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Research Article

Assessing the Pre-Service Science and Mathematics Teachers' Systems Thinking Skills through Case Scenarios

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Abstract – Addressing complex global problems requires more comprehensive and holistic approaches that highlight the necessity of systems thinking skills; however, existing studies indicate a significant gap in understanding the systems thinking skills of pre-service teachers, emphasizing the need for further research in this area. This exploratory case study research explored the systems thinking skills of pre-service science and mathematics teachers through scenario-based assessments. Three case scenario examples focused on a specific aspect of systems thinking: stock-flow, causal-loop, and dynamic thinking. The participants of this study were 14 pre-service teachers taking a systems thinking course at the teacher education program of a public research university. The data were coded using the Systems Thinking Rubric and the Dynamic Thinking Skills Rubric. The results revealed that participants made notable improvements in dynamic thinking. However, fewer participants exhibited growth in stock-flow thinking comparing the participants' disciplines, the results showed that pre-service science teachers demonstrated greater advancements in systems thinking skills than their mathematics counterparts. This exploratory research offers insights into assessing systems thinking skills in pre-service teachers. Integrating a systems thinking approach into teacher training programs could enhance teachers' preparedness to comprehend complex issues. Further studies employing systems thinking practices in teacher training programs could elucidate the optimal development of systems thinking among aspiring teachers. Therefore, this research demonstrates the potential of systems thinking to enrich pre-service teacher education.

Keywords: Pre-service teachers, systems thinking assessment, systems thinking skills, teacher learning.

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Introduction

Understanding complex issues may require a systems thinking approach (Forrester, 1994) because systems thinking may help individuals see how different components within a system interact and potentially influence each other (Ben-Zvi Assaraf & Orion, 2010; Evagorou et al., 2009). Developing systems thinking skills (STS) is crucial for identifying and interpreting the systems in the interconnected world we live in (Bielik et al., 2023; Hmelo-Silver & Pfeffer, 2004; Sweeney & Sterman, 2007). Integrating systems thinking into education may enhance individuals' comprehension of systems and hopefully manage real-world challenges effectively (Fisher & Systems Thinking Association, 2023; Senge, 1990; Eidin et al., 2023). Therefore, pre-service teachers (PSTs) need to develop strong STS to navigate the complexities of learning and teaching the topics in their field (Ateskan & Lane, 2018; Karaarslan Semiz & Teksöz, 2020; Lee et al., 2019). Assessing these skills can help teacher educators determine the preparedness of PSTs and highlight areas that may need further improvement (Lavi & Dori, 2019; Lee et al., 2019).

Systems thinking focuses on the interrelationships of parts of a system, while system dynamics utilizes conceptual or mathematical models to simulate these interactions over time (Senge, 1990; Sweeney & Sterman, 2000). Systems thinking and system dynamics provide frameworks that may make it easier to understand how systems work (Arnold & Wade, 2015). Within these frameworks, stock flow thinking, dynamic thinking, and closed-loop thinking are considered important skills in systems thinking (Dorani et al., 2015). Stock-flow thinking involves recognizing and differentiating system quantities (stocks) and the rates at which they change (flows) (Aşık & Doğanca Küçük, 2021; Sweeney & Sterman, 2000). Causal loop thinking is about determining feedback loops, where changes in one part strengthen or balance the changes within the system (Doganca Kucuk & Saysel, 2018). Dynamic thinking includes perceiving the system from a long-term perspective, which helps the learner anticipate the system's development and adaptation over time, usually in response to internal and external shifts (Dorani et al., 2015; Richmond, 1993).

Researchers emphasize the significance of developing skills like comprehending stock-flow, causal-loops, and dynamic thinking for the management of systems within environments (Hopper & Stave, 2008; Plate, 2010). These skills enable individuals to navigate systems and make decisions to generate expected outcomes. However, assessing STS has been challenging (Lee et al., 2019). The complexity and dynamic nature of systems pose challenges in assessing these skills (Fisher & Systems Thinking Association, 2023).

Conventional assessment methods, such as multiple-choice tests, are often considered inadequate in effectively evaluating an individual’s STS (Dorani et al., 2015). Moreover, there is no consensus among experts and educators regarding the definition and structure of systems thinking, which complicates the development of assessments of STS (Hopper & Stave, 2008; Lee et al., 2019; Stave & Hopper, 2007).

An individual's STS may be revealed by using scenarios to analyze how systems solve problems (Dorani et al., 2015). A person's comprehension and use of STS may be reflected in case-based scenarios. We can develop more effective methods of evaluating STS by integrating approaches and resolving evaluation flaws (Lee et al., 2019). This study uses three case scenarios from Dorani et al. (2015) to examine the STS of PSTs. The evaluation of pre-service teachers' systems thinking skills is of paramount importance as it aids in confirming their readiness to educate in an intricate and interlinked global context (Dorani et al., 2015). By equipping them with systems thinking skills, teachers can lay the groundwork for their students' success across various sectors, from the sciences and engineering to business and politics (Peretz et al., 2023).

Evaluating pre-service teachers' systems thinking skills can assist in identifying areas requiring further training or support (Karaarslan Semiz & Teksöz, 2020) and promote their ability to impart systemic perspectives to their future students (Kriswandani et al., 2022). Our research contributes to existing literature by offering examples for teacher education programs to promote STS development and investigating how a course focused on systems thinking impacts PSTs’ stock flow, causal loop, and dynamic thinking skills. This investigation deepens our knowledge of how targeted interventions can nurture these skills in educators potentially enhancing their ability to navigate complex educational systems and make well-informed decisions in their professional roles.

The primary research question guiding this study is: How does a systems thinking-oriented teacher education course change PSTs’ levels of stock-flow, causal loop, and dynamic thinking skills? The study addresses the following sub-questions:

(1) How do pre-service teachers' levels of stock-flow thinking change from pre-survey to post-survey?

(2) How do pre-service teachers' levels of causal loop thinking change from pre-survey to post-survey?

(3) How do pre-service teachers' levels of dynamic thinking change from pre-survey to post-survey?

This study aims to add to the expanding body of work on systems thinking in teacher training and provide ideas for creating teacher preparation programs that nurture these skills. By investigating these inquiries, our goal is to illuminate the process by which future teachers acquire STS and how teacher training programs can be improved to offer assistance in this area. The results could shape strategies for incorporating systems thinking into fields, within teacher education ultimately improving the thoroughness and effectiveness of preparing future educators to address intricate classroom issues.

Systems Thinking in Education

Understanding how different parts of a system interact and influence each other is essential in today's world (Forrester, 2007; Peretz et al., 2023). This way of thinking is especially important in education, because it may help future teachers grasp the dynamics within classrooms and improve the effectiveness of their teaching on complex issues (Karaarslan Semiz & Teksöz, 2020; Kriswandani et al., 2022; Uskola & Puig, 2022). Systems thinking in education also offers a way to perceive issues from various perspectives, which may empower teachers to create valuable learning experiences for their students (Boubonari et al., 2023; Mehren et al., 2018).

Educators use systems thinking to identify and address topics in various fields of education (Fisher & Systems Thinking Association, 2023; Meadows, 2008). This approach covers fields, such as science, technology, engineering, and mathematics (STEM), social sciences, and the arts, by integrating topics and relating them to real-world situations (Ben-Zvi Assarraf et al., 2013; York et al., 2019). Moreover, it boosts creativity and innovation by taking into account viewpoints (York et al., 2019). However, despite its advantages, the implementation of systems thinking, in education, is constrained by a lack of comprehension and resources (Fisher & Systems Thinking Association, 2023).

The incorporation of systems thinking into K-12 education faces obstacles because teachers may not be adequately prepared (Bartus & Fisher, 2016; Taylor et al., 2020). While educators often excel in skills, they may lack the know-how needed for systems thinking (Bartus & Fisher, 2016). Experts stress the importance of having a systems thinking framework in curriculum design as cross-disciplinary approaches can enhance education on a scale (Peretz et al., 2023). Many teachers lack training in this area, which hinders their effectiveness, in teaching and understanding systems.

Courses that focus on Pedagogical Content Knowledge (PCK) have proven to be more effective, in teaching systems thinking, compared to those that prioritize methods (Rosenkränzer et al., 2017). Professional development is crucial in aiding teachers in instructing systems and using models in science education (Yoon et al., 2017). PCK involves teaching systems through strategies rather than just definitions (Peretz et al., 2023; Rosenkränzer et al., 2017). A course on systems thinking does not have to cover all skills at once; assessments should align with objectives (Plate & Monroe, 2014).

This research explored the changes in PSTs' skills in stock flow, causal loop, and dynamic thinking from pre- to post-survey. This research aimed to contribute to the study of teaching and evaluating systems thinking in teacher education. Assessing the STS of PSTs is crucial for investigating their competencies to teach complex topics effectively (Dorani et al., 2015). Such evaluations assist in identifying areas that need improvement and supporting PSTs' skills to enhance their perspectives (Karaarslan Semiz & Teksöz, 2020; Kriswandani et al., 2022).

Assessment of Systems Thinking Skills

Various frameworks exist for evaluating STS in education (Arnold & Wade, 2015; Ben-Zvi Assarraf et al., 2005; Stave & Hopper, 2007). Each offers distinct approaches to defining and assessing systems thinking. Ben-Zvi Assarraf and colleagues (2005) categorized skills based on proficiency levels in the Systems Thinking Hierarchy (STH) model. The STH model emphasizes three core skills: (1) identifying the system's components and processes, (2) recognizing relationships among components, and (3) understanding the dynamic relationships within the system. Using similar levels in the STH model, Stave and Hopper (2007) developed a taxonomy including seven STS and identified commonly cited characteristics of systems thinking in the literature as distinguishing between flows and variables, understanding dynamic behavior, and recognizing feedback. Arnold and Wade (2015) introduced a framework that focuses on problem definition and system analysis.

Our research uses the STH model as a framework because the STH framework offers a comprehensive and structured approach to evaluating systems thinking by emphasizing the three core skills. These fundamental abilities are in line with the goal of our study, which is to evaluate how well teacher candidates understand the interdependencies and dynamic behaviors that are essential for climate teaching in addition to identifying system components. Moreover, the STH framework's focus on building from basic identification to understanding complex system interactions provides a developmental approach to assessing how individuals engage with systems thinking over time. Finally, the three core skills of the STH model are critical for comprehending climate systems, which are inherently complex and interconnected.

Assessment of individuals' STS includes diverse techniques including concept maps, questionnaires, interviews, case-based real-world scenarios, and observations (Ateskan & Lane, 2018; Batzri et al., 2015; Evagorou et al., 2009). Scenarios are used to evaluate learners' causal reasoning skills (Dorani et al., 2015). Detailed rubrics aligned with these frameworks help standardize the evaluation processes (Lee et al., 2019). Integrating assessment tools, with established frameworks, could improve the evaluation of STS (Budak & Ceyhan, 2024; Karaarslan Semiz & Teksöz, 2020). While challenges exist, utilizing qualitative and performance-based approaches has provided insights into the STS of individuals.

Assessing stock flow, causal relationships, and dynamic thinking may provide insights into individuals' overall understanding of systems. Evaluations often involve scenario-based tasks where learners explain the interaction between variables, create diagrams, predict system states, and consider delays. Developing these interconnected skills may equip individuals to effectively interpret and analyze real-world system complexities (Evagorou et al., 2009). Research on systems thinking has been conducted with a variety of participants, including elementary, secondary, and higher education; of fields, including science, mathematics, and engineering; and topics including sustainability and healthcare (Peretz et al., 2023). Peretz and colleagues (2023) stated that cross-disciplinary curricula that encourage systems thinking may be beneficial for science and engineering courses as well as for education in general.

The systems thinking approach has been studied in science education on biology (Ben-Zvi Assaraf et al., 2013; Riess & Mischo, 2010; Sommer & Lücken, 2010; Tripto et al., 2018); on chemistry (Delaney et al., 2021; Eaton et al., 2019); on earth science (Ben-Zvi Assaraf & Orion, 2005; 2010; Evagorou et al., 2009; Kali et al., 2003; Lee et al., 2019; Mehren et al., 2018); on Education for Sustainable Development (ESD) (Ateskan & Lane, 2018; Doganca Kucuk & Saysel, 2018; Karaarslan Semiz & Teksöz, 2020; Meilinda et al., 2018); on physics (Nuhoğlu, 2010). On the other hand, studies conducted with students, teachers, or teacher candidates in the field of mathematics education are limited (Salado, et al., 2019). Research in the literature reveals that different participant groups have exhibited a variety of skills across various aspects of systems thinking. These studies indicated that students' systems thinking skills are limited in understanding systems, highlighting the need for a systems thinking approach in teaching these subjects (Karga & Ceyhan, 2024).

Method

This study used qualitative research methodology, which allows for an in-depth understanding of the phenomenon under investigation (Gay et al., 2012). Specifically, an exploratory case study design was used in this study, which sought to answer the how and why of the phenomenon under investigation (Yin, 2009). Three case-based scenarios were implemented, each focusing on stock flow, causal loop, or dynamic thinking to evaluate the STS of PSTs. Participants were asked to fill out surveys before and after the course implementation where they were asked to answer open-ended questions based on case studies validated by Dorani et al. (2015). The researchers delve into the intricacies of how participants perceive science and math education by analyzing their written responses using predefined evaluation criteria and coding systems.

Context of the Study and Participants

This research was carried out at a public research university in Türkiye, with a reputation for offering undergraduate and graduate programs in various fields such as engineering, applied sciences, and social sciences. Purposive sampling is when the researcher deliberately selects a sample by identifying criteria (Gay et al., 2012). In this study, purposive sampling was used because the effect of the systems thinking course on the participants' skills was to be measured. The study focused on science and math educators in the Mathematics and Science Education Department who were taking a course on systems thinking in science and math education. The group of participants included 14 PSTs. Nine were from the science education program and five were from the math education program. These individuals were preparing to teach middle school students (grades five to eight). Among them, there were 13 female participants and one male participant. Twelve of them were nearing completion of their studies, while two were starting their year of a master's program focusing on science and math education. Their ages ranged from 22 to 25 years, with a mean age of 23.7 years (standard deviation = 1.26).

The elective course undertaken by study participants served as an introduction to systems thinking, tailored specifically for Mathematics and Science Education contexts.

Throughout the course, participants explored the definition and practical application of systems thinking processes. They received a comprehensive overview of fundamental concepts and systems dynamics tools. The curriculum provided a broad introduction to the systems thinking approach, examining in depth the characteristics of complex systems as outlined in Table 1. This course aimed to equip PSTs with the conceptual framework and analytical tools necessary to apply systems thinking principles in educational settings. By focusing on applications relevant to mathematics and science instruction, the course sought to enhance participants' skills to navigate and address multifaceted classroom challenges using a systems-oriented perspective.

Table 1 Flow of the Systems Thinking in Science and Mathematics Education Course

Weeks	Content
Week 1-2	Introduction to systems thinking approach and its relevance in science & math education (pre-survey)
Week 3	Behavior over time graphs and its applications in science & math education
Week 4-5	Stock & flow diagrams and its applications in science & math education
Week 5-6	Causal loop diagrams and its applications in science & math education
Week 7-8	Dynamic thinking and its applications in Science & Math Education
Week 9	Exploring systems thinking tools in lesson plans
Week 10-11	Modeling systems in education (STELLA)
Week 12-13	Developing lesson plans with systems thinking tools
Week 14	Wrap up the course (post-survey)

As shown in Table 1, the course also included integrating systems thinking principles into instructional design. The intention was to harmonize traditional pedagogical techniques with the holistic outlook of systems thinking. Additionally, the course advocated for implementing inquiry-based instructional strategies that align with the systems thinking approach. This approach highlights the significance of active participation and asking questions, which helps promote essential skills needed to understand and navigate the difficulties of complex system dynamics.

Procedure

This research used surveys before and, after a semester to assess changes in participants' STS (refer to Table 1). Three scenario-based cases, which were developed by Dorani et al. (2015), were used to assess participants' stock flow, causal loop, and dynamic thinking skills. The university's ethics committee approved the study and participants gave their consent to participate in the study. The research included three scenarios representing varying levels of system complexity. The first case illustrated a system with a minimal number of variables. The second case presented a system with multiple variables and feedback loops. The third case, the one depicted a dynamic system with numerous feedback loops and nonlinear relationships between variables. By using these scenarios, the research aimed to assess how well PSTs could apply systems thinking across levels of complexity.

Data Collection

Different data collection tools have been used in the literature to evaluate participants' systems thinking skills, including multiple-choice and skill-based tests, questionnaires, concept maps, and interview questions (Ben-Zvi Assaraf & Orion, 2005; Lee et al., 2019; Mambrey et al., 2020). However, Dorani's (2015) context-independent scenarios were chosen as a data collection tool because context-independent scenarios ensure that assessment outcomes are not affected by teachers' specific content knowledge, thus offering a more accurate evaluation of their overall systems thinking skills (Karga & Ceyhan, 2024). It was also noted that scenario-based questions are arguably better at assessing participants' potential behavior in realistic situations (Daniel & Mazzurco, 2020).

The Case on Stock-Flow Thinking

A stock-flow thinker can distinguish stocks and flows. This individual understands that changes in stock variables can only be achieved indirectly through adjustments in flow variables with a delay. To illustrate this concept, the study referenced a scenario where a city dealt with a rat infestation (Dorani et al., 2015). Despite implementing a temporary resolution by deploying rat poison, the problem reemerges due to disregarding the rat birth rate. A possible reply might mention the factor of the disrupted balance, where the high rate of rat reproduction has caused an increase in the rat community.

The Case of Causal Loop Thinking

A causal loop thinker recognizes that every action and decision can trigger unexpected outcomes, which subsequently shape the context for future decision-making. The scenario-based example of a farming village that opted to use a pesticide to combat a green bug infestation, not realizing that these green bugs also prey on detrimental red bugs, was used in this study (Dorani et al., 2015). Despite their efforts, the villagers continued to encounter crop damage. This unforeseen outcome was the surge in the population of red bugs due to the elimination of their natural predators. Participants were anticipated to discern that the decision to exterminate the green bugs has indirectly reshaped the future state of the problem, resulting in an escalation in the red bug population.

The Case of Dynamic Thinking

By definition, a dynamic thinker can discern incremental shifts and accurately recognize trends and behavior patterns over in a while. A question that can effectively evaluate this skill might present a decision-making scenario with two choices. In this study, the research focused on a situation where a person was comparing two real estate investments; a property, in a desirable city area and a bigger house, in a growing but affordable neighborhood (Dorani et al., 2015). An appropriate response would involve explaining the effects of different stakeholder perspectives, gradual changes, potential feedback loops, and delays on systemic behavior.

Data Analysis

Two rubrics were used to analyze participants' responses to the three cases. The Systems Thinking Rubric, developed by Lee et al. (2019), was used for the first two cases: stock-flow and causal loop thinking. Lee et al. (2019) used an inductive approach to develop the rubric to define different levels of STS and explore their application in proposed lessons on the water cycle.

The rubric manifested four distinct proficiency levels, with each participant's response accordingly coded to a specific level. The categorization of these levels was founded on an assessment of participants' responses, utilizing components of the Systems Thinking Hierarchical (STH) Model (Ben-Zvi Assaraf & Orion, 2005), interrelationships among subsystem processes and components, as well as the Next Generation Science Standards (NGSS) crosscutting concepts (NGSS, 2013). Lee et al. (2019) named the four levels novice, recognition, beginning, and intermediate. Regarding the advancement of the levels and to be aligned with the other rubric used in this study, the names of the four levels were revised as novice, developing, intermediate, and advanced (Table 2).

Table 2 The Systems Thinking Rubric (Adapted from Lee et al., 2019)

Level	Description
Novice (Level 0)	Lack of response or an explicit implication of unfamiliarity with the given system
Developing (Level 1)	Identifying a single part, process, or pattern within the system
	Lack of elaboration on the relationship between the parts and processes
Intermediate (Level 2)	Identifying at least two parts or processes
	Limited to one-directional cause and effect (e.g., A causes B) or recognizing a relationship solely between two components
Advanced (Level 3)	Identifying three or more parts or processes, with an understanding that involves at least two or more interacting parts
	Multiple interactions are recognized, demonstrating an increased complexity in understanding the system

The third case assessed participants’ dynamic thinking skill levels using the revised rubric developed by the authors (Karga & Ceyhan, 2024). The rubric was developed based on the revised System Thinking Rubric (Lee et al., 2019) to ensure consistency when analyzing data from the different scenarios. In developing the Dynamic Thinking Skills Rubric, an expert view was obtained regarding content coverage, criteria selection, and descriptor clarity (Karga & Ceyhan, 2024). The level descriptions of the Dynamic Thinking Skills Rubric are given in Table 3.

Table 3 The Dynamic Thinking Skills Rubric

Level	Description
Novice (Level 0)	No comprehension or application of dynamic thinking concepts
	Decisions are made based solely on personal preferences or immediate costs
Developing (Level 1)	Demonstrating an understanding of behavioral patterns within a system or over time, with consideration of short-term or temporary factors
Intermediate (Level 2)	Expanding the mental models to include past and future trends, with an awareness of potential growth or stability
Advanced (Level 3)	Explaining how different stakeholder views, gradual changes, feedback loops, and delays affect overall system behavior

Two of the researchers independently coded each participant's pre- and post-survey responses to the three cases using the Systems Thinking Rubric (Lee et al., 2019) for stock-flow and causal-loop thinking, and the Dynamic Thinking Skills Rubric (Karga & Ceyhan, 2024) for dynamic thinking. The first researcher has a Ph.D. in science and has conducted various research on systems thinking. The second researcher has a master's degree in science education and specializes in systems thinking in science education. Interrater agreement was calculated using the formula: # agreements / (# agreements + # disagreements) x 100 (Cooper et al., 2019). The researchers met and compared their scores for each participant, with initial agreement rates of .75 for stock-flow thinking, .71 for causal loop thinking, and .86 for dynamic thinking. Then, the researchers explained to each other the logic of the codes that they had done differently. They discussed their conflicts until they reached a complete agreement across their codes.

Results

To answer the research question in more detail, under three sub-research questions, this study examined PSTs’ levels of stock-flow thinking, causal loop thinking, and changes in dynamic thinking from pre-survey to post-survey. The results of the sub-questions were presented in three categories under this heading.

How do pre-service teachers’ levels of stock-flow thinking change from pre-survey to post-survey?

The pre-survey to post-survey levels of PSTs’ stock-flow systems thinking for Case 1 are shown in Figure 1. When the pre-survey responses of fourteen participants were analyzed to determine the stock-flow thinking levels, two participants were at Level 1, eleven were at Level 2, and one was at Level 3. When the participants' responses to the post-survey were analyzed, it was found that five participants were at Level 1, four were at Level 2, and five were at Level 3. No Level 0 respondents were recorded in either the pre- or post-survey.

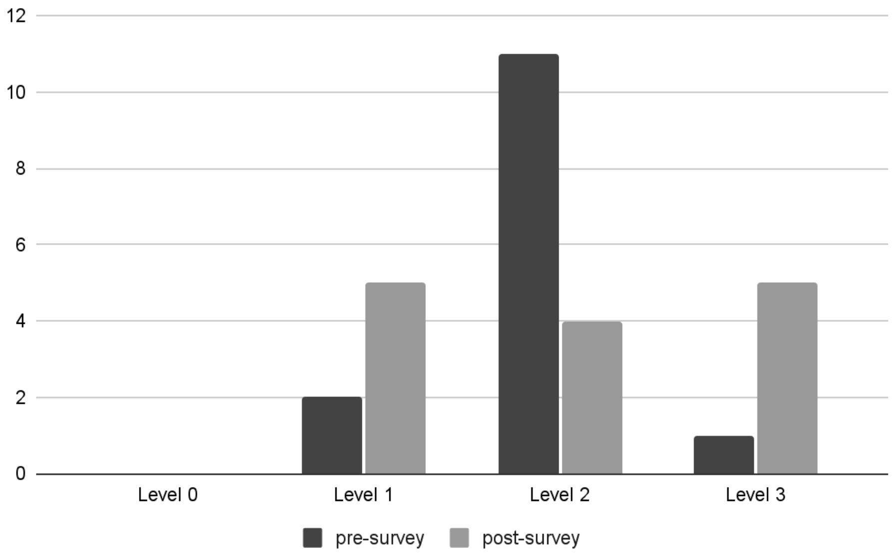

Figure 1 Participants’ Pre- and Post-survey Stock-flow Thinking Levels

Table 4 shows the sample quotes given by participants for Case 1 on the pre-and post-surveys.

Table 4 Participants' Stock-flow Thinking Levels and Sample Quotes for Case 1

Levels	Example quotes for pre-survey	Example quotes for post-survey
Level 0	-	-
Level 1	"The rest of the rats that survived can breed new ones. And as I know, they give birth to more than one at a time." (M3)	"I think the rats can become resistant to the poison." (S1)
Level 2	"A few mice that did not die may have developed resistance and multiplied due to the poison placed in the environment." (S6)	"Since the mice did not all die at the same time, the remaining mice may have developed a defense against the poison over time. Mice unaffected by the poison may have reproduced." (M4)
Level 3	"Pollution is seen more in tourist places due to population. Since rats generally live in dirty environments, it causes the mouse population to reappear. Since rat populations are not common in a clean environment, the main solution should be to give importance to environmental cleanliness." (M5)	"The increase in the number of rat species unaffected by the poison over time led to an increase in the number of rats in the city. The fact that the remaining species now ate the food sources of the poisoned mice and that they could easily find food, may have contributed to this. Eliminating just one of the environmental conditions does not solve the whole problem." (S5)

S stands for science PSTs, and M stands for mathematics PSTs. "-" stands for no answer.

How do pre-service teachers' levels of causal loop thinking change from pre-survey to post-survey?

Figure 2 shows the participants' pre- and post-survey causal loop thinking levels for Case 2. When the pre-survey responses of a total of fourteen participants are analyzed to determine the participants' causal thinking levels, it can be seen that one of the participants was at Level 0, four were at Level 1, six were at Level 2, and three were at Level 3. When the participants' responses to the post-survey were analyzed, it was found that three participants were at Level 2 and eleven were at Level 3. No Level 0 and Level 1 respondents were recorded on the post-survey.

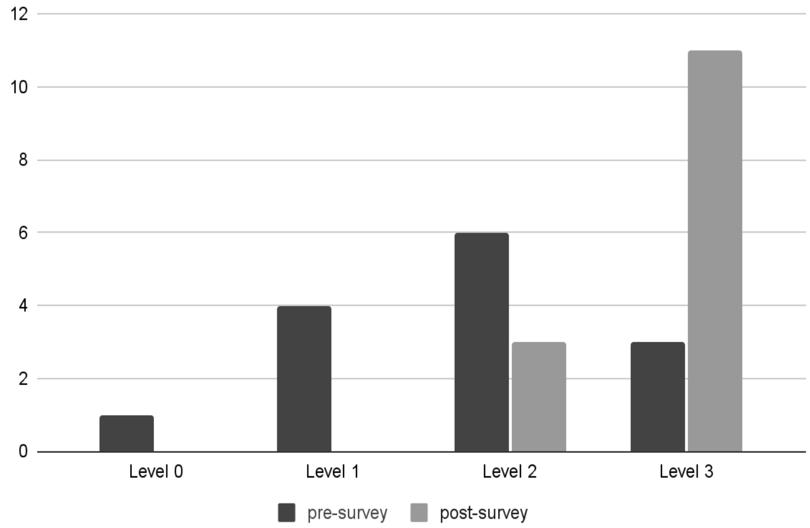

Figure 2 Participants' Pre- and Post-survey Causal Loop Thinking Levels

Table 5 shows the sample quotes given for Case 2 on the pre-and post-surveys.

Table 5 Participants' Pre-and-post Surveys Causal Loop Thinking Levels and Sample Quotes for Case 2

Levels	Example quotes for pre-survey	Example quotes for post-survey
Level 0	"Because they broke the system. Even though they think they have found a solution, it has created new problems." (S1)	-
Level 1	"The villagers have destroyed the food chains. It is a cycle and it causes problems for every part of the pieces of the system." (S8)	-
Level 2	"Just as in the food web, the extinction of the green insects led to the reappearance of the red insects, and at the same time there were changes in the number of animals, which increased and decreased as the system of the food chain was disrupted." (S5)	"The farmers did not focus on the main problem. They just tried to solve their problem in a way that was more appropriate for them. So they used the pesticide to kill the green bugs. To find the right solution, they have to find out why these things happen. This requires them to look at deeper levels of abstraction within the system that are not immediately obvious." (S4)
Level 3	"The farmer should try to destroy the red bugs so that the population of green bugs will decrease and his crops will remain healthy." (M5)	"Because the farmers had found a short-term solution. They did not consider the future possibilities. For a certain period after using this pesticide, the insect may become resistant, or the plants may be damaged by the pesticide." (S7)

S stands for science PSTs, and M stands for mathematics PSTs. "-" stands for no answer.

How do pre-service teachers' levels of dynamic thinking change from pre-survey to post-survey?

Figure 3 shows the participants' pre-survey and post-survey levels of dynamic thinking for Case 3. When the pre-survey responses of fourteen participants were analyzed to determine the dynamic thinking levels, six participants were at Level 0, seven were at Level 1, one was at Level 2, and no one was at Level 3. When the participants' post-survey responses were analyzed, it was found that two participants were at Level 0, two were at Level 1, nine were at Level 2, and one was at Level 3.

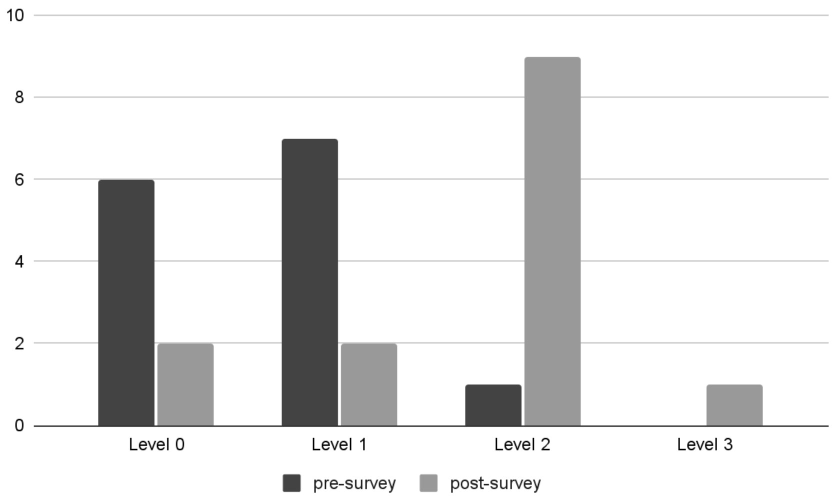

Figure 3 Participants’ Pre-and Post-survey Dynamic Thinking Levels

Table 6 shows the sample quotes given for Case 3 on the pre-and post-surveys.

Table 6 Participants' Dynamic Thinking Levels and Sample Quotes for Case 3

Levels	Example quotes for pre-survey	Example quotes for post-survey
Level 0	“I would choose a small house near the heart of the city because it is time efficient. Also, there are plenty of opportunities to socialize.” (S4)	“If I were Kramer, I would choose a big house because I think a big house is more useful. Also, it is less expensive, and I think the place where the big house is located is quieter than the big house.” (S3)
Level 1	“I would choose a large house in a less expensive but up-and-coming neighborhood. The big house is advantageous both in terms of area and budget, and I think it is the right choice because it is already developed.” (M1).	“I would prefer the second house because it is mentioned as an emerging neighborhood. So, it not only provides a comfortable living space for not but also has potential to be valuable.” (S1)

Table 6 (continued)

Levels	Example quotes for pre-survey	Example quotes for post-survey
Level 2	"I choose the second home because I prefer a place that is open to innovation rather than the existing one. Even if it is a cheaper house, I think it can be advantageous if it is bigger than the other one and the surrounding area is also developing." (S5).	"I would choose the big house. because it is both affordable and highly likely to increase in value in the future. and also for investment purposes, so it's better to have a big house." (M1).
Level 3	-	"If I were Kramer, I'd choose the house in the developing area. In the beginning, he will have both a larger and more affordable house, and at the same time, many different factors will change and develop, and he will have the advantage of the location of the first house in the future. Even if it is the case of choosing the first house, it should be taken into account that the conditions of the environment there may also change over time." (S5)

S stands for science PSTs, M stands for mathematics PSTs. "-" stands for no answer.

This study examined the contribution of a course using inquiry-based teaching strategies compatible with the systems thinking approach to developing STS of PSTs. This study evaluated how participants' stock-flow thinking skills for the first case, causal loop thinking skills for the second case, and dynamic thinking skills for the third case changed from the pre-survey to post-survey across three cases. Table 7 provides a holistic view of the participants' levels by scoring their responses to pre- and post-survey cases. The table shows which systems thinking skill(s), if any, changed for mathematics and science PSTs during the course from the pre- to post-survey.

Table 7 Pre and Post-survey Results of the Three Cases

	Case 1: Stock-flow thinking		Case 2: Causal loop thinking		Case 3: Dynamic thinking	
	Pre-survey	Post-survey	Pre-survey	Post-survey	Pre-survey	Post-survey
M1	Level 2	Level 1	Level 2	Level 3	Level 1	Level 2
M2	Level 1	Level 1	Level 3	Level 3	Level 0	Level 2
M3	Level 1	Level 1	Level 3	Level 3	Level 0	Level 2
M4	Level 2	Level 2	Level 1	Level 2	Level 0	Level 0
M5	Level 3	Level 3	Level 3	Level 3	Level 1	Level 2
S1	Level 2	Level 1	Level 0	Level 3	Level 0	Level 1
S2	Level 2	Level 3	Level 2	Level 3	Level 1	Level 2
S3	Level 2	Level 1	Level 1	Level 2	Level 0	Level 0
S4	Level 2	Level 2	Level 2	Level 2	Level 0	Level 1
S5	Level 2	Level 3	Level 2	Level 3	Level 2	Level 3
S6	Level 2	Level 3	Level 2	Level 3	Level 1	Level 2
S7	Level 2	Level 2	Level 1	Level 3	Level 1	Level 2
S8	Level 2	Level 3	Level 1	Level 3	Level 1	Level 2
S9	Level 2	Level 2	Level 2	Level 3	Level 1	Level 2

S stands for science PSTs, M stands for mathematics PSTs. "-" stands for no answer.

Stock-flow Thinking

When Table 7 is analyzed in terms of levels of stock-flow thinking, the number of participants at Levels 1 and 3 increased from the pre-survey to the post-survey, while the number of participants at Level 2 decreased. Two participants who were at Level 1 on the pre-survey showed no improvement on the post-survey and remained at Level 1. Eleven participants were at Level 2 on the pre-survey. On the post-survey, three dropped to Level 1, four remained at the same level, and four moved up to Level 3. The only participant at Level 3 on the pre-survey remained at the same level post-survey.

When the participants' stock-flow thinking level was evaluated regarding majors, it was determined that two of the five mathematics PSTs were at Level 1, two were at Level 2, and one was at Level 3 on the pre-survey. In the post-survey, both Level 1 participants, one Level 2 participant, and one Level 3 participant did not improve and remained at the same level. It was also noted that one Level 2 participant unfortunately dropped back to Level 1. Interestingly, the pre-survey found that all nine science PSTs were at Level 2. Unfortunately, two participants dropped to Level 1 in the post-survey, and three remained at the same level, showing no improvement. Fortunately, four of them moved up to Level 3.

Causal Loop Thinking

When Table 7 is analyzed in terms of levels of causal loop thinking from the pre-survey to the post-survey, the number of Level 2 respondents decreased, and the number of Level 3 respondents increased. Surprisingly, one participant at Level 0 on the pre-survey moved up to Level 3. Two of the four participants at Level 1 in the pre-survey moved to Level 2, and the other two moved to Level 3. Of the six participants at Level 2 on the pre-survey, one stayed the same, and the other five moved up to Level 3. Three participants at Level 3 on the pre-survey did not change levels on the post-survey.

When the participants' level of causal loop thinking was evaluated in terms of majors, it was found that one of the five mathematics PSTs was at Level 1, one was at Level 2, and the remaining three were at Level 3 in the pre-survey. In the post-survey, it is good to see that the Level 1 participant moved to Level 2 and the Level 2 participant moved to Level 3. The Level 3 participants did not progress and remained at the same level. In the pre-survey, one of the nine science PSTs was at Level 0, three were at Level 1, and the remaining five were at Level 2. In the post-survey, surprisingly, the Level 0 participant moved up to Level 3, one Level 1 participant to Level 2, and the remaining two Level 1 participants to Level 3. Four out of five Level 2 participants progressed to Level 3, but one remained at the same level and did not progress.

Dynamic Thinking

When Table 7 is analyzed in terms of levels of dynamic thinking from the pre-survey to the post-survey, it can be seen that the number of participants at Level 0 and Level 1 decreased, and the number of participants at Level 2 and Level 3 increased. Of the six participants at Level 0 on the pre-survey, two remained at the same level, two moved to Level 1, and the remaining two moved to Level 2 in the post-survey. All participants at Level 1 in the pre-survey moved to Level 2 in the post-survey. The participants at Level 2 in the pre-survey moved up to Level 3 in the post-survey.

When the dynamic thinking level of the participants was evaluated in terms of majors, it was found that three of the five mathematics PSTs were at Level 0, and the remaining two were at Level 1 in the pre-survey. In the post-survey, two participants at Level 0 moved up to Level 2, while one remained at the same level. It is good to see that all the participants at Level 1 in the pre-survey moved up to Level 2. In the pre-survey, three of the nine science PSTs were at Level 0, five were at Level 1, and the remaining one was at Level 2. In the post-survey, it can be seen that two of the three participants who were at Level 0 moved up to Level 2, and the remaining one remained at the same level with no improvement. It is nice to see that all of the participants at Level 1 in the pre-survey moved up to Level 2 in the post-survey. Only one participant at Level 2 on the pre-survey moved up to Level 3 on the post-survey.

Discussion

A society with the potential to be systems literate and adept may be hampered in dealing with complex and dynamic situations by limited awareness and grasp of systems thinking. This study explored the change in STS among PSTs after participating in a systems thinking-oriented teacher education course. Jordan and colleagues (2013) demonstrated that instructional techniques based on the Structure-Behavior-Function Theory significantly improved understanding of the various factors involved, particularly concerning behaviors and functions. Similarly, improvements in the ability of pre-service teachers to answer scenario-based questions about structure, behavior, and purpose were observed in the current study.

Hmelo-Silver et al. (2007) identified challenges novice teachers face in understanding complex systems. PSTs focused on static system components, while in-service teachers focused on structural, functional, and behavioral elements (Hmelo-Silver & Pfeffer, 2004). Similarly, Lee et al. (2019) found that both in-service and PSTs struggled to identify system components, processes, and hidden dimensions. The present study's results align with these barriers, showing STS levels of PSTs before instruction were consistent with these difficulties. Their STS levels in the stock flow case before the course were slightly more advanced than in the causal loop and dynamic thinking cases, but still did not include novice-level data.

After the systems thinking course, the results from the developing level increased, and differences in skill levels were observed in the PSTs' performance in the scenario focusing on stock and flow thinking skills compared to the pre-survey. As mentioned in Aşık and Doğanca Küçük's study (2021), individuals' difficulty in understanding and solving stock-flow scenarios may be due to their decision-making processes rather than a lack of contextual knowledge about the tasks. Moreover, the majority of participants were unfamiliar with stock-flow scenarios, which could potentially impact their performance (Aşık & Doğanca Küçük, 2021). This situation underscores a key area for development in science education and suggests that strengthening teachers' decision-making abilities, especially in the context of complex systems, could greatly enhance their understanding and teaching of stock-flow concepts, leading to improved student learning outcomes in science classrooms (Karga & Ceyhan, 2024).

Perkins and Grotzer (2000) showed that when participants are asked to explain a collection of complicated systems, they frequently provide relatively basic causal explanations, as seen in the current study before instruction. Understanding the behavior and functions of a system requires a more detailed understanding of the underlying phenomena and their interrelationships. It was seen that after the intervention, the development of participants in causal loops and dynamic thinking cases was improved more explicitly. On the other hand, Davis et al. (2020) revealed that students who found more connections between variables performed better at identifying feedback. In the current study, although PSTs performed better in identifying causal interactions, they did not explicitly mention balancing or reinforcing causal loops as seen in the study conducted with science teachers (Karga & Ceyhan, 2024). In addition, another reason for the significant increase in participants' success in causal loops compared to the pre-survey may be that they worked on identifying stock-flow relationships before causal loops in the course timetable during the semester.

Ateskan and Lane (2018) found that after the workshop in the context of Education for Sustainable Development (ESD), teachers were more likely to see problems as a series of interconnected problems and that systems are constantly changing, which are the aspects of dynamic thinking. Also, Palmberg and colleagues (2017) showed that none of the PSTs acquired an intermediate or advanced level of systems thinking, incorporating interconnections, feedback, and behavioral components. Teachers struggle to deliver suitable learning experiences if they don't comprehend the nature of complex systems. In the study of Karaarslan Semiz and Teksöz (2020), science PSTs showed improvement in twelve ESD context aspects of systems thinking, including dynamic and cyclic thinking skills. Most of the teacher candidates had advanced to the developing or mastery level. Therefore, the findings of this study underscore the necessity for well-designed interventions designed to enhance the systems thinking skills of pre-service teachers across all three dimensions as emphasized by Yoon and colleagues (2017) the critical importance of professional development for teachers to effectively instruct on complex systems.

Although the current study used a context-independent measurement approach with scenarios, the PSTs showed improvement in dynamic thinking skills, as mentioned in the literature (Palmberg et al., 2017). However, the number of participants who still reach the highest level of dynamic thinking skills is very limited or low. This could be because interpreting gradual changes in a system, potential causal loops, and delays requires a deeper understanding and skills. Therefore, the initiatives to develop PSTs in the context of systems skills, such as those explored in this study, are important in preparing PSTs for the profession, as it was seen that fewer PSTs reached the upper level in terms of thinking with stock-flows and dynamic thinking skills. In addition, one of the interesting results of this study is that when the STS levels of mathematics and science PSTs are compared, the improvement in all three skills is more evident.

Moreover, the difference between the STS of mathematics and science PSTs may be due to less exposure to courses and learning materials that may contribute to the development of STS levels (Peretz et al., 2023). Considering the fluctuating systems thinking skill levels of pre-service teachers in three aspects, as indicated by the results, this finding suggests that improving and standardizing the duration and quality of both theoretical education and practical classroom experience in systems thinking may be beneficial. Such enhancements could lead to more consistent and developed systems thinking skills among teachers. On the other hand, the scenario-based questions employed in this study illuminate on the degree to which teachers' responses can be used to gauge students' systems thinking abilities. Addressing the shortcomings of assessments allows us to develop new techniques and improved instruments for assessing systems thinking abilities.

This exploratory research serves as a foundation for larger studies to validate and expand upon the results. While this study focuses on science and math PSTs, STS are relevant across various educational contexts and disciplines. Future research could include PSTs from other disciplines, such as social studies or language arts, to explore STS development in different domains. Future research could also involve longitudinal studies that follow the STS of PSTs as they progress through their teacher education programs and transition into their careers. By tracking participants' development over time and examining how they implement STS in real-world teaching scenarios, researchers can better understand the long-term impact of systems thinking-oriented interventions and identify potential barriers or facilitators to successfully integrating systems thinking into educational practice.

Furthermore, this study shows that involving PSTs in systems thinking is feasible and beneficial, even in the early stages of their education. Therefore, further research on systems thinking should inform curricula that integrate systems thinking into higher education programs (Elsawah et al., 2022; Karaaraslan Semiz & Teksöz, 2024). To gain a more comprehensive understanding of the impact of systems thinking-integrated courses across different educational levels, it is recommended to conduct studies with undergraduate and graduate programs.

In conclusion, this study contributes to the growing body of research on systems thinking in teacher education. However, future research should aim to build upon and extend its findings. By pursuing the suggested directions, researchers can further advance our understanding of how to foster and assess STS among PSTs effectively. This will ultimately prepare PSTs to navigate the complexities of the modern educational landscape and equip their future students with the tools to thrive in an increasingly interconnected world.

Compliance with Ethical Standards

Disclosure of potential conflicts of interest

The authors declare no competing interests.

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Research involving Human Participants and/or Animals

Approval to conduct the research was received from the Human Research Ethics Committee of Bogazici University (E-84391427-050.01.04-132885).

Fen ve Matematik Öğretmen Adaylarının Sistem Düşüncesi Becerilerinin Vaka Senaryoları Aracılığıyla Değerlendirilmesi

Özet:

Karmaşık küresel sorunların ele alınması, sistem düşüncesi becerilerinin gerekliliğini vurgulayan daha kapsamlı ve bütüncül yaklaşımlar gerektirmektedir; ancak mevcut çalışmalar, öğretmen adaylarının sistem düşüncesi becerilerini anlamada önemli bir boşluk olduğunu göstermekte ve bu alanda daha fazla araştırma yapılması gerektiğini vurgulamaktadır. Bu keşifsel vaka çalışması araştırması, fen ve matematik öğretmen adaylarının sistem düşüncesi becerilerini senaryo tabanlı değerlendirmeler yoluyla araştırmıştır. Üç vaka senaryo örneği, sistem düşüncesinin belirli bir yönüne odaklanmıştır: stok akış, nedensel döngü ve dinamik düşünme. Bu çalışmanın katılımcıları, bir devlet araştırma üniversitesinin öğretmen eğitimi programında sistem düşüncesi dersi alan 14 öğretmen adayıdır. Veriler Sistem Düşüncesi Rubriği ve Dinamik Düşünme Becerileri Rubriği kullanılarak kodlanmıştır. Analizler, dinamik düşünme becerilerinde gelişmeler olduğunu göstermiş, ancak daha az sayıda katılımcı stok akışı düşünme konusunda gelişme göstermiştir. Fen ve matematik disiplinleri karşılaştırıldığında, fen bilgisi öğretmen adaylarının sistem odaklı düşünme becerilerinde matematik öğretmen adaylarına göre daha fazla ilerleme kaydettikleri görülmüştür. Bu ön araştırma, eğitimcilerde sistem düşüncesinin değerlendirilmesi ve geliştirilmesine yönelik içgörüler sunmaktadır. Sistem düşüncesi yaklaşımının öğretmen eğitimi programlarına entegre edilmesinin, öğretmenleri karmaşık sorunlarla etkili bir şekilde başa çıkmaya daha iyi hazırlayabileceğini öne sürmektedir. Öğretim yöntemlerinin kullanıldığı daha ileri çalışmalar, öğretmen adayları arasında sistem düşüncesi gelişiminin optimize edilmesine ışık tutabilir. Özünde bu araştırma, sistem düşüncesinin öğretmen eğitimini zenginleştirme potansiyelinin altını çizmektedir.

Anahtar kelimeler: Öğretmen adayları, sistem düşüncesi becerisinin ölçülmesi, sistem düşüncesi becerileri, öğretmen öğrenmesi.

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