7-31-2020

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Recommended Citation

Hartono, Natalia; Laurence, Laurence; and Chandra, Giovanni Hezekiah (2020). LIFE CYCLE ASSESSMENT IN SUPPLY CHAIN MANAGEMENT GAME. *Journal of Environmental Science and Sustainable Development*, 3(1), 1-29.

Available at: <https://doi.org/10.7454/jessd.v3i1.1045>

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LIFE CYCLE ASSESSMENT IN SUPPLY CHAIN MANAGEMENT GAME

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(Received: 4 June 2020; Accepted: 20 July 2020; Published: 31 July 2020)

Abstract

Educational games are essential in explaining theories to students as such activities create a fun learning environment. Most educational games in supply chain management (SCM) are focused on SCM or logistics theories. In the last decades, the research in environmentally conscious SCM has increased. However, the educational games related to such SCM are limited. This work is the first to use the detailed life cycle assessment (LCA) approach in teaching students SCM. The research output is a game called “Robo Factory,” which involves a simulation of a robot production supply chain. The research objective is to educate undergraduate students about the SCM structure, the duties and responsibilities of SCM actors, the LCA approach, and the cost types in SCM and LCA. The paper describes the game design process. The game design entails three steps: (1) game conceptualization and prototype design; (2) prototype trial, evaluation, and finalization of game rules; and (3) final games. Evaluation results indicate that the game successfully teaches undergraduate students about the theory of LCA in SCM in an enjoyable manner. The posttest shows an overall increase in students’ knowledge. The paper presents the future research directions and implications for scholars to enhance their contributions.

Keywords: educational game; life cycle assessment; supply chain management.

1. Introduction

The industrial world is in an unprecedented competitive environment where technological development, globalization, and limited resources provide new standards for companies to create products and services that exceed consumer expectations. Efficiency in production, enhanced management, and other factors are crucial in winning any competition. A company must consider the environmental impacts connecting suppliers, distributors, partners, and customers (Su et al., 2015). Supply chain management (SCM) is a coordination process in which resources are converted and utilized to fulfill specific orders in manufacturing or service

companies (Onu & Mbohwa, 2019). The role of supply chain managers is crucial as it involves planning and managing existing resources for the survival of their companies.

In the academic community in the field of SCM, a common issue is the development of teaching methods for SCM courses (Vanany & Syamil, 2016). In the last four decades, simulation, gaming, and other sources have been shown to serve as excellent tools for experimentation and learning (Mayer, 2009). Games can be an effective tool to engage college students and help them understand the processes in a supply chain. A classroom lecture is not enough for students to understand the concepts of SCM; educational games may be used to enrich student experience (Shovityakool et al., 2019).

The concept of SCM could be enforced through play (Kuijpers, 2009), and the complexity of SCM can be understood by experiment-based learning (Mehring, 2000; Hofstede, 2006). According to Engler (2012), Clark Abt first introduced the term “serious game” in 1968. Relative to traditional games, serious games are used for military training, advertising, simulation, and education. Serious games were initially used for flight simulation. Sawyer (2002) in Noemi and Maximo (2014) said that a serious game is a simulation of real events aimed at solving a problem. The game can be used as an analytical tool because it is flexible and adaptable; game formats can be scenario-based games, simulation games, and seminar games (Mayer, 2009).

The “beer game” is the oldest and most popular game in SCM; it is useful in understanding the “bullwhip effect” (Vanany & Syamil, 2016). This game was designed by Professor John Sterman of the Massachusetts Institute of Technology (MIT) and was a continuation of the ideas of Jay Forrester, a professor at MIT who conducted many studies on dynamic systems (Pujawan & Er, 2017). The original game was a board game developed in the 1960s as a role-playing simulation that simplifies a supply chain (Hieber & Hartel, 2003). The beer game itself has evolved from a board game into a computer simulation. The beer game provides lessons on the bullwhip effect, the advantages of reducing lead time, and the benefits of information sharing (Anderson & Morrice, 2000). The bullwhip effect is described as information distortion; under this effect, the demand that is relatively stable at the final customer level can fluctuate in the upstream supply chain, at which point it could increase considerably (Pujawan & Er, 2017).

The bullwhip effect occurs when the number of orders increasingly varies as the process flows in the upstream of the supply chain (Lee et al., 1997). The beer game physically and digitally simulates the workflow of a distribution center, in which each player can manipulate

the inventory as a retailer, wholesaler, distributor, or manufacturer. Other SCM games include the innovative practical games published by Vanany and Syamil in 2016 (Vanany & Syamil, 2016). This board game uses Lego® blocks to emphasize the role of a supply chain manager, which is crucial in determining the victory of a team. The supply chain manager is responsible for ordering, calculating, and assigning jobs to the operator. The game uses supply chain costs, which are calculated to determine the winning team, which reports the least cost. A summary of previous research on teaching SCM is available in the work of Vanany and Syamil (2016), where they collected 24 papers from 1998 to 2013; 62.5% of these papers used or developed games while 37.5% developed contents (curriculum) for teaching SCM subjects. The summary itself highlights the wide use of the beer game and other simulation games. Grandzol and Grandzol (2018) designed the “Chantey Castings” Simulation to teach SCM with a focus on a demand-driven approach and constraint management.

The game uses Play-Doh to teach students to match customer demand while learning the concept of SCM. Sato et al. (2017) designed a specific SCM game for milk to increase the awareness of food waste among university students in Japan. Liu (2017) used an open-source simulation video game to teach supply chain and logistics management. The educational games in SCM are based on different objectives. Hence, how lecturers develop educational materials to reinforce students’ learning and enrich their hands-on experience is an interesting topic.

In the Scopus database, a search for papers written in English and those in the final publication stage by using key terms such as “Supply Chain Management” in the title and “green” OR “sustainability” OR “sustainable” within the results yields 3,041 documents from 1995 to 2019. The key terms used in the search are based on how research papers usually refer to the environment using word such as “green,” “sustainable,” or “sustainability.” The analysis of the results shows a sharp rise in the consideration of the environment in the field of SCM in the past 10 years (Figure 1). This trend implies the growing importance of the environment in SCM.

Figure 1. Analysis of search results from the Scopus database using the key terms “supply chain” in the title and “green” OR “sustainability” OR “sustainable” within the results from 1995 to 2019

Source: [Scopus \(2020\)](#)

Sustainable supply chain management (SSCM) has become a major research hotspot due to the extensive efforts to protect our environment. [Carter et al. \(2019\)](#) performed a systematic literature review on the evolution of SSCM in the last 28 years and detailed the possible future direction of SSCM research. Different methods and frameworks for measuring SSCM performance have also been suggested ([Beske-Janssen et al., 2015](#); [Brandenburg et al., 2019](#); [Jensen, 2012](#); [Khalid & Seuring, 2019](#); [Lu et al., 2018](#); [Ni & Sun 2019](#); [Parmigiani et al., 2011](#); [Paulraj et al., 2017](#); [Qorri et al., 2018](#); [Ramezankhani et al., 2018](#); [Rebs et al., 2019](#); [Taghikhah et al., 2019](#); [Yun et al., 2019](#); [Zimon et al., 2019](#)). One of these methods is life cycle assessment (LCA) approach. The focus of SSCM research has shifted to three directions, namely, social and environmental problems in SSCM, measurement and management of sustainability performance in SSCM, and measurement of the impact of SSCM on company finances ([Beske-Janssen et al., 2015](#)).

Another term used in SSCM research is green supply chain management (GSCM). GSCM involves the integration of the environment in SCM ([Chin et al., 2015](#)). In SSCM and GSCM, researchers have carried out extensive discussions and implementations of environmental measurements to reduce environmental impact while increasing business profit. One environmentally relevant approach is LCA, whose strengths include the completeness of the life cycle perspective and its environment scope ([Hauschild, 2018](#)). According to ISO 14040, the LCA approach is a method for analyzing the environmental aspects and impacts related to products by compiling inputs and outputs from related inventories, evaluating potential environmental impacts associated with these inputs and outputs, and interpreting the results of

the inventory analysis and the impact assessment phase in relation to research objectives (ISO 14040:2006, 2016).

In LCA, the potential impact of certain factors on the environment is evaluated using groups of data obtained at the inventory analysis stage. IMPACT 2002+ is one of the most commonly used methods. This method uses transactions between industry sectors, including environmental data emissions (e.g., sulfur dioxide, particle matter, and carbon dioxide) and consumption of natural resources (e.g., coal, natural gas, and petroleum products), to determine the environmental impact of the entire supply chain within the economy. The integration of LCA in SCM was proposed by Fornasiero et al. (2017), Genovese et al. (2017), and Blass and Corbett (2018).

A serious game that teaches university students about environmental decisions in enterprises and supply chains was created by Qualters et al. (2006), Zhang and Zwolinski (2015), and Cuesta and Nakano (2017). The environmental issues in supply chains have gained popularity among researchers, who have thus designed education games related to environmental decisions in SCM. However, to the best of our knowledge, no educational game includes a detailed LCA in SCM. Hence, the current work attempts to fill the research gap by creating a game called the “Robo Factory,” which is expected to help explain the importance of environmental aspects in SCM. The study considers the “life cycle assessment” course offered by the University of Pelita Harapan.

In the SCM course, the Robo Factory game could be used as an introduction for students and as a bridge to understand the relation of LCA and SCM. Through this game, undergraduate students can distinguish the link between sustainability issues in SCM. The proposed game is designed to educate players about the SCM structure, the duties and responsibilities of SCM actors, the LCA approach, and types of costs in SCM and LCA. This research focuses only on LCA as a performance measurement of SCM. The paper is structured as follows. Following the introduction, the research methodology for game design and development is discussed, and the final game is analyzed. Conclusions are then presented, along with suggestions for further research.

2. Methods

In this part of the study, the literature related to SCM and its games is reviewed. Previous studies employed different approaches in developing games, but their goals are essentially the same, that is, to engage students’ interest and to enrich their experience. The purposes of

educational games vary for game developers. In particular, educational games should not only be entertaining but also be capable of addressing the specific requirements of learning objectives. Educational games should be carefully and systematically designed to ensure the accuracy of the process.

Bloom's taxonomy is widely used in the design of learning objectives for cognitive learning skills and in the measurement of learning outcomes for educational purposes (Adams, 2015; Adesoji, 2018; Ramirez, 2016). Bloom's taxonomy can connect the conceptual aspects of a game to the cognitive level (Brewer & Brewer, 2010). Moreover, it helps ensure that the steps for measuring the specifications of learning objectives are being followed. However, the only previous work related to SCM games based on Bloom's taxonomy is that by Vanany & Syamil (2016).

Herein, the selected process is the game design process by Duke (1981). The original work is not accessible but is detailed in the study of Kuijpers (2009). The selected process comprises three stages (Figure 2). The proposed Robo Factory game uses this game design process with modifications in the evaluation phase (stage 2) based on Bloom's taxonomy. The evaluation involves the use of open-ended questions. For the test, the question is designed and developed using the original framework of Bloom's taxonomy (Bloom, 1956). The structure has six main categories: knowledge, comprehension, application, analysis, synthesis, and evaluation.

Figure 2. Three stages in developing the Robo Factory game

Source: Authors (2020)

First Stage: Game Conceptualization and Prototype Design. The first stage involves the delineation of the initial concepts of the game and the design of the prototype. The initial concepts of the game include its name, purpose, parts, and description. The prototype design includes the design, input and game output, player role, product description, trial and error, transportation design, demand arrival standard, demand card, event card, and questionnaire.

Second Stage: Prototype Trial, Evaluation, and Finalization of Game Rules. The second stage involves the testing of the prototype, evaluation of the pretest and posttest of the players, analysis and improvement, and finalization of the game rules. *Third Stage: Final Game.* The

final game design covers the improvement of the prototype and the verification and validation of the final game.

3. Results and Discussions

3.1. First Stage: Game Conceptualization and Prototype Design

Initial conceptualization is the heart of game development; it is the most crucial stage. It involves naming the game, defining its purpose, identifying its parts, and deriving its description. In this work, the proposed game is the SCM in a robot factory, hence the name “Robo Factory.” Previous games in SCM are played differently. The beer game is played based on turns, whereas the innovative practical games are based on time. A time-based game requires a large number of players serving as timekeepers. As the Robo Factor game is intended to educate all players, it is designed to be a turn-based game. The purpose of this game is to inform players about the structure of SCM, the duties and responsibilities of SCM actors, the LCA approach, and the types of costs in SCM and LCA. The four elements of the game are the pretest, the introduction of the game to the players, the game proper, and the posttest (Figure 3).

Figure 3. Four elements of the Robo Factory game

Source: Authors (2020)

Figure 4 shows the parts used for the game prototype. For the “parts of the robot,” 540 Goldkids building blocks that resemble Lego® blocks are used. The “day marker” is made of paper on which the positions of shipping and players are marked. For the “transportation” prototype, a brown paper bag is used as a vehicle. The “turn marker” prototype indicates the turn in the game.

Figure 4. (a) Goldkids building blocks; (b) day marker prototype; (c) transportation prototype (paper bag); (d) turn marker prototype

Source: Authors (2020)

This game is a turn-based game that mimics the process in the supply chain of robot production. The players are the students in the SCM class. They are divided into several groups. Each group consists of two competing factories. Other players include a supplier, a customer, a supply chain manager, an operator, and a moderator. The moderator provides a pretest, introduces the rules of the game, and then assigns the students their different roles. The game commences. A posttest after is conducted after the game. The game begins with an order from the customer to the supply chain manager, who forwards the order to the supplier. The order is then assembled by the operator. The game ends when the customer receives the order. The group with the least total cost or the highest total score wins the game. The prototype is designed using the guidelines set by Peters et al. (1998), as explained by Kuijpers (2009). The framework is used to overcome the errors found in game development (Table 1).

Table 1. Game validity guidelines

Guide	Application
Work systematically.	The work starts with the determination of the game input and output, game components, game trials, and game improvements. The game is then tested until it is free from errors.
Make accurate measurements and implement small steps during the design	The improvement can be observed in the process, from prototype development to the

Guide	Application
phase.	final game.
Check the validity of the game by informing the players about the concept. Ask their opinions about the concepts and theories.	The evaluation results are explained to the players after the game.

Source: Authors (2020)

In designing the game, the input and output of the game must be described. Meijer (2009) described the input and output of a game session (Figure 5). The input is the game design, game situation, and players. The game design consists of the roles, rules, and objectives of the game. The game situation refers to the event card, which provides several delivery scenarios; it is explained further in the next section. The output of the game session is a player with knowledge and data to be processed (pretest and posttest data).

Figure 5. Game's input and output

Source: Authors (2020)

The details of the game are presented in the final phase of game development. They are explained briefly in this section to shorten the length of the paper. As the process is a step-by-step improvement, discussing all details may be redundant. This prototype comprises one customer, two factory teams (each team consists of one supply chain manager and one operator), two suppliers (supplier X and supplier Y), and one moderator. The customer takes a demand card and checks whether or not the demand that arrives has the right specifications or whether the delivery is delayed or on time. The supply chain manager is responsible for determining the number of orders, size of inventory, number of shipments, and transportation used. The supply chain manager also supervises the operator. The operator assembles the

products quickly and accurately and then sends the demand according to the instructions of the supply chain manager. The supplier is responsible for fulfilling the orders of the supply chain manager according to the sequence of the teams' orders, starting from those that were placed first. The moderator oversees monitoring the players and changing the turn marker in each turn.

For this game, the two products are the Alpha and Beta, which are represented by the Goldkids building blocks and serve as the basic ingredients of acrylonitrile butadiene styrene. The product Alpha consists of one A part, two C parts, one D part, one E part, three F parts, five G parts, and one J part. The product Beta consists of one B part, three C parts, one D part, three F parts, one G part, one H part, one I part, one J part, and one K part. The bills of materials of Alpha and Beta are shown in Figure 6.

A truck, a ship, and an airplane are used as the vehicles for the game. The design covers the demand arrival standard, holding cost calculation, and LCA score. The details of the final prototype design are provided after the trial and error phase. The trial and error is carried out by simulating the game with three different scenarios. After the game trial, the researcher and players discuss the results to improve the game further.

Figure 6. Bills of materials of Robo Factory for products Alpha and Beta

Source: Authors (2020)

The results of the trial and error of the Robo Factory prototype are analyzed to improve the game. First, the order from the supply chain manager to the supplier, with the product as a reference, is converted into parts, the numbers of which are limited as follows: three head parts for Alpha and three head parts for Beta in one turn. This limit is set to help the supplier in checking the availability of goods and the supply chain manager in devising strategies to win the game (i.e., the manager may want to deplete the supplier's stock so that the opponent cannot fulfill its product requirements). Second, three types of vehicles are used: trucks, ships, and aircraft. As the experiment progresses, only trucks and ships are used to simplify the game. The aircraft is excluded because the transportation time is classified as too fast (one turn), and 540 parts are not enough (they may run out too quickly).

Third, the initial plan is to provide additional scores for players who successfully fulfill orders that arrive earlier than the demand arrival standard. However, any additional score is no longer provided to simplify the calculation. The scores remain subject to reduction for each late-arriving demand, the value of which is one. Fourth, the initial plan is to provide additional scores for players who successfully match the orders with the bill of materials. However, this idea is abandoned to simplify the calculation. Nonmatching of orders for each product receives a one-point reduction. Fifth, the holding score is initially classified on the basis of the number of parts available at the end of the game. To provide knowledge about the holding cost, the conversion of the number of components to the holding score is performed by multiplying the number of parts with the holding cost. Finally, the calculation unit of the transportation score is changed from CO₂e to rupiah. This step is to add knowledge about LCA conversion from CO₂e to kilowatt/hour (kWh). The results are then converted to rupiah.

The details of the game parts after the trial and error are presented in this section. Trucks and ships serve as the modes of transportation to ship parts and products. The travel time of trucks takes two turns, and that of ships takes three turns. A truck can hold 15 parts, and a ship can hold 45 parts. The CO₂e of each truck changes on the basis of the number of parts it holds. The CO₂e of each ship remains the same regardless of the number of components it holds. However, if the ship only holds fewer than 39 parts, then the shipment is made in the next turn. Figure 7 shows the distance under the assumption that the customer is located in Semarang Tawang, Semarang; the factory is located in Gading Nias, North Jakarta; and the supplier is located in Margomulyo, Surabaya. The CO₂e values are obtained from product weight data of 4.5 tons (15 parts) and distance data processed using the SimaPro application (Tables 2 and 3). The locations are determined on the basis of the locations with easy access to the port.

Figure 7. Location flow in Robo Factory game

Source: Authors (2020)

Table 2. CO₂e from supplier to factory and from factory to customer

Transportation	CO ₂ e (×10 ⁴) From Supplier to Factory	CO ₂ e (×10 ⁴) From Factory to Customer
Truck	1.8	1.78
Ship	4.95	4.95

Source: Authors (2020)

Table 3. Truck's CO₂e from supplier to factory and from factory to customer

Part Quantity	CO ₂ e Truck (×10 ⁴) From Supplier to Factory	CO ₂ e Truck (×10 ⁴) From Factory to Customer
14	1.517	1.497
13	1.407	1.387
12	1.298	1.278
11	1.189	1.169
10	1.08	1.06
9	0.971	0.951
8	0.861	0.841
7	0.75	0.73
6	0.64	0.62
5	0.53	0.51
4	0.42	0.4
3	0.32	0.3
2	0.22	0.2
1	0.1	0.08

Source: Authors (2020)

Table 4. Demand arrival standard for Robo Factory

Demand#	Turn	Demand#	Turn	Demand#	Turn
1	7	8	14	15	21
2	8	9	15	16	22
3	9	10	16	17	23
4	10	11	17	18	24
5	11	12	18	19	25
6	12	13	19	20	26
7	13	14	20	21	27

Source: Authors (2020)

The demand arrival standard is set to calculate the delay of product arrival (Table 4). This standard is used by the customer to declare whether the demand is delayed or delivered on time. The demand card contains the customer requests per turn for the Alpha and Beta products. The quantity of demand for each product ranges from 0 to 2. This value is obtained from the total available products (20 Alpha products and 20 Beta products) divided by the first demand arrival standard (turn 7); the result is 2.85, rounded down to two Alpha products and two Beta products.

The event cards are created to mimic natural events that may occur in real life. Its purpose is to add an unexpected event that may lengthen or shorten the transportation time. This card is held by one of the suppliers, is taken at each turn before shipping, and applies only to the vehicle that will depart from the supplier to the factory. This card is separated from the deck after being taken. Two cards are used for each event card on the deck. Table 5 shows the content of the event cards in this game.

Table 5. Event cards for Robo Factory

Event Cards	Description
Today is bright, and nothing happens	No Event
Today is cloudy, and nothing happens	No Event
The wind blows lightly, and nothing happens	No Event
The weather is fine, and nothing happens	No event

Event Cards	Description
Full harbor	The harbor is full; ships turn off their engines and wait (i.e., the ships are placed on the delay day marker).
Harbor check	Additional harbor check is conducted; the ships turn off their engines and wait (i.e., the ships are placed on the delay day marker).
Flood	Flooding occurs; the truck cannot depart (i.e., the truck is placed on the delay day marker).
Truck maintenance	Truck maintenance; the truck cannot depart (i.e., the truck is placed on the delay day marker).
New road toll	A new toll opens; the trip is faster by one day (i.e., the truck is placed on the day 2 marker).
New road	A new road opens; the trip is faster by one day (i.e., the truck is placed on the day 2 marker).
Empty harbor	Empty harbor; the trip is faster by one day (i.e., the ship is placed on the day 2 marker).
New ship	A new and faster ship is available; the trip is faster by one day (i.e., the ship is placed on the day 2 marker).

Source: Authors (2020)

The evaluation phase is designed to measure the knowledge of the players before and after the game (pretest and posttest). In stage 1, the questionnaire for the prototype trial evaluation consists of seven questions. Questions 1 and 2 refer to the supply chain structure; question 3 refers to tasks and responsibilities; questions 4 and 5 discuss LCA; and questions 6 and 7 refer to the supply chain cost, LCA, and performance. The questionnaire for the prototype trial and the final prototype based on Bloom's taxonomy is presented in Figure 12. The game rules and instructions are described in the finalized version (improvement after trial).

3.2. Second Stage: Prototype Trial, Evaluation, and Finalization of Game Rules

The prototype trial is conducted at the University of Pelita Harapan. The trial involves seven players and three researchers, with one serving as the moderator and the other two serving as observers (Figure 8).

Figure 8. Prototype trial documentation

Source: Authors (2020)

According to the pretest and posttest results, the players achieve an overall increase in their knowledge after playing the game. The results for questions 1 to 7 indicate knowledge increases of 72.42%, 78.61%, 57.15%, 57.14%, 76.24%, 63.98%, and 71.44%. From these results, one can conclude that the players understand Robo Factory. However, a number of obstacles are identified in the game prototype.

1. Table CO₂e requires correction because the players have difficulties in calculating the LCA cost.
2. Transportation is difficult to distinguish because the paper bags do not greatly differ.
3. Upon reaching the supplier, the order lists of both teams are often mixed.
4. The explanation of the game is still difficult to understand.
5. The game instructions are too long.
6. Suppliers and customers do not participate in the calculation of the LCA cost. The objective of all players being able to perform the calculation is not achieved.

The improvements for the finalized game rules based on the prototype trial are listed below.

1. At the beginning of the game, the two factories do not have inventory.
2. The demand cards and event cards are placed upside down and shuffled. Cards that have been played are separated from the deck. When the deck is empty, the discarded cards are reshuffled and then returned to the deck for use.

3. Each shipment may only use a maximum of three vehicles.
4. Customer orders that arrive faster than the standard do not receive bonus points.
5. If the supplier cannot fulfill a factory order, then the order is declared forfeited.
6. At the end of the game, all orders that are in transit are considered as inventory.
7. In ordering parts from suppliers, supply chain managers must prioritize robot head parts (part A for Alpha products and part B for Beta products) as every order can only have a maximum of three A parts and three B parts. Ordering a robot body can only be done when ordering a robot head. The body and head parts must be in the same mode of transportation. Example: If the supply chain manager wants to order two Alpha products (14 parts) using a truck (15 parts), then the following scenarios are possible:
 - a. Order one A part: the bill of materials can only have one robot body part so that the supplier sends one Alpha product with 14 parts.
 - b. Order two A parts: the bill of materials can have a maximum of two robot body parts. However, because one maximum truckload is 15 parts, the truck contains one Alpha product and one A part A. The remaining body parts from one Alpha product in the bill of materials are deemed forfeited and may not be sent using other modes of transportation.

The game boundaries are listed below.

1. The supply chain manager can choose to use a truck or a ship, and the number of available vehicles is 20 units each.
2. The supply chain consists of the supplier, factory, and customer.
3. The LCA is limited to the calculation of CO₂e and kWh.
4. The CO₂e calculation is performed in Impact 2002+.
5. The calculation unit of the transportation score is changed from CO₂e to rupiah. This improvement is aimed providing knowledge about conversions in LCA. The conversion factor of CO₂e to kWh is added and then converted to rupiah.

The assumptions in this game are provided below.

1. Weight: Alpha product, 4.5 tons; Beta products 4,137 tons.
2. The truck used in this game is a double box colt diesel type with a capacity of 6.5 tons.

3. The holding cost is assumed to be 20% of the shipping cost.
4. Shipping cost is Rp. 11,250,000.
5. kWh to CO₂e conversion factor for (1 kWh)/(0.35156 CO₂e).
6. Electricity costs per kWh are used for household needs > 6,600 VA for Rp. 1,352.
7. The dividing factor in LCA cost is 10⁹ in rupiah.
8. Each month has 20 working days; hence, one year has 240 working days.

Tables 6, 7, 8, and 9 present the conversion from cost to score for this game after the discussion between the players and the researcher. The holding cost per part is Rp. 625 and is calculated at the end of the game. The calculations from assumptions 3, 4, and 8 show that the shipping cost is Rp. 11,250,000 multiplied by 20% and then divided by 240. The result is the holding cost per robot, that is, Rp. 9,375, which must be divided by 15 to obtain the holding cost per part, that is, Rp. 625. The remaining parts at the end of the game and the holding cost are multiplied and then compared against the holding score table. The holding score table is created to help the players calculate their final scores in an attempt to win the game (Table 6). As explained in the previous section, the holding score is initially calculated on the basis of the parts only. However, on the basis of the final decision, the holding cost is added as a conversion factor to obtain the holding score that mimics real-life events.

Table 6. Holding score for Robo Factory

Holding Cost	Holding Score
Below Rp. 50,000	+3
Between Rp. 50,000 and Rp. 100,000	+2
Above Rp. 100,000	+1

Source: Authors (2020)

A demand is deemed delayed if it arrives beyond the standard time of arrival presented in Table 4. The value of delay is always 1, and the number of days of delay are not considered. For example, demand #1 should arrive at the customer at turn 7, but it reaches the customer at turn 8; hence, demand #1 is delayed by 1. The next example is order #1 of the customer at turn 10; demand #1 is delayed by 1. A fast delivery gains no additional points. Total delay is then converted to delay score (DyS) based on Table 7.

Table 7. Delay score for Robo Factory

Delay Cost	Delay Score
≤ 1	+5
2–3	+4
4–5	+3
6–7	+2
> 8	+1

Source: Authors (2020)

The defect score (DfS) is only counted if the customer receives a defective product. In this game, a defect occurs when the product does not match the specifications; for example, a defect may be a wrong color, wrong parts in the product, etc. Every mistake is counted as one defect cost; hence, if a product received by the customer has the wrong color and wrong parts, two defect costs are incurred. The total defect is then converted to the defect score on the basis of Table 8. The defect score reduces the total score.

Table 8. Defect score (DfS) for Robo Factory

Defect Cost	Defect Score
1–3	–1
4–6	–2
> 7	–3

Source: Authors (2020)

The transportation score (TS) is obtained from the conversion of the total CO₂e into rupiah. The CO₂e value is then converted to kWh using the following formula:

$$\text{kWh value} = \text{CO}_2\text{e} \times \text{kWh to CO}_2\text{e converting factor}, \quad (1)$$

$$\text{LCA cost} = \text{value of kWh} \times (\text{electricity cost per kWh}) / (\text{dividing factor}). \quad (2)$$

The converting factor is 0.35156 CO₂e, the electricity cost per kWh is Rp. 1,352, and the dividing factor is 10⁹ in rupiah. Based on equations 1 and 2, LCA cost is equal to CO₂e value $\times 3.8457 \times 10^6$. The results are converted to TS on the basis of Table 9. The total score is obtained by adding the holding score (HS), delayed score (DyS), defect score (DS), and transportation score (TS).

Table 9. Transportation score for Robo Factory

LCA Cost	Transportation Score
<1	+4
1–2	+3
2–3	+2
>3	+1

Source: Authors (2020)

3.3. Third Stage: Final Game

The third stage is the final game. The improvements from the prototype to the final game are listed with some explanations. *First*, Tables 2 and 3 in the prototype are changed into a concise and simple table in the final game for players to use in the calculation. For ease of reference, the final table is presented in Figure 9. *Second*, this table shows the improvement for CO₂e transportation from the supplier to the factory. *Third*, the paper bags used for transportation are marked with stickers to avoid confusion. Different colors are assigned to factories A and B.

Transportation	CO ₂ e								
	x1	x2	x3	x4	x5	x6	x7	x8	x9
Truck	1,8	3,6	5,4	7,2	9	10,8	12,6	14,4	16,2
Ship	4,95	9,9	14,85	19,8	24,75	29,7	34,65	39,6	44,55

Part Quantity	CO ₂ e truck								
	x1	x2	x3	x4	x5	x6	x7	x8	x9
14	1,517	3,03	4,55	6,07	7,59	9,10	10,62	12,14	13,65
13	1,407	2,81	4,22	5,63	7,04	8,44	9,85	11,26	12,66
12	1,298	2,60	3,89	5,19	6,49	7,79	9,09	10,38	11,68
11	1,189	2,38	3,57	4,76	5,95	7,13	8,32	9,51	10,70
10	1,08	2,16	3,24	4,32	5,40	6,48	7,56	8,64	9,72
9	0,971	1,94	2,91	3,88	4,86	5,83	6,80	7,77	8,74
8	0,861	1,72	2,58	3,44	4,31	5,17	6,03	6,89	7,75
7	0,75	1,50	2,25	3,00	3,75	4,50	5,25	6,00	6,75
6	0,64	1,28	1,92	2,56	3,20	3,84	4,48	5,12	5,76
5	0,53	1,06	1,59	2,12	2,65	3,18	3,71	4,24	4,77
4	0,42	0,84	1,26	1,68	2,10	2,52	2,94	3,36	3,78
3	0,32	0,64	0,96	1,28	1,60	1,92	2,24	2,56	2,88
2	0,22	0,44	0,66	0,88	1,10	1,32	1,54	1,76	1,98
1	0,1	0,20	0,30	0,40	0,50	0,60	0,70	0,80	0,90

Figure 9. CO₂e calculation for Robo Factory

Source: Authors (2020)

Figure 10. Final day marker for Robo Factory

Source: Authors (2020)

Fourth, the day marker is fixed and printed in a 250 cm × 160 cm banner (Figure 10). *Fifth*, the game rules are simplified from a five-page document to a one-page document. *Sixth*, player role has been through some changes based on evaluation in stage 2. In this article, the final role of a player is presented in Figure 11.

Role	Number of player	Description
Customer	Customer (2)	Responsible to read the demand card and check the delay and product defect
Factory (2 team)	Supply Chain Manager (1)	Planning the supply with considering every boundary, planning the shipment strategy to customer, choose the transportation, and give order to operator
	Operator (2)	Took product from warehouse and assembly the product using the Bill of Material and send the finished product to customer as instructed by SCM manager
Supplier (2 Supplier)	Supplier (4)	Send the part to factory as demand from SCM Manager, took and read the event cards.
Moderator	Moderator (1)	Giving explanation of the game, observed the game, giving instruction, change the turn marker

Figure 11. Player roles and descriptions

Source: Authors (2020)

And *seventh*, the pretest and posttest questionnaires for the prototype are improved by rephrasing the questions to eliminate ambiguity. The difference between the previous questionnaire and the final questionnaire is only the points in each question, and there is one question added. To avoid repetition and make the article more concise, only the final questionnaire presented in Table 10.

Table 10. Final questionnaire for Robo Factory

Questions	Description	Point	Bloom's Taxonomy
A. Supply Chain Structure (100 Point)			
1. Who are the supplychain actor in game? (100 Point)	No answer or all false. Correct mention 1 actor. Correct mention 2 actors. Correct mention ≥ 2 actors.	0 33.34 66.67 100	Knowledge
2. Can you explain the relationship between supplychain actors in the game? (100 Points)	No answer or all false. Correctly explained the relationship between 2 actors Correctly explained the relationship between ≥ 2 actors	0 50 100	Application
B. Task and Responsibilities (100 Point)			
3. What are the roles of the SupplyChain Manager in the games (100 Points)	No answer or all false. Correct mention 1 role. Correct mention 2 roles. Correct mention 3 roles.	0 33.34 66.67 100	Knowledge
C. Life Cycle Assessment (100 Point)			
4. Describe with your own words where is the CO ₂ e function in the game? (100 Points)	No answer or all false. Right answer	0 100	Comprehension
5. What are the factors that affect the ammount of CO ₂ e in the game? (100 Points)	No answer or all false. Correctly mentions 1 factor that affects the CO ₂ e value Correctly mentions 2 factor that affects the CO ₂ e value Correctly mentions 3 factor that affects the CO ₂ e value	0 33.34 66.67 100	Application
D. Supply Chain Cost, Life Cycle Assessment, and Performance (100 Point)			
6. What are the types of costs in the game? (100 Points)	No answer or all false. Correct mention 1 cost. Correct mention 2 costs. Correct mention 3 costs. Correct mention 4 costs.	0 25 50 75 100	Knowledge & Evaluation
7. If the CO ₂ e is assumed to be A and the converting Factor is B, then the LCA Score is? (100 Points)	No answer or all false. Correct answer	0 100	Synthesis & Evaluation
8. What is the best strategy for winning this game? (100 Points)	No answer or all false.	0	Analysis & Evaluation

Source: Authors (2020)

The final game is conducted at the University of Pelita Harapan. The players are industrial engineering students in the SCM course. The total number of students is 35. The game is split into three sessions from 08:00 to 12:40. The documentation process is presented in Figure 12. The final game evaluation is carried out by verifying and validating the game.

Figure 12. Final game documentation

Source: Authors (2020)

3.3.1. Final Game Verification

An evaluation about whether the basic needs of the game are met or not is conducted to determine the performance of the proposed Robo Factory game. The basic requirements of this game are based on those by [Kuijpers \(2009\)](#).

1. The players can mention the SCM actors and explain the relationship between them.
2. The players can mention the role of the supply chain manager.
3. The players can explain what the CO₂e function is in the game and what factors affect the size of the CO₂e value.
4. The players can calculate the cost of the game. This calculation is done at the end of the game, and the players are informed about the types of costs in the LCA and SCM.
5. The game is fun. The level of fun is measured by asking the players to fill out questionnaires asking about their game experience. The results are as follows: 28.6% of the players find the game very fun, 57.1% find it fun, and 14.3% are neutral.
6. The players must have improved knowledge after playing the game.
7. Game sessions should not exceed 2 hours. The actual game per group does not exceed 2 hours.
8. A total of 8–12 people can play in one game session as the number of students per class ranges from 30 to 40.

9. The introduction and briefing before playing the game are conducted using a PowerPoint presentation. The players can raise questions during the session until they understand the game rules.

Basic needs numbers 1, 2, 3, 4, and 6 are measured in the pretest and posttest.

3.3.2. Final Game Validation

The guidelines (Table 1) for ensuring game validity are followed in the process of developing the game; hence, the game has no errors. The process of developing a game is not a pure sequential order, and some steps need to cycle back to the previous step to improve the final game. The "Robo Factory" has followed the steps and using the guideline to eliminate error while ensuring the objective of the game is achieved.

The objective is to improve the knowledge of students, which is measured using a questionnaire in the pretest and posttest. The game is deemed satisfactory if it improves at least 50% of the students' knowledge. Table 11 shows the increasing percentage from the pretest to the posttest; the minimum percentage is 51.43%. The percentage is calculated from the mean difference between the posttest and the pretest.

Table 11. Validation for final Robo Factory Game

Game Objectives	Pretest mean	Posttest mean	Percentage
Supply Chain Structure	48.58	100	51.43%
Tasks & Responsibilities	11.91	92.38	80.47%
Life Cycle Assessment	0	89.53	89.53%
SCM & LCA Costs	13.16	91.43	78.27%

Source: Authors (2020)

An increase in knowledge is noted for every objective. The knowledge targets related to supply chain structure, tasks & responsibilities, LCA, and SCM & LCA cost increase by 51.43%, 80.47%, 89.53%, and 78.27%, respectively. The smallest percentage is that for the supply chain structure, with the pretest average being higher than the averages of the other indicators. This result is due to the final game being conducted among students in the middle of their SCM courses. The other objective shows improvement by around 80% except for LCA. All the players have no knowledge about LCA and improve almost 90%.

The game design process is a repetitive cycle that calls for improvement in every stage, and it involves a step-by-step approach to creating a successful educational game design. The

verification and validation are a subjective task, and the researcher should follow the steps carefully to ensure the whole process could be somewhat more objective. This process also gives a direction for the goal of the game and improvement in the developing process.

4. Conclusion

The results of this research are satisfactory. The Robo Factory successfully teaches undergraduate students about LCA in SCM within an enjoyable environment. The game proves to increase the knowledge of students and is deemed enjoyable. The knowledge target related to supply chain structure increases by 51.43%, and the highest improvement is that for LCA at 89.53%. The game is rated to be fun and very fun by 85.7% of the students. Meanwhile, 14.3% of the students are neutral about the game. The contribution of this research is the Robo Factory game, which is expected to enrich the area of supply chain games with LCA to achieve an environmentally conscious SCM. The intellectual property rights of the Robo Factory game were registered in Indonesia on 21 March 2019 (no. EC00201933456).

The game design process and the parts of the game are described thoroughly in this work to help other researchers who are interested in developing the proposed game further. Further research can improve the game by extending its application, adding other actors in the game, adding other elements in the LCA, and adding or changing an environmental aspect in the game.

Acknowledgement

Universitas Pelita Harapan fully supports the research and the registration of intellectual property rights. The authors were thankful to support from LPPM-UPH with grant no P-007-FaST/VI/2018 for this work. The intellectual property rights of Robo Factory were registered in Indonesia on March 21, 2019 (no. EC00201933456).

Author Contribution

Natalia Hartono conceived the idea. Natalia Hartono, Laurence and Giovanni Hezekiah Chandra developed the theory. Giovanni Hezekiah Chandra developed the experiments. Natalia Hartono and Laurence check the method and the process of the experiments. Natalia Hartono and Laurence supervised the results. Natalia Hartono and Giovanni Hezekiah Chandra prepare the documents for intellectual property rights. Natalia Hartono prepares the final manuscript.

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