Id: 1882746

Participatory Educational Research (PER)
Vol.13(4), pp. 231-250, July 2026
Available online at http://www.perjournal.com
ISSN: 2148-6123
http://dx.doi.org/10.17275/per.26.57.13.4

Enhancing Metacognitive Awareness and Problem-Solving Skills Through a Systems Thinking-Based Global Environmental Issues Module

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Article history
Received:
05.02.2026

Received in revised form:
19.03.2026

Accepted:
02.04.2026

Key words:
Environmental education; systems thinking; higher-order cognitive skills; metacognitive awareness; problem-solving skills.

Fostering students' metacognitive awareness and perceived problem-solving skills is critical for both academic achievement and informed decision-making in daily life. This study examines the impact of a systems thinking-based global environmental issues module on middle school students' metacognitive awareness and perceived problem-solving skills, while exploring their views regarding the learning process. The study involved 49 seventh-grade students attending an elective environmental education course. While the control group followed the standard Ministry of National Education textbook, the experimental group engaged in activities designed with system dynamics tools. This study employed a mixed methods design. In the quantitative phase, a quasi-experimental design was employed, while the qualitative phase utilized a case study design. Quantitative data were collected through the *Metacognitive Awareness Inventory for Children* and the *Perceived Problem-Solving Skills Scale*, whereas qualitative data were obtained via semi-structured interviews. Independent samples t-tests were conducted for quantitative analysis, while descriptive analysis was applied to qualitative data. The findings revealed that the intervention activities significantly enhanced students' metacognitive awareness and perceived problem-solving skills. The qualitative findings indicated that the activities contributed to students' ability to develop diverse perspectives on environmental issues, understand complex cause-and-effect relationships, and transfer acquired skills to various contexts. These results highlight the potential of systems thinking in supporting higher-order cognitive skills.

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Introduction

The world we live in is embedded in numerous complex systems across social, economic, and environmental domains, while at the same time facing many dynamic and interrelated problems such as poverty, climate change, and environmental pollution. Developing sustainable solutions to these complex challenges of the twenty-first century requires a sound understanding of the elements that give rise to these problems and the web of relationships among them. In this context, systems thinking is recognized as an essential way of thinking for both scientists and society in addressing economic, social, and environmental issues (Capra & Luisi, 2014; Clancy et al., 2008; Lyneis & Fox-Melanson, 2001; Maani & Maharraj, 2004; Meadows, 2008; Ormancı et al., 2018; Rodriguez et al., 2015; Schoen & Fusarelli, 2008; Senge, 2006).

Systems thinking is a broad concept defined from multiple perspectives and across diverse disciplines. By examining existing definitions in the literature, Arnold and Wade (2015) describe systems thinking as "a set of analytical skills used to identify systems, predict their behaviors, and design modifications to produce desired effects" (p. 7). Over time, systems thinking has attracted the attention of practitioners and researchers in various fields such as systems engineering, business, economics, environmental science, politics, management, health, and education, and has become a widely applied research domain (Hossain et al., 2020). Particularly in recent years, systems thinking has been increasingly integrated into efforts to improve educational systems, with a growing number of empirical and theoretical studies emphasizing its educational value (Bozkurt & Bozkurt, 2024; Budak & Ceyhan, 2024; Küçükoğlu et al., 2023).

Senge (2006) emphasized the importance of systems thinking in education, criticizing current education systems for teaching students, from an early age, to understand complex problems by breaking the world down into smaller parts. Moreover, research has shown that when students are not engaged in systems thinking, they tend to interpret problems in linear, one-dimensional ways that focus only on visible variables and straightforward causal relationships which limit their ability to manage complexity (Covitt et al., 2009; Goldstone & Wilensky, 2008; Hmelo-Silver et al., 2017; Jacobson & Wilensky, 2006; Jordan et al., 2013; Shepardson et al., 2014; Sommer & Lücken, 2012; Sweeney & Sterman, 2007; Yoon, 2008).

Research on the integration of systems thinking into teaching and learning indicates that it contributes to the development of higher-order thinking skills such as critical thinking, decision-making, and problem-solving (Hammond, 2003; Lyneis & Fox-Melanson, 2001; Senge, 2006; Waddock, 2006; Waters Foundation, 2012). In this context, Mandinach and Cline (1994) defined systems thinking as a problem-solving strategy that explains the changing components of a dynamic system. Systems thinking enables learners to view problems holistically, providing them with insight into understanding why system elements behave in certain ways and helping them identify implicit connections among those elements (Luong & Arnold, 2016). Moreover, systems thinking is closely associated with metacognitive skills such as monitoring solution processes, exploring and analyzing tasks, planning and implementing solutions, and verifying results. These skills included monitoring solution processes, exploring and analyzing tasks, planning and implementing solutions, and verifying results (Schoenfeld, 2016). Schaffernicht and Groesser (2016) emphasized that systems thinking inherently requires the active use of metacognitive skills. Conscious applications within educational processes, therefore, enhance metacognitive skill development, improve understanding of systems thinking tools, and promote their effective use (Cabrera & Cabrera, 2019).

Although systems thinking can be associated with all areas of education, one of the most significant fields of application is environmental education. This is because environmental science, by its very nature, is a system science encompassing complex phenomena such as ecosystems, natural cycles, resource accumulation and management, and energy transfers. Considering the inherent complexity of environmental systems, the dynamics within them, and the difficulty of predicting their potential consequences, it becomes evident that systems thinking is of great value in environmental education (Grant, 1998). Systems thinking helps individuals recognize interrelationships, cycles, and feedback mechanisms among events, thereby contributing to a deeper understanding of the multidimensional nature of environmental problems (Meadows, 2008). In this regard, systems thinking-based environmental education plays a vital role in raising awareness of environmental problems, developing solution strategies, and fostering sustainable lifestyles (Gonzalez-Gaudiano, 2005). However, despite the growing interest among educational researchers and policymakers in systems thinking (Jacobson & Wilensky, 2006; Next Generation Science Standards [NGSS], 2013; Verhoeff et al., 2018), it has been emphasized that similar to other areas of education, there remains a lack of adequate instructional materials and assessment tools based on systems thinking in environmental education, as well as a limited number of experimental studies exploring its benefits and learning outcomes (Mandinach & Cline, 1994; Ormancı et al., 2018; Sweeney & Sterman, 2007; Zaraza & Fisher, 1999).

Considering the importance of systems thinking in environmental education, the present study is considered valuable for its contribution to understanding the effectiveness of systems thinking in relation to different variables, providing a holistic perspective on environmental issues, supporting the development of systems thinking-based instructional materials, and serving as a guide for teachers who wish to integrate systems thinking into their lessons. Accordingly, this study aims to examine the effects of a systems thinking-based global environmental issues module on middle school students' metacognitive awareness and perceived problem-solving skills, as well as their views regarding the learning process. In line with this purpose, the study seeks to answer the following questions:

(1) To what extent does the systems thinking-based global environmental issues module affect students' perceived problem-solving skills and metacognitive awareness?
(2) What are students' views on this module?

Theoretical Framework

Systems thinking and global environmental issues in education

Systems thinking helps create a common language that enables people to collaborate and to understand one another and the world as an interconnected whole (Taylor et al., 2020). Efforts to integrate systems thinking into educational systems are clearly reflected in educational frameworks such as the NGSS (2013). These standards have served as a driving force for teachers and educators to incorporate systems thinking concepts into curricula (Cabrera et al., 2015).

The earliest initiatives related to systems thinking in education can be traced back to 1987, following a conversation between Gordon Brown, the retired dean of engineering at MIT, and Jay Forrester in the Catalina Foothills School District of Arizona (Hight, 1995). As a result of this meeting, educational activities related to systems thinking began to grow and gain visibility among K-12 students in the region (Forrester, 2007).

Systems thinking has been described as a "way of thinking" that allows individuals to understand and manage human and environmental systems, particularly in relation to the complex challenges that arise in the sustainable use of natural resources (Bosch et al., 2007; Orion, 2002). Moreover, in understanding the interaction between the environment, ecosystems, and humans, it is impossible to disregard the concepts of interconnection, relationship, system, complexity, and behavior (Graefe, 2010). Therefore, systems thinking skills are considered both a fundamental component of environmental education and a higher-order cognitive ability that fosters the cognitive flexibility required to collaboratively analyze and address complex environmental issues, an ability that draws upon multiple critical disciplines (Evagorou et al., 2009). Additionally, systems thinking is regarded as a foundational component of other higher-order thinking skills such as critical thinking, decision-making, problem-solving, and metacognitive awareness (Fanta et al., 2019; Holyoak, 2011; Peters, 2017).

Systems thinking and higher-order thinking skills

Addressing current environmental issues and solving complex system problems require students to demonstrate higher-order thinking skills (Maani & Maharraj, 2004). Environmental problem solving necessitates understanding interactions among system components rather than focusing solely on social or ecological dimensions (Krasny, 2009; Ruiz-Primo, 2009; Spellman et al., 2016). In this respect, systems thinking offers a shared conceptual framework and vocabulary that support interdisciplinary communication and collaborative intellectual engagement throughout the problem-solving process (Grant, 1998). Moreover, research has identified systems thinking as a significant predictor of problem-solving ability (Checkland, 1999; McKim & McKendree, 2020; Senge, 2006).

In addition, studies in the literature (Aşık & Doğança-Küçük, 2021; Cabrera et al., 2015; Gregory, 2000; Lyneis & Fox-Melanson, 2001) indicate that consciously and intentionally engaging in skills such as thinking about complex systems, identifying systems and their relationships, and employing multiple perspectives is closely associated with metacognitive awareness. Moreover, researchers have pointed out that key characteristics of metacognition such as recognizing inconsistencies, evaluating outcomes, and identifying constraints show strong parallels with systems thinking skill domains.

Problem solving requires understanding conceptual interconnections among knowledge, whereas metacognitive awareness involves evaluating the effectiveness of strategies and modifying them when necessary. Metacognition is considered a crucial component of problem solving, as it entails monitoring multiple cognitive pathways and guiding thinking toward appropriate solutions (Schraw et al., 2006). In this regard, metacognitive awareness includes strategies for understanding problems, designing and implementing effective plans, and evaluating solutions, often through systems thinking tools (Aşık & Doğança-Küçük, 2021). Likewise, systems thinking supports recognizing relationships among variables and perspectives and identifying effective intervention points (Covitt et al., 2009; Hofman-Bergholm, 2018; Roychoudhury et al., 2017; Wiek et al., 2011).

Ultimately, considering the contributions of systems thinking to environmental education and its relationship with higher-order thinking skills, it becomes evident that students should be provided with opportunities to apply systems thinking throughout the teaching-learning process

(Eilam & Reisfeld, 2017; Hmelo-Silver et al., 2017).

System dynamics tools

System dynamics tools support the visualization, development, and communication of thought processes and are considered the language through which systems thinking is expressed. Within a systems thinking approach grounded in system dynamics, three key tools are employed: behavior-over-time graphs, stock-flow diagrams, and causal loop diagrams (Fisher & Systems Thinking Association, 2023). These tools originate from the system dynamics approach and modeling method developed by Jay Forrester in the 1950s to examine the behavior of complex systems over time. System dynamics allows systems thinking to be more clearly defined and provides a practical and effective methodology for its application (Göktepe, 2022).

Behavior-over-time graphs. Change over time refers to the variation of system elements as they influence one another through their interrelationships. The flows within a system, by definition, cause changes in the stocks over time. A behavior-over-time graph, in which the horizontal axis represents time and the vertical axis represents the range of variable values, captures the dynamics of a key system variable (Fisher & Systems Thinking Association, 2023).

Stock-flow diagrams. Stock-flow diagrams consist of three components: stocks, flows, and variables (or converters). A stock is a concept used for variables representing the current state of a system and is regarded as a fundamental accumulation within it (Aşık & Doğança-Küçük, 2021; Sweeney & Sterman, 2007). The elements that make a system dynamic—that is, those that change over time—are the flows. Flows fill, drain, or modify stocks by moving "through" them, thereby driving change within the system (Forrester, 1994). This approach can be illustrated through a simple bathtub analogy: the "water" in the bathtub represents the stock, while the "faucet" and "drain" represent the inflows and outflows. The amount of water in the bathtub results from the balance between these inflows and outflows (Barlas, 2007).

Causal loop diagrams. Causal loop diagrams illustrate how system behavior emerges and also depict the causal connections and circular feedback loops within the system. In some cases, a cause becomes an effect, while in others, the effect becomes a cause. These diagrams allow the visualization of continuously changing and reciprocal cause-and-effect relationships throughout the feedback process (Forrester, 1994).

There are no specific limitations on the implementation of system dynamics tools in classroom settings. To analyze a given problem, a behavior-over-time graph is first created. The variables are then identified as "stocks," and the flows that change these stocks, along with the factors influencing these flows, are determined. Flows may be described using general expressions such as "increase" or "decrease," or more specific terms like "birth," "death," or "evaporation." After these elements are defined, the stock-flow diagram is constructed to visualize the functioning of the system. This diagram presents a conceptual model of the topic under study; however, if the system boundaries are narrowly defined, causal loops may not always emerge (Göktepe, 2022).

Method

Research Design

This study employed a mixed methods design integrating both quantitative and qualitative research approaches. Mixed methods research compensates for the weaknesses of each approach by utilizing all available data collection instruments (Christensen et al., 2015; Creswell, 2014). Among the various mixed-methods research designs, an embedded mixed design was adopted. In this design, a qualitative phase is embedded within a quantitative phase or vice versa to support the overall structure of the study (Creswell & Plano-Clark, 2018). In the present study, the quantitative phase constituted the main design, while the qualitative phase served as the supporting component. The quantitative phase was conducted using a quasi-experimental pretest-posttest control group design, whereas the qualitative phase was designed as a case study to gain a deeper understanding of the process.

Participants

The participants consisted of seventh-grade students enrolled in an elective environmental education course at a public middle school during the second semester of the 2021–2022 academic year. Based on the results of the pre-test conducted before the intervention, two classes that were determined to be equivalent were randomly assigned, with one serving as the experimental group and the other as the control group. In the quantitative phase of the study, a total of 49 students participated, including an experimental group (N = 24; 11 girls and 13 boys) and a control group (N = 25; 12 girls and 13 boys). In the qualitative phase, following the implementation of the systems thinking-based global environmental issues module, semi-structured individual interviews were conducted with 15 volunteer students from the experimental group (8 girls and 7 boys).

Data Collection Tools

In the quantitative phase of the study, data were collected using the *Metacognitive Awareness Inventory for Children* and the *Perceived Problem-Solving Skills Scale*. In the qualitative phase, students' experiences regarding the process were obtained through semi-structured interview questions. Detailed information about each data collection instrument is presented below. In addition, the necessary permissions for the use of the scales were obtained.

Metacognitive awareness inventory

The *Metacognitive Awareness Inventory for Children* was originally developed by Sperling et al. (2002) and later adapted into Turkish by Karakelle and Saraç (2007). The scale consists of 18 items and 4 subdimensions. In the present study, the Cronbach's alpha coefficient for the scale was calculated as .73, indicating that the instrument demonstrated an acceptable level of reliability.

Perceived problem-solving skills scale

To examine the effect on seventh-grade students' perceptions of problem-solving skills, the *Perceived Problem-Solving Skills Scale* developed by İnel-Ekici and Balım (2013) was used. The scale comprises two factors: *perceptions of problem-solving skills* and *perceptions of willingness and determination toward problem-solving*. In this study, the Cronbach's alpha coefficient of the scale was calculated as .80, demonstrating high reliability.

Semi-structured interview form

A semi-structured interview form was developed to determine middle school students' views on the systems thinking-based global environmental issues module. The questions in the interview form aimed to reveal the academic, social, and emotional gains students achieved through the activities and the fundamental characteristics that distinguish systems thinking-based activities from other instructional methods and techniques. The form was reviewed by four experts in science education and curriculum and instruction, and finalized based on their feedback. Each interview lasted approximately 8-9 minutes, and the resulting transcripts were shared with the students for verification of accuracy.

Validity and Reliability

In this context, various methodological measures were implemented to support the validity and reliability of the study. The experimental and control groups were determined by random assignment from among existing seventh-grade classes, no participant attrition occurred during the application period, and no external intervention that could affect the dependent variables outside the experimental process was observed. Pre-tests and post-tests were administered to both groups using the same measurement tools and under the same conditions; the time interval between administrations reduced potential testing effects. Normality assumptions were met for quantitative data, while the quality of qualitative data was supported by expert opinions and direct quotations; all data were stored to ensure verifiability.

Systems Thinking-Based Global Environmental Issues Module

The study was conducted within the scope of the *"Global Environmental Issues"* module included in the elective environmental education curriculum for middle schools developed by the Ministry of National Education (MoNE). While the lessons in the seventh-grade class assigned as the control group were conducted using the activities provided in the MoNE elective environmental education textbook, the lessons in the experimental group were carried out through activities designed with system dynamics tools, aligned with the same learning objectives of the unit. During the first two weeks of the module, introductory activities on systems thinking were implemented, adapted from the works of Sweeney and Meadows (2010) and the Creative Learning Exchange (2002). The lessons in the experimental and control groups were conducted by a researcher in the field of education who, prior to the implementation, had completed the systems thinking in education practitioner training program. Throughout approximately one semester, the researcher also held weekly online consultations with three field experts in systems thinking, during which the planned instructional activities were reviewed and refined based on expert feedback.

Table 1 presents the weekly content of the activities included in the systems thinking-based global environmental issues module, along with the system dynamics tools employed in each lesson.

Table 1. Weekly Content of the Systems Thinking-Based Global Environmental Issues Module

Weeks	Activity Title	Activity Description (40 + 40 minutes)	System Dynamics Tools Used
Week 1	*Spider Web and Mammoth Game*	Through the "Spider Web" activity, students explore the relationships between living and non-living elements, concretely experiencing the environment as an interconnected system. In the "Mammoth Game," they simulate the birth, death, and life cycles of a mammoth population by rolling dice, then graph the data to discuss population dynamics and environmental impacts.	Behavior-over-time graph, Causal loop diagram
Week 2	*In and Out Activity*	In the "In and Out" activity, students track movements into and out of a designated stock area, allowing them to concretely experience the concepts of stock, inflow, and outflow. They then graph the data and analyze the changes over time.	Behavior-over-time graph, Stock-flow diagram
Week 3	*Plastics Everywhere*	Students examine data on plastic production and circulation in the environment, identify key variables affecting the amount of plastic, visualize these variables using stock-flow diagrams, and engage in discussions about the results.	Behavior-over-time graph, Stock-flow diagrams
Week 4	*Warming Globe*	Using visual data on Arctic melting, students analyze key variables and relationships related to global warming through stock-flow and causal loop diagrams.	Behavior-over-time graph, Stock-flow diagram, Causal loop diagram
Week 5	*The Story of the Drying Lake*	Students investigate the changes in the Aral Sea over the years using satellite images and data, discuss the causes of changes in water levels, and represent this process using a stock-flow diagram.	Behavior-over-time graph, Stock-flow diagram
Week 6	*From Spark to Extinction*	Using data from the *Global Forest Watch*, students examine changes in forest areas in Türkiye over the years, create behavior-over-time graphs, and then discuss the cause-and-effect relationships of deforestation, representing forest cover using a stock-flow diagram.	Behavior-over-time graph, Stock-flow diagram
Week 7	*Clean Air Is a Right*	Together with students, real-time air quality index data from around the world (https://waqi.info/) are examined. Then, changes in particulate matter levels across Turkish provinces are analyzed, and the factors affecting these changes are discussed using a stock-flow diagram.	Stock-flow diagram
Week 8	*The Climate Is Changing*	Students identify key variables from a climate change animation and, through group work, construct stock-flow diagrams. They then use these diagrams to discuss the causes, consequences, and possible solutions to climate change.	Stock-flow diagram

Data Analysis

Analysis of the Quantitative Data

In the quantitative dimension, descriptive statistics were first employed to examine data from experimental and control groups. Before comparing problem-solving perceptions and metacognitive awareness scores, the suitability of the data for parametric tests was evaluated via skewness/kurtosis coefficients and the Shapiro-Wilk test. Following Hair et al. (2010), coefficients between −1.96 and +1.96, along with non-significant Shapiro-Wilk results ($p > .05$), confirmed a normal distribution. Since parametric assumptions were met, independent samples t-tests were performed to analyze group differences. All analyses were conducted using SPSS 22.0, with results presented in Table 2.

Table 2. Normality Test Results for the Perceived Problem-Solving Skills Scale and Metacognitive Awareness Inventory

	Group	N	Skewness	S.E.	Kurtosis	S.E.	Shapiro-Wilk (p)
Metacognition awareness inventory	Experimental Group, Pre-Test	24	-.474	.472	.895	.918	.426
	Experimental Group, Post-Test	24	-.356	.472	.475	.918	.311
	Control Group, Pre-Test	25	-.573	.464	-.376	.902	.344
	Control Group, Post-Test	25	-.514	.464	-.418	.902	.324
Perceived problem-solving skills scale	Experimental Group, Pre-Test	24	-.244	.472	-.496	.918	.744
	Experimental Group, Post-Test	24	.563	.472	.579	.918	.437
	Control Group, Pre-Test	25	-.446	.464	-.210	.902	.588
	Control Group, Post-Test	25	-.199	.464	-.814	.902	.855

Analysis of the Qualitative Data

Descriptive analysis was employed for the qualitative data. Descriptive analysis is a qualitative data analysis method that involves summarizing and interpreting data according to predefined themes. In this type of analysis, the researcher frequently incorporates direct quotations from participants in order to vividly reflect their opinions and perspectives (Creswell, 2014).

The analysis was conducted in four stages. In the first stage, a thematic framework was established; the questions from the semi-structured interview form were determined as themes. In the second stage, the qualitative data were read and codes were generated in accordance with this thematic framework; the students associated with each code were identified, and direct quotations to be used were selected. In the third stage, the data were organized and presented in tabular form along with direct quotations. At this stage, the 15 students who participated in the semi-structured interviews were identified with codes ranging from S1 to S15. In the fourth stage, the data obtained from the semi-structured interviews were interpreted. To enhance the reliability of the analysis, the coding process was carried out collaboratively by the two researchers and subsequently reviewed by a field expert.

Results

Comparison pre-test results of experimental and control groups

Before the experimental study, an independent samples t-test was conducted to determine whether the experimental and control groups differed significantly in terms of pre-test scores. The analyses revealed no significant difference between the experimental and control groups in terms of pre-test scores for problem-solving skills perception and metacognitive awareness ($p > .05$). The independent samples t-test results are presented in

Table 3. This finding indicates that the groups were equivalent in terms of the relevant variables before starting the experimental process.

Table 3. Pre-Test Results of Problem-Solving Perception and Metacognitive Awareness in the Experimental and Control Groups

Scale	Group	N	X̄	SD	sd	t	p
Perceived problem-solving skills scale	Experimental	24	79.00	7.61	47	.23	.81
	Control	25	78.40	9.81			
Metacognitive awareness inventory	Experimental	24	66.37	5.95	47	1.47	.14
	Control	25	63.48	7.63			

p > .05

The Effect of the Systems Thinking-Based Global Environmental Issues Module on Metacognitive Awareness and Perceived Problem-Solving Skills

To determine whether there was a significant difference between the experimental and control groups in terms of post-intervention metacognitive awareness and perceived problem-solving skills, an independent samples t-test was conducted, and the results are presented in Table 4.

Table 4. t-Test Results for Experimental and Control Group Students' Post-Test Scores on Metacognitive Awareness and Perceived Problem-Solving Skills

Scale	Group	N	X̄	SD	sd	t	p
Perceived problem-solving skills scale	Experimental	24	90.62	6.00	47	3.41	.00*
	Control	25	81.28	13.59			
Metacognitive awareness inventory	Experimental	24	71.66	5.64	47	3.49	.00*
	Control	25	64.28	9.66			

* p < .05

Table 4 shows that there was a statistically significant difference in favor of the experimental group between the experimental and control groups' problem-solving skill perception scale scores (X̄experimental = 90.62, SD = 6.00; X̄control = 81.28, SD = 13.59; t(47) = 3.41, p < .05). Similarly, a significant difference in favor of the experimental group was also found between the experimental and control groups in terms of metacognitive awareness inventory scores (X̄experimental = 71.66, SD = 5.64; X̄control = 64.28, SD = 9.66; t(47) = 3.49, p < .05). The results indicate that the systems thinking-based global environmental issues module had a statistically significant effect on the experimental group students' perceptions of their problem-solving skills and metacognitive awareness levels relative to the control group. Accordingly, the Cohen's d effect size coefficient was calculated to evaluate the magnitude of these statistically significant differences. Cohen's d, a standardized measure of effect size, is interpreted as a small effect for d = .20, a medium effect for d = .50, and a large effect for d = .80 (Christensen et al., 2015). Based on these calculations, Cohen's d was found to be 0.88 for the *Perceived Problem-Solving Skills Scale* and 0.93 for the *Metacognitive Awareness Inventory for Children*. According to Cohen's criteria, both values indicate large effect sizes.

Students' Views on the Systems Thinking-Based Environmental Module

The interview data conducted with middle school students were analyzed. As a result of the analysis, the findings were grouped into eight categories based on their contributions to students' thinking skills. These categories, along with their descriptions, the corresponding student codes, and illustrative quotations, are presented in Table 5.

Table 5. Themes Derived from Students' Views on the Systems Thinking-Based Global Environmental Issues Module

Themes	Description of the themes	Relevant Student Codes	Illustrative Quotation
Recognizing Change Over Time	Witnessing how a problem situation changes over time	S1,S15	"We were discussing things like why air pollution increased here and why it decreased there." (S15)
Understanding Causal Loops	Discovering the connections between events	S1, S2, S3, S4, S6, S7, S8, S9, S11, S12, S14, S15	"I learned what kind of bad consequences global warming causes in the world and how the Earth's whiteness affects those outcomes." (S2)
Making Predictions	Interpreting possible future situations using existing data	S2, S5, S8, S9, S10, S13, S15	"I was really surprised by the amount of plastic production, and we made predictions about what might happen in the future if recycling doesn't happen." (S8)
Visualizing Ideas	Making students' ideas visible through diagrams	S1, S7, S11, S12, S13, S14	"Drawing the stock-flow diagram helped me show my ideas to everyone." (S7)
Problem-Solving	Producing solutions to existing problems	S2, S3, S4, S6, S8, S9, S10, S13, S14	"The stock-flow diagram showed us that there can be more than one solution to a problem, what factors affect that stock, and how we can find ways to solve problems." (S3)
Developing Different Perspectives	Evaluating events from different variables and relationships	S3, S4, S5, S6, S8, S9, S10, S11, S12, S13, S14, S15	"Teacher, we now talk about environmental problems much better. It made us look at an event from many different angles." (S11)
Transferring Knowledge	Applying what has been learned to a new situation	S1, S3, S5, S14, S15	"Teacher, two weeks after your lesson we saw graph interpretation again in math class. Drawing and interpreting graphs really helped us." (S5)
Thinking Holistically	Evaluating a problem together with all its variables	S1, S2, S3, S5, S7, S8, S10, S11, S14, S15	"People are causing a huge lake to dry up, but that's not all it also leads to migration, loss of livelihoods, poisoning, and even death." (S1)

Middle school students stated that, through systems thinking activities, they understood how global environmental problems change over time. For example, S1 expressed, *"I learned how the Aral Sea changed over time, how the population in that region shifted, how to interpret the graph, and that the main factor in the lake's shrinkage was humans."*

Students also reported that the activities helped them develop different perspectives on environmental issues. For instance, S15 commented, *"Teacher, the activities changed my perspective on events and people. They helped me look at things from different angles. Not just superficially, but to think about issues more deeply."*

The students emphasized that systems thinking activities contributed to generating different solution ideas for environmental problems. For example, S9 noted, *"Through the stock-flow diagram, I learned different ways to solve environmental problems, how damages occur, and which methods are used to address them."*

The activities also helped students recognize causal loops related to environmental issues. For instance, S14 explained, *"Thanks to the activities, I learned what chain reactions could occur because of even our smallest mistakes."* S3 stated, *"I realized that people, knowingly or unknowingly, cause very bad things."*

Students further indicated that systems thinking activities enabled them to adopt a holistic perspective on environmental problems. For example, S2 remarked, *"Through the circle activity, I realized that everything around me is connected, and that one thing affects another."* S8 added, *"For example, we learned about how the number of forest fires, the area burned, the factors influencing forest fires, and their effects are all related."*

Students described the stock-flow diagrams they created during the activities as drawings that helped them externalize and visualize their thoughts. For example, S11 noted, *"When we drew the stock-flow diagram, we started to look at things from another angle and think about what else could happen. Then we drew it on paper. It was like solving a puzzle."* S13 added, *"Stock-flow really requires intelligence. We tried to think about the cause of something; it was quite difficult. And then we also had to think about its result. Thinking about both at once was confusing, but then we drew what we thought."*

Students also reported that the systems thinking activities improved their ability to make predictions related to environmental issues. For instance, S13 stated, *"In the Mammoth Game, we predicted when an animal species might go extinct."*

Finally, students emphasized that they were able to transfer some of the skills they acquired through systems thinking activities to solving problems in other subjects. S14 explained, *"Interpreting graphs is very important in math and science lessons, and this helped me gain knowledge in that area."*

Conclusion and Recommendations

This study examined the impact of a systems thinking-based global environmental issues module on middle school students' perceptions of problem-solving skills and metacognitive awareness, along with their views on the learning process.

Quantitative findings indicated that the systems thinking-based global environmental issues module enhanced experimental group students' perceptions of problem-solving skills, consistent with prior research. The Waters Foundation (2010) reported that systems thinking supports the development of students' problem-solving abilities, while Nuhoğlu (2008) identified significant improvements in middle school students' problem-solving skills through system dynamics tools. Similarly, Doğança-Küçük and Saysel (2018) demonstrated that system dynamics-based environmental education is more effective than traditional instruction in understanding complex environmental problems and fostering systems thinking skills. Karayol and Umdu-Topsakal (2025) further highlighted that systems thinking as a pedagogical approach strengthens students' abilities to establish connections, recognize relationships, and generate creative solutions to complex problems, while promoting a shift from factual knowledge toward conceptual understanding of global interconnections.

The qualitative data obtained from student interviews also supported these findings. Based on students' perspectives, systems thinking activities helped them recognize changes in global environmental issues over time. Moreover, the interviews indicated that these activities contributed to students' ability to propose alternative solutions to environmental problems.

Supporting this result, Mathews et al. (2008) found that when students understand systems thinking, they can identify leverage points within problems, generate hypotheses, and thereby strengthen their problem-solving capacities. Likewise, Forrester (2007) reported that teachers and researchers using system dynamics tools in their classrooms observed that students developed a better understanding of the potential consequences of interdisciplinary problems.

Qualitative findings showed that systems thinking activities enhanced students' ability to develop multiple perspectives and evaluate environmental problems holistically. This finding is consistent with prior studies (Covitt et al., 2009; Goode & MacGillivray, 2023; Hofman-Bergholm, 2018; Lyneis & Fox-Melanson, 2001; Nuhoğlu, 2008; Pimdee & Seechaliao, 2025; Roychoudhury et al., 2017; The Creative Learning Exchange, 2002; Waters Foundation, 2012; Wiek et al., 2011), which highlight that systems thinking supports holistic problem solving by examining multiple variables, perspectives, and interrelationships. Similarly, Demssie et al. (2023) found that students engaged in a systems thinking-based climate-change module produced more complex and integrated responses, demonstrating stronger abilities to interpret systems through interconnected and dynamic reasoning. Peters (2017) emphasized that systems thinking facilitates addressing complex real-world problems through holistic analysis, while Melton et al. (2022) noted that it expands system boundaries, enabling students to understand relationships among components from broader perspectives.

Another significant finding emerging from student interviews was that systems thinking activities enabled students to transfer some of the skills they had acquired to solving problems in other subjects. Benson (2007) supported this result, emphasizing that systems thinking-oriented learning environments encourage students' active participation in problem-solving processes, promote interdisciplinary connections, and enhance critical-thinking processes. Likewise, Karayol and Umdu-Topsakal (2025) noted that integrating system dynamics tools with different teaching methods across various disciplines contributes to the development of the literature and enriches educational practices. In summary, the systems thinking-based global environmental issues module not only improved students' perceived problem-solving skills but also encouraged them to approach environmental problems from broader and more holistic perspectives.

Another quantitative finding of the study revealed that the systems thinking-based global environmental issues module enhanced middle school students' metacognitive awareness. This finding aligns with previous research suggesting that systems thinking can be considered not only a conceptual framework but also a metacognitive skill (Eilam & Reisfeld, 2017; Hmelo-Silver et al., 2017; Mehren et al., 2018). Supporting this view, McKim and McKendree (2020) stated that individuals' tendencies to internally evaluate their own thoughts contribute to developing a broader and more systematic understanding of external factors. The authors further emphasized that when educators verbalize not only the correct answer but also the reasoning process that led to it while analyzing interconnected systems, they help foster both systems thinking and metacognitive development in students.

The qualitative data obtained from student interviews also reflected the contribution of systems thinking activities to metacognitive awareness. The finding that the activities enhanced students' ability to make predictions about environmental problems was interpreted as an indicator of improved metacognitive awareness. This interpretation is consistent with several studies (Aşık & Doğança-Küçük, 2021; Cabrera et al., 2015; Gregory, 2000; Lyneis & Fox-Melanson, 2001) highlighting that the characteristics of metacognition such as recognizing inconsistencies, identifying constraints, and evaluating outcomes closely parallel the skill domains of systems thinking. In this context, Mehren et al. (2018) described systems thinking as a metacognitive strategy that enables a more predictable understanding of systems' internal and external interactions and complexities. Similarly, Aşık and Doğança-Küçük (2021) emphasized that systems thinking offers various metacognitive strategies for identifying perceived problems and possible causes of failure within a system, which supports the present study's findings.

Another finding indicated that drawing causal-loop diagrams helped students identify relationships between events and externalize their thinking through visual representations. This result is consistent with the Waters Foundation (2012), which emphasized that systems thinking makes students' thinking visible and helps them recognize connections among ideas. Similarly, Shepardson et al. (2007) reported that systems thinking enables students to explore their mental models, while Ben-David and Orion (2012) highlighted that visual tools such as stock-flow and causal-loop diagrams facilitate metacognitive learning. Previous studies have also emphasized that systems thinking supports the organization of thought processes and knowledge transfer. Crawford and Jordan (2013) found that students who used metacognitive strategies through system models developed deeper understanding of socio-ecological systems (as cited in Spellman et al., 2016). Likewise, Tripto et al. (2016) demonstrated that improvements in metacognitive awareness facilitated students' use of system language to describe interactions and patterns, and Gell-Mann (1995) argued that systems thinking enhances monitoring of knowledge and thinking skills, promoting knowledge transfer across disciplines. Overall, these findings align with existing literature by demonstrating that systems thinking supports both perceived problem-solving skills and metacognitive awareness.

In conclusion, it is evident that complex global environmental problems such as climate change, global warming, forest fires, and air pollution cannot be resolved through simple or short-term solutions. Systems thinking plays a vital role in building a society capable of addressing these challenges by developing holistic and creative solutions. Therefore, educating future generations through a strong pedagogical approach grounded in systems thinking is of critical importance for equipping them with the awareness and cognitive skills necessary to effectively tackle such issues.

However, the significant findings obtained in favor of the experimental group in this study should be interpreted by considering certain methodological factors. One confounding factor is that the intervention process was conducted by a researcher trained in systems thinking. The researcher's expertise ensured that the module was implemented with high intervention fidelity and in full alignment with the theoretical framework, thereby enhancing the internal validity and reliability of the findings. This expert-led implementation was essential to demonstrate the potential effectiveness of the module under optimal pedagogical conditions. Nevertheless, the results of this study should not be interpreted as the module being restricted only to expert use. The developed module is supported by structured activities and comprehensive teacher guide materials, designed to provide the necessary scaffolding for science teachers without specialized expertise in systems thinking to manage the process effectively. The current findings indicate significant improvements in students' perceptions of problem-solving skills and metacognitive awareness immediately following the systems thinking-based intervention. Lastly, a limitation of this study is the absence of a retention test to evaluate the long-term sustainability of the observed effects. The current findings reflect cognitive changes occurring immediately following the intervention.

Recommendations for Future Research

Future research should employ longitudinal designs incorporating retention tests to examine in greater depth how systems thinking-based approaches contribute to students' perceptions of problem-solving skills and long-term metacognitive development. Exploring the effects of systems thinking across different educational levels and within interdisciplinary learning contexts would further enrich the existing body of knowledge in the field. It is recommended that further empirical investigations be conducted to test the validity and reliability of the results by implementing systems thinking-based environmental education with similar or different variables. Replicating the study with diverse sample groups could provide comparative insights into the overall effectiveness of the approach. Furthermore, future research should investigate the effectiveness of such modules when implemented by science teachers with varying levels of systems thinking expertise, including those without prior training. Such research would provide crucial insights into the scalability, transferability, and broader applicability of the approach.

Declarations

Funding: *This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.*

Ethics Statements: *Ethical approval for the study was obtained from the Atatürk University Ethics Committee with decision no. 03/20 dated 24.02.2022. All procedures performed in studies involving human participants were conducted in accordance with the ethical standards of the institutional and/or national research committees. Informed consent was obtained from all individual participants and their parents.*

Conflict of Interest: *The authors declared no competing interests.*

Informed Consent: *Informed consent was obtained from both the participating students and their parents prior to the implementation of the study. Participation was voluntary, and both students and parents were informed about the purpose of the study, the procedures involved, confidentiality principles, and their rights as participants.*

Data availability: *The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.*

Author Note: *This manuscript is based on the first author's doctoral dissertation.*

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