

Conceptual Understanding and Systems Thinking Skill in Carbon Neutralization in Farming Role Play Board Game for Science Teacher Professional Development

Kulthida Nugultham, Sunisa Thapseang, Nantarat Kruea-In and Tussatrin Wannagatesiri

Faculty of Education and Development Sciences, Kasetsart University, Kamphaen Saen campus, Nakhon Pathom, Thailand

kulthida.n@ku.th (corresponding author)

sunisathapseang@gmail.com

tussatrin.k@ku.th

nantarat.p@ku.th

Abstract: Carbon Neutralization play the important criteria for the global air pollution problems, and it is the one of the sustainable development goals about air quality. The Carbon Neutralization concept is about the amount of Carbon dioxide (CO₂) absorption should equal the amount of CO₂ emission depending on the activity in any areas. The Farming Role Play Board Game was design for learning in Carbon Neutralization concept including activity card in theme color for CO₂ emission items in red, CO₂ absorption items in blue, and special items in green. Each item shows the amount of CO₂ from 10- 100 ppm and price from 10 – 500 coins. The participants were the 15 science teachers who teach in grade 7-9 in science subject in the western school area of Thailand. The group players, 3-4 teachers, role play to be a farmer who can produce plants, fruit and animals for buying and selling goods. At the game started every group received a budget 2,000 coins to buy any items in the board game. After that they had to play and learn by a random 9 events/rounds which occurred in the concept to calculate in balanced carbon and wrote the number in an activity's worksheet. A winner should balance well in the amount of CO₂ in the last round. The board game engaged the teachers to learn the conceptual understanding in Carbon Neutralization. They reflected about the fundamental system thinking skills that the boardgame need the players to plan the number of plants, animals, alternative or clean energy effected to the amount of CO₂ in ppm, and they need to relate the component of absorption and emission activities. The events were the lesson to practice the system thinking skills, identify the farming problem, finding and feedback the relationship between absorption and emission. Furthermore, they need to be aware dynamic events that effect in every farm that reflect the responsibility for making the better place for the air quality.

Keywords: Carbon neutralization, Systems thinking, Board game, Science teacher professional development

1. Introduction

Climate change, driven largely by human-induced carbon emissions, poses a significant threat to the global environment and human health. Among the many strategies proposed to address this crisis, carbon neutralization has emerged as a vital approach to reduce net carbon dioxide (CO₂) emissions and improve air quality. Carbon neutralization refers to achieving a balance between CO₂ emissions and CO₂ absorption through human and environmental activities. This concept is strongly aligned with the United Nations Sustainable Development Goals (SDGs), particularly those focused on climate action and sustainable resource use. For effective climate education, it is essential that science teachers possess a deep conceptual understanding of carbon neutralization and the interconnected processes that influence it. However, teaching and learning about complex environmental systems remains a challenge in many educational contexts. Traditional instructional methods often fail to promote holistic thinking or to engage learners in understanding the dynamic interactions between human activities and natural systems. As a result, there is a growing need for innovative, experiential approaches to science teacher professional development that foster both conceptual understanding and systems thinking.

One promising approach is the use of educational games, which provide interactive and meaningful learning experiences. Role-play board games can simulate real-world systems and allow participants to explore cause-effect relationships, feedback loops, and the consequences of decision-making in a safe, engaging environment. This study explores the use of a Farming Role Play Board Game specifically designed to teach the principles of carbon neutralization and promote fundamental systems thinking skills among secondary school science teachers in Thailand. The aim of this research is to examine how the board game supports science teachers in developing a conceptual understanding of carbon neutralization and in practicing key systems thinking skills such as identifying components, analysing interactions, recognizing feedback, and responding to dynamic changes. By integrating game-based learning into professional development, this study contributes to a more effective and engaging model for teaching complex environmental concepts in science education.

2. Theoretical Framework

2.1 Carbon Neutralization Concept and Extended in Daily Life

Carbon neutrality, also known as carbon neutrality, refers to achieving a balance between greenhouse gas (GHG) emissions produced and the equivalent amount removed or offset from the atmosphere (IPCC, 2021). This concept plays a key role in global efforts to mitigate climate change and is consistent with international frameworks such as the Paris Agreement, which aims to limit the increase in global temperatures to well below 2°C above pre-industrial levels (UNFCCC, 2021). The basic principle can be expressed through the following equation: Emission = Reductions + Offsetting. This theoretical model provides a foundation for understanding how individuals, organizations, and systems, including agricultural ecosystems, can contribute to net-zero carbon (Fankhauser and Gennaioli, 2021). The process of becoming carbon neutral involves three main strategies: 1) Reducing emissions at source through improved practices and technologies, 2) Increase carbon sequestration, such as through reforestation, soil carbon sequestration, and regenerative agriculture. And 3) Offsetting remaining emissions through investment in carbon credits, renewable energy projects, or other verified emission reduction projects. These strategies are not only essential for achieving national and international climate goals but also serve as a framework for educational interventions aimed at promoting sustainability literacy among educators and learners (Wills et al., 2022).

2.2 Role-Play Board Game on Agricultural and Carbon Neutrality

The design of the Farming Role-Play board game, which focuses on carbon neutrality in agriculture for the professional development of science teachers, is consistent with many existing educational board games that focus on sustainability and environmental literacy. However, this board game stands out by incorporating carbon accounting mechanisms, stakeholder dynamics in role-playing, and targeted applications in teacher education. Another relevant example is The Carbon Footprint Game, developed by researchers at the University of Milan (Sartori et al., 2021). The game introduces players to everyday choices that affect their personal carbon footprint through scenario-based gameplay. Although both games use carbon labels and tracking mechanisms, Farming Role Play Board Game extends this concept by incorporating systemic trade-offs and long-term planning around emissions, sequestration, and offsetting—a level of complexity does not present in The Carbon Footprint Game, which focuses more on decisions about urban lifestyles than agricultural practices. A third related game is Changing the Game – Neighborhood, an EU-funded board game designed to engage communities in local energy transitions (Bouwmeester et al., 2022). The game uses creative mechanics, such as excess energy management and “comfort coins,” to model a society’s acceptance of green technologies. These elements are in line with the Farming Role Play Board Game’s ethos of balancing productivity and ecological impact. However, Changing the Game – Neighborhood focuses on urban energy systems, while Farming Role Play Board Game applies similar systems thinking to rural and agricultural contexts, offering a new way to expand the framework. Finally, MainKassandra (Hoffmann & Rennings, 2021), a business-focused climate risk simulation, uses role-playing to teach resilience and adaptation strategies. While useful for professional training, it does not directly focus on carbon neutrality or integrate agricultural practices.

In summary, board games address issues of sustainability, carbon awareness, and role-playing, but Farming Role-Play uniquely combines all these elements within an agricultural context, specifically designed for science teacher development. The combination of realistic carbon metrics, collaborative decision-making, and systems thinking make this board game a new and impactful tool in the growing field of sustainability education.

2.3 Science Teacher Professional Development in Systematic Thinking

Systems thinking is increasingly recognized as an important skill for science educators, particularly in the context of sustainability education (Wiek et al., 2021). Systems thinking enables teachers to understand and teach the complex, dynamic, and interdependent relationships within environmental and socioeconomic systems, a skill that is essential to addressing global challenges such as climate change and biodiversity loss (Boyes & Stanisstreet, 2020). In response, professional development programs are turning to experiential and simulation-based learning formats, which promote deeper intellectual engagement and systems understanding among educators (Papagiannopoulou et al., 2022). One important recent finding is that traditional professional development workshops often fail to instill systems thinking, due to their reliance on theoretical teaching and discrete content delivery (Morrison, 2022). In contrast, participatory and interactive learning approaches, such as role-playing, board games, and scenario-based learning, have been shown to be more effective in developing this skill. For example, Sipos et al. (2020) found that experiential learning

environments encourage teachers to explore cause-and-effect relationships, feedback loops, and the long-term consequences of decisions. This is a key component of systems thinking.

A growing body of research highlights the value of role-playing and game-based learning in supporting teachers' development in systems thinking. As Hadjichambis et al. (2021) state, these methods allow teachers to assume from multiple perspectives, simulate interactions between stakeholders, and navigate trade-offs between economic, ecological, and social dimensions of sustainability, which is consistent with the instructional design of the Farming Role-Play board game, which allows teachers to immerse themselves in agricultural decision-making scenarios related to carbon neutrality, resource allocation, and environmental impact assessment. Furthermore, reflective thinking exercises after playing the game have been identified as an important mechanism for enhancing systems thinking skills (Sterling, 2021). Structured debriefing sessions allow teachers to articulate, evaluate decision-making strategies, and apply insights to real-world teaching contexts. This reflective thinking process not only enhances individual understanding but also enhances their ability to design classroom activities that promote student-centered inquiry-based learning about sustainability topics (Papagiannopoulou et al., 2022). A recent meta-analysis further indicated that integrating systems thinking into teacher education improves curriculum design. Interdisciplinary integration and student engagement (Reydon et al., 2023). Teachers who develop strong systems thinking skills are more likely to create lessons that emphasize complexity, interdependence, and long-term planning, which are key characteristics of effective sustainability education (Wiek et al., 2021).

3. Methodology

The participants were the 15 science teachers who teach in grade 7-9 in science subject in the western school area of Thailand. The group players, 3-4 teachers, role play to be a farmer who can produce plants, fruit and animals for buying and selling goods on the Farming Role Play Boardgame. The qualitative research was used. The data collecting instruments were an opened interview conceptual understanding of Carbon Neutralization and the observation for engagement and feedback on the Farming Role Play Board Game.

3.1 The Farming Role Play Board Game

The design of the Farming Role Play board game, which focuses on carbon neutrality in agriculture for the professional development of science teachers, is consistent with many existing educational board games that focus on sustainability and environmental literacy. However, this board game stands out by incorporating carbon accounting mechanisms, stakeholder dynamics in role-playing, and targeted applications in teacher education. The Boardgame was structured around nine progressive scenarios, each representing a real-world environmental, economic, and social challenge faced by farmers. The scenarios are designed to promote systems thinking, encourage collaborative decision-making, and deepen understanding of carbon neutrality principles among science teachers participating in the professional development program. Each scenario introduces new variables, such as climate change impacts, policy interventions, or market volatility, that affect the outcome of the game and require players to adjust their strategies accordingly. For clarity and consistency, the key elements of each scenario are summarized in Table 1 below.

Table 1: The nine scenario of the board game and its environmental and economic impacts.

Scenario No.	Description	Environmental Impact / Gameplay Mechanics
1	Government regulation on carbon dioxide emissions	Each farm must reduce CO ₂ by at least 100 ppm through compensatory planting or adoption of alternative energy sources. Teams must make at least one purchase during this scenario.
2	Increased tourism demand for local produce	Farmers are encouraged to sell cabbage, oranges, and pork to a central distribution point to meet high tourist demand.
3	Industrial development increases local CO ₂ emissions	Each farm receives an additional 100 ppm of CO ₂ due to nearby clothing factory operations. The government offers to buy plants or livestock from farms up to a maximum of 200 coin per farm.
4	Unusually cold winter season	Cold weather prompts increased demand for wool and cotton for winter clothing production. Farms unable to supply these materials incur an additional 50 ppm of CO ₂ .
5	Heavy rainfall and flooding damage crops and livestock	Damaged crops (e.g., water spinach, taro) and livestock (e.g., shrimp, fish) result in decomposition-related emissions: 10 ppm CO ₂ per crop plot or livestock unit (per species).

Scenario No.	Description	Environmental Impact / Gameplay Mechanics
6	Introduction of renewable energy technologies	Renewable energy representatives offer equipment that reduces carbon-emitting energy use. Farms may purchase these tools to lower emissions.
7	Government financial support for young farmers	Each farm receives 500 coins in funding and must make at least one purchase to invest in sustainable practices.
8	Outbreak of Foot-and-Mouth Disease (FMD) affecting livestock	Livestock mortality (cattle, chickens, ducks) requires burial, resulting in decomposition emissions: 10 ppm CO ₂ per livestock unit or coop (per species).
9	Farmer networking and resource-sharing initiative	Farms may exchange or trade agricultural goods (crops, livestock, tools) based on negotiated agreements to promote collaboration and sustainability.

Through these transformative scenarios, participants will experience first-hand how individual agricultural decisions impact the wider ecosystem. For example, Scenario 5 models the impacts of extreme weather on agricultural yields, while Scenario 6 promotes investment in renewable energy solutions. The final scenario promotes community-level collaboration and resource sharing, reinforcing the importance of collective action in achieving sustainability goals.

For the game rules and play, the players are divided into a team of 3–4 members each. Each team assigns internal roles for farm management including Farm Manager, Carbon Emission Controller Purchasing and Accounting Officer. Each team must play the game according to 9 predefined scenarios. Throughout the gameplay, teams are required to manage carbon dioxide (CO₂) emissions on their farm to achieve carbon neutrality, meaning that the amount of CO₂ emitted should equal the sum of compensation and emission reductions. The CO₂ quantities are calculated based on carbon labels provided for each item.

At the beginning of the game, each team receives an initial budget of 2,000 coins to establish their farm. Teams must use this budget to purchase items from a central marketplace based on carbon-labeled products, under the following conditions: Field Crops and Livestock Group: 20 plots total, with at least 5 different crop types. Livestock Group: At least 5 types of livestock animals and Perennial Plants Group: Exactly 5 trees. A minimum of 1,000 coins must be spent to establish the initial farm setup. In-game Purchases: During gameplay, each team may purchase new items at the beginning of every scenario. Before starting each new scenario, each team must calculate the total CO₂ emissions generated by their farm based on the carbon labels and record it on the Farm Management Score Board. This step is essential for planning purchases and managing CO₂ levels effectively. Once all teams have completed setting up their initial farms, the game begins with the first scenario and continues through the ninth scenario. Throughout the scenarios, each team must manage and operate their farm to complete the assigned tasks.

At the end of the game, the winning team is the one that successfully manages its farm to achieve carbon neutrality, where the total amount of CO₂ emissions equals the sum of carbon compensation and emission reductions.

Table 2: The character and CO₂ activities of the cards

Emitted Card	Offset Card	Reduce Card	Special Card
<p>The Field Crops and Livestock Group can be purchased in every scenario. Upon purchase, the associated carbon dioxide (CO₂) emissions are calculated immediately in every scenario. If spoilage occurs, an additional CO₂ emission value equal to twice the original amount must be accounted for.</p>	<p>The Perennial Plants Group can be purchased in every scenario. Once purchased, the associated carbon dioxide (CO₂) emissions are accounted for starting in the following scenario and can be applied toward CO₂ management in all subsequent scenarios. If fruits from perennial plants are bought or sold, the trees remain on the farm.</p>	<p>Renewable energy items can be purchased in every scenario. Once purchased, the associated carbon dioxide (CO₂) value begins to take effect in the following scenario and can be applied toward CO₂ management in all subsequent scenarios.</p>	<p>Carbon reduction technology can be purchased in any situation. Once purchased, it can be immediately applied to reduce carbon dioxide (CO₂) emissions, but the technology's effects are only effective in the current situation.</p>

4. Results

4.1 The Conceptual Understanding of Carbon Neutrality

For the observation and interview, teachers could gain an understanding of the principles of carbon neutrality through gameplay during the fourth round, in which the scenario tiles are revealed. In each round, the game gradually builds foundational knowledge regarding processes of carbon dioxide emissions, absorption, and reduction resulting from agricultural activities and the transportation of agricultural products. Upon completing the game, teachers were able to conclude that the amount of carbon dioxide emitted must equal the amount absorbed. Therefore, teachers formulated a simple mathematical equation and attempted to select various activities that would result in the total sum of emissions, absorption, and reduction of carbon dioxide equating to zero.

4.2 Teachers' Engagement and Feedback on the Farming Role Play Board Game

Teachers were able to engage with the game in their assigned roles, although some expressed a desire to take on multiple responsibilities, acting as moderators of decisions both within and between groups. This behavior reflected emerging leadership tendencies in some participants, particularly in the initial scenarios (Scenarios 1–3), where teachers followed structured game play activities and gradually developed an understanding of the specific characteristics of each card type. Overall, teachers provided constructive feedback indicating that the scenarios could benefit from greater variety in agricultural challenges and constraints. They suggested that agricultural purchases and sales occur in smaller quantities, such as 1–2 items per round, to allow for more informed decision-making, which would reduce the cognitive burden associated with simultaneously monitoring residual carbon levels and managing financial budgets for subsequent rounds. In addition, several teachers noted that the initial capital provided at the beginning of the game was relatively high, which reduced the urgency or need to strategically procure crops or livestock for trade with other groups, and as a result, the economic stresses and resource scarcity in the game were less pronounced.

Despite these observations, most teachers reported enjoying the process of selecting crops, livestock, and transportation methods that minimized carbon emissions. They found these aspects interesting and educationally valuable in understanding the trade-offs between yield and sustainability. However, they also noted the difficulty of measuring the impact of unexpected events, such as crop failure or livestock death. These elements do not generate income but rather increase carbon emissions. These elements elicit emotional reactions related to loss and uncertainty, which, while reflecting the risks of real-world farming, are challenging to measure within current game structures.

5. Discussions and Conclusions

Integrating role-playing board games into the professional development of science teachers has emerged as an effective approach to foster systems thinking, particularly in the context of sustainability education. A farming role play board game, designed to model agricultural systems and carbon neutrality strategies, provides teachers with an experiential learning environment that promotes holistic understanding, interconnected decision-making, and long-term strategic planning, all of which are essential components of systems thinking (Wiek et al., 2021). Systems thinking involves recognizing how different elements within a system are interconnected and influence each other (Sterling, 2021), a skill that is essential for teaching complex topics such as climate change and sustainable agriculture. In the game, teachers assume roles such as farm manager, carbon controller, and buyer/seller, each responsible for different aspects of the farm operation. As teachers deal with environmental and economic scenarios such as extreme weather, policy changes, or market fluctuations, teachers begin to see how individual actions (e.g., the use of synthetic fertilizers) can have ripple effects on soil health, emissions, and profitability. This mechanism supports the development of thinking models that reflect real-world complexity, helping teachers understand agriculture not only as a production system, but also as part of a broader ecological and socio-economic network. (Papagiannopoulou et al., 2022) A key feature of systems thinking is the ability to identify feedback loops, lags, and non-linear relationships (Boyes & Stanisstreet, 2020). Game designs require players to track cumulative CO₂ emissions over multiple rounds, forcing them to anticipate the long-term consequences of their choices. For example, planting trees may reduce emissions in future rounds but also reduce cropland in the short term. Similarly, purchasing renewable energy equipment may reduce emissions in the long term, but requires upfront investment. These dynamics encourage teachers to think outside the immediate outcomes box and consider trade-offs in the system, reinforcing the idea that environmental decision-making often involves balancing conflicting priorities, a skill essential for effective teaching of sustainability topics. Role-playing is an important mechanism by which

games promote systems thinking. By assigning different roles with conflicting goals (e.g., maximizing output versus minimizing emissions), games simulate the interactions of stakeholders encountered in real-world sustainability challenges. Teachers must negotiate, collaborate, and compromise. This skill reflects the interdisciplinary and collaborative nature of climate action (Sipos et al., 2020). This aspect of game play helps educators understand the complex nature of problems that involve multiple perspectives, enhancing their ability to teach sustainability as a systems-based discipline rather than a set of isolated facts. After playing the game, a structured debriefing session allows teachers to reflect on their experiences, discuss decision-making processes, and explore how lessons learned can be applied to classroom teaching. This reflective practice is essential to embedding systems thinking into their teaching practices (Morrison, 2022). Such reflective teachers often design lessons that emphasize cross-disciplinary connections, real-world problem-solving, and student-led inquiry, which are essential characteristics of effective sustainability education. Overall, the Farming Role Play Board Game is an effective tool for science teacher professional development, particularly in promoting systems thinking skills through its simulation of agricultural ecosystems, its focus on long-term planning, its promotion of perspective-taking, and its support for reflective learning. The board game provides teachers with an understanding of the concepts and practical tools needed to teach complex environmental topics. As Thailand continues to prioritize the green economy transition, the game will play an increasingly important role in preparing science teachers to lead sustainability education in the 21st century.

Acknowledgements

The research team would like to express their sincere gratitude to Science Education Program, Department of Teacher Education, Faculty of Education and Development Sciences, for their financial support for this project. This research was made possible by their continued support and commitment to promoting innovative practices in science education. We also express our gratitude to the teachers and institutions that participated in the development and implementation of a role-playing board game on carbon neutrality in agriculture. Their insights and contributions greatly contributed to the success of this project. We would also like to thank experts from various disciplines who collaborated to design the educational content and gameplay mechanics.

Ethics and AI Declaration: This research adheres to the highest standards of academic integrity and ethical conduct throughout its design, implementation, and reporting. All data collected from participating science teachers during the development and testing of the Farming Role Play Board Game were obtained with the consent of interested teachers to participate in the project and will be used solely for educational research purposes. Participants were fully informed of their rights, including the ability to withdraw from the study at any time without consequence. Anonymity and confidentiality of all responses were maintained in strict accordance with the ethical guidelines for educational research involving human participants. In addition, the authors wish to disclose that artificial intelligence (AI) tools were used to assist in drafting, editing, and formatting this manuscript. These tools were used solely to improve clarity, grammar, and structure, and all content was reviewed, edited, and approved by the human authors. The use of AI did not affect the conceptual development, interpretation of the data, or conclusions presented in this research.

References

- Bouwmeester, M.C., van den Hurk, M. & Kramer, R., 2022. *Changing the Game – Neighborhood: A Board Game for Local Energy Transition*. Utrecht: Copernicus Institute of Sustainable Development.
- Boyes, E. & Stanisstreet, M., 2020. *Teaching about climate change: Developing students' understanding of complex systems*. London: Earthscan.
- Fankhauser, S. and Gennaioli, C. 2021. Valuing the carbon benefits of nature-based solutions. *Nature-Based Solutions for Climate Policy*, 12(2), pp. 45–58.
- Hadjichambis, A.C., Reis, P. & Papagiannopoulou, C., 2021. Promoting systems thinking through educational simulations: Implications for education for sustainability. *Journal of Environmental Education*, 52(4), pp. 247–265
- Hoffmann, V.H. & Rennings, K., 2021. MainKassandra: A serious game for teaching business responses to climate change. *Simulation & Gaming*, 52(1), pp.45–67.
- IEA, 2022. Energy efficiency 2022: an overview. International Energy Agency [online]. Available at: <https://www.iea.org/reports/energy-efficiency-2022> [Accessed 10 April 2024]
- IPCC, 2021. Global Warming 1.5°C. Geneva: *Intergovernmental Panel on Climate Change*.
- Morrison, J.A., 2022. Sustainability as a co-curriculum priority: Embedding systems thinking in teacher education. *Environmental Education Research*, 28(6), pp. 975–992
- Papagiannopoulou, C., Hadjichambis, A.C. & Reis, P., 2022. Promoting systems thinking in education for sustainability: *The role of simulation games* *Environmental Education Research*, 28(5), pp.763–780.
- Papagiannopoulou, C. et al. 2022. Climate Education and Youth Advocacy: Exploring Collaboration for Climate Action. *Environmental Education Research*, 27(2), pp.173–189.

- Sartori, G., Biral, G. & Nota, G., 2021. Gamification to promote sustainable lifestyles: The carbon footprint game. *Journal of Cleaner Production*, 294, pp. 126-259.
- Sipos, Y., Battisti, B. & Grimm, K., 2020. Achieving transformative sustainability learning: Engaging the brain, hands, and heart. *Canadian Journal of Environmental Education*, 25, pp. 10–28.
- Reydon, T.A.C., van der Schee, J.A. & Klaassen, K., 2023. Bridging science and society through systems thinking in education. *Sustainability*, 15(3), p.2301.
- Smith, P. et al. 2022. Potential for greenhouse gas mitigation in agriculture through improved land use change and management. *Global Change Biology*, 22(3), pp.1092–1105.
- Sterling, S., 2021. *Systems thinking for sustainability: applications in higher education*. Abingdon: Routledge.
- UNFCCC, 2021. *Paris Agreement*. Bonn: United Nations Framework Convention on Climate Change.
- Wiek, A., Xiong, W., Brundiers, K. & van der Leeuw, S., 2021. Planning research efforts to enhance systems thinking. *Sustainability Science*, 16(3), pp.981–997
- Wills, J. et al. 2022. Developing climate literacy through gaming. *International Journal of Sustainability in Higher Education*, 21(3), pp. 450–464.