Impact of a Cloud-Based Applied Supply Chain Network Simulation Tool on Developing Systems Thinking Skills of Undergraduate Students

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Abstract

As modern supply chains continue to evolve into increasingly integrated global networks, logistics decisions that balance customer value with cost are becoming more complex. Due to the dynamic nature of a supply chain system, the interrelationships between decision-making criteria are not always obvious to individuals who are preparing for careers in logistics and supply chain management, resulting in decisions being conceptualized and framed in terms of linear cause-and-effect paradigms. Since a logistician must be able to view the supply chain as a system to design the resources, flows, and solutions that support an organization's competitive strategy, learning tools that stimulate holistic thinking in regard to logistics can be helpful in developing an individual's systems thinking skills. The purpose of this research is to evaluate the impact of a cloud-based, applied simulation of a global supply chain on students' ability to think in systemic terms. Responses to questions examining various systems thinking competencies are evaluated based on a two-wave longitudinal study, before and after the simulation, to determine the impact on holistic thinking skills of students. The research's results show several significant relationships between students' systems thinking skills in the pre-test and post-test.

Keywords
Logistics; supply chain; system thinking; simulation; undergraduate education.

1. Introduction

This paper discusses the use of a cloud-based applied simulation tool to enhance the ability of undergraduate students to conceptualize the supply chain as a holistic system with a porous boundary, across and within which factors in the internal and external environment converge to impact performance. The simulation is administered in a senior-level global logistics course after students have completed coursework in different areas of logistics and supply chain management, such as procurement and inventory control, warehousing, transportation, and enterprise resource planning (ERP) systems. The course aims to expand students' ability to manage logistics in the complex and uncertain international environment by taking a broad look at the dynamics and levers of a supply chain. In addition to having an international focus, the course is also comprehensive as it integrates concepts taught in other supply chain courses. The goal of the simulation is to teach students how to structure and balance multiple conflicting factors, such as cost, speed, availability, and sustainability, to minimize supply chain failure while maximizing value to supply chain constituents.

The course objective that this teaching approach aims to support is to provide students with an understanding of the supply chain so that they are "able to explain how effective design and management of global logistics systems can create a competitive advantage for an organization by reducing costs and risks and improving supply chain performance." The program-learning outcome that this objective is linked to is the development of students' ability "to analyze, design, optimize, and manage global logistics systems or processes." The goals of this study are to determine whether the use of a supply chain simulation in the global logistics course enhances students' ability to (i) view the supply chain holistically as a single entity, (ii) recognize the behavioral patterns of inventory flows, costs, and carbon emissions, and (iii) adjust the system flows by impacting key leverage points to improve supply chain performance. The research question being investigated in this study is whether the use of an applied simulation tool improves students' systems thinking ability.

1.1. The Supply Chain as a System

The groundwork for supply chain management (SCM) originated from Jay W. Forrester's work in system dynamics modeling in the 1960s (Salvatore, 2013). However, the terms "supply chain" and "supply chain management" were coined in the early 1980s by Keith Oliver. Oliver used the term "supply chain" to refer to a network of firms managed as a single entity to fulfill customer orders as efficiently as possible (Heckman et al., 2003). Firms in the network participate either directly in the creation of value, as in the case of raw material suppliers, manufacturers, distributors, and retailers; or indirectly, in supporting intra-organizational activities, as for transportation, financial, and other firms (Chopra, 2016).

Supply Chain Management is described as a collection of techniques and approaches used to integrate and manage the entire system of linked firms and associated processes involved in supplying a good or service to meet customer requirements (Coyle, 2017; Christopher, 2016; Simchi Levi et al., 2008). This definition underscores the systemic nature of the supply chain as the fundamental defining characteristic that differentiates a supply chain from a loosely bound group of firms involved in delivering a good or service. The emphasis on managing the supply chain as a system is further clarified by Simchi-Levi et al. (2008) and Lambert (2014) who indicate that the objective of supply chain management is efficiency and effectiveness across the entire system by taking a holistic approach.

A supply chain is a system with a specific purpose. Poirier and Reiter (1996) state that "a supply chain is a system through which organizations deliver their products and services to their customers……a network of interlinked organizations, or constituencies, that have, as a common purpose, the best possible means of affecting that delivery" (Poirier and Reiter, 1996, p. 3). The goal of supply chain management is, therefore, to manage the network to generate increased value for all supply chain firms by delivering products and services that meet customer requirements at the lowest total cost. Chopra (2016) indicates that the objective of every supply chain is to maximize the overall value or supply chain surplus across all entities in the network. Inherent in these perspectives is the capability of a supply chain to produce results that surpass the performance of individual firms acting alone or in their self-interests.

Today, the most mature supply chains are recognized as those that are tightly integrated from the initial supplier to end customer and managed as a single, extended enterprise (Coyle, 2017). In this regard, supply chain management can be considered as an evolving field, moving towards the idealistic state of full and total integration of all entities with the goal of driving increasingly higher performance results. Taking this view, it becomes apparent that the skill-set needed to manage supply chains in the future must correspondingly evolve to include those competencies that support the design and management of a supply chain from a systemic perspective.

1.2. Logistics as a Subset of Supply Chain Management

A key characteristic of a supply chain is its dynamic nature due to the constant flows of inventory, cash, and information between the network entities (Coyle, 2017; Chopra, 2016). The management of these flows falls under the purview of logistics, a discipline with roots in the military (David, 2018).

The Council of Supply Chain Management Professionals (CSCMP) defines logistics as "that part of supply chain management that plans, implements, and controls the efficient, effective forward and reverse flow and storage of goods, services and related information between the point of origin and the point of consumption to meet customers' requirements." (CSCMP, 2019). The essential role of logistics is to integrate supply chain entities by coordinating and optimizing logistics activities to support the lowest total cost concept (CSCMP, 2019; Coyle, 2016).

The flows through a supply chain shape its dynamic character, as they vary over time based on decisions and factors in the internal and external environment. Within the supply chain environment, forecasting methods, planning and scheduling of orders, and risk preferences that impact decisions regarding product availability and cost can be both causes and consequences of the behavior of supply chain flows (Simchi-Levi et al., 2008; Moon & Dong-Jin, 2005). In the external environment events, such as natural hazards, can impact the nature of supply chain flows.

As information becomes increasingly critical for driving agile supply chains, information flows must be coordinated with other flows to avoid phenomena such as the bullwhip effect (Simchi-Levi et al., 2008) that result in a build-up of excess inventory and cost in the supply chain. Coordinating information flows to avoid supply chain failure by having the right product in the right quantity and quality at the right place, and the right time, with the minimum lead time, waste, cost, and carbon footprint is the critical function of logistics. Optimizing performance goals and constraints require making trade-offs that can only be achieved by taking a holistic perspective of the supply chain.

1.3. Systems Thinking

Early contributions to systems theory were made by Ludwig von Bertalanffy (Giachetti, 2010; Lavassani & Movahedi, 2010). A system is a group of interacting components organized in a logical way to achieve a goal or purpose that exceeds what the individual parts, acting alone, could collectively attain (Giachetti, 2010). Interactions between system components are dynamic in nature due to causalities and flows that generate emergent behavioral patterns over time. All systems have boundaries. In open systems, the boundary is porous, allowing influences from the environment to impact the system's dynamics, underscoring the importance of time in understanding a system.

The application of systems theory to understand system behavior is known as systems analysis. Various tools are employed in systems analysis, one of the most prevalent being systems thinking (Authenticity Consulting, n.d.). Systems thinking facilitates identification and analysis of a system to predict its behavior so that changes can be implemented to shift current performance toward an ideal or improved state (Arnold & Wade, 2017; Richmond, 2001). Systems thinking requires the development of two sets of capabilities: (i) the ability to gain improved insight of a system and (ii) the ability to apply systemic thinking to impact the system (Arnold and Wade, 2017). In both of these phases, a number of skills are applied to detect obscure relationships and non-linear interactions between constituent parts.

Systems thinking skills identified in the academic literature include the ability to visualize the holism of a system as well as the detail of its component parts; the ability to develop a simplified mental model of a system that consists of relevant components; the use of stock and flow diagrams to model a system; the ability to think in dynamic terms to discern behavioral patterns; the ability to identify feedback loops, delays, synergy, and the impact of these forces on a system; the ability to see the relationships between elements in a system in terms of cause and effect; the ability to develop multiple perspectives based on the behavior of a system (Richmond, 1993; Arnold and Wade, 2015; Stave and Hopper, 2007; Sweeney and Sterman, 2000). Richmond (1993) defines six competencies that must be developed to support systems thinking capabilities: (i) dynamic thinking, (ii) cause and effect thinking, (iii) system as cause thinking, (iv) forest thinking, (v) closed-loop thinking, and (vi) stock and flow thinking (Richmond, 1993). These competencies are listed in Table 1.

Table 1. A Summary of Essential Competencies to Improve Systems Thinking Skills.

Two Dimensions of Systems Thinking Skills Arnold & Wade (2017)	**Six Competencies for Systems Thinking Richmond (1993)**
Gaining improved insight of a system	Dynamic Thinking
Applying systemic thinking to impact the system	Cause and Effect Thinking
	System as Cause Thinking
	Forest Thinking
	Closed-Loop Thinking
	Stock and Flow Thinking

To gain an understanding of a system, the first step is to develop a mental model – a simplified version of the real system that incorporates only those factors that are germane to understanding the behavior of the system (Richmond, 2001). For instance, to facilitate developing a mental model of a supply chain, many textbooks depict the supply chain in terms of a simple four-stage network of facilities that consists of raw material suppliers, manufacturers, distributors, and retailers, along with the product, information, and financial flows. Other factors such as the quality of transportation or information infrastructure are typically omitted since these are considered to be irrelevant for the purpose of teaching supply chain basics.

Three essential skills that facilitate modeling of a system are (i) the ability to take a "big picture" view, (ii) the ability to rationalize the elements that have a direct impact on the performance areas of interest, and (iii) the ability to think in dynamic terms. Once a mental model is conceived, it can be depicted using stock and flow diagrams and forward and reverse loops (Richmond, 2001). The system can then be simulated to determine whether it is an appropriate depiction of the system and can be used to analyze its behavioral characteristics (Richmond, 2001). Systemic behavioral patterns must be understood to devise ways to impact the system to achieve the desired results (Arnold & Wade, 2017; Giachetti, 2010). Behavioral patterns that emerge over time provide an understanding of key leverage points that can be influenced to impact system performance.

1.4. Systems Thinking Applied to Logistics and Supply Chain

Various authors raise the link between highly-developed systems thinking skills and effective supply chain management in firms (Schneider, D. (2013); Moon and Kim, 2005). Systems thinking is recognized as an element of systems dynamics, which becomes relevant to supply chains because of the flows of materials, cash, and information in the supply chain (Schneider, D., 2013; Moon and Kim, 2005). Thus, the development of systems thinking skills at the undergraduate level is an important aspect of preparing future logistics and supply chain managers.

Carter et al. (2015) raise a pertinent concern about the manner in which a supply chain is conceptualized as a simple network of suppliers, manufacturers, and distributors or a complex group of entities with unclear boundaries. Systems theory provides an enhanced understanding of the domain and functioning of the supply chain (Gripsrud et al., 2006 in Lavassani & Movahedi, 2010) by laying a foundation for envisioning the supply chain as a holistic system consisting of several interacting subsystems. Systems thinking has been identified as a key capability for decision-making regarding the efficient management of inventory and production (Moon and Kim, 2005) and is particularly useful in the area of logistics, which focuses on the design and management of supply chain flows.

For future supply chain and logistics professionals to meet the growing expectations of workplace demands, it is critical to develop a clear understanding of the supply chain: its physical infrastructure, constituents, boundaries, environment, activities, and goals. How the supply chain is viewed impacts the approach used to make supply chain decisions: that is, either by taking a holistic view that supports various levers of performance simultaneously or by taking a reductionist approach that applies a restricted view of the supply chain problem and its solution. However, for any kind of complex system, there is a need to deploy a "system approach" to understand the overall behavior of the system and to offset the challenges stemming from the evolutionary nature of the system (Alfaqiri, 2019; Hossain et al., 2016; Hossain and Jaradat, 2018, Hossain 2019; Nagahi et al., 2019a,b; Stirgus et al., 2019).

1.5. Description of the Simulation

For this study, an online applied collaborative simulation game designed and hosted by SCMGlobe was used in a global logistics course for senior undergraduates. Prior to selecting this simulation, the authors investigated other serious games and Internet-based simulations. The simulation was selected for several reasons: (i) a visually-appealing interface that allows players to superimpose a supply chain against a world map or a satellite map, (ii) the ability to make supply chain operations decisions to manage inventory, facilities cost, transportation cost, and carbon emissions, (iii) the ability to make strategic decisions to redesign the supply chain network, including opening and closing of facilities and changing transportation options, and (iv) the emphasis on making trade-offs to balance performance outcomes to impact performance of the overall supply chain, (v) a library of case studies, and (vi) supporting videos and tutorials. In addition, the simulation needed to be engaging, challenging and focus on distribution.

The specific case study used was *S & J Trading Company, Angola*. This simulation was selected to provide students with an international supply chain experience in a distribution, rather than a manufacturing, environment as this perspective aligns more closely with the program goals. The simulation consists of a network of facilities and associated inventory, cost, and carbon emissions flows. The challenge of the simulation is to run the supply chain for 20 to 30 days at the minimum operating cost and with the least amount of inventory.

With supply chains spanning country borders, students' ability to apply systemic thinking to solve challenges in the international environment must be developed. For supply chains operating in the international environment, the mental model developed for a supply chain must be expanded to include factors that are absent in the domestic environment but impact performance in an international context. While this may not be possible through an overseas assignment, a simulation can help to build this perspective. Simulations are useful, particularly for students in industrial technology programs who have been found to learn best using kinesthetic and visual methods (Katsioloudis & Fantz, 2012). Figure 1 depicts the SCM simulation global interface, while the simulation model of three flows is illustrated in Figure 2.

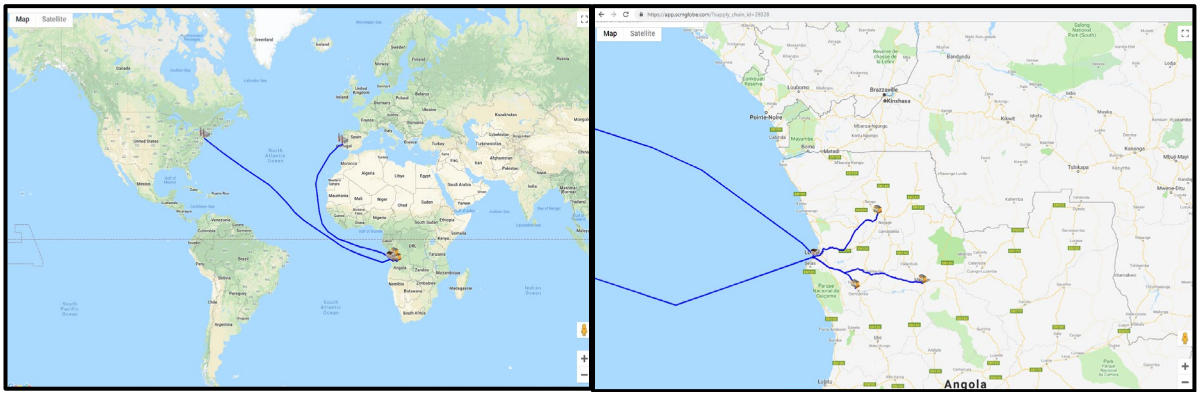

Figure 1. SCM Globe Simulation Interface

2. Related Literature

A review of the literature indicates that testing of systems thinking skills falls along at least two lines: presentation of a problem-based scenario followed by open-ended questions or use of serious games, including simulations. Open-ended questions appear to be more commonly used in situations that assess the capacity to apply systems thinking to solve a problem that transcends disciplinary boundaries, while games are more commonly applied to develop systems

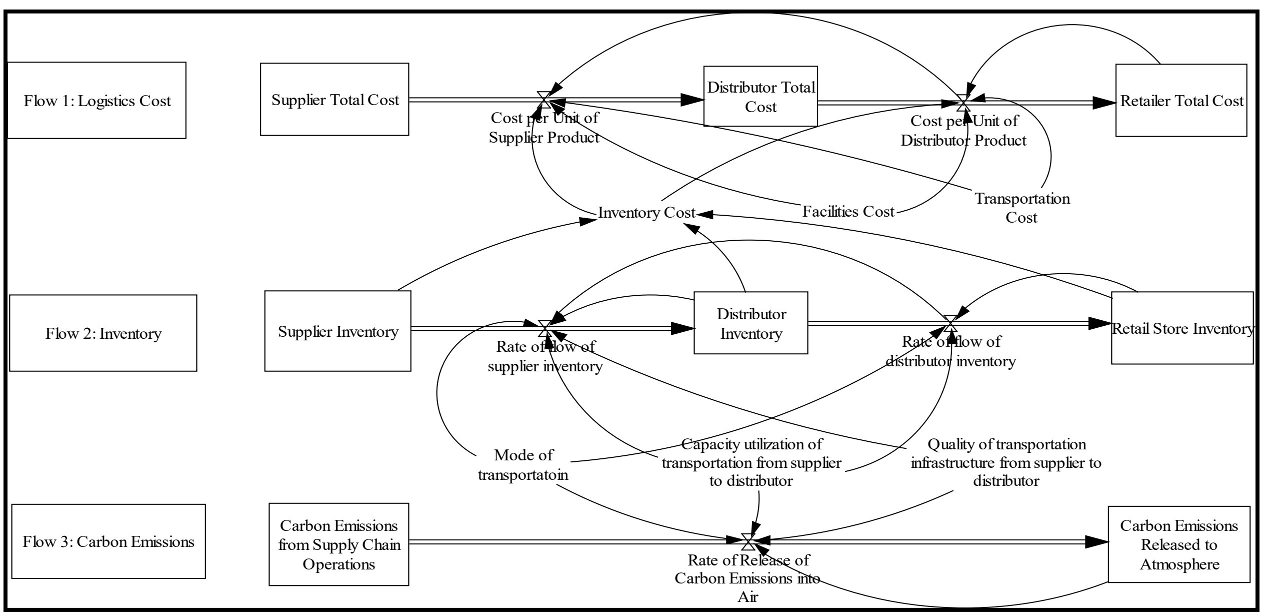

Figure 2. Model of the Three Flows in the Simulation – Total Cost, Inventory, and Carbon Emissions

thinking skills in contexts that require a specialized body of knowledge. Due to the nature of systems thinking skills, which requires one to discover interrelationships, linkages, and feedback loops, the development of questions with pre-defined responses, as in the case of multiple-choice or true-false questions, do not appear to be among the recommended approaches. The recommended assessment of systems thinking skills appears to be along a continuum, in the majority of cases, to assess the extent to which the skills have been developed.

2.1. Use of Problem-Based Scenarios to Assess Students' System Thinking Skills

Various approaches to assess systems thinking skills are evident in the academic literature. Sweeney and Sterman (2000) used bathtub and cash flow diagrams to test students' understanding of stocks and flows. Various scenarios were presented in a short paragraph describing water and cash inflows/outflows with respect to a bathtub/cash account. The scenarios were followed by questions requiring a graphical answer to depict the behavior of the systems' accumulations over time. Armstrong et al. (2012) used case studies to test two skills: the ability of students to think holistically and discover interrelationships and conflicts. The case scenario is a sustainability problem in an apparel firm. Students are asked to discuss challenges and conflicts and develop solutions to solve the problem. Assessment of systems thinking capacity is done using a rubric that rates the level of systems thinking ability on a Likert scale from 0 to 5. Dorani et al. (2015) identified six systems thinking competencies based on a review of the literature and describe an approach to test the level of skill development with respect to each competency by presenting a short scenario and soliciting an open-ended response. Each scenario is developed using a recommended structure. The six competencies assessed are: dynamic thinking, cause-effect thinking, system-as-cause thinking, holistic thinking, closed-loop thinking, and stock and flow thinking. Lavi et al. (2017) designed an instrument for assessing systems thinking ability of undergraduate industrial and information engineering students. Hossain et al. (2019) developed an instrument to evaluate the systems thinking performance of systems engineers. Based on a literature review, ten assessment criteria were defined and mapped to six system attributes. Students enrolled in an information-systems engineering course were required to develop a conceptual model for a project, which was rated on a scale of 0 to 3. Soleimani et al. (2018) found out undergraduate students' cognitive and meta-cognitive strategy usage has correlation with their scores in reading comprehension scenarios. Grohs et al. (2018) developed a framework, an assessment tool, and a scoring rubric to assess general systems thinking competency of undergraduate students across disciplines. The assessment tool presents a scenario followed by several questions to prompt student responses in the areas of information processing, problem response, and critique of the options. The framework was designed to be adaptable to different technical and contextual scenarios. A scenario-based instrument developed for assessing systems thinking skills for logistics and supply chain management was not identified in the literature.

2.2. Use of Games to Develop Systems Thinking Capabilities in Supply Chain Management

Envisioning the dynamic nature of a supply chain's factors and flows, the interactions that occur, and the balance that must be achieved to elevate performance can be difficult for inexperienced logisticians. Richmond (2001) notes that the use of simulation tools to develop this dimension of thinking is beneficial as memorization of concepts alone do not facilitate the development of mental models to support learning (Richmond, 2001). Richmond (2001) notes that that students need to become proficient in recognizing both horizontal and vertical linkages in a system.

The use of games to develop supply chain management skills is documented in the literature (Mustafee & Katsaliaki, 2010; Vanany & Syamil, 2016; William et al., 2018). Examples of serious games include the Beer Distribution Game, Blood Supply Chain Game, Distributor Game, ThinkLog, and Business on the Move. These games are played as board games, online digital games, or computer simulations (William et al., 2018). The use of games promotes active learning as students become engaged, participate in role-playing, and develop strategies to achieve desirable outcomes.

In supply chain courses, games are used to teach fundamental concepts of information sharing, coordination of supply chain flows, agility and responsiveness, and leadership and strategy (William et al., 2018). Games are structured to allow multiple players or single players to participate and may be designed to allow sequential or concurrent decision-making. One of the most popular games used to teach supply chain management concepts is the Beer Distribution Game, a four-stage supply chain game developed by a team of MIT professors. The game aims to introduce the phenomenon of the bullwhip effect and to demonstrate the importance of information sharing in coordinating supply and demand flows. The fundamental point that the game seeks to get across is the systemic nature of the supply chain, which requires one to apply holistic thinking. However, the limitation of the game is that it has been designed to develop an understanding of a concept, rather than to facilitate practice in managing a supply chain. The game scenario is a fixed four-stage supply chain, consisting of a supplier, manufacturer, distributor, and retailer, and cannot be altered. The game scenario is not location dependent and does not include complexities existing in the internal or external environment.

3. Methodology

The site of the study was a face-to-face upper-level undergraduate course in global logistics conducted during the 2019 spring semester. A mixed-method research approach consisting of qualitative and quantitative methods was used to collect and analyze the data. A qualitative questionnaire using open-ended questions was developed and administered to the class twice during the semester. Then, a quantitative method, namely, a two-wave longitudinal study was performed to analyze the coded data. Twenty-one students participated in the pre-simulation survey, and 14 students participated in the post-simulation survey. The seven students who did not complete the post-simulation survey were dropped from the analysis. The questionnaire was administered in electronic form using Qualtrics via a link posted in BlackBoard. The survey required approximately 30-40 minutes to be completed.

To determine whether the simulation had any effect on the systems thinking capabilities of the students, a longitudinal survey was utilized to assess the capabilities of students before and after the simulation. The questionnaire was designed based on the recommendations of Dorani et al. (2015). The approach recommended by Dorani et al. (2015) was selected because it describes a standard structure for presenting a scenario and for posing questions to evaluate each of six systems thinking competencies identified in the literature. Table 2 provides a description of each of these competencies and the recommended question structure. Two additional questions were included in the questionnaire to collect demographic information for the candidates. In keeping with the recommendations of Dorani et al. (2015), each question presented a scenario. The questions were designed as open-ended questions in accordance with the recommendations of Stave and Hopper (2007), who describe systems thinking skills as existing on a continuum from the recognition of interconnections (lowest level of skill) to the testing of policies (highest level of skills).

Table 2. Description of Six Competencies of Systems Thinking

Type of Systems Thinking Skill	**Description**	**Question Structure**
Dynamic Thinking	Ability to perceive gradual changes and trends over time rather than predict events.	Two types of questions have been identified to evaluate this competency by presenting a decision scenario with two possible options. One option reflects the best solution given the current situation. The second option presents an opportunity that could lead to a better option in the future.
Cause-Effect Thinking	Ability to recognize if all other variables remain constant, the effect is a result of a change in the cause.	This question presents a problem that originates from a main cause. The main cause of the problem is ignored by the main decision-maker in the problem, and other factors are assigned as the cause. A solution is proposed based on the erroneous assumption between cause and effect. Participants are then asked to comment on the proposed solution or state the mistake made in the deduction process.
System as Cause Thinking	Ability to see the internal structure of the system as the cause of systemic behaviors rather than as the result of forced or imposed external forces.	This question is structured by depicting a problem or desired outcome that is attributable to the structure of a system rather than an outside agent. Participants are asked to comment on this observation.
Forest (Holistic) Thinking	Ability to see the interrelationships and interdependencies of a group of parts that extend far in place and time.	A situation is presented in which some or all of the elements of the system improve; however, the behavior of the system not only does not show an improvement but also worsens. Participants are asked to explain why this happened.
Closed-Loop Thinking	Recognizes that causality is not one-directional but ongoing and that every decision or action has unintended consequences.	A solution to a problem is depicted without consideration for unintended consequences. These consequences worsen the situation. Participants are asked to comment on the source of the deterioration status of the system.
Stock and Flow Thinking	The ability to recognize the delays created by accumulating the difference between the inflow and outflow of a process.	A situation is depicted in which a change in the stock variable is desired. To achieve such a change, one of the flow variables changing the stock levels is considered, and the other is ignored, resulting in an unimproved situation. Participants are asked to explain why the desired situation is not achieved.

The scenarios presented and questions asked were based on the skills and knowledge that senior students in a logistics program should have acquired and did not require further knowledge or skill sets to answer the questions. A rubric for grading the answers was adapted based on the recommendations of Arnold & Wade (2017). The rubric defined a five-point Likert scale ranging from low maturity to high maturity.

The simulation was played for over three weeks. Students worked in teams of 3 to 4 members. Twice per week, students were presented with a different supply chain network problem to be resolved, as indicated in Table 3 below:

Table 3. Simulation Assignments

Challenge	Description
#1	Expand the number of retail stores and run the supply chain without failure for 30 days
#2	Design and run the supply chain for 30 days at the lowest inventory cost
#3	Design and run the supply chain for 30 days at the lowest transportation cost
#4	Design and run the supply chain for 30 days at the lowest total logistics cost
#5	Continuous improvement of the supply chain to reduce total logistics cost and carbon emissions

4. Results and Analysis

Responses to the questions were coded using a Likert scale from 1 to 5, with 1 representing the absence of the respective systems thinking skill and 5 representing a highly developed skill level.

Twenty out of 21 respondents in the pre-simulation survey were pursuing a major or a concentration in logistics, with only one student in an alternative program. In the post-simulation survey, all 14 students were pursuing either a major or concentration in logistics. In both the pre-simulation and post-simulation surveys, the total number of students pursuing a concentration was three.

In the pre-survey, eight of 21 respondents had taken three to five logistics-related courses, and 10 of 21 had taken six to eight courses, while three out of 21 had taken two or less. In the post-simulation survey, one student out of 14 had taken two or less, six had taken three to five courses, and seven had taken six to eight courses.

In the pre-simulation results, students showed some rudimentary ability towards systems thinking in the areas of dynamic thinking with regard to emerging, ambiguous information, cause-effect thinking, and stock and flow thinking. There was a lower level of development with regard to system-as-cause thinking, holistic thinking, and closed-loop thinking. The spread of the data showed that with the latter three areas, the standard deviation was lower, while with the former three there was a greater spread, indicating that some students were on either end of the spectrum.

A two-wave longitudinal study consistent with Frye and Garber's (2004) use of structural equation modeling in AMOS software version 24.0 was conducted to investigate the students' systems thinking skills during pre-simulation and post-simulation. It is appropriate to use structural equation modeling for regression analysis of survey data (e.g., Ahmadi et al., 2014a,b). Figure 3 shows the standardized solution for path analysis of the proposed theoretical model in AMOS. The proposed theoretical model is a saturated model, which perfectly fits the data. As a result, the theoretical model has evidence of construct validity. In other words, the proposed model is valid and reliable and is able to measure what was intended to be measured. Figure 3 presents a standardized solution for the proposed theoretical model.

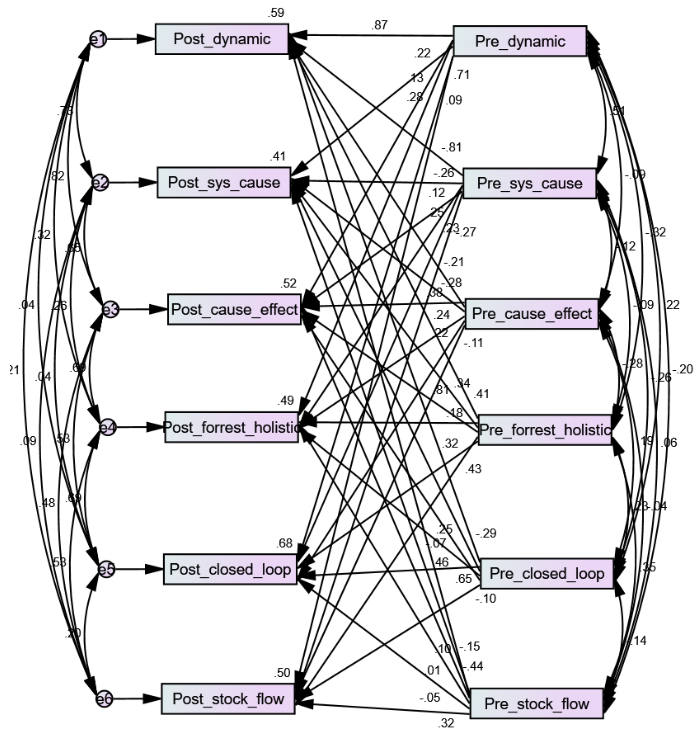

Figure 3. The Standardized Solution for the Proposed Theoretical Model.

Figure 4 shows the significant relationships between systems thinking skills pre-simulation and post-simulation tests. The students' "pre-dynamic thinking" has positive impacts on both "post-dynamic thinking" (with β = +0.87, t = 3.21, and p = 0.001) and "post-stock and flow thinking" (with β = +0.71, t = 2.37, and p = 0.018). The students' "pre-system as a cause thinking" has a negative impact on "post-dynamic thinking" (with β = -0.81, t = -3.23, and p < 0.001). Also, students' "pre-stock and flow thinking" has a negative impact on "post-dynamic thinking" (with β = -0.44, t = -2.06, and p = 0.039). The students' skill in "cause-effect thinking" in the pretest has a positive impact on their corresponding skill in the post-test (with β = +0.38, t = 1.70, and p = 0.088). Additionally, "pre-forest thinking" has positive impacts on "post-cause-effect thinking" (with β = +0.81, t = 3.04, and p = 0.002) and "post-dynamic thinking" (with β = +0.41, t = 1.66, and p = 0.096). Finally, the students' "pre-closed-loop thinking" has positive impacts on "post- closed-loop thinking" (with β = +0.65, t = 3.02, and p = 0.003) and "post-forest thinking" (with β = +0.46, t = 1.70, and p = 0.089).

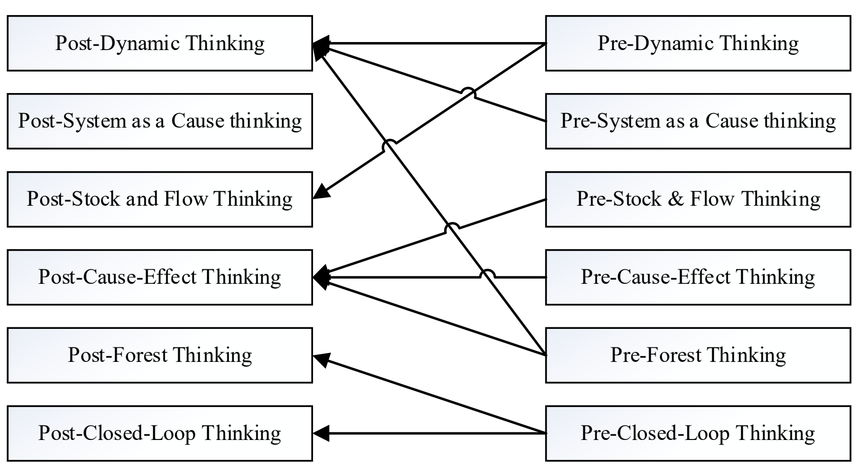

Figure 4. The Significant Relationships between Systems Thinking Skills Pre-test and Post-test.

5. Concluding Remarks

The current study identifies interesting results about the impact of a cloud-based, applied simulation of a global supply chain on students' systems thinking skills. All the inter-relationships among students' systems thinking skills in the pre-test and post-test in a simultaneous manner using two-wave longitudinal design are assessed. Several significant relationships among students' systems thinking skills in the pre-test and post-test are observed. The students' "pre-dynamic thinking" has the highest impact on "post-dynamic thinking" of students. The students' "pre-forest thinking" has the highest impact on "post-cause-effect thinking" of students. None of the six systemic skills in the pre-test significantly impact students' systemic skills in the post-test. We should mention that correlational analysis is used in the current study. As a result, no causality should be inferred from the results of the study.

This study has some limitations such as the small sample size, respondents' drop-out rate, and lack of a control group. Since the current research is an initial study, the mentioned limitations will be considered in the main study. Some areas for improvement can be considering a larger sample of students, a carefully designed experiment, adding impacting control variables, and using more than one reviewers for scoring the qualitative responses.

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