulatory messages, instilling a sense of joy and motivation to continue playing the game. Acknowledging players' energy-saving achievements within the game fosters a sense of belonging and recognition for their efforts.

Fig. 2: Mini-game 1: The house

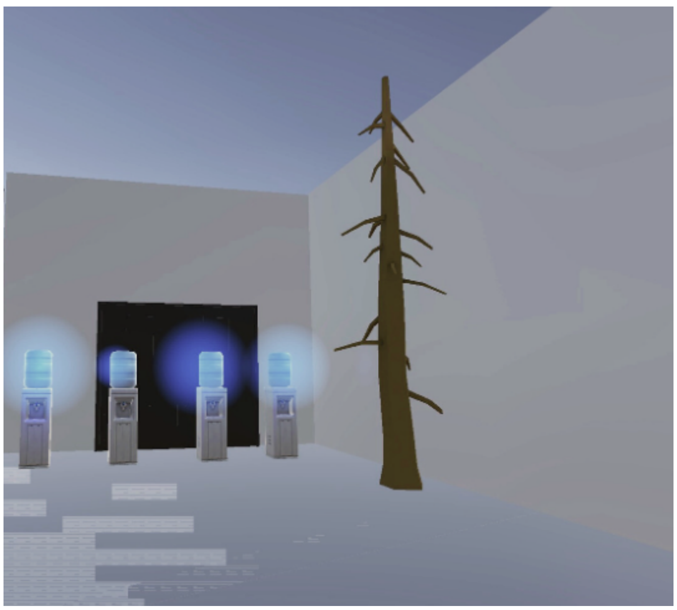

Fig. 3: Mini game 2: The school

Fig. 4: Mini game 3: The farm

IV. Results & Analysis

A. Experimental Setup

The objective of the GreenMate project is to investigate the effectiveness of a serious game in educating children aged 6-12 years about energy conservation and its environmental implications. The game aims to increase the players' knowledge, awareness, and motivation to adopt energy-saving behaviors in their daily lives. A diverse group of 36 children aged 6-12 years participated in the study, comprising 21 boys and 15 girls. The age distribution was as follows: 12 children aged 6-7 years, 14 children aged 8-9 years, and 10 children aged 10-12 years. Participants represented various geographical backgrounds, including India, Greece, and the UK (Table V). They had access to the game for a designated period of one week. Ethical approval was obtained before the study, and consent forms were signed by all parents or legal guardians of the participants, granting permission for their child's involvement in the study. Participants' privacy and confidentiality were strictly maintained throughout the research process.

TABLE V: Participants Demographics

Gender	Age			Nationality		
	6-7	8-9	10-12	India	Greece	UK
Male	8	7	6	10	6	5
Female	4	7	4	5	6	4

GreenMate is a single-player web-based game accessible on desktop and mobile devices designed with an approximate gameplay duration of 30 minutes. The game starts promptly after the players receive their initial instructions, guiding them on how to play the game and comprehend its main objective. However, there is no time limit, allowing players to complete tasks at their own pace. The game environment consists of various locations, including a house, a school and a farm. In every location, there are small yet meaningful tasks – such as turning off the lights upon leaving a room, closing the tap after brushing the teeth, and opting for energy-efficient transportation to school – that directly contribute to reducing carbon footprint and energy consumption. The main goal for players is to actively engage in these small yet impactful tasks, with the ultimate aim of contributing to the achievement of energy conservation goals. By conscientiously carrying out activities like turning off lights, conserving water, and making sustainable transportation choices, children can play a crucial role in collectively reducing carbon footprint and promoting energy efficiency within their respective settings. This active participation forms the core strategy in working towards the overarching objective of energy conservation.

Prior to initiating gameplay, participants completed a pre-game questionnaire designed to gather baseline data on their energy knowledge and attitudes. This questionnaire comprised a series of questions assessing participants' understanding of energy use and conservation practices. The pre-game questionnaire includes the following questions:

1) *Do you usually check which electric appliances are working before leaving your room?*
2) *Do you understand what energy use means?*

3) *Do you understand what the different colors mean in the waste bins?*
4) *Do you take actions at home to save energy?*

Following game completion, participants filled out a post-game questionnaire, which mirrored the pre-questionnaire and included additional questions to evaluate comprehension levels and measure the game's effectiveness in educating children about energy efficiency. The post-game questionnaire includes the following questions:

1) *Will you check which electric appliances are working before leaving your room?*
2) *Do you better understand what energy use means?*
3) *Do you better understand what the different colors mean in the waste bins?*
4) *Are you going to take appropriate actions at home to save energy?*
5) *Does the color of the trees help you to better understand energy use?*
6) *Are you now more aware of how to preserve energy?*
7) *Are the game's energy saving practices appropriate?*
8) *How much did you enjoy playing the game?*

The pre- and post-game questionnaires typically took participants approximately 15-20 minutes to complete, ensuring minimal disruption to their gameplay experience. Responses were collected using a 5-point Likert scale, ranging from 'Never' to 'Always', which we recorded on a scale from -1 to 1 (-1: 'Never', -0.5: 'Seldom', 0: 'Sometimes', 0.5: 'Often', and 1: 'Always'). For question 8, responses were collected using a 5-point Likert scale ranging from 1 to 5, with 5 indicating the highest level. The first four questions of the questionnaire, administered both before and after gameplay, were designed to assess the following attitudes:

1) *Attention to turning off electrical appliances when not in use.*
2) *Understanding of the term "energy use".*
3) *Recognition of the colors of waste bins.*
4) *Willingness to take actions to save energy.*

We evaluated whether these attitudes improved before and after gameplay, considering factors such as gender, age, and nationality. Additionally, we recorded the time taken by each player to complete the game.

B. Experimental Results

In this part, we delve into the specifics of our experimental findings, aiming to unveil the nuanced layers of insights revealed by our study. Our focus centers on key metrics related to participants' energy knowledge and behaviors, as well as addressing the following questions that emerged from our findings:

- **Q1:** Does GreenMate immediately impact children's awareness of environmental issues?
- **Q2:** If yes, does this change depend on factors such as gender, age, or nationality?
- **Q3:** Is there a correlation between the time it takes for children to complete the game, their enjoyment of it, and their attitude toward environmental protection prior to playing?

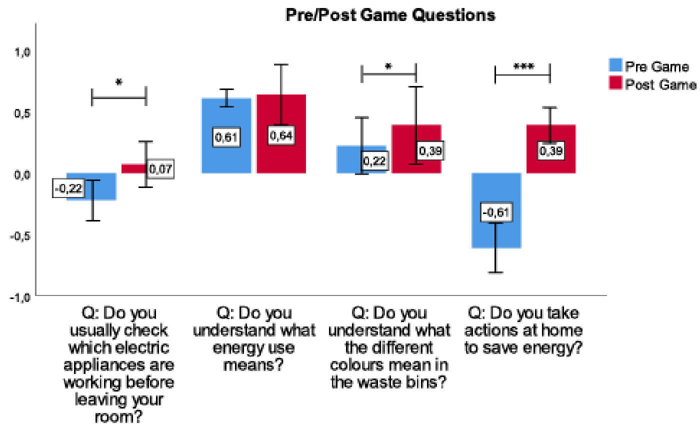

Fig. 5: Results before playing and after playing the game

Through the positive game experience, children demonstrated an increased ability to focus on their surroundings, fostering heightened awareness of energy consumption within the environment. The analysis encompasses changes in participants' responses to specific questions outlined in the pre and post questionnaires (see Figure 5). We anticipated that engagement with the GreenMate game would positively impact participants' knowledge, attitudes, and behaviors related to energy conservation. Our hypotheses regarding the influence of the game on specific aspects of energy awareness serve as a guiding framework for interpreting the observed changes in participant responses. Detailed within are the quantitative analyses of pre and post questionnaire data, providing insights into the effectiveness of the GreenMate game in influencing the targeted outcomes. We tested all recorded variables for normality but, with the exception of the game completion time, all variables were found not to be normally distributed. For this reason, we used non-parametric tests (e.g., Wilcoxon Signed Rank Test and Kruskal-Wallis Test).

The aptitude to check which electrical appliances work before leaving one's room showed improvement after the game, increasing from an average of -0.22 ±0.08 to an average of 0.07 ±0.09. This signifies a 14.5% increase in the Likert scale entire range (2, ranging from -1 to 1). The observed increase is statistically significant ($p = 0.02$, Wilcoxon Signed Rank Test). The comprehension of the meaning of energy use showed a marginal improvement after the game, rising from an average of 0.61 ±0.03 to an average of 0.64 ±0.12. This represents a 1.5% increase in the Likert scale entire range, however, the observed increase is not statistically significant ($p = 0.36$, Wilcoxon Signed Rank Test).

The comprehension of the meaning of the colors of the different waste bins exhibited improvement after the game, increasing from an average of 0.22 ±0.11 to an average of 0.39 ±0.16. This accounts for an 8.5% increase in the Likert scale entire range. However, it is worth noting that the observed increase is not statistically significant ($p = 0.30$, Wilcoxon Signed Rank Test). Finally, the aptitude to take actions at home to save energy experienced a significant improvement after the game, rising from an average of -0.61 ±0.04 to an average of 0.39 ±0.07. This marks a substantial 50.0% increase

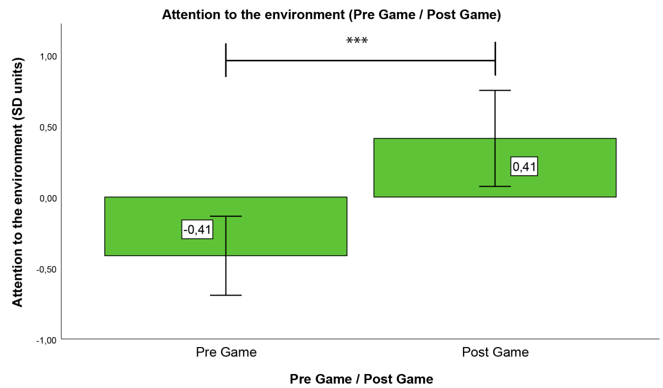

Fig. 6: Attention to the environment before and after playing the game

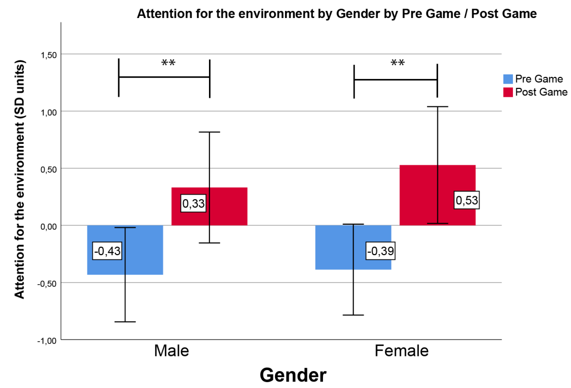

Fig. 7: Attention to the environment before and after playing the game by gender

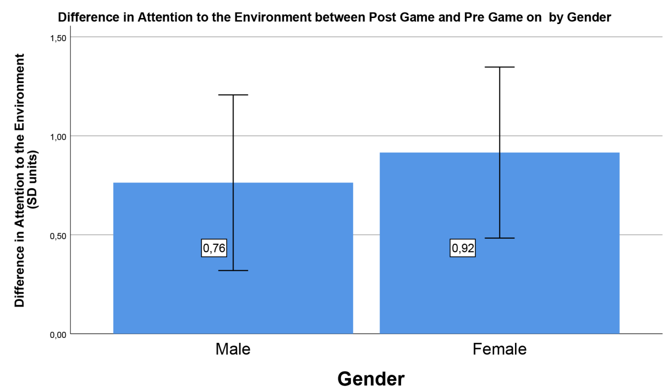

Fig. 8: Difference in Attention to the environment before and after playing the game by gender

in the Likert scale entire range. Importantly, the observed increase is statistically very highly significant ($p < 0.001$, Wilcoxon Signed Rank Test). Following this, we applied Principal Component Analysis (PCA) to the preceding four items to consolidate them into a singular variable representing attentiveness to the environment. The first principal component, which accounts for 45.9% of the explained variance, was extracted and labeled "Attention for the environment". This new synthesised variable has zero mean and a standard deviation equal to one. A value of zero indicates being in the mean. A positive value indicates being above the mean and a negative value indicates being below the mean. The numerical value indicates by how many standard deviations you are above or below the mean. Its values before and after the game were compared, as shown in Figure 6. The Attention for the Environment exhibited an increase after the game, rising from an average of -0.41 SD ±0.14 SD to an average of 0.41 SD ±0.16 SD. This reflects a 41.0% increase of the entire normalised range (2, ranging from -1 to 1). Importantly, the observed increase is statistically highly significant ($p < 0.001$, Wilcoxon Signed Rank Test). We used non-parametric tests because this variable was also not normally distributed, although it was very close to normality (Kolgomorov-Smirnov test p-value = 0.046 and Shpiro-Wilk test p-value = 0.212).

A notable aspect of our findings concerns the potential influence of gender, age, and nationality on the observed increase in attitude toward environmental conservation before and after gameplay. We noted a statistically significant increase in attitude toward environmental conservation for both males and females ($p = 0.004$ and $p = 0.002$, respectively, Wilcoxon Signed Rank Test), as shown in Figure 7. An observed trend suggests that females may exhibit greater sensitivity to the game than males (0.92 ±0.78 SD versus 0.76 ±0.97 SD), as illustrated in Figure 8. However, this difference is not statistically significant ($p = 0.72$, Mann-Whitney Test).

We found a statistically significant increase in attitude toward environmental conservation among children aged 6-7 and 10-12 years both before and after playing the game ($p = 0.003$ and $p = 0.022$, respectively, Wilcoxon Signed Rank Test). However, no significant change was observed for children aged 8-9 years ($p = 0.087$, Wilcoxon Signed Rank Test), as shown in Figure 9. A trend appears to suggest that the youngest children (aged 6-7 years) were more responsive to the gaming experience compared to older age groups (1.15 ±0.70 SD for children aged 6-7 years versus 0.36 ±0.74 SD and 1.09 ±1.07 SD for children aged 8-9 and 10-12 years, respectively), as shown in Figure 10. However, this difference is not statistically significant ($p = 0.216$, Kruskal-Wallis Test).

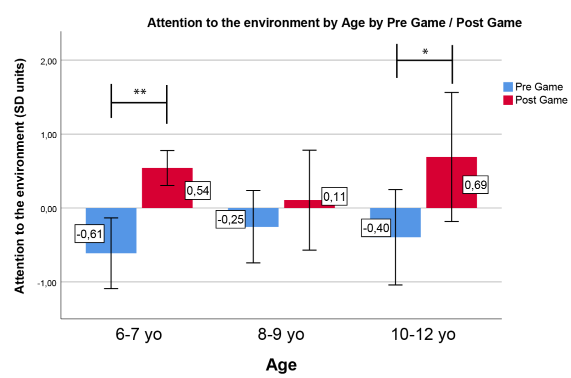

Fig. 9: Attention to the environment before and after playing the game by age

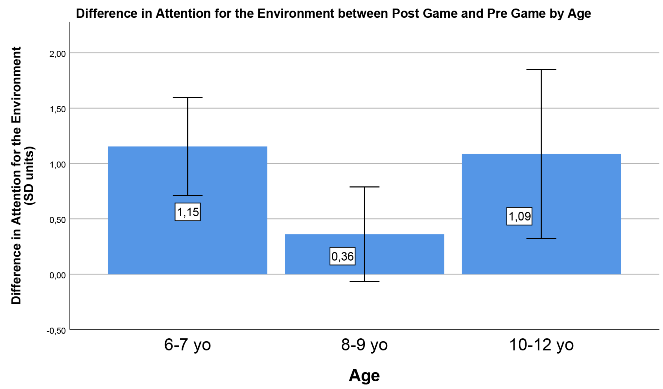

Fig. 10: Difference in Attention to the environment before and after playing the game by age

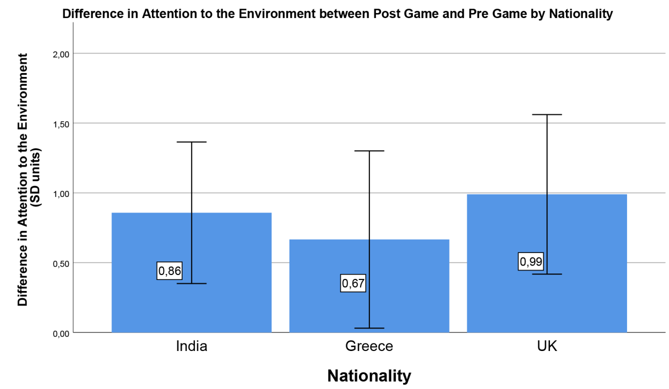

Fig. 12: Difference in Attention to the environment before and after playing the game by nationality

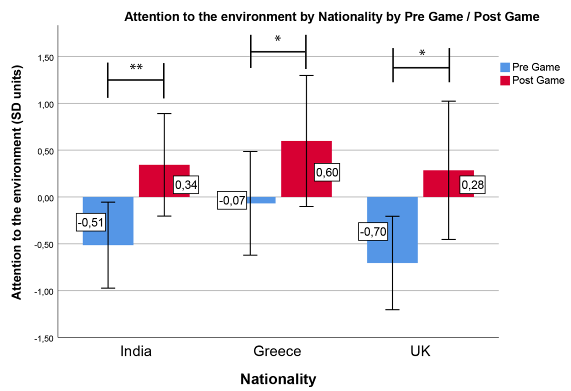

Fig. 11: Attention to the environment before and after playing the game by nationality

We found a statistically significant increase in attitude toward environmental conservation both before and after playing the game for children of all three nationalities (p = 0.005, p = 0.047, and p = 0.11 for Indian, Greek, and British children, respectively, Wilcoxon Signed Rank Test), as shown in Figure 11. A trend appears to suggest that British children aged 6-7 years were more responsive to the game compared to their counterparts (0.99 ±0.74 SD for the British children versus 0.86 ±0.91 SD and 0.67 ±1.00 SD for the Indian and Greek children, respectively), as shown in Figure 12. However, this difference did not reach statistical significance (p = 0.72, Kruskal-Wallis Test).

We investigated whether there exists a relationship between children's gameplay duration, enjoyment, and their pre-game attitude toward environmental protection (**Q3**). Our analysis revealed that a more positive attitude towards the environment is associated with less time taken to play the game. Specifically, children with a more favorable attitude toward the environment tended to complete the game in less time (Spearman correlation coefficient = -0.378, p = 0.023), suggesting that gameplay might be facilitated for those with pre-established environmentally friendly attitudes. Similarly, we found a negative correlation between children's understanding of energy use and waste bin color coding before gameplay and their gameplay duration (Spearman correlation coefficient = -0.321, p = 0.047), indicating that a better understanding of these concepts may expedite gameplay. Furthermore, our analysis demonstrated a positive correlation between children's enjoyment of the game and their expressed desire to work on reducing energy consumption. Specifically, children who reported higher enjoyment of the game were more likely to express a willingness to reduce energy consumption and contribute to environmental conservation efforts (Spearman correlation coefficient = 0.388, p = 0.019).

We also investigated whether enjoyment of the game varied across different age groups and whether younger children took longer to complete the game. Our analysis revealed that children of all age groups reported high levels of enjoyment, as shown in Figure 13.Additionally, there was no significant difference observed in enjoyment levels across age groups (p = 0.72, Kruskal-Wallis test). The average enjoyment ratings, measured on a scale of 1 to 5, were 4.67 ±0.65 , 4.71 ±0.47 , and 4.50 ±0.71, for children aged 6-7, 8-9, and 10-12, respectively.Furthermore, we investigated whether there were variations in gameplay completion time based on the age of the children. It was observed that, consistent with expectations, younger children generally took longer to complete the game compared to older children. The average completion times were 26.08 ±4.06 min, 24.43 ±2.34 min, and 19.50 ±1.58 min for children aged 6-7, 8-9, and 10-12 years, respectively, as shown in Figure 13. Normality tests indicated that the game completion time variable was normally distributed (Kolmogorov-Smirnov test p = 0.073 and Shapiro-Wilk test p = 0.259). Consequently, we conducted a one-way ANOVA ($p<0.000$) with post hoc tests, revealing a highly statistically significant difference between the game completion times of 6-7-year-old children and 10-12-year-old children ($p<0.000$). Similarly, there was a highly statistically significant difference between the game completion times of 8-9-year-old children and 10-12-year-old children ($p<0.000$). However, there was no statistically significant difference between the game completion times of 6-7-year-old children and 8-9-year-old children (p = 0.154).

Finally, we investigated whether the immediate effect of GreenMate differed based on children's sensitivity to environmental issues before gameplay. The children were divided

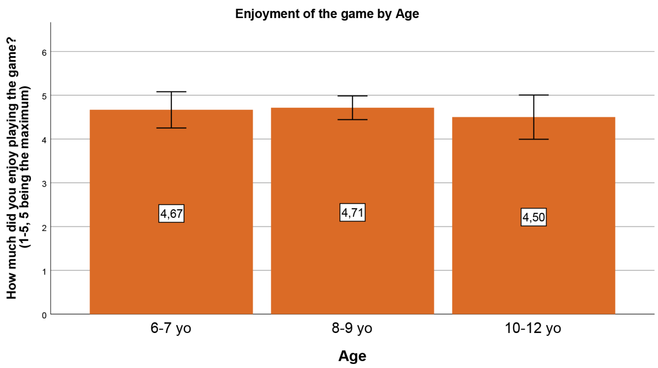

Fig. 13: Enjoyment of the game by age

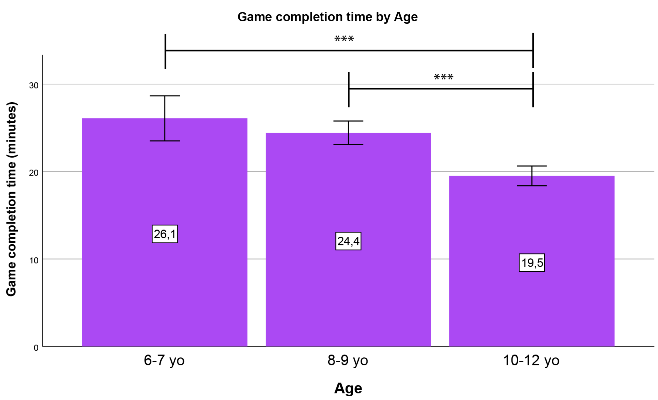

Fig. 14: Game completion time by Age

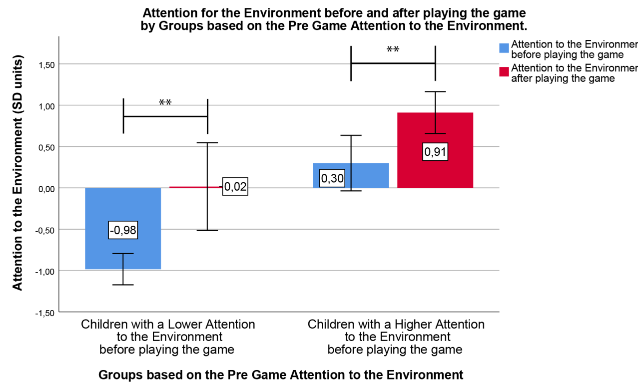

Fig. 15: Attention to the Environment before and after playing the game for the groups of children with a Lower and Higher Attention to the Environment (with respect to the median value) before playing the game, respectively.

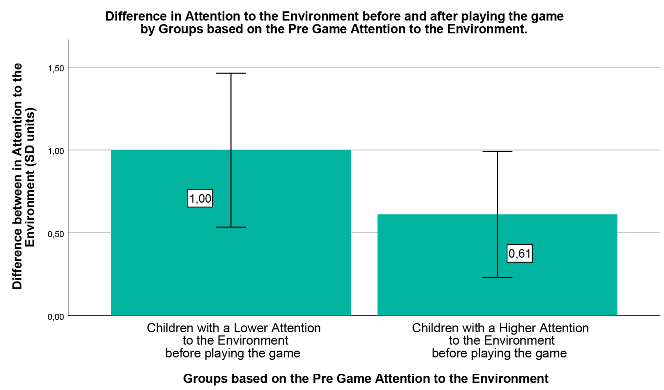

Fig. 16: Difference in Attention to the Environment before and after playing the game for the groups of children with low and high Attention to the Environment before playing the game, respectively.

into two groups based on their pre-questionnaire answers regarding their Attention to Environment score, distinguishing between those whose scores were below or above the median. Our analysis revealed that both groups, regardless of their initial sensitivity to environmental issues, demonstrated significant improvement in Attention to Environment after playing GreenMate, as depicted in Figure15. Specifically, children with lower initial attention to the environment showed a statistically significant improvement of 1.00 ±0.99 SD (p = 0.001, Wilcoxon Signed Rank Test), while those with initially higher attention showed a statistically significant improvement of 0.61 ±0.71 SD (p = 0.009, Wilcoxon Signed Rank Test), as shown in Figure 16. An observed trend suggests that GreenMate may have a more pronounced immediate impact on children with lower environmental awareness before gameplay compared to those who are already environmentally sensitive. However, this difference did not reach statistical significance (p = 0.116, Kruskal-Wallis Test), possibly due to a ceiling effect. No significant differences were found between the two groups in terms of enjoyment of the game (p = 0.57, Mann-Whitney Test) and game completion time (p = 0.85, independent samples t-test).

V. Conclusions

The aim of this paper was to investigate the hypothesis that a serious game incorporating different learning methodologies can enhance the comprehensive understanding of children aged 6-12 regarding the importance of energy conservation. The experimental results offer valuable insights into the impact of the GreenMate game on children's energy knowledge, attitudes, and behaviors. Through a detailed exploration of various metrics related to energy awareness, our analysis has uncovered nuanced layers of insights. The results indicate improvements in understanding energy-saving concepts, such as checking electrical appliances and taking energy-saving actions at home, supporting the game's objective to increase players' knowledge about energy conservation. Additionally, the game's impact on increasing awareness is evident through the significant rise in participants' 'Attention for the Environment' scores. Positive feedback highlighted the helpfulness of the tree leaves' colours in conveying energy use concepts, emphasizing the game's role in promoting environmental awareness and energy-saving practices. The observed enhancements in energy-saving actions, coupled with positive feedback indicating a greater understanding of energy preservation, suggest that GreenMate successfully motivates children to embrace energy-saving habits in their daily routines. This effectiveness is further supported by comparisons with similar games such as We Energy Change [21] and Social Mpower [4], where GreenMate stands out by providing tailored guidance within the game, potentially enhancing its effectiveness as an educational tool for promoting energy-saving behaviors among children.

In addition to the questionnaire responses, our analysis of game completion time revealed significant correlations. Children with a strong understanding of energy concepts completed the game more swiftly, suggesting that GreenMate resonates particularly well with individuals who already possess some degree of energy awareness. Furthermore, older participants completed the game more quickly than younger ones, indicating age-related differences in game engagement and comprehension. Moreover, we observed a positive association between game enjoyment and the inclination to reduce energy consumption at home, underscoring GreenMate's potential to influence real-world behaviors. Notably, these findings remained consistent across gender, age, and nationality, demonstrating GreenMate's promise as an effective educational tool. In conclusion, the GreenMate game has demonstrated its effectiveness in positively influencing children's energy-related behaviors and awareness. The study provides valuable insights for refining and enhancing the game's content to address specific areas of improvement. Future iterations of the game can benefit from a nuanced approach to cater to the diverse perspectives and preferences of the target audience. Overall, these findings contribute to the ongoing development of serious games aimed at fostering environmental awareness and sustainable behaviors among children.

REFERENCES

[1] C. V. Angelelli, G. M. de Campos Ribeiro, M. R. Severino, E. Johnstone, G. Borzenkova, and D. C. O. da Silva. Developing critical thinking skills through gamification. *Thinking Skills and Creativity*, 49:101354, 2023.

[2] M. Bayley, S. Snow, J. Weigel, and N. Horrocks. Serious game design to promote energy literacy among younger children. In *Proceedings of the 32nd Australian Conference on Human-Computer Interaction*, pages 531–537, 2020.

[3] B. S. Bloom. *Taxonomy of Educational Objectives: Handbook II*. David McKay, 1956.

[4] A. Bourazeri and J. Pitt. Collective attention and active consumer participation in community energy systems. *International Journal of Human-Computer Studies*, 119:1–11, 2018.

[5] V. Brakovska, R. Vanaga, G. Bohvalovs, L. Fila, and A. Blumberga. Multiplayer game for decision-making in energy communities. *International Journal of Sustainable Energy Planning and Management*, 38, 2023.

[6] P. Caserman, K. Hoffmann, P. Müller, M. Schaub, K. Straßburg, J. Wiemeyer, R. Bruder, S. Göbel, et al. Quality criteria for serious games: serious part, game part, and balance. *JMIR serious games*, 8(3):e19037, 2020.

[7] R. De la Torre, B. S. Onggo, C. G. Corlu, M. Nogal, and A. A. Juan. The role of simulation and serious games in teaching concepts on circular economy and sustainable energy. *Energies*, 14(4):1138, 2021.

[8] P. W. De Vries, E. Knol, B. Qeam, et al. *Serious Gaming as a Means to Change Adolescents' Attitudes Towards Saving Energy; Preliminary Results from the EnerCities Case*. SSRN, 2020.

[9] E. Delemere and P. Liston. Engaging serious games for energy efficiency. In G. Meiselwitz, A. Moallem, P. Zaphiris, A. Ioannou, R. A. Sottilare, J. Schwarz, and X. Fang, editors, *HCI International 2022 - Late Breaking Papers. Interaction in New Media, Learning and Games*, pages 567–580, Cham, 2022. Springer Nature Switzerland.

[10] E. Delemere and P. Liston. Exploring the use of behavioural techniques in serious games for energy efficiency: A systematic review and content analysis. *Behavior and Social Issues*, 31(1):451–479, 2022.

[11] J. D. Fijnheer, H. van Oostendorp, G.-J. Giezeman, and R. C. Veltkamp. Competition in a household energy conservation game. *Sustainability*, 13(21), 2021.

[12] O. Garay Garcia, C. E. van Daalen, E. Chappin, B. van Nuland, I. Mohammed, and B. Enserink. Assessing the residential energy rebound effect by means of a serious game. In *Simulation Gaming. Applications for Sustainable Cities and Smart Infrastructures: 48th International Simulation and Gaming Association Conference, ISAGA 2017, Delft, The Netherlands, July 10-14, 2017, Revised Selected Papers 48*, pages 129–138. Springer, 2018.

[13] R. Hunicke, M. LeBlanc, R. Zubek, et al. MDA: A formal approach to game design and game research. In *Proceedings of the AAAI Workshop on Challenges in Game AI*, volume 4, page 1722. San Jose, CA, 2004.

[14] R. S. Jacobs. Serious games: Play for change. In *The video game debate 2*, pages 19–40. Routledge, 2020.

[15] D. Johnson, E. Horton, R. Mulcahy, and M. Foth. Gamification and serious games within the domain of domestic energy consumption: A systematic review. *Renewable and Sustainable Energy Reviews*, 73:249–264, 2017.

[16] T. H. Laine and R. S. Lindberg. Designing engaging games for education: A systematic literature review on game motivators and design principles. *IEEE Transactions on Learning Technologies*, 13(4):804–821, 2020.

[17] J. McTighe and G. Wiggins. *Understanding by Design Professional Development Workbook*. ERIC, 2004.

[18] J. McTighe and G. Wiggins. Understanding by design framework. *Alexandria, VA: Association for Supervision and Curriculum Development*, 2012.

[19] L. Morganti, F. Pallavicini, E. Cadel, A. Candelieri, F. Archetti, and F. Mantovani. Gaming for earth: Serious games and gamification to engage consumers in pro-environmental behaviours for energy efficiency. *Energy Research & Social Science*, 29:95–102, 2017.

[20] E. Ostrom. The challenge of common-pool resources. *Environment: Science and Policy for Sustainable Development*, 50(4):8–21, 2008.

[21] T. Ouariachi, W. J. Elving, and F. Pierie. Playing for a sustainable future: The case of we energy game as an educational practice. *Sustainability*, 10(10):3639, 2018.

[22] H. Pearce, L. Hudders, and D. Van de Sompel. Young energy savers: Exploring the role of parents, peers, media and schools in saving energy among children in belgium. *Energy Research & Social Science*, 63:101392, 2020.

[23] C. Phongthanachote, P. Rattanadecho, C. Com-arch, and R. Prommas. Animation and computer games design to build awareness of energy conservation. *Science & Technology Asia*, pages 21–29, 2019.

[24] J. Piaget. Part i: Cognitive development in children–piaget development and learning. *Journal of research in science teaching*, 40, 2003.

[25] D. Qiu, Z. Dong, X. Zhang, Y. Wang, and G. Strbac. Safe reinforcement learning for real-time automatic control in a smart energy-hub. *Applied Energy*, 309:118403, 2022.

[26] D. Ruggiero. "the effect of a persuasive social impact game on affective learning and attitude": Corrigendum. 2018.

[27] A. Saitua-Iribar, J. Corral-Lage, and N. Peña-Miguel. Improving knowledge about the sustainable development goals through a collaborative learning methodology and serious game. *Sustainability*, 12(15):6169, 2020.

[28] R. Sharma, E. F. Melcer, and D. Kao. Exploring relevance, meaningfulness, and perceived learning in entertainment games. DiGRA, 2022.

[29] C. K. Tan and H. Nurul-Asna. Serious games for environmental education. *Integrative Conservation*, 2(1):19–42, 2023.

[30] V. Velayutham, S. Kumar, A. Kumar, S. Raha, and G. C. Saha. Analysis of deep learning in real-world applications: Challenges and progress. *Tuijin Jishu/Journal of Propulsion Technology*, 44(2):2023, 2023.

[31] M. K. Watson, J. Pelkey, C. Noyes, and M. O. Rodgers. Using Kolb's learning cycle to improve student sustainability knowledge. *Sustainability*, 11(17):4602, 2019.

[32] K. A. Whalen, C. Berlin, J. Ekberg, I. Barletta, and P. Hammersberg. 'All they do is win': Lessons learned from use of a serious game for circular economy education. *Resources, Conservation and Recycling*, 135:335–345, 2018.

[33] G. P. Wiggins, G. Wiggins, and J. McTighe. *Understanding by design*. Ascd, 2005.

[34] X. Wu, S. Liu, and A. Shukla. Serious games as an engaging medium on building energy consumption: A review of trends, categories and approaches. *Sustainability*, 12(20):8508, 2020.

[35] J. Zeng, S. Parks, and J. Shang. To learn scientifically, effectively, and enjoyably: A review of educational games. *Human Behavior and Emerging Technologies*, 2(2):186–195, 2020.