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Eco Leaders: Game-Based Learning Supported by Artificial Intelligence and Data Analysis

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Abstract

This study introduces a hybrid educational board game called Eco Leaders, designed to raise awareness of ecological sustainability among teachers and gifted students. The game was developed based on integrated STEM processes and the Mechanics-Dynamics-Aesthetics (MDA) framework for game design and research, and is supported by a mobile application [1],[2]. Players take on the role of city managers; those who answer mobile app questions correctly, use strategy cards effectively, and manage the carbon credit system properly are considered "conscious city managers." The mobile app includes multiple-choice questions, which are read aloud by artificial intelligence and can be modified by the teacher. In addition, with the support of data analysis, players' correct–incorrect ratios are visualized, and the ability to modify the questions allows the game scenario to be differentiated at the group and class levels and integrated into interdisciplinary curricula.

Eco Leaders is supported by a mobile application developed with MIT App Inventor and visuals designed with Canva. Mathematical thinking processes are reflected through the carbon credit system and end-of-game score calculations. Scientific concepts related to ecological sustainability are presented through mobile application questions and game cards that reflect ecological city design practices. The game set includes a game mat, eco-friendly and harmful city application cards, strategy cards, game currency, carbon credits, and a leadership board.

The practices carried out with 9 teachers and 28 gifted students were evaluated through descriptive analysis of teacher feedback. The findings indicate that the game offers an effective, engaging, innovative, and content-rich educational experience for both teachers and gifted students. Moreover, it was emphasized that the game has the potential to support the development of key 21st-century skills such as collaboration, persuasion, responsibility, decision-making, and problem-solving. The findings obtained are in parallel with other studies in the literature that show game-based learning supports learning motivation, engagement, and the development of 21st-century skills [3],[4],[5],[6].

Keywords: *STEM Education, Game-Based Learning, Gifted Education, Environmental Sustainability*

1. Introduction

The increasing urgency of global challenges such as climate change, biodiversity loss, and environmental pollution has positioned environmental sustainability as one of the most critical issues of the 21st century. Education plays a central role in addressing these challenges by equipping individuals with the knowledge, skills, and values required for sustainable development [7]. In this regard, international frameworks—most notably the United Nations Sustainable Development Goals (SDGs)—emphasize education as a key driver in fostering sustainable societies [8].

Despite this global emphasis, environmental education is often inadequately implemented in school contexts. Sustainability-related topics are frequently addressed in a fragmented manner, and many teachers report limited training opportunities and a lack of instructional resources [9],[10]. To overcome these limitations, research highlights the need for innovative, student-centered pedagogical approaches grounded in effective instructional design models [11]. In particular, interactive and experiential learning approaches have been shown to enhance learners' engagement and conceptual understanding of sustainability-related issues [12].

Within this context, game-based learning and serious games have emerged as promising approaches for sustainability education. By situating learners in simulated environments where they actively make decisions and experience consequences, game-based learning can foster pro-environmental awareness, systems thinking, and sustainable decision-making [5],[13]. Moreover, previous studies consistently report that such environments support learner motivation, engagement, and the development of key 21st-century skills, including collaboration, critical thinking, and problem-solving [3],[4].

Developing an environmentally sustainable school culture requires a whole-school perspective in which both students and teachers are positioned as active learners within a lifelong learning framework. Teachers, in particular, play a crucial role in translating sustainability-oriented curricula into meaningful classroom practices and therefore require continuous professional development and

pedagogical support [9],[10]. Research further emphasizes that fostering ecological awareness across age groups contributes to the development of long-term pro-environmental values and behaviors [14],[6].

While environmental sustainability constitutes a universal educational priority, gifted students represent a particularly relevant target group due to their advanced cognitive abilities, capacity for complex systems thinking, heightened moral sensitivity, and leadership potential. Previous research suggests that gifted learners are well positioned to act as future change agents capable of addressing complex global challenges such as climate change [15],[16]. However, conventional curricula often fail to provide sufficient cognitive challenge for these learners, which may lead to disengagement. Consequently, differentiated and enriched learning environments are essential to support their advanced learning needs.

The pedagogical design of Eco Leaders is grounded in Constructivist and Social Constructivist learning theories. From a constructivist perspective, learners actively construct knowledge through experience and reflection [17]. Social Constructivism further emphasizes the role of social interaction, discussion, and negotiation in learning processes [18]. These theoretical perspectives align with the collaborative and discussion-based mechanics of the game, which require players to justify decisions and co-construct knowledge within a social context.

In this regard, educational board games offer a valuable medium for modeling complex sustainability-related systems. In Eco Leaders, game mechanics such as strategy cards and a carbon credit system enable learners to engage with ecological and economic trade-offs through hands-on decision-making. Such mechanics illustrate how sustainability concepts can be represented within game-based simulations to promote deeper conceptual understanding and engagement [5],[19].

To bridge the gap between digital and analog learning environments, this study introduces Eco Leaders, a hybrid educational board game supported by a mobile application. The game was developed based on integrated STEM processes [1] and the Mechanics–Dynamics–Aesthetics (MDA) framework [2]. Its mechanics draw on principles of green urbanism [20] and ecological city design [21] to support sustainability education. Accordingly, the purpose of this study is to (a) examine whether a STEM-based board game can effectively support environmental sustainability education—particularly for gifted students—and (b) explore teachers' perceptions regarding the pedagogical value, usability, and educational contribution of the Eco Leaders board game.

2. Method

2.1 Stem Integration for Game Design

STEM is an interdisciplinary approach that integrates science, technology, engineering, and mathematics to develop innovative, hands-on solutions to real-world problems. It involves processes such as problem identification, design, prototyping, and testing, and is commonly used in the development of educational materials that foster applied learning and critical thinking [1].

In the design of the Eco Leaders; the science component was reflected through the inclusion of ecological and smart city practices developed based on real-world urban sustainability principles, such as energy efficiency, green transportation, microgeneration, and responsible consumption [20],[21]. In the technology and engineering phases, the MIT App Inventor platform was used to develop a mobile application that enables dynamic interaction (See Fig. 1), while Canva supported the creation of consistent and visually engaging materials.

Mathematical thinking was embedded into the design through the carbon credit system, which required the development of a numerical scoring mechanism to ensure functional balance and realism. This mechanism operates as a market-based carbon offset model, where carbon credits function as tradable assets used to offset ecological liabilities [22].The system requires players to perform cost-benefit analyses, calculating point-based exchanges between conscious and unconscious city managers to simulate real-life environmental policy incentives. The overall game structure was guided by principles of clarity, simplicity, and visual harmony to ensure a user-centered and pedagogically grounded design [11]. For the development of the game as a formal system, the MDA framework [2]—which views the game as a system—was used.

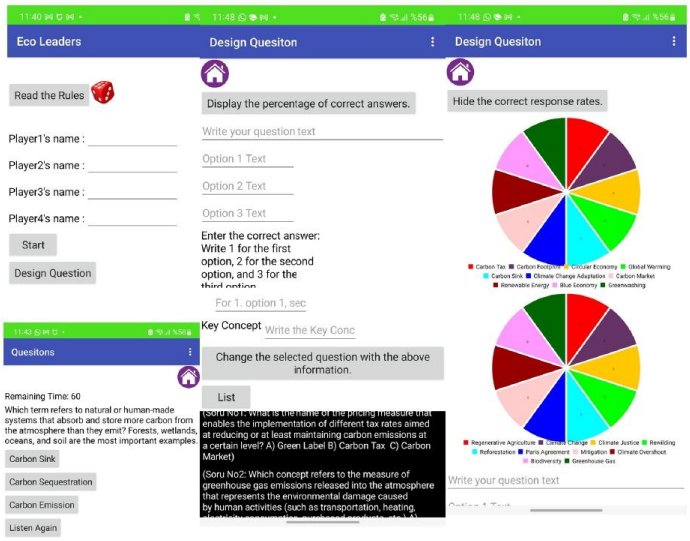

Fig. 1. Sample mobile application screens.

2.2 Mobile Application Supported Game-Based Learning

MIT App Inventor was used for developing mobile app. Text-to-speech functionality for AI support and TinyDB for data analysis were utilized. Three screens were designed in the mobile application. The home screen allows players to roll the dice, enter their names, and listen to the game rules. From this screen, users can navigate to the question design screen or start the game. On the question screen, 20 climate-related questions are voiced by artificial intelligence within a 60-second limit. In the first round, player names are also voiced by AI. Players select their answers and can replay the question. A 'start discussion' button is available between questions to initiate strategy card matching. For correctly answered questions, player scores are announced and voice feedback is provided. On the 'design question' screen, existing questions can be viewed, replaced with new ones, and the accuracy rates of key concepts are visualized using a pie chart.

2.3 Game Elements Design

Canva digital design technology was used (See Fig. 2).
Game mechanics include the game mat, eco-friendly city practice cards, environmentally harmful city practice cards, strategy cards, carbon credits, game currency, the mobile application, and the rules. Game dynamics; consist of quiz-based knowledge competition, discussion, strategy development, competition and collaboration, individual and team activities, and the role of the city manager. Aesthetic elements include emotion and awareness, achievement and satisfaction, educational fun, connectedness, competition, excitement, empathy, and recognition.
Game Mat is divided into four regions for four players. The regions representing the cities are separated by thick green lines and placed adjacent to each other, symbolizing the mutual influence of the city managers representing the players. The leadership board is designed to be hung on the classroom wall. For classroom-based implementations, player names can be written with a whiteboard marker in the "Most environmentally friendly city manager" and "Best collaborating team" sections and displayed. The erasable feature of the names allows the design to be reused multiple times.

2.4 Game-Based Learning Scenario

The game is designed for 4 players. Each player represents a city manager. Game rules are available both in printed form and as audio through the mobile application. There are 20 climate-related questions included in the mobile application. 50 eco-friendly city practice cards are placed in their own box, 50 strategy cards in theirs, and 40 environmentally harmful city practice cards in their respective box. At the beginning of the game, each player receives 3 strategy cards and 10 game coins.
One gamer takes on the role of the banker. The game begins by rolling the dice through the mobile app. Players enter their names according to the determined order. If a player answers a question incorrectly, they receive 2 environmentally harmful city practice cards. If they answer correctly, they receive 2 eco-friendly city practice cards and 2 carbon credits. A conscious city manager who answers climate questions correctly makes their city more sustainable. The leadership board reflects both individual and team performance.

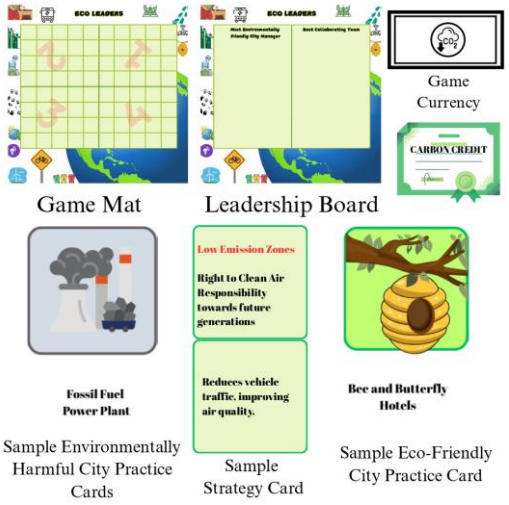

Fig. 2. Game elements design.

Carbon credit system: This is a functional scoring mechanism that integrates players' knowledge levels directly into the game economy and strategic decision-making processes. This system creates a strategic exchange environment where "unconscious" managers—who receive grey cards representing environmentally harmful city practices due to incorrect answers on the mobile app—purchase credits from "conscious" managers—who earn carbon credits by answering questions correctly—using game currency. To ensure game balance and incentivize pro-environmental leadership, a mathematical advantage model was developed. According to this model, when a conscious manager sells an earned credit, they gain 3 units of game currency; however, they lose the 1 point value of the credit and thus obtain a net 2 point advantage at the end of the game. Conversely, an unconscious manager pays 3 units of game currency to the seller for a carbon credit. In this process, the unconscious manager exchanges the carbon credit with the bank by using a grey card and converts the relevant area into an eco-friendly practice, thereby gaining a net 1 point advantage by the end of the game. Because players cannot purchase carbon credits directly from the bank, they are encouraged to engage in information sharing and strategic negotiation. This mechanism increases both individual and team scores while fostering collaborative learning (See Fig. 3).

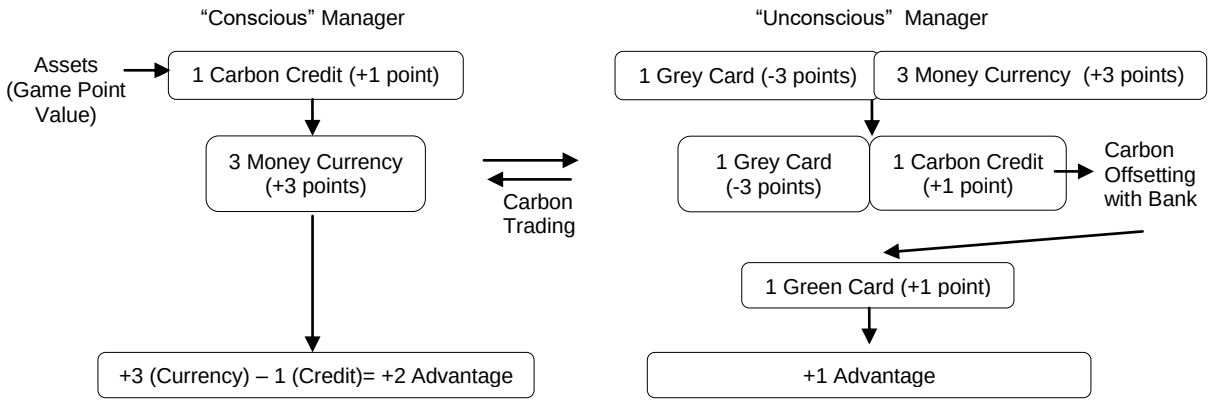

Fig. 3. Carbon credit system

Strategy cards: At the beginning of the game, each player is given three strategy cards containing clues about the objectives of eco-friendly city practices. During their turn, players have the right to exchange one strategy card for a new one from the bank. Based on the provided clues and their own knowledge, players attempt to match the clues with eco-friendly city practices they have already acquired on the game mat. Between questions, players can initiate a one-minute discussion period by pressing the "Start Discussion" button to persuade others about the target and philosophy of the selected city practice. If the majority agrees, the strategy card is placed on top of the corresponding eco-friendly city practice and added to the player's city, providing a point advantage at the end of the game. This mechanism encourages players to conduct preliminary research on sustainable city strategies before playing the game.
End of the game: Environmentally harmful city practices are worth -3 points. Eco-friendly city practices, strategy cards, carbon credits, and game coins are each worth +1 point. To earn a team score, at least 30 points must be collected across the entire game mat (which requires correctly answering at least 3 out of every 5 questions). The city manager with the highest score is listed under the "Most Environmentally Friendly City Manager" section on the Eco Leaders Board, while, if the team success criterion is met, the names of all team members are listed under the "Best Collaborating Team" section. These achievements are displayed within the classroom to recognize and celebrate student performance.

2.5 Implementation of the Game with Teachers and Students

A total of 28 gifted 5th-grade students and 9 teachers from a Science and Art Center participated in the study. A convenience sampling method was utilized, given that the Eco Leaders game was in its pilot phase. This approach enabled the collection of initial feedback to guide future improvements. It provided valuable insights into the game's development process. A semi-structured interview form comprising 7 questions was administered to the teachers, who observed students' experiences while also playing the game themselves. Each question corresponded to a specific theme. The data were analyzed using descriptive analysis, a qualitative research method, and expert consultation was sought. The identified themes were: Teacher Experience, Game Rules, Classroom Applicability, Player Motivation, Student Experience, Skill Development, and Mobile Application.

3. Descriptive Analysis of Teacher Interviews

Data were collected from nine teachers representing different subject areas. Five teachers indicated prior experience participating in activities involving game-based learning, whereas four reported no such experience. Eight participants had between 10 and 20 years of professional experience, and one participant had less than 10 years. A descriptive analysis of the teachers' responses was conducted.

3.1 Theme 1: Teacher Experience

All participating teachers reported that the game could foster changes in knowledge, beliefs, and attitudes among teachers. Additionally, three teachers emphasized the game's instructive nature. "Playing this game was highly effective and educational for me. During the gameplay, I became more aware of environmental issues and developed a deeper understanding of the importance of ecological sustainability. Such games have the potential to influence awareness and attitudes." (Teacher 7).

3.2 Theme 2: Game Rules

Six teachers stated that the rules were clear and understandable. Two teachers suggested that the rules could be shortened, while one teacher noted that understanding the rules through verbal instruction was challenging. "Listening to the rules verbally was difficult, and I lost focus. I had to ask additional questions about the rules." (Teacher 3). "I found the rules to be clear and understandable, although some expressions could be made more concise." (Teacher 2).

3.3 Theme 3: Classroom Applicability

All teachers agreed that the game could be implemented in classroom settings. "I believe it is suitable for middle and high school students." (Teacher 2). "I think it can be integrated into classroom activities and can enhance students' knowledge of environmental sustainability." (Teacher 9).

3.4 Theme 4: Player Motivation

All participants highlighted engaging aspects of the game. Three teachers stated that the carbon credit system contributed significantly to the game's appeal and enjoyment. "The process of purchasing carbon credits with in-game currency and neutralizing environmentally harmful practices through the bank system was particularly engaging." (Teacher 9). One teacher noted that the game's visuals and the mobile application were particularly attention-grabbing. Five teachers emphasized that the overall design of the game was highly engaging and sparked curiosity. "The game visuals and mobile application were highly engaging and enjoyable." (Teacher 5). Furthermore, four teachers mentioned that the diversity of scenarios and the inclusion of contemporary concepts contributed positively to student engagement. "The diversity of the scenarios presented in the drawn cards was intriguing and helped keep students active during the game." (Teacher 6).

3.5 Theme 5: Student Experience

All nine teachers agreed that the game could enhance students' awareness regarding environmental sustainability issues. "It can enhance knowledge and awareness levels and contribute to raising environmentally conscious individuals. It fosters knowledge, responsibility, value formation, decision-making, and problem-solving skills from the individual to the community level." (Teacher 1). "Yes, it can. This game can create awareness about environmental sustainability, encourage active participation in the learning process, and contribute to the development of environmentally sensitive individuals." (Teacher 7).

3.6 Theme 6: Skill Development

Based on the teachers' responses, the game was perceived as promoting communication, collaboration, persuasion, multiple perspectives, decision-making, problem-solving, sensitivity, responsibility, and environmental awareness skills. "It fosters growth in knowledge and awareness levels, promotes multiple perspectives, and enhances decision-making and problem-solving skills." (Teacher 1). All teachers stated that they would recommend the game. One teacher mentioned that they would recommend it due to its ability to make the learning process enjoyable and promote active student engagement. Another teacher emphasized its alignment with updated curriculum content, while another described it as a universally applicable educational tool. Three teachers highlighted the game's potential for fostering environmental sensitivity among students. "Yes. It contributes to acquiring diverse knowledge and enhancing information accumulation." (Teacher 6). "I would recommend it. It is very enjoyable. Each subject area should integrate it according to their respective learning outcomes." (Teacher 5). "Yes. Activities like this are crucial for raising a generation sensitive to environmental issues." (Teacher 4). "Yes. Environmental sustainability is an interdisciplinary topic that requires widespread awareness, and activities promoting student engagement are critical for drawing attention to such issues." (Teacher 9).

3.7 Theme 7: Mobile Application

Five teachers reported that the mobile application provided ease of use. Four teachers noted that it enhanced student motivation. One teacher remarked that the application contributed to participants feeling more valued. Four teachers emphasized that the ability to modify questions would enable the customization of future gameplay and help maintain engagement by avoiding repetition. Six teachers suggested that the question analysis feature could be utilized to assign tasks such as research and presentations on incorrectly answered concepts, thereby reinforcing student learning and enabling progress monitoring. One teacher indicated that discipline-specific questions could be incorporated to foster an interdisciplinary approach. "The application is user-friendly and contains features that enhance student interest and motivation, encouraging active participation." (Teacher 2). "The mobile application facilitated the game flow, made it more comprehensible and enjoyable, and introduced an innovative approach." (Teacher 5). "The application improved tracking of the game's progress. The ability to change questions allows for the assessment of different concepts in repeated plays. Data analysis based on key concepts can support the assignment of research and presentation tasks to address misconceptions." (Teacher 9).

Based on the feedback received from the teachers, the game rules were simplified and printed. Additionally, the functionality of the strategy cards were modified to match with the eco-friendly city practices cards and a "Start Discussion" button was integrated into the mobile application to facilitate this interaction.

4. Conclusion and Future Work

A technology-supported board game that can contribute to environmental education was developed using STEM processes and the game-based learning method. The game is supported by a mobile application and is suitable for use from middle school age groups to teacher training. The Eco Leaders game stands out from existing applications through its mobile-supported structure, the provision of ease of use and flexibility by eliminating the need to upload audio files when questions are modified thanks to the artificial intelligence-based text-to-speech feature, and the presentation of correct answer rates for key concepts to guide teachers. Based on the conducted implementation and descriptive analysis, which was limited to a short-term application period, it was determined that the game offers an effective, engaging, innovative, informative, and content-rich method, and can be recommended for both teachers and student groups. The findings suggest that the game has the potential to enhance learners' environmental awareness while contributing to the development of players' collaboration, persuasiveness, responsibility, decision-making, and problem-solving skills, which are frequently associated with game-based learning environments [3][4][5].

- Future long-term studies involving diverse student and adult populations are recommended to test the effectiveness of the Eco Leaders game in fostering environmental awareness and to monitor changes in attitudes and behaviors over time.
- For adult groups, the removal of headings on the strategy cards could increase the difficulty of card matching tasks.
- For younger age groups, the carbon credit system could be removed to simplify the gameplay.
- By using a cloud database, collected data could be analyzed at the class, school, and provincial levels.
- Integrating flipped learning strategies with research activities focused on sustainability goals within city applications could significantly improve the educational impact of the game.
- Software development could be extended to include devices operating on platforms other than Android.
- The game could be enhanced for outdoor use by connecting it to real-life environmental activities.
- Mobile application questions could be organized in the database according to different age groups, allowing selection based on participant profiles.
- By integrating comprehension-level questions from different subjects instead of climate-related questions, interdisciplinary instruction can be achieved.
- The criterion for best collaboration (e.g., the total number of green pieces collected) could be measured through image processing techniques at the end of the game.
- The application could be adapted for multiple languages to make the game accessible to speakers of different languages.
- A non-mobile application version of the game could also be developed to ensure accessibility for individuals without mobile device access.
- New versions of the game could be designed to address social and economic sustainability as well.

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