



Article

Simulation-Assisted Learning about a Complex Economic System: Impact on Low- and High-Achieving Students

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Abstract: Sustainable learning requires students to develop knowledge and skills for survival in increasingly complex and dynamic environments. The development of systems thinking skills for exploring complex dynamic systems is regarded as crucial to sustainable learning. To facilitate student thinking and learning about complex systems, computer simulations have been widely promoted. However, learning using computer simulations involves complex cognitive processes, which may impose a high level of cognitive demand on learners, especially on low achievers. It remains unclear whether and how high- and low-achieving students may benefit differently from learning with computer simulations. To address the gap, we conducted this study with university students who participated in simulation-assisted learning about the economy as a complex system. The results show that the students developed subject knowledge and systems thinking skills by the end of the study; high-achievers outperformed low-achievers in a subject knowledge test, but there were no significant differences between the two groups in their systems thinking skills, cognitive load, and affective experience. The findings indicate that both low- and high-achieving students can benefit from simulation-assisted learning of a complex system. In addition to developing systems thinking skills, there is a need to help students to improve the construction of their subject knowledge when learning with computer simulations.

Keywords: complex systems; systems thinking; computer simulations; economic education; low- and high-achieving students



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1. Introduction

To help students develop knowledge, skills, and resilience for survival in immensely complex and unpredictable situations, sustainable learning has been increasingly promoted [1,2]. Sustainable learning is more than the retention of knowledge and skills; it involves ongoing, purposeful, responsive, and proactive learning, to effectively and reflectively build knowledge and skills in complex dynamic environments. Sustainable learning requires the development of higher-order thinking skills, among which systems thinking is regarded as crucial [1,2].

Systems thinking is a way of making sense of the complexity of the world by viewing it as a complex dynamic system [3,4]. A complex system consists of distinct, interrelated, mutually dependent elements or agents interacting with each other and their environment. Students are expected to see the whole, rather than the parts, of a system; furthermore, they need to understand the structure and nonlinear behavior of a complex system. In other words, students are expected to develop systems thinking skills for exploring complex systems based on the understanding of complex dynamic relationships between the agents or elements in the system [3,5]. In particular, students are expected to see patterns of change, rather than static snapshots, within a complex dynamic system; further, they need to identify dynamic responses, such as long-run and short-run responses to a policy or

intervention. Moreover, they are expected to analyze emergent phenomena arising from the interactions between the many individual agents in a complex system (e.g., a traffic jam results from individual cars speeding up and slowing down, even when the drivers of individual cars do not intend to cause the jam).

To facilitate student thinking and learning about complex systems, computer simulations have been widely promoted, and have shown promising effects on student learning [6]. However, learning using computer simulations involves complex cognitive processes, which may impose a high level of cognitive demand on learners, especially on low achievers. It remains unclear whether and how high- and low-achieving students may benefit differently from learning with computer simulations.

To address the gap, we conducted this study with university students who participated in simulation-assisted learning about the economy as a complex system. We investigated student learning outcomes in terms of subject knowledge and systems thinking skills, as well as their learning experiences related to cognitive load, motivation, and emotions. In addition, we examined whether and how students with high and low levels of academic achievement might benefit differently from simulation-based learning about a complex economic system.

2. Literature Review

We reviewed the literature relevant to this study, identified the research gap, and then formulated the research questions of our study. First, we summarized existing research on simulation-based learning in different disciplines, the effects of simulation-based learning, and the challenges to low-achieving students arising from the complex cognitive processes involved in learning in such contexts. Second, we discussed existing studies on incorporating computer simulations into economics education, and the limitations of the existing work in this field. Based on the identified research gaps, we outlined the purpose of this study and specified the research questions.

2.1. Learning with the Support of Computer Simulations

To support student thinking and learning about complex systems, simulation-based learning has been promoted as a promising approach in various disciplines, including science, economics, business, management, and healthcare [6–15]. Computer simulations are increasingly being used to mimic real-world scenarios to impart knowledge and skills, and to provide an active learning experience by motivating learners to interact with simulation models [10]. This allows students to obtain hands-on experience and real-time feedback through trial and error [16,17]. Simulation-based interactive learning has shown promise for improving student understanding of complex concepts and principles, and for developing practical skills for work with complex real-world problems, by transferring knowledge into practice [6,18,19].

Despite its promising effects, simulation-based learning involves complex cognitive processes that may pose challenges to students [19,20]. When learning with computer simulations, students need to engage in complex operations with simulation models, such as observing multiple forms of data and information on the simulation panel and manipulating variables to test the system behavior. Such processes may place a high level of cognitive load on learners. Previous studies have indicated that learners find it challenging to understand the complex phenomena presented in computer simulations [21]. The challenge can be serious for low-achieving students, who often have inadequate skills to complete complex cognitive processes. Many teachers claim that tasks involving higher-order thinking are appropriate only for high-achieving students, whereas low-achieving students tend to have inadequate ability to perform such tasks [22]. It is therefore important to investigate whether and how students at different levels of academic achievement may benefit differently from simulation-based learning about complex systems. Such issues have been inadequately examined in previous studies.

2.2. Computer Simulations for Learning Economy as a Complex System

This study focused on simulation-assisted learning about the economy as a complex system. The economy is a complex system made up of dynamically interacting, heterogeneous agents, whose behaviors, strategies, and relationships evolve over time [23,24]. Teaching economics in traditional chalk-and-talk teaching environments focuses on memorizing the text and manipulating mathematical equations [25]. Many students have difficulty in understanding the complex and abstract economic concepts and principles defined in textbooks and mathematical models [13,15,26–29]. In particular, students that are challenged by mathematics find it very difficult to learn economics. As a consequence, many students feel that learning economics is tedious, and even become turned-off to economics at an early stage in their education.

To address this problem, computer simulations are incorporated into the teaching and learning of economics and business management subjects [13,15,30–32]. Simulations serve as a visual platform, enabling learners to explore complex dynamic behaviors and phenomena such as market monopoly and price inflation in economic systems [13,33,34]. They have shown promise for stimulating student interest and improving the retention of subject knowledge. Nevertheless, computer simulations in economics and business management applications have mainly been used for system dynamics experiments and professional training, with inadequate studies to investigate simulation-assisted teaching and learning in classrooms [13,14].

2.3. Purpose of the Study

As mentioned above, computer simulations have been widely promoted and have shown promise for improving student learning in various disciplines. This study focused on simulation-assisted learning in economics education, where computer simulations are being increasingly incorporated into teaching and learning about the economy as a complex system. Meanwhile, it is noted that learning with computer simulations involves complex cognitive processes, which may impose a high level of cognitive demand on learners, especially on low achievers. It therefore remains unclear whether and how high- and low-achieving students may benefit differently from learning with computer simulations.

To address the gap, we conducted this study with university students who participated in simulation-assisted learning about the economy as a complex system. In our study, a computer-based simulation system was implemented to support student learning of money supply as a complex economic system, and monetary policy as an intervention in the system. Money supply refers to the supply of money in an economy, and monetary policy refers to the policy for controlling the money supply. This learning subject was selected for two reasons: (1) the supply of money in an economy is a complex system involving multiple agents interacting in a complex way; and (2) understanding money supply and monetary policy is essential to economics education [35–38].

This study aimed to investigate whether and how students with high and low levels of academic achievement might benefit differently from simulation-based learning about a complex economic system. We examined student learning outcomes in terms of their subject knowledge and systems thinking skills. Moreover, we investigated the students' learning experience with respect to their cognitive load and affective experiences (motivation and emotions) during the study. The reason for investigating affective experiences was that simulation-based learning about complex systems involves complex processes that might be difficult for students. Prior research shows that cognitive experiences are closely intertwined with affective experiences [39]. If a learning task is too complex, students may have difficulty engaging in effective thinking; further, they may feel anxious and bored. Such negative emotions can impede cognitive processes [40].

The research questions of this study were:

1. What are the learning outcomes acquired by students from simulation-based learning about a complex economic system?

2. Do high- and low-achieving students differ in learning outcomes (subject knowledge and systems thinking skills) acquired from simulation-based learning about a complex economic system? If so, what are the differences?
3. Do high- and low-achieving students differ in their perceived cognitive load from simulation-based learning about a complex economic system? If so, what are the differences?
4. Do high- and low-achieving students differ in their affective experiences (motivation and emotions) acquired from simulation-based learning about a complex economic system? If so, what are the differences?

3. Method

3.1. Participants

The study was conducted at an ordinary university in southern China. The study received ethical approval from the Human Research Ethics Committee of the researchers' university. The participants in the study were expected to have basic knowledge of economics. Accordingly, 50 undergraduates (14 male and 36 female) were randomly selected from students majoring in economics and management. They signed a consent form for participation in this study. Their average age was 20.32 years. Based on the literature, the levels of academic achievement among students are often determined based on knowledge test scores [22]. Students in this study were categorized into high- and low-achieving groups according to their pre-study knowledge test scores.

3.2. Measures and Instruments

Pre-study and post-study knowledge tests were used to assess the students' subject knowledge. Three categories of simulation-based learning tasks were used to assess the students' system thinking skills. Survey questionnaires were used to measure the students' cognitive load and affective experiences (motivation and emotions) during the study, based on relevant scales developed in the literature. A five-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree) was used to measure the responses to all survey questions. In addition, a written survey was used to collect the students' comments on the learning program. Details of the knowledge tests, learning tasks, and surveys are described below.

3.2.1. Pre-Study Knowledge Test

A pre-study knowledge test was administered to the participants to test their knowledge of the basic economic concepts and principles that are a prerequisite for the study of money supply and monetary policy. The pre-test included eight multiple-choice questions, eight fill-in-the-blank questions with a total of ten blanks, and nine true/false questions. In total, it included 27 items to be scored. The score for each item was either 0 (incorrect) or 1 (correct). The scores for the test, ranging from 0 to 27, were converted to scores ranging from 0 to 100 for analysis.

3.2.2. Post-Study Knowledge Test

At the end of the study, a post-study knowledge test was used to assess the participants' knowledge about money supply and monetary policy. The post-test consisted of three essay questions. In each question, students were asked to suggest a monetary policy in response to a given economic situation, and to provide relevant explanations and justifications for the suggestion. An example of the questions is: "When the societies were affected by the COVID-19 pandemic for a period of time with declined market liquidity and economy deflation, what monetary policy can be considered by the central bank to adjust the economic situation?" Students' answers were assessed in three dimensions, including the correctness of the suggestion, their explanation of the mechanism of the suggested policy, and their justifications for the suggestion. The score for each dimension ranged from

0 (incorrect) to 5 (correct). The scores for the test, ranging from 0 to 45, were rescaled to a range of 0 to 100 for analysis.

3.2.3. Systems Thinking Skills

Each student was asked to complete three categories of simulation-based learning tasks, and to present the findings and explanations in a written report. The three categories of tasks corresponded to systems thinking skills in three dimensions: (1) analyzing change patterns (ACP) in a complex dynamic system; (2) identifying dynamic responses (IDR) such as long-run and short-run responses to a policy or intervention in a complex system; (3) explaining emergent phenomena (EEP) such as unanticipated side effects arising from interactions between many individual agents in a complex system.

Examples of the tasks included: “Observe the changing pattern of the money supply when the economic situation is stable and explain the underlying mechanism”; “Observe and analyze how the monetary policy for adjusting the required reserve ratio may influence the money supply by considering long-run and short-run responses to the policy”; and “Observe and explain how the gap between rich and poor people may change when the money supply increases”.

The content of the task reports was analyzed to assess the students’ systems thinking skills in the three dimensions mentioned above. The content of the reports for each task was assessed in terms of (a) correctness of the findings, (b) reasonableness of the explanations, and (c) sufficiency of the explanations. The score for each task ranged from 0 to 30. In this study, students were asked to complete one task on ACP, three tasks on IDR, and two tasks on EEP. The scores for the tasks in the same category were averaged for analysis.

3.2.4. Cognitive Load

In this study, the cognitive load scale developed by Hwang et al. [41] was adopted to assess the cognitive load perceived by the students during the learning process [42,43]. The cognitive load in learning contexts involves two aspects: mental load and mental effort [44]. Mental load is related to the complexity of the learning task in relation to the expertise required to complete the learning task, while mental effort refers to how learning materials are organized and presented in relation to how much effort a student needs to make in order to comprehend them. Accordingly, the study’s cognitive load items focused on two constructs: two items for mental load (e.g., “The learning task in this study was difficult for me”), and two items for mental effort (e.g., “I need to put a lot of effort to comprehend the instructions”). Regarding the reliability of the survey questionnaire, the Cronbach’s alpha values in this study were 0.73 for mental load and 0.92 for mental effort.

3.2.5. Affective Experiences

A questionnaire survey was administered to collect the students’ affective experiences. Affective experiences in educational contexts mainly consider motivational and emotional experiences. Regarding motivation, twelve survey items were developed based on the Instructional Materials Motivation Survey (IMMS) framework designed by Keller [45]. The questions focused on four constructs: attention (e.g., “the study can hold my attention”), relevance (e.g., “the study is useful to me”), confidence (e.g., “I felt confident during the study”), and satisfaction (e.g., “I enjoyed the study”). The literature shows that the IMMS is useful in assessing students’ motivation in a self-directed instructional setting [46]. Regarding the reliability of the survey questionnaire, Cronbach’s alpha values for this study were 0.76 for attention, 0.78 for relevance, 0.82 for confidence, and 0.80 for satisfaction.

With respect to emotion, anxiety and boredom are typical negative emotions [40] that students may experience when learning complex subject matter. In this study, based on the emotion scales designed by Pekrun et al. [40], six survey items were adopted to assess the students’ emotional experiences in terms of anxiety (e.g., “I felt tense during the study”), and boredom (e.g., “I felt this study dull and monotonous”). In this study, Cronbach’s

alpha values were 0.86 for anxiety, and 0.83 for boredom, which confirmed the reliability of the survey questionnaire.

3.2.6. Comments on Learning Program

Students' comments on the learning program were collected for triangulation in data analysis. The participants were asked to give written responses to two open-ended questions: (1) "What are your views on the advantages of the learning program?" and (2) "What are your views on the weaknesses of the learning program?".

3.3. Simulation-Based Learning Environment

In this study, NetLogo was used as a tool to implement a computer-based simulation system based on agent-based modeling (see Figure 1).

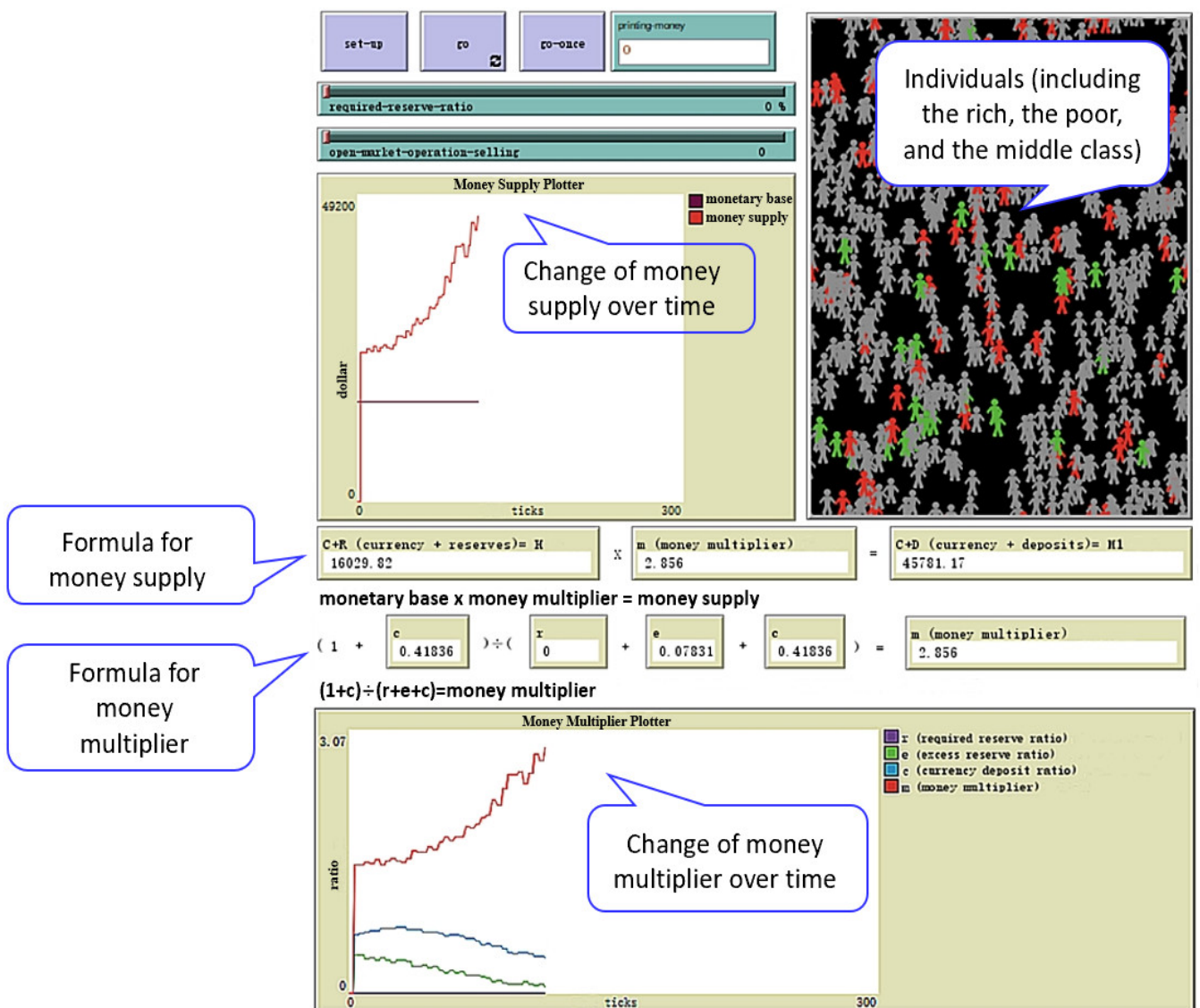


Figure 1. Simulation-supported learning environment.

The simulation model consisted of multiple agents, including a central bank, three commercial banks, and many individuals (including the rich, the poor, and the middle class). The central and commercial banks constituted the banking system for the simulation model, in which the commercial banks performed a range of business operations, such as the balance of payments, deposit operations, and mortgage operations. The central bank

took the role of regulating the commercial banks and implementing monetary policy by means of three instruments: open market operations (the purchase and sale of securities in the open market by a central bank), the required reserve ratio (setting the fraction of deposits that a commercial bank must hold in reserve), and printing money. The simulated people made transactions or investments, such as depositing money into savings accounts, applying for loans, and repaying loans according to predesigned rules. The individuals were displayed on the monitor of the simulation system as red icons (the poor), gray icons (the middle class), and green icons (the rich). During the simulation, real-time values of relevant indicators (e.g., amount of money supply and money multipliers) were displayed on the plotters for observation and analysis.

The teacher used the simulation system to demonstrate the structure and behavior of the money supply system, illustrating relevant concepts and principles. The students used the system to run simulations and perform simulation-based learning tasks. The system enabled students to implement monetary policy by manipulating variables and numerical values, and to analyze the impact of the policy by observing multiple sets of data and lines on the plotters.

3.4. Procedure

The study lasted for five days. The study procedure is outlined in Figure 2.

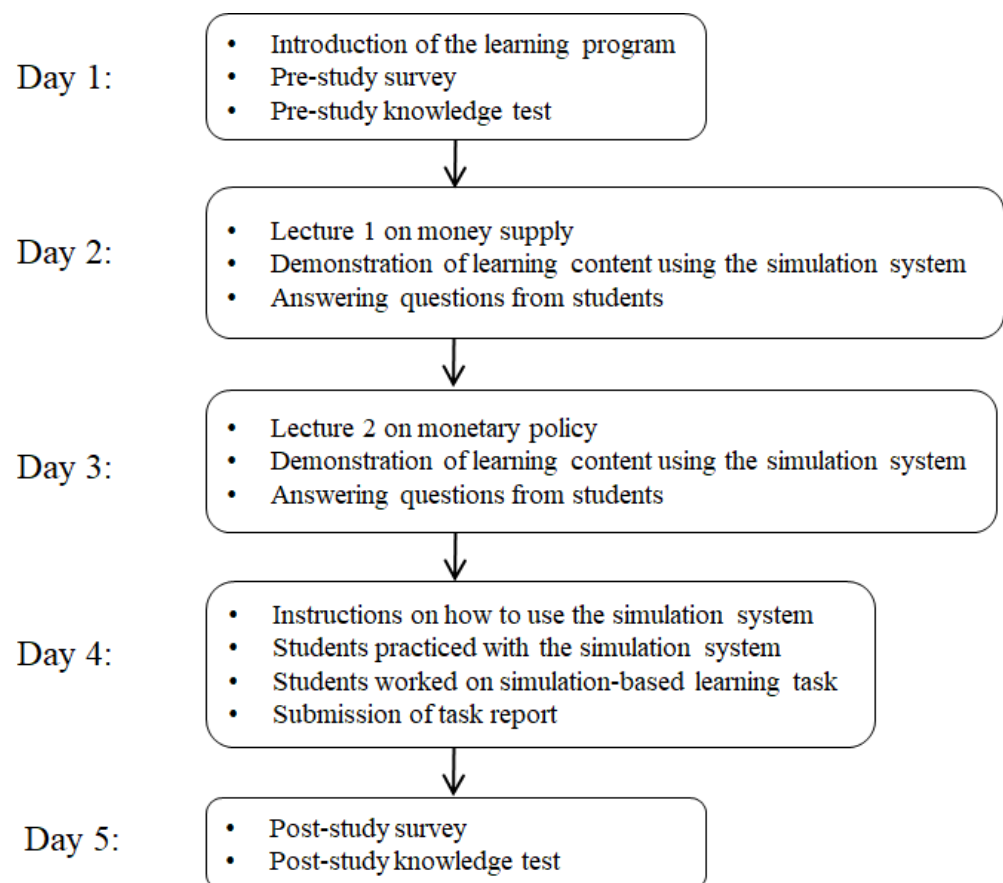


Figure 2. Study procedure.

On Day 1, after the researcher introduced the learning program for about 20 min, and then the students who agreed to participate in this study signed the consent form to confirm their participation. Next, the participants completed the pre-study survey and knowledge test, which took about 30 min. The survey was used to collect the students' demographic information and their motivation for learning economics before they participated in this

study. The pre-study knowledge test was to test their knowledge of basic economic concepts and principles.

On Day 2, students attended a face-to-face lecture on the mechanism of, and the key factors influencing, money supply, followed by the teacher's demonstration of the mechanism of money supply as a complex system using the simulated system. Afterwards, students were given opportunities to ask questions and receive responses from the teacher. The session lasted for about 135 min.

On Day 3, the teaching and learning activities were similar to those of Day 2, with the only difference being that the learning topic focused on monetary policy and its impact on the money supply system. This session also lasted for about 135 min.

On Day 4, students received face-to-face instructions on how to use the simulated system (e.g., how to run the model, how to adjust the parameters and variables, and how to observe and interpret the data shown by multiple plotters). After becoming familiar with the simulation system, students were asked to perform a set of simulation-based tasks to improve their understanding of money supply and monetary policy as a complex system. To complete the tasks, they were encouraged to interact with the simulated system according to the task questions, adjust the parameters or variables, and observe the data changing over time. Students were asked to complete the task independently and to submit a task report at the end of the session. The whole session lasted for about 100 min.

On Day 5, students completed the post-study survey and knowledge test, which took about 60 min. The post-study survey was administered to collect the students' perceptions about cognitive load, affective experiences (motivation and emotions), and comments on the learning program. The post-study knowledge test assessed the participants' knowledge about money supply and monetary policy.

3.5. Data Analysis

The following methods were used to analyze the collected data.

First, the first author and a trained researcher graded the students' post-study knowledge test papers and task reports blindly and independently, and then their scores were averaged. In terms of the knowledge test, the inter-rater reliability measured using the intraclass correlation coefficient (ICC) was 0.99. In terms of systems thinking skills reflected in task reports, ICC values of 0.83, 0.84, and 0.90 were obtained between the two raters for ACP, IDR, and EEP, respectively.

Second, descriptive statistics were used to describe the basic features of the data, and paired sample *t*-tests were conducted to compare the differences in students' motivation before and after the study.

Third, students were categorized into high- and low-achieving groups according to their pre-study knowledge test scores. Next, a set of independent samples *t*-tests was conducted to evaluate the differences between the two groups in terms of post-study knowledge test scores, systems thinking skills, cognitive load, and affective experiences.

Fourth, thematic content analysis was performed to probe common themes in the students' responses to the open-ended questions. The analysis followed an iterative process of code and theme generation in a bottom-up manner. Discrepancies between the two coders in the themes emerging from the responses were discussed and reconciled by further examination of the data. The first and second authors independently coded all students' responses according to the confirmed coding framework, leading to an inter-rater reliability of 0.82 (Cohen's kappa). All the differences in their coding results were then discussed and resolved.

4. Results

4.1. Descriptive Statistics

The descriptive statistics of the students' subject knowledge, systems thinking skills, cognitive load, and affective experience before and after study are presented in Table 1.

Table 1. Descriptive statistics.

Variable		Min	Max	Mean	SD
Pre-study Subject knowledge		33.33	77.78	56.59	10.66
Pre-study Motivation	Attention	1.67	5.00	3.32	0.76
	Relevance	2.00	5.00	3.73	0.67
	Confidence	1.67	4.67	3.13	0.73
	Satisfaction	1.33	4.67	3.13	0.77
Post-study Subject knowledge		11.11	80.00	47.38	18.92
Systems thinking skills	ACP	0	18.00	3.96	5.37
	IDR	0	30.00	15.00	6.33
	EEP	0	14.00	9.04	3.14
Cognitive load	Mental load	2.00	5.00	3.32	0.82
	Mental effort	1.50	5.00	2.65	0.90
Post-study Motivation	Attention	2.00	5.00	3.71	0.63
	Relevance	3.00	5.00	3.97	0.58
	Confidence	1.33	5.00	3.30	0.78
	Satisfaction	2.00	5.00	3.58	0.59
Emotions	Anxiety	1.33	4.67	3.11	0.84
	Boredom	2.00	5.00	3.40	0.77

ACP = Analyzing change patterns; IDR = Identifying dynamic responses; EEP = Explaining emergent phenomena.

4.2. Motivation for Learning Economics before and after the Study

The students' motivation for learning the subject before and after the study was compared using paired sample *t*-tests. The results presented in Table 2 show significant improvement in their motivation in terms of attention ($t = 2.96, p = 0.005$), relevance ($t = 2.32, p = 0.024$), and satisfaction ($t = 3.66, p = 0.001$).

Table 2. Motivation for learning the subject.

Variable	Before the Study		After the Study		<i>t</i>	<i>p</i>
	Mean	SD	Mean	SD		
Attention	3.32	0.76	3.71	0.63	2.96	0.005 **
Relevance	3.73	0.67	3.97	0.58	2.32	0.024 *
Confidence	3.13	0.73	3.30	0.78	1.77	0.084
Satisfaction	3.13	0.77	3.58	0.59	3.66	0.001 **

* $p < 0.05$; ** $p < 0.01$.

4.3. Differences in Learning Outcomes and Cognitive Load between High- and Low-Achievers

The students were divided into low- and high-achieving groups by a median split according to their pre-study knowledge test scores. The mean scores of the low-achieving student (mean = 47.85, SD = 6.41) and high-achieving student (mean = 65.33, SD = 5.65) groups were significantly different ($t = 10.24, p < 0.001$).

Students' post-study knowledge test scores, systems thinking skills, and cognitive load were compared between the two groups using independent samples *t*-tests. The results shown in Table 3 reveal significant differences between the high- and low-achieving groups in subject knowledge ($t = 2.64, p = 0.012$), but not in systems thinking skills in terms of ACP ($t = 0.16, p = 0.876$), IDR ($t = 0.40, p = 0.692$), and EEP ($t = 0.36, p = 0.722$). The two groups also experienced a similar level of cognitive load in terms of mental load ($t = 0.51, p = 0.610$) and mental effort ($t = -0.55, p = 0.587$).

Table 3. Differences in learning outcomes and cognitive load.

Variable		Low-Achieving Group		High-Achieving Group		<i>t</i>	<i>p</i>
		Mean	SD	Mean	SD		
Subject knowledge		40.71	21.09	54.04	13.92	2.64	0.012 *
Systems thinking skills	ACP	4.08	6.18	3.84	4.54	0.16	0.876
	IDR	14.64	7.26	15.36	5.36	0.40	0.692
	EEP	8.88	3.66	9.20	2.58	0.36	0.722
Cognitive load	Mental load	3.26	0.86	3.38	0.79	0.51	0.610
	Mental effort	2.72	0.98	2.58	0.83	−0.55	0.587

ACP = Analyzing change patterns; IDR = Identifying dynamic responses; EEP = Explaining emergent phenomena; * $p < 0.05$.

4.4. Differences in Affective Experiences between High- and Low-Achievers

Students' motivation and negative emotions were compared using independent samples *t*-tests. As shown in Table 4, there were no significant differences between low- and high-achieving students in their motivation for learning the subject in terms of attention ($t = 0.98$, $p = 0.334$), relevance ($t = 0.73$, $p = 0.467$), confidence ($t = 0.18$, $p = 0.858$), and satisfaction ($t = 0.87$, $p = 0.388$). Similarly, there were no significant differences between the two groups in their emotions in terms of anxiety ($t = 0.78$, $p = 0.439$) and boredom ($t = 0.61$, $p = 0.546$).

Table 4. Differences in motivation and emotions.

Variable		Low-Achieving Group		High-Achieving Group		<i>t</i>	<i>p</i>
		Mean	SD	Mean	SD		
Motivation	Attention	3.63	0.65	3.80	0.60	0.98	0.334
	Relevance	3.91	0.60	4.03	0.55	0.73	0.467
	Confidence	3.32	0.74	3.28	0.83	0.18	0.858
	Satisfaction	3.51	0.61	3.65	0.58	0.87	0.388
Emotions	Anxiety	3.01	0.86	3.20	0.83	0.78	0.439
	Boredom	3.33	0.82	3.47	0.73	0.61	0.546

4.5. Differences in Comments between High- and Low-Achievers

The analysis output of the students' comments on the advantages of the learning program is presented in Table 5. The advantages reported by most students included: improved understanding of the learning subject (80%), innovative learning experience (56%), and useful for knowledge application (50%). It was noted that high-achieving students had slightly more positive comments on the benefits of the learning program in supporting knowledge memorization and understanding.

The analysis output of the students' comments on the weaknesses of the learning program is presented in Table 6. Some students mentioned having difficulties in learning complex concepts (22%). Moreover, they felt that the lectures on theories and concepts were a bit boring (20%) and suggested having more teacher–student interaction during class (14%).

Table 5. Student comments on the advantages of the learning program.

Theme	Illustrative Example	Frequency		
		Low-Achieving Group (N = 25) K (%)	High-Achieving Group (N = 25) K (%)	Total (N = 50) K (%)
Understanding of the learning subject	The models allowed me to better understand monetary policy.	18 (72%)	22 (88%)	40 (80%)
Intuitive presentation	The simulation model allowed me to see the effects of monetary policy more intuitively.	11 (44%)	9 (36%)	20 (40%)
Hands-on learning	This course gave us more opportunities to manipulate simulation models.	7 (28%)	10 (40%)	17 (34%)
Knowledge application	(This course) integrated theory and practice, which helped us learn better.	13 (52%)	12 (48%)	25 (50%)
Knowledge memorization	(The simulation model) could improve my memory of the formulas.	2 (8%)	8 (32%)	10 (20%)
Thinking skills	Compared with traditional learning, (this course) helped strengthen my logical thinking capability.	8 (32%)	5 (20%)	13 (26%)
Motivation	This course stimulated my interests in learning monetary policy.	2 (8%)	5 (20%)	7 (14%)
Innovative learning experience	This course provided innovative learning experiences, different from my previous courses.	15 (60%)	13 (52%)	28 (56%)
Interesting course	The course is fun and interesting.	11 (44%)	12 (48%)	23 (46%)
Autonomous and flexible learning	The course allowed more flexibility and autonomy in learning.	5 (20%)	5 (20%)	10 (20%)
Easy to learn	The simulation models are easy to understand and convenient to get started.	2 (8%)	4 (16%)	6 (12%)

N = total number of students; K = number of students giving responses under each theme; % = K/N .

Table 6. Student comments on the weaknesses of the learning program.

Theme	Illustrative Example	Frequency		
		Low-Achieving Group (N = 25) K (%)	High-Achieving Group (N = 25) K (%)	Total (N = 50) K (%)
Learning difficulty	Some concepts were complicated.	7 (28%)	4 (16%)	11 (22%)
Boring lectures	The lectures on theories and concepts were a bit boring.	5 (20%)	5 (20%)	10 (20%)
Teacher–student interaction	More interactions between the teacher and students were needed.	3 (12%)	4 (16%)	7 (14%)

N = total number of students; K = number of students giving responses under each theme; % = K/N .

5. Discussion

5.1. Learning Outcomes, Cognitive Load, and Affective Experiences of All Participants

Regarding learning outcomes, the average scores from the knowledge tests revealed that the students had developed an understanding of money supply and monetary policy from this five-day study, although they did not obtain an in-depth understanding of this difficult learning subject. The average scores for the students' systems thinking skills, as reflected in their task performance, demonstrated that the students had developed systems thinking skills to some extent, although they encountered some challenges, particularly in explaining change patterns and emergent phenomena in the complex economic system. The students' task performance can be explained by their inadequate understanding of the subject knowledge, and by their comments. The results are in line with findings from previous studies on simulation-assisted learning of economics [13,26,28,29,47]. Findings also concur with previous research in that students must develop a thorough understanding of the basic concepts and theories in order to engage in effective learning of complex problems in simulated environments [11,15,48,49]. In the meantime, students in this study did not experience high levels of mental load during their learning activities, which echoes the findings of previous research that simulations can facilitate learners' cognitive processes [50].

In respect to affective experiences, the results showed that the students had positive perceptions about their motivation and emotional experience in learning about the complex economic system. Specifically, the participants' motivation for learning economics improved after taking part in the simulation-assisted learning about a complex economic system. This is consistent with previous research on simulation-supported learning [6,14,51], suggesting that simulations have inherent entertainment value that can enhance learners' motivation. In addition, our findings on emotions showed that the students experienced a relatively low level of anxiety. The findings are aligned with the literature on simulation-supported economics education [52,53]; that is, the motivation for learning economics using simulations can stimulate students' enthusiasm, which will, in turn, encourage them to overcome their negative emotions about learning complex topics or tasks.

5.2. Differences in Learning Outcomes and Cognitive Load between High- and Low-Achievers

The findings suggest that the differences in subject knowledge between low- and high-achieving students still existed at the end of the study. One plausible explanation is that money supply and monetary policy is a complex subject to learn, which requires learners to acquire a certain degree of subject knowledge as a prerequisite to making sense of the simulation model [21,54]. Although computer simulations can promote the understanding of complex concept and theories, it is still challenging for students with inadequate knowledge foundations to develop an in-depth understanding of the learning subject. Previous research demonstrates the positive effects of integrating knowledge construction and knowledge application when learning about complex problems in simulated environments [48,49]. Thus, to make simulation-supported learning more effective for low-achievers, it is important to support the construction of their subject knowledge while they engage in hands-on learning and practice with computer simulations.

Meanwhile, we found low- and high-achieving students had similar performances in systems thinking. This result is consistent with previous research in that the difference between the abilities of high- and low-performing students to explain the behaviors of a complex system disappeared after participating in learning activities using computer simulations [8]. The finding is also in line with previous research which has found that both high- and low-achievers can benefit from technology-enhanced interactive learning approaches (e.g., simulations, games, computer programs) that facilitate higher-order thinking [55–57]. In this study, the simulated system and guidelines for the simulation-based learning tasks enabled both high- and low-achieving students to explore the key variables and different plotters available in the simulations, which, in turn, allowed them to engage in effective thinking and learning about the complex economic system.

Moreover, the results showed that there was no significant difference between high- and low-achievers in terms of perceived cognitive load during the study. In other words, students from the high- and low-achieving groups experienced similar levels of cognitive load during simulation-assisted learning about a complex economic system. It is worth noting that low-achieving students did not report greater cognitive load. Previous studies have suggested that low achievers tend to have more difficulty performing tasks requiring higher order thinking skills [22]. Nevertheless, our findings demonstrated that well-designed simulation-based learning has a potential to impart the complex information and phenomena that emerge from complex systems [31,50,56], which, in turn, may reduce the cognitive load of both high- and low-achievers.

5.3. Differences in Affective Experiences between High- and Low-Achievers

In this study, a simulation-supported learning approach was used to address the weakness of the conventional chalk-and-talk method in teaching economics as a complex system. The developed simulated system encouraged students to explore a complex economic system and observe changes in key variables when manipulating monetary policies. The results indicated that both high- and low-achieving students had the same level of motivation for simulation-assisted learning about the complex economic system. Similarly, the analysis of students' emotions showed no significant differences between the two groups in terms of anxiety and boredom. A possible explanation for this result is that the computer-based simulated system provided an enjoyable and engaging learning environment that stimulated both high- and low-achievers' interests and engaged them in active learning processes, regardless of their prior academic achievements. Simulations can provide immersive environments that foster productive engagement and thus help students to overcome potential negative emotions and improve motivation [6,30]. Compared to the conventional chalk-and-talk method, the visualization and interactive features of computer-based simulations allow students to explore complex systems and develop understanding of complex and abstract concepts and principles in a more enjoyable manner [31]. For instance, one student in this study mentioned, "It was a great experience, very innovative; it focused my attention on the changes in the simulation model and promoted my motivation for learning." Since computer simulations can stimulate students' enthusiasm for learning about economics, they will, in turn, encourage students to overcome potential negative emotions in learning about the complex economic system.

5.4. Differences in Comments between High- and Low-Achievers

Regarding the students' positive comments for the proposed learning approach, our findings suggested that the simulation system provided an innovative, enjoyable, and engaging medium for learners, and that it helped them to understand the learning subject and to apply complex economic knowledge. The results are consistent with the students' high level of motivation for learning.

Further, we found the high achievers had slightly more positive comments than the low achievers in regard to knowledge memorization and understanding of the learning subject, implying that students with higher levels of prior knowledge tended to perceive themselves as more capable of understanding and remembering knowledge, and felt more confident in their knowledge acquisition. Their positive perceptions are consistent with their better performance in the post-study knowledge test compared to that of the low achievers.

With respect to the students' comments on the weakness of the learning program, more low-achieving students mentioned that they had learning difficulties in understanding the concepts (e.g., "the concepts were too complicated to understand, I felt that I couldn't remember many fundamental concepts."), which indicates that low achievers may need extra learning assistance or scaffolding to help them develop an adequate understanding of fundamental concepts—which is crucial to effective learning with computer simulations [6,15]. Moreover, some students, including both high- and low-achievers, commented that the

lectures were a bit boring, and suggested the need for more teacher–student interactions during class.

6. Conclusions

Sustainable learning requires students to develop the knowledge and skills for survival in increasingly complex and dynamic environments. The development of systems thinking skills for exploring complex dynamics systems is regarded as crucial to sustainable learning. To facilitate student thinking and learning about complex systems, computer simulations have been widely promoted. However, learning using computer simulations involves complex cognitive processes, which may impose a high level of cognitive demand on learners, especially on low achievers. It remains unclear whether and how high- and low-achieving students may benefit differently from simulation-assisted learning.

To address the gap, we conducted this study with university students who participated in simulation-assisted learning about the economy as a complex system. We investigated student learning outcomes and learning experiences, and examined whether and how students with high and low levels of academic achievement might benefit differently from a simulation-based learning program. The results showed that the students developed subject knowledge and systems thinking skills by the end of the study; high-achievers outperformed low-achievers in the knowledge test, but there were no significant differences between the two groups in their systems thinking skills, cognitive load, and affective experience.

The findings of the study may contribute to several aspects of knowledge in this field. *First*, although simulation-based learning involves complex cognitive processes, both low- and high-achieving students can benefit from simulation-assisted learning of complex systems, which can help them to develop subject knowledge and systems thinking skills. *Second*, in addition to developing systems thinking skills, there is a need to help students to improve the construction of their subject knowledge when learning using computer simulations. Otherwise, it is challenging for them to benefit from the full potential of simulation-assisted learning in regard to developing an in-depth understanding of the learning subject. *Third*, computer-based simulation systems can provide an enjoyable and engaging learning environment which has a potential to boost both high- and low-achievers' motivation for learning complex subjects, regardless of their prior academic achievements. *Fourth*, while learning about a complex economic system involves higher-order thinking processes that are challenging for low-achievers, computer simulations may allow both high- and low-achievers to experience a similar level of cognitive load and anxiety and to engage them in active learning processes.

This study has some limitations. First, the study was based on a one-group design with a small sample size, which may limit the generalizability of the findings to some extent. Future studies will adopt a control group design with a larger sample size to explore the impact of computer simulations on learning about the economy as a complex system. Second, the findings of the study suggest the need for more support for students, especially low achievers, to help them to improve their learning of subject knowledge through computer simulations of complex systems. Future research will incorporate relevant approaches into simulation-assisted learning programs for the effective development of both subject knowledge and systems thinking skills required for working with complex dynamic systems.

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