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Development of an Instructional Package on Sustainable Supply Chain Innovation Management through the Carbon Heroes Board Game for Undergraduate Students in Logistics and Supply Chain Management

*Panyavacharawongse S.
**Ariya Jidtrakornpanya A.

*Faculty of Logistics and Aviation Technology, Southeast Bangkok University, Bangkok, Thailand
**Sustainable Innovative Technology Co.,Ltd. 119/149, Bang Krang Subdistrict, Mueang Nonthaburi District, Nonthaburi Province 11000, Thailand. E-mail: naan.ariya@gmail.com
Corresponding author Email: chetphanat@gmail.com

Abstract

This research developed and evaluated an instructional package on "Sustainable Supply Chain Innovation Management" using the Carbon Heroes board game for undergraduate Logistics and Supply Chain Management students. The study employed a five-phase R&D approach: 1) needs assessment through literature review and surveys, 2) curriculum design integrating ESG concepts and experiential learning, 3) expert validation (IOC $\geq$ 0.80), 4) pilot testing with 15 students at Southeast Bangkok University, and 5) data analysis using t-tests, E1/E2 effectiveness criteria, and content analysis. Results showed the instructional package achieved the highest quality level (mean = 4.63, S.D. = 0.30) across all dimensions. Effectiveness scores exceeded the 80/80 criteria with E1 = 84.48% and E2 = 87.33%, demonstrating significant learning enhancement. Student satisfaction was at the highest level ($\bar{x}$ = 4.69, S.D. = 0.32), particularly in knowledge acquisition ($\bar{x}$ = 4.81) and learning activities ($\bar{x}$ = 4.78). The game-based instructional package successfully enhanced both academic achievement and learner motivation, proving suitable for expansion to other educational contexts to strengthen ESG competencies in sustainable supply chain management.

Keywords: Sustainable Supply Chain Management, Game-Based Learning, Educational Innovation, Carbon Heroes Board Game, Experiential Learning, Curriculum Development, Learning Effectiveness, Learner Satisfaction.

Introduction

In an era of increasingly complex environmental, economic, and technological changes, Sustainable Supply Chain Innovation Management has become a critically essential skill for modern logistics and supply chain professionals. This is particularly important as organizations worldwide are emphasizing business operations based on ESG (Environmental, Social, and Governance) principles, which encompass reducing environmental impact,

caring for society and stakeholders, and maintaining good governance (Elkington, 1997; PwC, 2021; World Economic Forum, 2023). However, transferring the necessary knowledge and skills to integrate ESG factors with supply chain innovation management at the undergraduate level remains challenging, as traditional teaching methods such as lectures, PowerPoint presentations, or rote memorization cannot effectively create deep understanding of the holistic connections and complex dynamics between supply chain decision-making and impacts across all three dimensions. This is especially true in the Thai context, where there is still a lack of learning media design that can connect environmental issues with economic systems at local and national levels (Phipma, 2021; UNDP Thailand, 2022).

Therefore, this research aims to develop a training curriculum to enhance such knowledge and skills using the "Carbon Heroes" board game, which is an innovative experiential learning tool specifically designed to simulate the challenges of creating balance between economic goals (production, trade, investment), social objectives (population satisfaction, employment), and environmental concerns (carbon management, resource utilization) in the context of city management and interconnected supply chains.

This game allows players to assume the roles of five types of city leaders who must strategize development, manage resources, negotiate trade deals, invest in projects ("Investing Cards"), and respond to unexpected "situation cards," where every decision impacts CO2 emissions, population satisfaction, and economic stability of their own and other cities. Learning through real-situation simulation, data analysis, and reflection from playing Carbon Heroes aligns perfectly with Active Learning, Problem-Based Learning, and Collaborative Learning approaches (Prince, 2004; Kolb, 1984; Hmelo-Silver, 2004), which will help prepare students to effectively apply knowledge in managing sustainable supply chain innovation in the real working world.

Research Objectives

1. To develop an instructional package on Sustainable Supply Chain Innovation Management using the Carbon Heroes board game for undergraduate students majoring in Logistics and Supply Chain Management.
2. To test the effectiveness of the instructional package to meet the established criteria of 80/80.
3. To determine learner satisfaction with the developed instructional package.

Research Methodology

This research is applied research that aims to develop and test the effectiveness of a training curriculum on Sustainable Supply Chain Innovation Management using the "Carbon Heroes" board game as an experiential learning tool. The study applies the Research and Development (R&D) approach based on Borg & Gall's (1983) methodology, which consists of five main phases.

Phase 1 Problem and Needs Assessment

The researchers conducted a literature review related to Sustainable Supply Chain Innovation concepts, ESG (Environmental, Social, and Governance) principles, and Game-Based Learning to analyze contemporary trends and practices relevant to training curriculum development. Additionally, a needs assessment survey was

conducted among students and faculty in the Logistics and Supply Chain Management field to identify learning gaps and learner engagement behaviors in the current context (Kolb, 1984; Phipma, 2021).

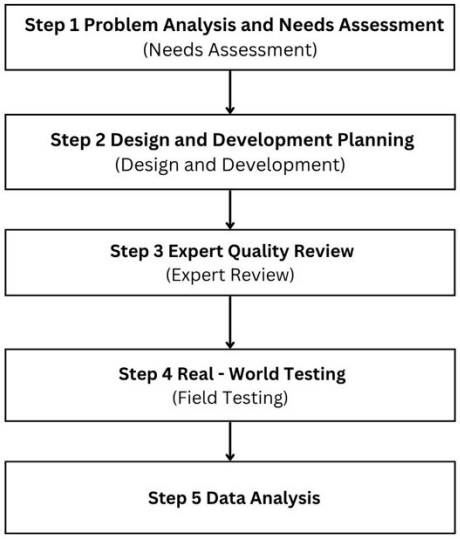

Figure 1 Research Process Steps

Phase 2 Curriculum Design and Development

The "Carbon Heroes" board game was designed based on Experiential Learning principles that emphasize role-playing and decision-making in simulated situations, enabling learners to understand economic, social, and environmental management systems under ESG concepts through game mechanisms such as production, investment, carbon emissions, and trading (Lin et al., 2015). This was coupled with the design of training activities comprising lectures, full-scale game play, and reflection according to the principles of McGuire (1969) and Jonassen (1991).

Phase 3 Quality Validation

The researchers presented the curriculum draft, game prototype, and assessment tools to three experts in curriculum design, logistics management, and game design to evaluate Content Validity using the Index of Item-Objective Congruence (IOC). The evaluation results showed that the index was at an appropriate level (IOC $\geq$ 0.80).

Phase 4 Pilot Implementation

The curriculum and Carbon Heroes game were tested with a sample group of 15 fourth-year undergraduate and graduate students majoring in Logistics and Supply Chain Management at Southeast Bangkok University. Data were collected before and after training through academic achievement tests, the ECCI-I creativity assessment (adapted from Torrance Tests), satisfaction evaluation forms, and focus group interviews to analyze in-depth learning experiences.

Phase 5 Data Analysis and Conclusion

The researchers analyzed quantitative data using paired t-test statistics to compare pre- and post-training scores and analyzed curriculum effectiveness using the E1/E2 index. Descriptive statistics such as mean and standard deviation were also used to assess learner creativity and satisfaction. Additionally, qualitative data from behavioral observations and group discussions were analyzed using Content Analysis to synthesize findings and recommendations for curriculum improvement (Patton, 2002).

Table 1: "Universal Basic Needs & Overall Interdependence Table" (Per Round, for CPL=5)

Universal Basic Needs Categories	Required Resources/Services (Per Round for CPL=5)		Service Provider Cities (Diversifying Dependencies)	Impact If Not Received (Linked L0-L3 Satisfaction)			
				L0 Crisis	L1 Shortage	L2 Sufficient	L3 Abundant
				Units / Score	Units / Score	Units / Score	Units / Score
1. Sustenance	Food	5-6 units	Agriculture (A)	< 3 / -4	3-4 / 0	5-6 / +2	> 7 / +3
2. Utilities Pillar	Standard Energy	5-6 units	Energy (E) / Industry (A)	< 3 / -2	3-4 / 0	5-6 / +2	> 7 / +3
	Basic Construction Parts	1-2 units	Industry (A)	0 / -1	- / -	1 / +1	2 / +2
3. Well-being & Happiness	Consumer Goods	2-3 units	Industry (A)	< 2 / 0	- / -	3-3 / +1	> 3 / +2
	Recreation Services	1-2 packages	Tourism (B)	- / -	0 / 0	1 / +1	2 / +2
	Communication Networks	1 system	Technology (C)	- / -	0 / 0	1 / +1	> 1 / +1

Table 2: Production Resources, Average Prices & Impact "Table" (Production, Price & Impact Table)

Industrial City	Code	Resource/Service Produced	Type	(Production Cost/Unit)	Central Price/Unit	Carbon Impact/Unit	Primary Use Notes
Industrial	A1	Basic Construction Parts	Basic	10 Coins	20 Coins	+10	Maintenance, basic construction (all cities)
	A2	Consumer Goods	Basic	5 Coins	15 Coins	+5	Quality of life (all cities)
	A3	Specialized Machinery & Tools	Specialized	35 Coins	60 Coins	+30	Mining/scouring, agriculture, energy, technology development
	A4 Alternative	Fossil Fuel Energy	Basic	5 Coins	10 Coins	+50	Energy alternative (High carbon)
Tourism City Tourism	B1	Recreation & Cultural Services	Basic	10 Coins	25 Coins	+5	Quality of life (all cities)
	B2	Service & Marketing Expertise	Specialized	20 Coins	40 Coins	+2	Promotion, building acceptance (Specialized)
เมืองเทคโนโลยี Technology	C1	Communication & Data Networks	Basic	15 Coins	30 Coins	+3	Quality of life, basic operations (all cities)
	C2	Tech Solutions & Innovations	Specialized	40 Coins	70 Coins	+15	Efficiency development, carbon reduction, innovation
เมืองเกษตร/Agricultural	D1	Food	Basic	5 Coins	10 Coins	+5	Food security (all cities)
	D2	Bio-Materials & Processed Agri-Products	Specialized	15 Coins	35 Coins	+2 If planted forest absorbs -5	New industries, tech research, economy, Essential energy (all cities)
เมืองพลังงาน Energy	E1	Standard Clean Energy	Basic	10 Coins	15 Coins	+5 Carbon absorption technology from production -20	Energy development
	E2	Advanced Energy Tech & Management	Specialized	40 Coins	65 Coins	-10	storage, tech jobs

Table 3: "Specialized Needs & Inter-City Interdependence" (Specialized Needs & Interdependence)

(Needing City)	ต้องการพัฒนาเพื่อประสิทธิภาพ	ทรัพยากร/บริการเฉพาะทางที่ต้องเป็น (จากการลงเยี่ยมเมือง)	เมืองผู้ให้/ให้บริการหลัก (Supplying City)
Industrial City (A)	- Create new/eco-friendly products - Increase factory efficiency	B2 (Bio-Materials) C2 (Tech Solutions & Innovations)	Agricultural (D) Technology (C)
Tourism City (B)	- Create new tourism experiences/Marketing - High-quality services	B2 (Bio-Materials) A2 (Consumer Goods - Premium grade)	Agricultural (D) Industrial (A)
Technology City (C)	- Innovation research/high-tech equipment production - AI/software development	B2 (Service & Marketing Expertise) E2 (Advanced Energy Tech & Management - for labs)	Tourism (B) Energy (E)
Agricultural City (D)	- Increase productivity/smart agriculture - Agricultural product processing	E2 (Advanced Energy Tech & Management - for labs) C2 (Tech Solutions & Innovations)	Energy (E) Technology (C)
Energy City (E)	- Build new power plants/Smart Grid - [illegible]	A3 (Specialized Machinery & Tools) B2 (Service & Marketing Expertise)	Industrial (A) Tourism (B)

Figure 2 Game Board Setup for the Carbon Heroes Board Game

Research Results

The quality assessment results of the instructional package on Sustainable Supply Chain Innovation Management through the Carbon Heroes board game from five experts using a 5-level rating scale questionnaire are presented in Table 1. The effectiveness results of the instructional package from 15 learners are shown in Table 2, and the learner satisfaction assessment results regarding the developed instructional package are presented in Table 3.

Table 1 Quality Assessment Results of the Instructional Package

Assessment Items	Mean	S.D.	Interpretation
1. Learning Format	4.70	0.30	Highest
2. Teaching Content Materials	4.48	0.29	High
3. Teaching and Learning Media	4.56	0.31	Highest
4. Activity Organization Process	4.78	0.29	Highest
5. Experimental Kit/Teaching Materials	4.64	0.32	Highest
6. Measurement and Evaluation	4.63	0.30	Highest

Based on the quality assessment results of the instructional package by 5 experts using a 5-point Likert scale questionnaire, it was found that the developed instructional package had an overall quality at the "highest" level (overall mean = 4.63, S.D. = 0.30), with all components receiving high-level assessments, indicating appropriateness and alignment with learning objectives across all dimensions. These included the game-integrated learning format ($\bar{x}$ = 4.70), the instructional content materials which, despite having the lowest mean score ($\bar{x}$ = 4.48), still remained at the "high" level, the interesting and flexible instructional media ($\bar{x}$ = 4.56), the activity management process which received the highest score ($\bar{x}$ = 4.78) reflecting the design of activities that truly promote participation and interactive learning, as well as the experimental kit/instructional materials ($\bar{x}$ = 4.64) and measurement and evaluation ($\bar{x}$ = 4.63) that were appropriately designed and aligned with the content.

These assessment results therefore reflect that the instructional package on "Sustainable Supply Chain Innovation Management through the Carbon Heroes Board Game" has high quality and can be effectively implemented for learning management, consistent with the concepts of experiential learning (Kolb, 1984) and game-based learning (Pihwma, 2021), which emphasize learner participation, hands-on practice, and integrated learning. The obtained results represent a crucial step in confirming the quality of the instructional package before proceeding to efficiency determination using the E_1/E_2 criteria, with efficiency standards set at 80/80 as shown in Table 2.

Table 2 Learning Effectiveness from the Instructional Package

Person	E1 Score (40 points)	E2 Score (40 points)
1	33	34
2	34	35
3	29	33
4	30	32
5	37	38
6	35	35
7	32	33
9	34	35

Person	E1 Score (40 points)	E2 Score (40 points)
10	38	39
11	33	34
12	34	35
13	33	34
14	35	35
15	36	37
Total Score	**473**	**489**
Average Score	**84.48%**	**87.33%**

Figure 3 Atmosphere of Activities Using the Instructional Package

From the effectiveness analysis of the instructional package, considering the scores during learning (E1) and after learning (E2) of 15 students, it was found that the average E1 score was 33.79 points out of 40, equivalent to 84.48%, and the average E2 score was 34.93 points, equivalent to 87.33%. Both values exceeded the established standard efficiency criteria of 80/80, thus concluding that the developed instructional package effectively promotes learning achievement both during and after learning. Additionally, learners showed continuously improved achievement after participating in activities, reflecting the design of content and activities that can effectively stimulate learning.

To ensure comprehensive evaluation across all dimensions, the researchers conducted an assessment of learner satisfaction with the instructional package combined with learning through the "Carbon Heroes" board game. The overall evaluation results were at the "highest" level, indicating learner acceptance in terms of content, game attractiveness, teaching methods, and learning atmosphere, particularly regarding the appropriateness of activities that promote participation and practical learning. These evaluation results confirm that the developed instructional package can effectively meet learner needs in both content and format while creating sustainable motivation for learning.

Table 3 Learner Satisfaction Assessment Results

Assessment Items	Mean	S.D.	Interpretation
1. Instructional Package	4.63	0.49	Excellent
2. Teaching Media	4.59	0.17	Excellent
3. Teaching and Learning Activities	4.78	0.21	Excellent
4. Alignment with Course Content	4.65	0.49	Excellent
5. Knowledge Gained	4.81	0.25	Excellent
Overall Average	**4.69**	**0.32**	**Excellent**

Table 3 shows the learner satisfaction assessment results for the instructional package through the "Carbon Heroes" board game, revealing that the overall satisfaction mean was 4.69 with a standard deviation of 0.32, which is at the "highest" level across all aspects. This reflects that learners were comprehensively satisfied with the designed learning process. The item with the highest mean was knowledge gained ($\bar{x}$ = 4.81, S.D. = 0.25), indicating that learners perceived that the content and activities clearly enhanced their knowledge acquisition. This was followed by teaching and learning activities ($\bar{x}$ = 4.78), which indicates the attractiveness and participation in the concrete learning process.

Although teaching media had the lowest mean at 4.59, it still remained at the "highest" level, showing that the media used could create good satisfaction but may have areas for further development. In conclusion, the instructional package that integrates the board game as a learning tool not only demonstrates effectiveness in terms of achievement but also significantly creates learning experiences that satisfy learners across all dimensions.

Discussion

1. The development of the instructional package on "Sustainable Supply Chain Innovation Management" through the Carbon Heroes board game received evaluation from five experts and was found to have "highest" quality ($\bar{x}$ = 4.63, S.D. = 0.30), covering learning format, activity organization, assessment and evaluation, and content. This reflects the appropriateness of the design that aligns with experiential learning concepts (Kolb, 1984) and game-based learning approaches (Phipma, 2021). Particularly, the Carbon Heroes game, which simulates city management roles across economic, social, and environmental dimensions, helps students systematically and realistically understand the complexity of ESG and carbon management (Lin et al., 2015).

2. Testing the effectiveness of the instructional package according to the 80/80 criteria showed that the learning effectiveness assessment from 15 students revealed an average during-learning score (E1) of 84.48% and post-learning score (E2) of 87.33%, which exceeded the established standard criteria of 80/80. This demonstrates that the instructional package can significantly enhance learning achievement. Learners showed continuous knowledge development before and after learning, particularly in complex issues such as CO_2 impact

analysis, strategic planning, and systemic connections in supply chains, reflecting the potential of learning with participation mechanisms and contextual decision-making (Gee, 2007).

3. Learner satisfaction with the instructional package: Survey results showed that overall satisfaction was at the "highest" level ($\bar{x}$ = 4.69, S.D. = 0.32), particularly in "knowledge gained" ($\bar{x}$ = 4.81) and "learning activities" ($\bar{x}$ = 4.78). This indicates that learners deeply perceived the value of content and experiences from the Carbon Heroes game, as well as activities designed to promote participation, enjoyment, and motivation, consistent with Active Learning concepts and game-based learning that can truly create motivation and understanding of complex subjects (Plass et al., 2015).

Recommendations

Based on the research results and pilot implementation of the sustainable supply chain innovation management training curriculum through the Carbon Heroes board game, the researchers offer the following recommendation.

Recommendations from the Research

1. Integration of the Carbon Heroes board game as the core of training curricula in higher education institutions to develop students' deep understanding of ESG concepts and sustainable logistics management, effectively addressing future skills requirements.

2. Balancing some game mechanisms, such as slightly increasing initial capital or providing formal trial rounds, to accommodate learners without strategic board game backgrounds and increase confidence in in-game decision-making.

3. Developing question guidelines and post-game reflection frameworks (Debriefing Framework) that help connect game experiences with theories and real case studies to enhance learners' ability to apply knowledge deeply and comprehensively.

Recommendations for Future Research

1. Testing the curriculum and Carbon Heroes board game with learners in other fields such as business administration, engineering, information technology, and upper secondary education levels, as well as industrial personnel to assess effectiveness in diverse contexts.

2. Designing and evaluating a Game Facilitator Training Program to enable teachers and instructors to use the game effectively.

3. Developing a digital version of the Carbon Heroes board game to reduce limitations regarding time, location, and number of players, while enhancing the ability to analyze gameplay data.

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