Light Up: Educational Board Games with FLOW and Experiential Learning Theory

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Abstract: Games are powerful educational tools that enhance engagement, active learning, and problem-solving. While many sciences educational board games aim at teaching science concepts, they often struggle to sustain student interest. Integrating FLOW Theory with Experiential Learning Theory (ELT) in science board game design can create a more engaging and cognitively enriching learning experience. “Light Up" is a science educational board game designed based on FLOW Theory and Experiential Learning Theory. The game aims to help students understand the impact of carbon dioxide emissions from fossil fuel power plants. In the game, players need to strategize electricity production between coal-fired plants and wind power plants to supply electricity to a growing city. The cost of the power plants, the social cost and the environmental cost are part of the game as well as the interaction between players that simulate the current CO_2 situation among all countries. The Video Game Dispositional FLOW Scale (VGDFS) was chosen to measure the FLOW state of the gameplay. Participants were asked to evaluate VGDFS after the gameplay. Qualitative data from student interviews will reflective process, students were able to connect their in-game experiences to real-world concepts. Preliminary results reveal that students experienced FLOW, characterized by deep concentration, enjoyment, and challenge. Through qualitative interviews, students' immersion and engagement during gameplay were examined. The study found a positive correlation between FLOW states and learning achievement, emphasizing the potential of immersive gaming experiences to enhance education.

Keywords: Educational board game, FLOW and Experiential learning theory

1. Introduction

Games have long been valued as educational tools, offering interactive and engaging ways to learn (Gee, 2003). Unlike traditional lectures, games promote active participation, problem-solving, and decision-making, which enhance understanding and retention. Board games have been widely used across subjects, but many fail to sustain student engagement due to their lack of immersion and excitement, leading to reduced motivation and learning outcomes.

A key difference between highly engaging online games and educational games is the ability to induce FLOW—a psychological state of deep focus, enjoyment, and immersion (Csikszentmihalyi, 1990). FLOW occurs when challenge and skill are balanced, feedback is immediate, and players feel control over their actions (Cowley et al., 2008). FLOW has been shown to boost student engagement, persistence, and active participation (Hamari et al., 2016). However, educational board games often lack dynamic challenges, immediate feedback, and clear goals, limiting their ability to sustain FLOW and causing boredom and disengagement.

To address this, our project integrates FLOW Theory and Experiential Learning Theory (ELT) in designing *Light Up*, a science board game. FLOW Theory emphasizes deep immersion and enjoyment, while ELT focuses on learning through experience, reflection, conceptualization, and experimentation. Combining these frameworks, *Light Up* aims to enhance cognitive engagement and deepen science understanding.

The project’s objectives are: (1) to design an educational board game applying FLOW and ELT principles for an immersive learning experience; (2) to help students understand the environmental impact of electricity production, especially carbon dioxide emissions from fossil fuels; and (3) to evaluate *Light Up*’s effectiveness in promoting FLOW and improving science learning outcomes.

The study addresses these research questions:

RQ1. How does the FLOW experience differ between general games and science educational board games?

RQ2. How can a high-FLOW science educational board game be developed in a science context by integrating FLOW Theory and Experiential Learning Theory (ELT)?

RQ3. How does the FLOW experience change after enhancing FLOW elements in an existing science educational board game?

2. Literature Review

FLOW Theory

FLOW Theory, introduced by Mihaly Csikszentmihalyi, refers to a state of optimal experience in which individuals become deeply engaged and intrinsically motivated while performing an activity. This state is characterized by intense focus, a sense of control, and enjoyment that makes the activity feel rewarding on its own. FLOW arises when there is a balance between the challenge of the task and the individual’s skill level—too little challenge leads to boredom, while too much causes anxiety. Csikszentmihalyi (1990) identified nine dimensions of FLOW: clear goals, immediate feedback, challenge-skill balance, merging of action and awareness, concentration, loss of self-consciousness, a sense of control, transformation of time, and autotelic experience.

Recent research has applied FLOW Theory to board game design to foster engagement and learning. Nauert et al. (2025) developed a FLOW-based mathematics board game for Thai primary students, incorporating clear goals, immediate feedback, and balanced challenge. Their study reported improvements in both achievement and motivation. Similarly, Chang et al. (2022) designed a chemistry game that induced high FLOW states, finding that wooden game tokens enhanced immersion through tactile experience. Chou and Chang (2023) examined FLOW in a university-level media literacy board game, comparing competitive and cooperative play. Both formats enhanced FLOW and learning outcomes, demonstrating the versatility of FLOW-based design. Tsai and Lin (2021) emphasized FLOW’s role in mediating situational interest, suggesting that FLOW-enhancing mechanics help sustain engagement and reduce cognitive overload.

In summary, FLOW Theory offers a strong framework for designing engaging educational experiences through optimal challenge, clear goals, and feedback. Its use in board games has yielded promising results in motivation and learning across subjects. By promoting deep focus and enjoyment, FLOW-based games create immersive environments that sustain engagement. These findings underscore FLOW Theory’s potential as a design principle for effective and meaningful educational games.

Experiential Learning Theory (ELT)

Experiential Learning Theory (ELT) provides a foundational framework for understanding how learners acquire knowledge through active engagement, reflection, and application (Kolb, 1984). This theory has been increasingly adopted—explicitly or implicitly—in the design of educational games. Many game-based learning approaches follow the experiential learning cycle, even if not explicitly labeled as ELT.

Alarcón et al. (2024) developed an escape-room style physics board game where players engaged in hands-on problem-solving and iterative challenges—concrete experiences that stimulated reflection and conceptual understanding, aligning with Kolb’s model. Similarly, Chou and Chang (2023) incorporated structured debriefing activities after gameplay to support reflective learning and connect game experiences with real-world applications, aligning with the reflection and abstraction stages of ELT. Gee (2003) also argues that well-designed games naturally foster active learning through immersive problem-solving, reinforcing the situated nature of experiential learning.

In conclusion, ELT offers a robust foundation for designing educational games that promote meaningful learning through action, reflection, and application. Its alignment with game-based learning—whether explicitly acknowledged or not—demonstrates the theory’s versatility and relevance. As shown in recent studies, integrating hands-on challenges and structured reflection deepens understanding and enhances engagement. These insights highlight ELT’s enduring value in shaping educational experiences that are not only informative but transformative.

Integrates FLOW Theory and Experiential Learning Theory (ELT) into educational board game

This study proposes a novel game-based learning model that intentionally integrates FLOW Theory and Experiential Learning Theory (ELT) into both game mechanics and the learning cycle. While previous research has explored FLOW to enhance engagement or ELT to support reflection, few studies have systematically combined both theories in the design of educational board games. This research addresses that gap by developing a science-themed board game embedding FLOW elements (e.g., clear goals, challenge-skill balance, immediate feedback) within gameplay, while aligning ELT stages—Concrete Experience, Reflective Observation, Abstract Conceptualization, and Active Experimentation—with the game's progression and post-play reflection. The dual-theoretical framework aims to foster both deep engagement and meaningful learning.

In recent years, FLOW and ELT have been applied to digital and non-digital game design to create immersive, motivating experiences. Games that support FLOW can improve focus, persistence, and learning outcomes. Research such as Kiili et al. (2012) and Kiili (2005) demonstrates how games can be intentionally structured to promote FLOW by aligning challenge with player skills and providing timely feedback. Kiili's "Experiential Gaming Model" integrates FLOW and ELT by guiding learners through cycles of meaningful challenges, feedback, and opportunities for reflection and experimentation. These studies highlight ELT's compatibility with game-based learning and its potential for creating effective educational experiences.

Integrating FLOW and ELT offers a powerful approach to educational board game design. FLOW enhances emotional engagement and sustained attention, while ELT ensures reflection and real-world application. Although few empirical studies have implemented this integration, its theoretical synergy is well supported. This study builds on Kiili's conceptual model by applying it in practice, designing a board game that incorporates FLOW elements and ELT stages to support both cognitive and affective engagement.

3. Methodology

The research study on the *Light Up* educational board game employed a pre-experimental design (T1L X T2F T2L), which allowed for the assessment of both learning outcomes and FLOWFLOW experiences among the participants. This design aimed to capture the impact of the game on students' engagement and their understanding of energy concepts.

Table 1 Research Design.

T1L	X	T2F	T2L

- **T1L** represents the pre-test of learning outcome before using the science educational board games
- **X** represents the instructional intervention using the science educational board games
- **T2F** represents the FLOWFLOW assessment (VGDFS) after using the science educational board games
- **T2L** represents the post-test of learning outcome after using the science educational board games

Table 1 outlines the research phases aligned with both FLOW Theory and Experiential Learning Theory (ELT). The Pre-Test (T1L) gauges students' initial knowledge, representing ELT's Concrete Experience stage. The Intervention (X) involves playing *Light Up*, providing an immersive learning experience that fosters FLOW components like Challenge-Skill Balance, Clear Goals, and Unambiguous Feedback, while also reflecting ELT's Active Experimentation. The Engagement Phase (T2F) uses VGDFS to measure FLOW experiences during gameplay. Finally, the Post-Test (T2L) assesses knowledge gained, aligning with ELT's Reflective Observation and Abstract Conceptualization stages. Together, these phases demonstrate how the gameplay fosters both FLOW engagement and experiential learning.

3.1 Participants

Fifty students from grades 4–9 participated in this study during the first semester of the 2025 academic year. This diverse age range provided a broad perspective on the effectiveness of the *Light Up* game across different educational stages.

3.2 Instruments

The study utilized several instruments to collect data and evaluate the effectiveness of the *Light Up* board game

3.2.1 Educational Game – "Light Up"

FLOW Theory, plays a central role in shaping the game mechanics. It emphasizes the importance of achieving a balance between challenge and skill, which is key to fostering deep concentration, enjoyment, and immersion in an activity. *Light Up* is designed to create a balance between challenge and skill through several key approaches. The game is designed with a gradually increasing level of difficulty, beginning with simple scenarios—such as managing a small number of power plants—and progressively introducing more complex elements, including environmental costs and global events. It incorporates complex decision-making paired with immediate feedback; players must choose between coal or wind energy and instantly see the outcomes, such as changes in CO_2 emissions or the number of houses receiving electricity. This design ensures that challenges remain engaging yet manageable. The ability to replay the game allows students to deepen their understanding and develop increasingly effective strategies. Additionally, multiplayer interaction introduces unpredictability and dynamic challenges, requiring constant adaptation and strategic thinking. These aspects help maintain an optimal FLOW experience, where players are challenged but not overwhelmed or bored. Carefully crafted game mechanics keep players within this FLOW zone, fostering concentration, motivation, and active engagement in learning through gameplay.

Experiential Learning Theory (ELT), developed by David Kolb (1984), outlines a four-stage learning cycle that emphasizes learning through direct experience(Kolb, 1984). *Light Up* incorporates these stages into its game design to enhance educational outcomes. The first stage of Experiential Learning Theory, Concrete Experience, takes place during gameplay as players make strategic decisions and interact with core game mechanics such as managing the recurring fuel costs of coal-fired power plants, which increase significantly when generating electricity for a large number of houses, unlike wind power plants that have no such ongoing costs. The second stage, Reflective Observation, occurs during post-game discussions, where players analyze their decisions and outcomes. For example, they may come to realize that although coal power appears cost-effective in the short term, it leads to higher long-term expenses—especially when event cards like coal shortages cause fuel prices to spike. The third stage, Abstract Conceptualization, enables players to connect their in-game experiences to broader scientific and environmental concepts, gaining a deeper understanding of the long-term economic and ecological impacts of different energy sources. Finally, the Active Experimentation stage encourages players to apply newly developed strategies in subsequent rounds—such as switching to wind power after accumulating enough money in order to reduce future fuel costs and emissions. By incorporating all four stages of the learning cycle, Light Up promotes deep engagement and meaningful understanding, allowing players to explore complex concepts through immersive and enjoyable hands-on experiences

Game Concept: "Light Up" – A Strategic Exploration of Energy Choices

In Light Up, each player takes on the role of a mayor of a city on an island, tasked with supplying electricity to their citizens while keeping carbon dioxide emissions within the designated limits. All players begin with an equal budget and must strategically choose between building coal-fired power plants, which are less expensive but polluting and require ongoing fuel costs, or wind power plants, which are more environmentally friendly but have higher construction costs. Players earn income each round by successfully providing electricity to their population. However, failure to meet the city's energy needs results in citizens migrating to other cities, while fully meeting demand leads to population growth. Carbon dioxide emissions from all players are collectively tracked, and if the total exceeds the allowed threshold, it negatively affects everyone. The game ends when a player accumulates the target amount of income while maintaining emissions within the acceptable range; if emissions exceed the limit, all players lose. The game encourages strategic decision-making about energy and environmental responsibility. The central challenge of the game lies in balancing energy production from two contrasting sources: coal-fired power plants and wind power plants. Players must carefully consider not only the cost of energy production but also the environmental impact and social consequences of their decisions, reflecting real-world dilemmas faced by energy planners globally.

The game is thoughtfully designed with several key features that enhance the learning experience for players. First, it presents strategic decision-making under various constraints. Players must generate enough electricity to meet the needs of citizens while navigating the complexities of energy production. Each type of power plant offers distinct advantages and limitations, requiring players to carefully manage resources and consider the environmental impact of carbon dioxide emissions. This scenario mirrors real-world challenges faced by energy policymakers and planners. Additionally, Light Up incorporates interactive gameplay that emphasizes the dynamics of international cooperation and competition in addressing carbon emissions. Since carbon dioxide from all players is accumulated as a collective total, the game highlights the interconnectedness of energy choices and their global environmental consequences. Moreover, the game includes dedicated phases for reflection and discussion, encouraging players to critically evaluate their decisions, share insights, and deepen their understanding through experiential learning. For example, players are prompted to reflect on the long-term costs of different energy sources—coal-fired power plants require ongoing coal expenses, unlike wind power plants which incur no fuel cost. Over time, coal becomes more expensive, and its emissions impact everyone in the game, reinforcing the idea that individual actions can have collective consequences. These reflective elements are essential to achieving the game's educational objectives, creating a well-rounded experience that integrates action, reflection, and meaningful learning.

Table 2: Integrates FLOW Theory and Experiential Learning Theory (ELT) into Light Up board game

FLOW Component	ELT Stage	Game Design Application
1.Optimal Challenge	Active Experimentation	Players apply strategies to solve challenges with increasing difficulty,

FLOW Component	ELT Stage	Game Design Application
		encouraging trial and error without overwhelming or boring them.
2. Clear Goals	Concrete Experience	Each game turn or mission presents specific and visible objectives that guide players toward purposeful activity.
3. Immediate Feedback		Additionally, real-time updates provided by the game mechanics support reflection after gameplay, reinforcing learning through feedback and experience.
4. Distraction-Free		The game design minimizes unnecessary complexity and external interruptions, allowing for uninterrupted engagement in learning tasks.

Figure 1: Game Setup: This figure shows the initial setup of Light Up. Each player gets a city board, starting budget, residential houses, and coal-fired and wind power plant options. Components are arranged on the table, highlighting readiness for strategic decisions. This phase helps players understand their resources and choices for the game

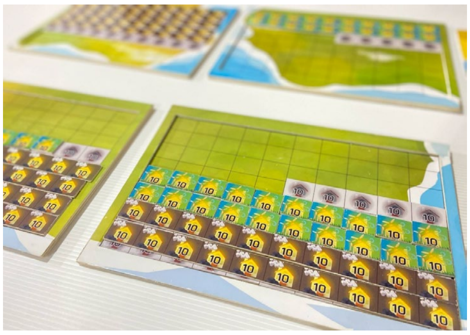

Figure 2: Power Plant Placement: This figure shows a player's city board with power plants placed over houses, indicating those homes receive electricity. Players decide based on budget and strategy—coal plants are cheaper but have fuel costs and pollution, while wind plants cost more but are eco-friendly with no operating costs. The image highlights resource allocation and strategic thinking in the game

Figure 3: CO_2 Emission Board: This figure shows the central CO_2 Emission Board tracking rounds and total carbon emissions from all players each turn. A marker indicates cumulative CO_2 from coal power. When emissions pass a threshold, a scenario card triggers global effects impacting all players. The image emphasizes how individual actions collectively affect the environment

This board game challenges students to manage electricity supply for a growing city using coal-fired and wind power plants. Players must balance costs, social and environmental consequences, and navigate international CO_2 scenarios. The game was developed through a rigorous process, including:

- A literature review on FLOW Theory and ELT.
- Feedback from experts and iterative revisions of the game design.
- Prototype Development: Create a prototype and refine it through playtesting. Try-outs with a pilot group, followed by final adjustments based on student interactions and advisor recommendations.

Game Design:

- Clear Goals: Set clear objectives for players (e.g., efficient energy production).
- Balance of Challenge and Skill : Incorporate challenges that match player skills.
- Immediate Feedback: Provide immediate responses to player actions.
- Playability : refers to how enjoyable, accessible, and functional a game is for players. It's a key concept in game design and evaluation, especially when designing educational games.

3.2.2 VGDFS (Video Game Dispositional FLOWFLOW Scale)

The VGDFS (Cai et al., 2022) was chosen for its specific focus on measuring the dispositional FLOWFLOW state in the context of video games. This scale provides a comprehensive assessment of the player's experience and includes several dimensions of FLOWFLOW. This instrument was employed to assess the nine dimensions of the FLOWFLOW experience: Challenge-Skill Balance (CSB), Clear Goals (CG), Unambiguous Feedback (UF), Concentration (CON), Action-Awareness Merging (AAM), Loss of Self-Consciousness (LSC), Sense of Control (SC), Transformation of Time (TT), and Autotelic Experience (AE). The scale utilizes a five-point Likert format, ranging from 1 (Strongly Disagree), 2 (Disagree), 3 (Neutral), 4 (Agree), to 5 (Strongly Agree).

3.2.3 Learning outcome questionnaire

Developed to assess students' understanding of energy in daily life, this questionnaire underwent a comprehensive development process. It included an analysis of curriculum objectives, a literature review on learning assessment, validation by experts and advisors, and pilot testing for reliability.

3.3 Data Collection Procedure

The data collection process was structured as follows:

- Students completed a pre-test to assess their baseline understanding of energy concepts.
- They played the *Light Up* board game over 2–3 sessions, each lasting 30–40 minutes.
- After gameplay, students completed the VGDFS to assess their FLOW experiences.
- Students completed a post-test to measure any changes in their understanding of energy concepts.
- Semi-structured interviews were conducted to gather qualitative insights into students' learning experiences and their perceptions of the game.

3.4 Data Analysis

The data analysis involved both quantitative and qualitative methods:

- Quantitative Analysis: A comparison of pre- and post-test scores was conducted, along with an analysis of VGDFS component scores to measure the impact of the game on both FLOW experiences and learning outcomes.
- Qualitative Analysis: A thematic analysis of student interview data was performed to identify common perceptions of engagement, FLOW experiences, and conceptual understanding gained through the game.

Through this methodology, the study aimed to assess how the *Light Up* board game influenced students' learning and engagement, particularly in relation to energy concepts and environmental awareness.

4. Results

The results from the VGDFS (Video Game Dispositional FLOW Scale) revealed the following average scores across the nine FLOW dimensions.

Table 3: The results from the VGDFS.

FLOWFLOW dimensions	Result of Light Up
Challenge-skill balance (CSB)	4.18
Clear goals (CG)	4.56
Unambiguous feedback (UF)	4.40
Concentration (CON)	4.29
Action-awareness merging (AAM)	4.26
Loss of self-consciousness (LSS)	4.19
Sense of control (SC)	4.33
Transformation of time (TT)	4.42
Autotelic experience (AE)	4.47
Average	4.35

These preliminary findings indicate a promising trend in both student engagement and learning. Students reported experiencing a clear sense of FLOW during gameplay—particularly highlighting deep concentration, enjoyment, and a strong sense of control over their decisions. These elements align well with the core principles of **FLOW Theory**, which emphasizes full engagement and a balance between challenge and skill to sustain attention.

In addition, the post-game test results demonstrated a statistically significant improvement in students' understanding of energy-related concepts. This suggests that *Light Up* is effective in enhancing scientific knowledge, particularly regarding electricity generation, energy sources, and environmental impacts. Interview data further supported these findings. Students exhibited high levels of engagement during gameplay. For example, one student commented.

Table 4: Mapping Student Reflections to ELT Phases

Quote from Student Interview	ELT Phase	Explanation
"In the following rounds, once enough money has been accumulated, players may switch to coal-fired power plants to quickly generate income without incurring high production costs."	Abstract Conceptualization (AC)	Student shows strategic thinking and understanding of trade-offs between cost and production.
"While coal plants are effective for short-term profit, they are not suitable for long-term use due to their environmental impact and recurring fuel expenses."	Reflective Observation (RO)	Student reflects on cause-effect relationships and internalizes long-term consequences.
"At first, I thought the game was only about competition, but after a while, everyone had to work together to reduce CO_2."	Concrete Experience (CE) → Reflective Observation (RO)	Shift from individual to group goal awareness shows deeper engagement and cooperative learning.
"The student helping to reduce CO_2 said those who didn't were selfish and made everyone else suffer."	Reflective Observation (RO)	Social and ethical reflection occurs; student perceives interconnected consequences.
"If another city does not release carbon dioxide above the standard, my city will win because I plan to use clean energy. However, carbon dioxide levels exceeded the standard before I could switch from coal power plants to wind turbine power plants. In the next round, I hope everyone will help to reduce carbon dioxide emissions."	Abstract Conceptualization (AC) → Active Experimentation (AE)	Student realizes limitation of individual action and anticipates future group behaviour.

Quote from Student Interview	ELT Phase	Explanation
"I will change my strategy in the next round to use more clean energy because my people were affected when carbon dioxide levels exceeded the standard."	Active Experimentation (AE)	Student adapts strategy to avoid repeated failure — shows application of learned concepts.
"I didn't want to stop; I didn't even realize how much time had passed."	Concrete Experience (CE)	Student fully immersed in gameplay; time distortion is a strong FLOW indicator.

These reflective comments highlight the importance of post-game reflection—an essential element of **Experiential Learning Theory (ELT)**. Through this reflective process, students were able to connect their in-game experiences to real-world concepts. The interviews reveal that the game not only fostered active participation but also promoted meaningful reflection, deepened learning, and enhanced conceptual understanding.

5. Discussion

The integration of **FLOW Theory** and **Experiential Learning Theory (ELT)** significantly enhanced the learning outcomes associated with the *Light Up* educational board game. The game was carefully designed to maintain a balance between challenge and skill, offer meaningful choices, and encourage reflective thinking—factors that support both FLOW experiences and the comprehension of scientific concepts.

This study also underscores the value of embedding reflective learning activities directly into the game structure to strengthen knowledge retention. Game rules were designed so players understood the goals clearly, had direction, and never felt uncertain about how to play.

The game set both short-term goals—such as supplying electricity to keep up with population growth—and long-term goals—like accumulating enough money through electricity sales while avoiding excessive carbon dioxide emissions. Players received immediate and clear feedback on their progress toward these goals, which helped guide their strategic adjustments. For example:

- Players earned money when they supplied power to citizens.
- Population increased with consistent power supply.
- Wind power plants did not emit CO_2.
- Citizens decreased in number when power was not supplied.
- CO_2 levels increased when coal-fired plants were used.
- The cumulative CO_2 level was shown at the end of each round, with environmental consequences.

The game's challenges were carefully matched to player skill levels. For instance, players needed to anticipate how others' actions might impact them—such as rising CO_2 levels affecting the entire group. They also had to strategize to meet financial goals before other players.

The game required decision-making skills (e.g., choosing between different power plant types, weighing their advantages and limitations), money management, and planning to ensure full energy distribution without exceeding CO_2 limits.

Additionally, the game demonstrated strong **playability**, combining technical performance, interactive design, and game mechanics to create an engaging experience. *Light Up* encouraged experimentation with different strategies. A key mechanic required players to collectively manage CO_2 emissions, creating shared consequences that impacted all players. Players also had autonomy in their choices, including whether or not to purchase power plants, reinforcing freedom within the gameplay.

The findings from this study suggest that Light Up holds strong potential for use not only within formal educational settings but also in informal learning environments, driven by students' interests. Many participants expressed a desire to continue playing the game during their free time, citing its engaging mechanics, relatable themes, and opportunity for strategic thinking. This indicates that Light Up has the capacity to bridge formal and informal learning by aligning with students' intrinsic motivation—an important factor emphasized in both FLOW Theory and Experiential Learning Theory.

By integrating gameplay into extracurricular clubs, science camps, or community-based environmental activities, Light Up can foster deeper interest in sustainability and energy issues in a way that feels voluntary and enjoyable. The game's real-world relevance and immediate feedback allow players to continuously experiment with new strategies, reinforcing their understanding of complex environmental concepts outside the classroom context. Furthermore, in non-formal settings, students are more likely to take initiative, collaborate with peers across age groups, and explore broader discussions—such as the impact of energy choices on global climate policy or local environmental challenges—thus expanding the depth and application of their learning.

In essence, Light Up supports a flexible and learner-centred approach, offering meaningful educational experiences that extend well beyond traditional instruction. Encouraging its use in student-led or interest-based settings can not only enhance engagement but also contribute to long-term awareness and action regarding sustainable energy use.

6. Conclusion and Recommendations

Light Up demonstrates that well-designed educational board games grounded in **FLOW Theory** and **Experiential Learning Theory (ELT)** can significantly boost student motivation and promote deep learning. The findings support the integration of realistic, experience-based games in science education, especially for complex topics like sustainability and energy. Moving forward, the game content will be expanded, game mechanics refined based on user feedback, and long-term studies will be conducted to evaluate the retention of learning outcomes over time.

Ethics declaration: Ethical clearance was not required, as the research involved teaching practices commonly used by educators.

AI declaration: In the preparation of this paper, AI tools were used to assist with English translation and language refinement. The use of AI was limited to linguistic support only; all ideas, analyses, and interpretations presented in this paper are the original work of the author.

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