SCIENCE TEACHERS' UNDERSTANDING OF SYSTEMS AND SYSTEMS THINKING SKILLS, AND THEIR VIEWS ON IMPLEMENTING A SYSTEMS THINKING APPROACH IN THE CLASSROOM

by

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B.S., Science Education, Boğaziçi University, 2020

Submitted to the Institute for Graduate Studies in
Science and Engineering in partial fulfillment of
the requirements for the degree of
Master of Science

Graduate Program in Mathematics and Science Education
Boğaziçi University
2023

ACKNOWLEDGEMENTS

I would like to extend my special thanks to all those whose support and guidance were invaluable in the completion of this thesis. First and foremost, I would like to express my sincere appreciation to my advisor Assist. Prof. Gaye Defne Ceyhan for her invaluable support, guidance and encouragement in the completion of this thesis. I would like to express my infinite gratitude to her for improving my research and academic skills, supporting me to conduct additional studies in the field and attend conferences, and giving me constructive feedback at every stage of my study.

I would also like to thank my committee members, Assoc. Prof. Ebru Zeynep Muğaloğlu, Assist. Prof. Zerrin Doğanca Küçük, and Assist. Prof. Osman Akşit for accepting to serve on the committee, for sparing their time, for sharing their expertise, and for their valuable contributions to this study.

I would like to express my infinite gratitude to Ülkem Yararbaş for lighting the spark that made me want to work in this field in my undergraduate education, to Emre Göktepe who has shown me his support in every stage of my development in this field and my thesis and has explained every question I have asked for hours regardless of hours and days, and to Meltem Ceylan Alibeyoğlu who has always provided me with opportunities and support to closely observe the work in this field.

Throughout the process of writing this thesis, I have received a lot of support from my friends. To my precious friends Ömür Boran Kanargı, Beyza Nur Çelik, Bilge Türkmen, Buğçe Büçkün, and Öznur Erkoca, I thank you for being by my side whenever I needed you and for your everlasting emotional support. I would also like to thank Beyza Nur Çelik as my dear friend and research buddy for always being there to help me and for being my companion throughout this process.

Finally, I would like to express my gratitude to my mother for her love, prayers and sacrifices in raising me and preparing me for my future. Dear Brother Sebahattin Karga, I am grateful to you for always being by my side and being my guide.

ABSTRACT

SCIENCE TEACHERS' UNDERSTANDING OF SYSTEMS AND SYSTEMS THINKING SKILLS, AND THEIR VIEWS ON IMPLEMENTING A SYSTEMS THINKING APPROACH IN THE CLASSROOM

In recent years, the world has been facing many serious and complex problems such as climate change, water crisis, and health problems. More comprehensive, holistic, and interdisciplinary approaches are needed to resolve such complex and global problems. The systems thinking approach in education provides a holistic approach that focuses on the interactions and relationships among components within complex systems at different levels and includes systems thinking skills to solve these complex problems. This study aims to investigate the understanding of science teachers about a system and systems thinking skills, and their views on implementing a systems thinking approach in the classroom. The eight middle school science teachers were the participants of the study. Data was collected through online interviews and the qualitative content analysis was carried out to analyze the data. The findings revealed that teachers defined the system as a part-whole relationship; systems thinking as holistic thinking. The results showed that teachers had limited ability to think in terms of stock flows, dynamically, and in causal loops in the context of domain-general scenario-based questions and the water cycle. The teachers emphasized that the systems thinking approach should be used in education and indicated different methods and tools for teaching different subjects from the science curriculum with systems thinking. The results of the study suggest that the systems thinking and system dynamics approach can be incorporated into teacher training curricula and workshops to improve teachers' competencies on knowledge, skills, and practices.

ÖZET

FEN ÖĞRETMENLERİNİN SİSTEM VE SİSTEM DÜŞÜNCESİ BECERİLERİNİN ANLAŞILMASI VE SİSTEM DÜŞÜNCESİ YAKLAŞIMININ SINIFLARDA UYGULANMASINA İLİŞKİN GÖRÜŞLERİ

Son yıllarda dünya, iklim değişikliği, su krizi, ve sağlık sorunları gibi birçok ciddi ve karmaşık sorunla karşı karşıyadır. Bu tür karmaşık ve küresel sorunların çözümü için daha kapsamlı, bütüncül ve disiplinler arası yaklaşımlara ihtiyaç duyulmaktadır. Eğitimde sistem düşüncesi yaklaşımı, karmaşık sistemler içindeki bileşenler arasında farklı düzeylerdeki etkileşimlere ve ilişkilere odaklanan ve bu karmaşık sorunları çözmek için gerekli olan sistem düşüncesi becerilerini içeren bütünsel bir yaklaşım sunmaktadır. Çalışmanın amacı, fen bilimleri öğretmenlerinin sistem ve sistem düşüncesi becerileri hakkındaki anlayışlarını ve sistem düşüncesi yaklaşımının sınıfta uygulanmasına ilişkin görüşlerini incelemektir. Çalışmanın katılımcıları sekiz ortaokul fen öğretmenidir. Veriler çevrimiçi görüşmeler yoluyla toplanmış ve verileri analiz etmek için nitel içerik analizi yapılmıştır. Bulgular, öğretmenlerin sistemi bir parça-bütün ilişkisi; sistem düşüncesini bütüncül düşünme olarak tanımladıklarını ortaya koymuştur. Sonuçlar, öğretmenlerin senaryo temelli sorular ve su döngüsü bağlamında stok akışlarla, dinamiklerle ve nedensel döngülerle düşünme becerileri açısından sınırlı becerilere sahip olduklarını göstermiştir. Öğretmenler, sistem düşüncesi yaklaşımının eğitimde kullanılması gerektiğini vurgulamış ve fen müfredatındaki farklı konuların sistem düşüncesi ile öğretilmesi için farklı yöntem ve araçlar belirtmişlerdir. Çalışmanın sonuçları, sistem düşüncesi ve sistem dinamiği yaklaşımının, öğretmenlerin bilgi, beceri ve uygulamalar açısından yeterliliklerini geliştirmek için öğretmen eğitimi müfredatları-na ve atölye çalışmalarına dahil edilebileceğini desteklemektedir.

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LIST OF ACRONYMS/ABBREVIATIONS

MEB	Milli Eğitim Bakanlığı
MoNE	Ministry of National Education
NGSS	Next Generation Science Standards
ST	Systems Thinking
STA	Systems Thinking Approach
STH	The System Thinking Hierarchical
STS	Systems Thinking Skills

1. INTRODUCTION

In the 21st century, rapidly developing technology and science are driving the economic, social, and cultural changes in humanity. At the same time, these rapid changes bring many challenging situations to the world. In recent years, the world has been facing many serious and complex problems such as climate change, water, and food crisis, clean energy, economic inequalities, and health problems (Doganca Kucuk & Saysel, 2018). The current paradigm emphasizes the ability to solve complex problems encountered. Complex systems or problems involve multi-level organization, interconnections, various components, and invisible dynamic processes (Hmelo-Silver et al., 2007). Therefore, more comprehensive, holistic, and interdisciplinary approaches are needed to solve such complex and global problems since it is not enough to approach these problems in the context of a simple and single discipline and understanding (Arnold & Wade, 2015; Hmelo et al., 2000).

The systems thinking approach in education provides a holistic approach that focuses on the interactions and relationships among components within complex systems at different levels (Assaraf & Orion, 2005; Evagorou et al., 2009; Dutton-Lee et al., 2019; Meadows, 2008; York et al., 2019) and it includes systems thinking skills that are necessary for people to be systems thinkers and to provide solutions to these complex problems (Fisher & Systems Thinking Association, 2023). The literature emphasizes that systems thinking (ST) is an effective tool for dealing with the world's problems (Shaked & Schechter, 2017). Systems thinking is regarded as a higher-order skill that is required in the domains of science, technology, and everyday life (Assaraf & Orion, 2005). Systems thinking skills may help individuals to view the system and complex situations as a whole to understand how the operation of the system changes over time, the organization and relationships of the parts within the system, the cyclic nature of the system, and how the system relates to other systems (Assaraf & Orion, 2005) and thus, hopefully, they can provide and evaluate alternative solutions to these complex problems.

The multifaceted and inclusive nature of the systems thinking approach and the development of systems thinking skills in students are consistent with the goals of science education. Science education aims to develop students' higher-order thinking skills, such as scientific process and critical thinking skills, to explore connections across the four domains of science, which are life, physical, earth, and space sciences, and to provide solutions to complex problems, and to develop a coherent and scientifically-grounded view of the world around them (Ministry of National Education [MoNE], 2018; Next Generation Science Standards [NGSS], 2013). Therefore, improving systems thinking can be considered as one of the goals of science education (Bianchi et al., 2022; Vare et al., 2022).

Moreover, science education includes various topics that can be taught using the systems thinking approach, such as sustainable development, climate change, global warming, water, carbon, and nitrogen cycles in the ecosystem as well as the human body systems. These topics require people to consider their many aspects as a whole and from a broader perspective. At this point, the systems thinking approach is the key approach to addressing complex, multifaceted issues. However, in order to provide students with systems thinking skills, it is important first to examine to what extent science teachers have these skills (Skaza et al., 2013). Therefore, this study examined how science teachers define systems and systems thinking approach and their reported implementations.

1.1. Statement of the Problem

The science curriculum has an important place in the development of systems thinking skills, both because of the complex systems it contains and because of its relationship to other disciplines. Understanding the parts, functions, and interactions of complex systems in science education and considering the systems as a whole are important skills that individuals who have difficulty in dealing with these complex systems should have in an ever-changing world. Systems thinking is a holistic approach that covers these skills, and it is important for teachers who are practitioners of science programs to have a certain level of systems thinking skills so that they can present the complex problems for the students effectively, establish connections between disciplines, and ensure that science subjects are comprehended as a whole. Therefore, it is important to investigate science teachers' understanding of a system and the systems thinking skills, and their views on implementing systems thinking approach in the classroom Approaches should be developed to enrich teachers' understanding, skills, and teaching practices in systems thinking, with evaluation and discussion to be made in line with the results.

1.2. The Purpose of the Study

The purpose of this study is to investigate the understanding of science teachers about a system and the systems thinking skills, and their views on implementing systems thinking approaches in the classroom.

1.3. Significance of the Study

In today's world, we encounter complex and global problems. 21st-century skills require individuals to be skilled in addressing complex problems, producing and evaluating sustainable alternatives, and applying them to current problems. Therefore, systems thinking skills are crucial for individuals to handle complex problems in order to better anticipate them and, eventually, adapt their outcomes (Arnold & Wade, 2015; Assaraf & Orion, 2010). In the literature, limited research and understanding about teachers' systems thinking approach in the context of science education and the complexity in the process of understanding and interpreting systems appeared in science education as well. In research including earth systems, water cycles, and human body systems, it was revealed that individuals varied from K-12 students to teachers had difficulty in reaching higher systems thinking skills (Assaraf & Orion, 2005; 2010; Dutton-Lee et al., 2019). Also, Arndt (2006) stated that system dynamics is still underutilized by teachers, and the primary reason for this may be teachers' lack of system dynamics skills. Systems thinking is crucial to improve our capacity to comprehend the problems that confront our society, to come up with answers, and to act as global citizens. Therefore, it is quite important to investigate the teachers' systems understanding and the systems thinking skills because teachers may guide students to be better equipped with the complex issues around them. This study may provide a perspective for the improvement of teachers' understanding, skills, and practice of systems thinking.

1.4. Research Questions

This study aims to explore science teachers' understanding of a system, their systems thinking skill levels, and how they incorporate their systems thinking understanding and skills into their teaching practices. The research questions are:

RQ.1: What are science teachers' understanding of a system and systems thinking approach?
RQ.2: What are science teachers' systems thinking skill levels?
RQ.3: What are science teachers' views on teaching systems and implementing systems thinking approach in their classroom?

2. LITERATURE REVIEW

2.1. Definitions of Systems, Systems Thinking and System Dynamics

For the definitions of system and systems thinking in the following sections, first of all, it is necessary to explain the concepts of systems thinking and system dynamics that we encounter in the literature. According to the System Dynamics Society (n.d.), systems thinking is a means of explaining and comprehending the relationships and causality between the various factors that make up a system. Systems thinking is a causality-based, comprehensive method to describe the dynamic interactions between system components as well as external effects. On the contrary, system dynamics measures how these interactions affect each other. By quantifying interactions and creating a time-dependent view of how the system behaves, system dynamics complements systems thinking. The systems dynamics covers creating digital simulations of complex problems that include dynamic behavior. These models reveal interactions with fewer obvious connections, dynamic complexity, delays, and unexpected outcomes (System Dynamics Society, n.d.). In brief, while both systems thinking and system dynamics share common aspects, they have some differences in terms of framework, foci, and methodologies.

The term system may apply to a wide range of topics, including social systems, ecological systems, and technological systems (Assaraf & Orion, 2005). To elaborate on the systems thinking approach, first of all, a system should be defined. According to Merriam Webster Online Dictionary (2022), a system is defined as "a regularly interacting or interdependent group of items forming a unified whole" (Merriam-Webster's online dictionary, n.d.). Similarly, Assaraf and Orion (2005), who are prominent researchers in systems thinking, defined the system as the existence and functioning of a system as a whole with the interaction of its components (p. 519).

Besides the definition of a system, there are various definitions of systems thinking in the literature. Forrester (1994), one of the pioneers of system dynamics, stated that there is no clear definition of a system and stated that systems thinking entails a broad and general understanding of the system. He added that systems thinking improves personal skills to understand the nature of the systems in which we work and live. Similarly, Richmond (1994), who is a well-known researcher in the field of systems thinking and system dynamics and is credited with coining the term systems thinking in 1987, provided a more concrete definition and defined systems thinking as developing a deeper grasp of the underlying structure to make more accurate conclusions about behavior. Forrester (1994) and Richmond (1994) made significant contributions to the field of systems thinking and system dynamics. In the late 1980s, Richmond developed the well-known STELLA (Structural Thinking, Experimental Learning Laboratory with Animation) software package, which allows for the dynamic modeling and simulation of intricate systems. The users can develop dynamic models, including components and connections with the graphical interface STELLA. The STELLA program has mainly four icons, which are stock, flow, converter, and connector. The program also contains places for numeric values.

According to Senge (1990), who works in the field of systems thinking, systems thinking focuses on recognizing the interconnections between the parts of a system and then combining them into a unified view of the whole which includes recognizing patterns and interrelationships and learning how to structure those interrelationships into more effective ways of thinking. Senge (1990) emphasized how the parts act together in a system of different relationships. Sweeney and Sterman (2000) approached systems thinking as an ability and defined it as the "ability to assess and represent dynamic complexity" (p. 2). Systems thinking researchers have a common approach that systems thinking requires understanding systems as a whole with their parts and believe that instructions with systems thinking and system dynamics promotes significant thinking skills (Sweeney & Sterman, 2000).

On the other hand, Meadows (2008), another leading researcher in system dynamics, defined systems thinking as a way of thinking that is both systemic and dynamic, and indicated that systems include the following features: the parts, the interaction between these parts, and the purpose of the system. This definition is consistent with Assaraf and Orion's (2005) definition , and there are common points, in terms of elements and relationships, but Meadows (2008) considers the factor of a system's behavior over time. The system's purpose is derived by seeing the difference between the individual and collective behavior of the parts as a system, and the persistence of the behavior of the whole structure over time under various conditions. In this sense, Meadows (2008) emphasized that the system formed by decoupling the parts is more than the sum of the parts. Similar to Meadows (2008), Arnold and Wade (2015) considered predicting the system's behaviors over time, so dynamic behavior. Additionally, Arnold and Wade (2015) emphasized systems thinking skills in their definition and described it as a collection of synergistic analytical abilities used to enhance the capacity to perceive and comprehend systems, predict their activities, and design modifications to them in order to achieve desired outcomes. Arnold and Wade (2017) expanded on their 2015 definitions by proposing a set of skills that support systems thinking. These skills support the four basic principles of Arnold and Wade's systems thinking definition in 2015 as mindset, content, structure, and behavior domains.

Hopper (2007), a prominent researcher in system dynamics, suggested approaches to evaluate interventions aimed at enhancing systems thinking within the scope of a meta-analysis. The key characteristics of the systems thinking approach were revealed by examining different research areas, from the system dynamics to biology and geographical science. The seven systems thinking components or traits around which a consensus seems to exist in the literature are: recognizing interconnections, identifying feedback, understanding dynamic behavior, differentiating types of flows and variables, using conceptual models, creating simulation models, and testing policies (Hopper, 2007). In the current research, by considering the aspects of the system dynamics mentioned above, the three most frequently encountered systems thinking characteristics among these seven components were investigated, which are differentiating types of flows and variables, understanding dynamic behavior, and identifying feedback.

2.2. Definitions of Systems Thinking Skills

The National Research Council (2010) defined systems thinking skills as the ability to understand how a system works; how an action, change, or malfunction in one part of a system affects the rest of the system. On the other hand, systems thinking skills are defined by many researchers in the literature (Elmas et al., 2021; Hopper, 2007; Sweeney & Sterman, 2000). This section addresses the elements of systems thinking skills identified by researchers.

Richmond (1993; 1997; 2000) defined seven systems thinking skills and offered a non-hierarchical classification. These are to investigate how a system's behavior changes over time, to consider what's causing the system to act the way it does, to take into account the entire system's behavior, to concentrate on the factors in a system and how they influence its behavior, to take into account the cyclical impact of system-related factors on one another, to look at system variables' relative effects rather than their absolute effects, and to put models and predictions regarding a system's behavior to the test. On the other hand, Sweeney and Sterman (2000) specified the systems thinking skills as six skills. These skills include similar aspects to skills Richmond (2000) defined, which are to determine the behavior and patterns of a system with the interactions over time, to discover the feedback processes and nonlinearities, and to identify stock-and-flow relationships. Sweeney and Sterman (2000) also indicated recognizing delays and their impacts and challenging the boundaries of mental models. The need to comprehend system dynamics and feedback loops in systems thinking is stressed by Richmond (2000), Sweeney and Sterman (2000). The general comprehension of system behavior, system structures, and a system's operational components are given higher weight in Richmond's (2000) framework. The paradigm developed by Sweeney and Sterman (2000) emphasizes the value of testing hypotheses, establishing boundaries, and tracking system behavior over time.

Assaraf and Orion (2010) created the framework: "The System Thinking Hierarchical (STH) Model" (p. 541) to determine the level of systems thinking skills of the learners. The model depicts the progression of systems thinking in the context of earth systems education in three stages as the analysis, synthesis, and implementation levels in an hierarchical order. The STH model was suggested in a study on 8th-grade students (Assaraf & Orion, 2005) and supported in a study on high-school students (Assaraf et al., 2013; Orion & Basis, 2008;). This model consists of eight characteristics of systems thinking skills. Structure–behavior–function (SBF) theory (Goel et al., 1996) is another framework used in systems thinking literature used in especially biology contexts (Hmelo et al., 2000; Hmelo-Silver & Pfeffer, 2004; Momsen et al., 2022). According to this framework, structure denotes the components of the system, whereas behavior denotes the internal processes and connections that explain how structures are connected. Structures and behaviors work together to help the system carry out its function or what it does. The various interconnected layers and dynamic dynamics of a complex system are taken into account by SBF theory (Goel et al., 1996). By characterizing a system's subcomponents, their function within the system, and the process that supports their functions, the SBF framework enables effective reasoning about the functional and causal roles of structural elements in a system (Hmelo-Silver & Pfeffer, 2004).

Moreover, Stave and Hopper (2007) conducted a thorough analysis of the systems dynamics literature comprising the Hierarchical Model of Systems Thinking Elements. This model includes seven aspects of systems thinking skills, and these skills are also mapped in Bloom's taxonomy levels. Of the aspects mentioned by the previous researchers, Stave and Hopper (2007) defined skills as recognizing interconnections, identifying feedback, understanding dynamic behavior, and differentiating stocks and flows. On the other hand, Stave and Hopper (2007) also emphasized using conceptual models, creating simulation models, and testing policies among skills.

To sum up, Assaraf and Orion (2010) aimed to assess systems thinking skills as domain-specific, while other researchers categorize the systems thinking skills as domain-general (Arnold & Wade, 2015; 2017; Richmond, 2000; Stave & Hopper, 2007; Sweeney & Sterman, 2000;). These frameworks' structural differences, in addition to their context reliance, are a key component of these frameworks. The links among systems thinking skills are not stated in some of these frameworks (e.g. Richmond, 2000; Sweeney & Sterman, 2000). Another collection of frameworks highlights the hierarchical nature of systems thinking skills (Assaraf & Orion, 2010; Stave & Hopper, 2007; Tripto et al., 2017). Although there are different frameworks, i.e., domain-specific, domain-general, or hierarchical, commonly mentioned skills are stock-and-flow thinking, dynamic thinking, and closed-loop thinking. Therefore, this study focused on these three systems thinking skills.

2.2.1. Conceptual Definitions of Stock-and-Flow Thinking

Stock and flow thinking is a core concept in system dynamics (Asık & Doganca Kucuk, 2021; Sweeney & Sterman, 2000). Stocks are accumulations that can increase or decrease. A stock can only change through its inflow or outflow. Stock-and-flow thinking is the ability to differentiate between stock and flow variables (Dorani et al., 2015) For example, a population in a city is a stock that is increased by birth rates and decreased by death rates which are named flows. Other examples include the water in a reservoir and the inventory of a business. Stocks may create delays by accumulating the difference between the inflow to a process and its outflow (Sterman, 2001; Sweeney & Sterman, 2000).

2.2.2. Conceptual Definitions of Dynamic Thinking

Dynamic thinking is the ability to see and infer patterns of behavior exhibited by a system rather than focusing on events and trying to predict them (Dorani et al., 2015). It allows us to frame an issue in terms of how it behaves over time (Richmond, 1993; 2000; Sweeney & Sterman, 2000). Dynamic thinking skills are developed by tracing changing patterns of behavior over time and reflecting on the underlying closed-loop processes that loop to produce specific events.

Dynamic thinking suggests that the mental models should have a broad enough time frame that encompasses the past to understand how a problem has originated and extends into the future to consider the delayed and indirect consequences of our actions. In other words, the thought process should take into account both the historical and future context of a problem to gain a comprehensive understanding of its causes and potential outcomes (Dorani et al., 2015; Richmond, 2000).

Dynamic thinking skill in system dynamics also involves the ability to communicate effectively and collaboratively with others to build and refine system models and to use these models to inform decision-making and problem-solving (Maani & Maharaj, 2004). Dynamic thinking requires an openness to new information and feedback, the ability to think creatively and critically, and a willingness to revise one's thinking based on new insights and evidence.

2.2.3. Conceptual Definitions of Causal/Closed-loop Thinking

Diagrams of causal loops are closed loops with causal links (Doganca Kucuk & Saysel, 2018). Causal-loop/Closed-loop thinking helps to recognize causality as an ongoing, interdependent process rather than a one-time, one-directional event caused by independent factors. Causal-loop thinking means appreciating the fact that causal relations do not run one way; instead, they can be reciprocal and usually form loops (Ossimitz, 2000; Richmond, 1994; 2000). Causal-loop diagrams can create reinforcing and balancing cycles. For example, as the number of chickens in a poultry farm increases, the number of eggs also increases. As the number of eggs increases, the number of chickens also increases. There is a change in the number of eggs and chickens in the same direction and increasing (Nuhoğlu, 2008).

2.3. Systems Dynamics Tools

There are tools used in the application of systems thinking and system dynamics approach in K-12 to examine the structures and models underlying the systems (Fisher & Systems Thinking Association, 2023). These tools include the iceberg model, behavior over time graph, stock-flow diagram, causal-loop diagram and inference ladder (Benson, 2007). System dynamics tools are important to acquire systems thinking skills and provide more effective learning for students (Lyneis, 2000).

- **Stock-flow diagram:** It includes the factors that cause accumulations to increase or decrease over time. Accumulations can be concrete or tangible (Forrester, 1994; Sweeney & Sterman, 2000). Stocks are usually represented with rectangles, flows are represented with taps, and connectors are represented with circles.
- **Behavior over time graph:** It shows how elements or events change over time. It consists of line graphs with time on the horizontal axis and the behavior to be studied on the vertical axis (Fisher & Systems Thinking Association, 2023; Senge, 1994).
- **Causal-loop diagram:** It provides a way to comprehend and explain how a dynamic system interacts with its elements. It shows the causal relationships and circular cycles within the system (Forrester, 1994).
- **The ladder of inference:** It shows a common mental pathway used to make sense of situations in order to take action (Senge, 1994).
- **The iceberg model:** It is used to deal with the underlying causes of an event or problem by examining multiple levels of it. The levels include the event, pattern, structure and mental model (Senge, 1994).

As examples of practice in education, students can use behavior over time graphs to examine the behavior of events such as the amount of carbon in the atmosphere or the current rise in global average temperature. With the help of stock-flow diagrams, students can solve and model complex problems such as population growth, world hunger or the growth of bacteria (Lyneis, 2000). Also, they can use causal-loop diagrams among warming, melting ice and albedo effects. Moreover, They can use the ladder of inference and iceberg model to evaluate their behavior and take action and decision on social issues.

2.4. Systems Thinking Approach in Education

In the literature, there is research about the systems thinking approach in different domains of science education, such as physical, natural, geographical, chemical, and biological systems conducted with different participant groups such as pre-service and in-service teachers, and K-12 level students (Mambrey et al., 2020).

In the context of earth systems, Assaraf and Orion (2005, 2010); Dutton-Lee et al. (2019); Batzri, et al. (2015) examined the development of systems thinking skills on the topic of the water cycle and reached similar results, although the participants were pre-service & in-service teachers, and K-12 students. Participants had difficulty in reaching higher systems thinking skills, such as recognizing hidden dimensions. Also, the results revealed that the participants had difficulty in identifying components and processes and recognizing multiple interactions and relationships between subsystems.

In the context of biology education, Assaraf et al. (2013), Raved and Yarden (2014), Hmelo et al (2000), Ormancı et al (2018) conducted studies about the different systems in the human body system with students and they emphasized that the human body systems are suitable for processing with the systems thinking approach because of its complex and detailed mechanisms. These studies concluded that the students were better at low-level systems skills, such as identifying components in the subject of human body systems. On the other hand, the students were lower at high-level thinking skills, such as recognizing interrelationships among several earth systems and hidden parts of the hydrological system (Assaraf & Orion, 2005; 2010). These studies also concluded that the systems thinking skills of the students were insufficient in the unit of human body systems, and there is a need to gain a systems thinking approach while teaching this topic.

When the studies with teachers and teacher candidates are examined (Ateskan & Lane, 2018; Karaarslan, 2016; Karaarslan Semiz & Teksöz, 2020; Dutton-Lee, 2015; Schuler et al., 2018), the literature indicates that systems thinking is a main and necessary skill to become an equipped teacher about education for sustainable development which is a topic requires systems thinking approach. Also, findings implied that there are struggles to achieve certain systems thinking skills, and the attempts to be carried out will create a positive improvement in the systems thinking skills of teachers.

According to the studies in the literature, different participant groups, from K-12 students to teachers, have shown various skills in different aspects of systems thinking in the context of physical and biological systems (Assaraf & Orion 2005; 2010; Dutton-Lee et al., 2019). The gap between systems thinking in teacher education and in-service teaching has been noted in the literature on systems thinking in education (Dutton-Lee et al., 2019). Therefore, it is important to determine the status of teachers in terms of systems thinking understanding, and skills. Accordingly, this study investigates how science teachers define a system and the systems thinking approach and how they explain the implementation practices for teaching systems thinking in middle school science contexts.

2.5. System Dynamics Approach in Water Cycle

In the context of the water cycle, system dynamics can be used as the systems thinking and modeling methods to understand the behavior of the water cycle as a complex system. Assaraf and Orion (2010) studied the water cycle based on systems thinking skills. In terms of system dynamics, the water cycle process involves identifying the stocks-and-flows for water, as well as the various feedback loops and interdependencies that affect the whole behavior of the water cycle (Assaraf & Orion, 2010).

With the help of the system dynamics, researchers and educators can develop computer models of the water cycle that simulate the interactions between different components of the system, such as precipitation, evaporation, and infiltration in the water cycle. These models can help to identify the key factors that influence the behavior of the water cycle and to examine how changes in one part of the system can affect other parts of the system.

A valid and commonly encountered example of stock-and-flow thinking in secondary school science education is understanding the water cycle. In this system, the stock represents the amount of water in the atmosphere, oceans, rivers, lakes, and groundwater, while the flows represent the movement of water through various processes, such as evaporation, precipitation, runoff, and infiltration. Using the STELLA program, the system dynamics model of the water cycle is presented in the following sections. Students can develop a deeper understanding of the water cycle and the factors that influence its behavior by using stock-and-flow thinking. For example, they can create a system model that shows the different stocks and flows and identify the feedback loops that occur when changes in one part of the system affect other parts.

With the help of system dynamics and models, students can improve their stock-and-flow, dynamic, and causal-loop thinking skills to analyze the impacts of human activities such as the effects of climate change, water management practices, and land use on the water cycle. The models allow students to try different scenarios and combinations, and become more confident in their decision-making process. For example, they can explore how changes in land use, such as deforestation or urbanization, can affect the flow of water and the availability of freshwater resources on the earth. In general, stock-and-flow and causal-loop thinking skills provides a powerful method for understanding complex systems in science education and can help students develop critical thinking skills that are essential for coping with real-world problems and making conscious decisions about the future sustainable world (Skaza et al., 2013). In addition, through dynamic thinking practices students can see how their actions and decisions will lead to future outcomes based on the past. By developing models that include these factors, researchers and educators can gain a better understanding of the complex interactions between human activities and the water cycle and develop more effective strategies for managing freshwater resources. Consequently, the use of system dynamics in science education provides a powerful approach for comprehending and dealing with complex systems like the water cycle. It provides opportunities to promote sustainable solutions that consider the interconnectedness of different components within the system.

3. METHODOLOGY

This chapter gives detailed information about the design of the study, the sample for the study, data collection instruments, and data analysis. This research is conducted as a qualitative research design to establish answers to three research questions. The study was conducted through online interviews with eight science teachers and the qualitative content analysis was carried out to analyze the data.

3.1. Participants of the Study

Participants of this study were determined by purposive sampling. In purposive sampling, participants are determined according to pre-selected criteria relevant to a particular research question (Gay et al., 2011). The criterion was that teachers were trained in systems thinking in education and applied systems thinking practices in their classrooms. These criteria were set to ensure that teachers were familiar with the terminology of systems thinking and system dynamics and were better able to engage with the research content. The participants were eight middle school science teachers (teaching grades 5 to 8) working in a private school. The teachers voluntarily received training in the systems thinking approach provided by the systems thinking association in Turkey. Teachers first completed the three hour asynchronous theoretical training about systems and systems thinking tools, and then they completed eight weeks of practical training synchronously for thirty minutes each week. Teachers volunteered to work with the systems thinking trainers to develop content for the corresponding units for grades 5, 6, 7, and 8 and to implement the content in their classrooms. In addition to the content development and classroom implementations, the teachers conducted an overall evaluation by meeting with the systems thinking educators after each practice. Teachers have been actively engaged in systems thinking since 2020. Demographic information about the participant is given in Table 3.1 below. According to the table, only two of the eight teachers are male, and they have varied years of experience.

Table 3.1. The demographic information about the participant.

Participants	Gender	Years of experience	Education	Year of training received	How long ST has been practiced
A	Female	14	Undergraduate	2021	1 year
B	Female	7	Graduate	2020	3 years
C	Male	9	Undergraduate	2022	1.5 years
D	Female	4	Graduate	2020	3 years
E	Male	7	Undergraduate	2020	3 years
F	Female	6	Undergraduate	2020	2 years
G	Female	6	Undergraduate	2020	2 years
H	Female	14	Undergraduate	2022	4 months

3.2. Data Collection Instruments

In accordance with the purpose of the research, the structured interview method was used to gather in-depth information about the participants' opinions and experiences. Interview questions were developed and implemented based on the studies in the literature.

3.2.1. Interview Questions

Interviewing is one of the methods that is most commonly used for qualitative research in education. As a qualitative study aimed at acquiring a deeper understanding of the participants' systems thinking understanding and skills, interviews were used as the basis for data collection in this study. Interviews were used to clarify middle school science teachers' knowledge of systems thinking, skills, and ideas for implementing systems thinking in science classrooms.

At the beginning of the interview questions, the questions that include the demographic information about the participants were placed. The interview questions are composed of three sections as shown in Table 3.2. The interview protocol is given in Appendix A. Appendix B shows which questions were analyzed under which research question. In the first section, there were nine open-ended questions, which were adapted from the study of Dutton-Lee et al. (2019). After the questions in the original study were translated into Turkish, necessary revisions were made to ensure the integrity of language and meaning in the Turkish context. The questions included four identified themes which include defining water cycle systems as a continuous pattern, determining differences between high- and low-level systems thinkers, identifying pedagogical approaches for teaching systems thinking, and determining participants' challenges in teaching systems thinking (Dutton-Lee et al., 2019).

Table 3.2. Questions in each section of the interview.

Sections	Subsections	Number of items
First section	Defining system	3
	Defining water cycle as a system	4
	Identifying pedagogical approach	1
	Determining challenges	1
Second section	Stock-and-flow thinking	1
	Dynamic thinking	1
	Causal-loop/Closed-loop thinking	1
Third section	Defining systems thinking and systems thinking tools	2
	Position to systems thinking skills in education	1
	Implementation of systems thinking approach	6

In the second section of the interview, three scenario-based questions were asked to explore how science teachers demonstrate systems thinking skills (Dorani et al., 2015). The questions were related to the stock-and-flow thinking, dynamic thinking, and causal-loop/closed-loop thinking skills. The questions were context-independent, scenario-based, and adapted from the research of Dorani and his colleagues (2015) on the development of question sets to assess three systems thinking skills. After the questions in the original study were translated into Turkish, expert validity for the Turkish version of the questions was provided by educational researchers and systems thinking researchers in order to ensure integrity of language and meaning and to maintain validity that the questions refer to the relevant skills.

In the last section of the interview protocol some questions were adapted from the study of Gilissen et al (2020). In this section, the aim was to determine how science teachers define systems thinking, their position to systems thinking skills in education and their views on implementing systems thinking approach and the systems thinking skills in teaching practices.

3.2.2. Validity and Reliability of Interview Protocol

The questions were formed based on the relevant literature. An expert from the Systems Thinking Association in Turkey checked the clarity and accuracy of the interview questions elicited with the interview protocol after translation. A pilot study was conducted by the researcher to validate the clarity of the interview protocol. Some changes were made in accordance with the pilot study in order to maintain the clarity and integrity of meaning in the question structures and interview framework. Regarding the pilot stıdy, the following changes have been administered to the interview protocol. The order of the sections of the interview was changed as knowledge, skills and practices as in the research questions. In the third section of the interview, the time adverbs in question six were rewritten and question prompts such as “Please explain the questions” and “Can you describe it by writing or drawing?” have been added to the interview. In the third section of the interview, a question was added about how teachers conduct assessment and evaluation processes.

3.3. Researcher Positionality

The exposure of an author's self-identifications, experiences, and privileges as they relate to research methodologies is known as positionality (Berg & Lune, 2017). The researcher of this study has a background in systems thinking and system dynamics education. She earned her bachelor's degree in science education and since 2020, she has been following the works, meetings and practices of the System Thinking Association in Turkey. She participated in preparing content and an article about system dynamics implementations with the System Thinking Association. The researcher also has experience in qualitative research methods. She took a course on qualitative research during graduate education and has one qualitative research article. The researcher's development as a science teacher in the process of systems thinking and system dynamics made her want to conduct this study.

The researcher knew the science teachers who participated in the study from their practical lessons and the activities of the System Thinking Association. She met them face to face and online several times. She had the opportunity to observe teachers' practices involving systems thinking and system dynamics and to work on the systems dynamics contents together with them. To conduct the interviews in this study, the researcher contacted the teachers individually. Researcher's insider role, knowing them personally as teachers, may have a positive impact on their open sharing of ideas, but this insider role may also raise teachers' concerns about being evaluated on their systems thinking knowledge and skills. However, this concern was tried to be minimized at the beginning of the interview by saying that the research results would not be used outside the research and that the participants' information would not be shared and that they would be referred to anonymously.

3.4. Procedure

The data were collected using the interview method. Before data collection for the study, the necessary permission for conducting research was taken from the Ethical Committee of Boğaziçi University (Appendix C) and the Ministry of Education (Appendix D). The participants were contacted by e-mail and the place and time of the interview were determined. Then, the permission of the participants was obtained through a consent form (Appendix E). The interviews were conducted online because the teachers preferred it due to their work schedule. Their audio was recorded during the interviews.

3.5. Data Analysis

The interviews were first transcribed and then analyzed qualitatively. The method of analysis was based on a qualitative approach (Creswell, 2009). First, the interview questions in the three sections mentioned above were grouped according to the research questions they were intended to measure. The names of the teachers were replaced with pseudonyms through an analysis process in accordance with ethical rules. The audio recordings of the interviews were transcribed and codes were created inductively and deductively. In this study, the Systems Thinking Rubric which was developed by Dutton-Lee et al. (2019, p.150) was used to analyze the interviews because of that rubrics are useful for educators and learners to assess their understanding and application of system dynamics concepts, identify areas for improvement, and track progress over time (Dutton-Lee et al., 2019). The codes developed by the researcher and the codes were re-read by a second researcher. The codes were finalized together by coming to a consensus in the discrepancies on the codes and categories. The analysis method of preparing a model from the teachers' answers to the first and third scenario based questions and questions referring to the water cycle was seen in Davis and his colleagues study in 2020. The question analyses were repeated by the second researcher. In addition, teachers' responses were analyzed only under the research question to which they were related. The quotations presented in the results section were extracted from the teachers' responses to the relevant question and not all statements were given in the tables.

3.5.1. System Thinking Rubric

The Systems Thinking Rubric was created by Dutton-Lee et al. (2019). The process of creating the Systems Thinking Rubric involved analyzing data inductively to identify patterns, themes, and categories from in-service and pre-service teacher responses to identify systems thinking levels and to explore systems thinking within proposed lessons on the water cycle (Dutton-Lee et al., 2019). These levels were determined based on an evaluation of participant statements using components of the The System Thinking Hierarchical (STH) Model of systems thinking, interactions among subsystem processes and components, and NGSS crosscutting concepts (Dutton-Lee et al., 2019). The final rubric had four levels (novice, beginning, intermediate, and advanced) with each participant's response coded to a particular level.

In this study, the rubric was revised in terms of the number of components and processes since the number of components and processes that distinguish between the levels of systems thinking in the original rubric was not distinctive in the context of this study because the models in this study included more components and processes. Therefore, the number of components and processes in the current rubric was revised to include a percentage ratio. The levels of the teachers were divided into four equal levels according to the inclusion of 0-24%, 25-49%, 50-74% and 75-100% of the total number of components defined in the possible models. The revised Systems Thinking Rubric was given in Appendix F.

3.5.2. Dynamic Thinking Skills Rubric

The responses to the question "What is a system?" (Question number 1 in the first section of the interview) were given in Table 3.3 below. The parts that teachers emphasized about the system as a whole and the parts that they emphasized that it consists of parts and elements or concepts were shown as a bold font in Table 3.3. While Teachers A, B, E, F, G, H emphasized the system as the part-whole relationship, Teacher C emphasized the cause-effect relationship, and Teacher D gave a comprehensive description of the system based on the relations between concepts by taking into account the dynamic movement not mentioning about creating a whole.

Table 3.3. Rubric for dynamic thinking skills.

Levels	Description of Levels	Potential answers
Novice Level (Level 0)	Lack of Dynamic Thinking: Individuals show no understanding or application of dynamic thinking principles.	Mert would choose either the small house or the large house based on immediate factors such as personal preference or immediate affordability, without considering the behavior patterns or long-term implications of the real estate market.
Recognition Level (Level 1)	Recognizing Behavior Patterns: Individuals focus on identifying and deducing behavior patterns within a system.	Based on the behavior patterns observed such as real estate prices in the city and the emerging neighborhood, Mert would choose the option that aligns with the expected long-term appreciation in value.
Beginning Level (Level 2)	Framing Problems in Terms of Behavior over Time: Individuals frame problems or issues in terms of their behavior over time.	Mert would choose the option that aligns with his understanding of the behavior of real estate values over time, considering the potential growth or stability of the areas.

Table 3.3. Rubric for dynamic thinking skills (cont.).

Intermediate Level (Level 3)	Incorporating Time Horizon in Mental Models: Individuals expand the time horizon of their mental models in terms of past and future trends.	Mert would choose the option that aligns with his assessment of the historical trends and future prospects of the real estate market in both locations.
Advance Level (Level 4)	Embracing Change and Gradual Shifts: Individuals fully embrace the dynamic nature of systems and actively analyze gradual changes.	Mert would choose the option that aligns with his understanding of the dynamic nature of the real estate market and its potential for future growth or change. He might choose the option that aligns with his long-term vision and promotes sustainable development.

4. RESULTS

4.1. Results of The First Research Question

RQ.1: What are science teachers' understanding of a system and systems thinking approach?

4.1.1. Teachers' Definition of a System

The responses to the question "What is a system?" (Question number 1 in the first section of the interview) were given in Table 4.1 below. The parts that teachers emphasized about the system as a whole and the parts that they emphasized that it consists of parts and elements or concepts were shown as a bold font in Table 4.1. While Teachers A, B, E, F, G, H emphasized the system as the part-whole relationship, Teacher C emphasized the cause-effect relationship, and Teacher D gave a comprehensive description of the system based on the relations between concepts by taking into account the dynamic movement not mentioning about creating a whole.

Table 4.1. Teachers' statements for defining the term system.

Categories	Teachers	Teachers' Statements for a System Definition
Part-whole relationship	A	I define it as **a whole**, of course. It is the whole formed by relating **the parts** to each other.
	B	I define the system as the relationship between **parts** and **wholes**. I say it is a big pattern of small **interrelated parts**.
	E	A system is an order for me. To provide this order, it is actually a holistic approach and holistic creation by **bringing together** small and small **parts**.

Table 4.1. Teachers' statements for defining the term system (cont.).

	F	I can describe it as a set of events that shows everything that is related to the system in an interconnected way, **a set of events** that shows **the parts** together.
	G	I can define it as **a whole** with **structures** that interact with each other and influence each other.
	H	I can talk about **the wholeness** that forms a unity or that I think of as **a phase** of the things I implement. So think of it as everything that I relate to the subject.
Cause-effect relationship	C	We can define it as **a cause-and-effect relationship**. In the sciences, there are **parts of the subject**we study that develop this subject or there are parts that hinder the development of this subject. Let me add again from classical systems thinking. There are input flows and output flows. These input flows and output flows can increase or decrease the subject we are working on. I can define it this way, so we can think of a system with input and output flows.
Dynamic relations with concepts	D	As soon as I want to show **the relationship(s) between** any two existing **concepts**, or even if a concept has a relationship with itself, I can start at that point. So I can describe the system as a result of **elements, relationships, their connections and any dynamic movement.**

4.1.2. Teachers' Definition of Systems Thinking

The responses to the question "How do you define systems thinking?" (Question number 1 in the third section of the interview) were given in Table 4.2 below. Teachers A, B, H and E emphasized the systems thinking as a whole and holistic thinking, Teachers C, G and F emphasized relationships between the concepts/variables and modeling their relationships, Teacher D described systems thinking as a way of thinking and a method of communication.

Table 4.2. Teachers' statements for defining systems thinking.

Categories	Teachers	Teachers' Statements
Holistic thinking	A	**Reaching the whole or seeing the whole** by making sense of the relationship between the parts. In other words, to reach the whole by combining the parts, or to separate the whole into parts, but to make sense of them by understanding the relationships between them.
	B	**A holistic thinking** that allows us to see the main cause of a situation and helps us to find the reason for its occurrence.
	E	I see systems thinking as an idea that teaches **a holistic approach to a problem**. In other words, I define it as a thought that seeks solutions not by defining a problem in its upper definition, but by going deeper, by going deeper.

Table 4.2. Teachers' statements for defining systems thinking (cont.).

	H	When you act with the systems thinking in mind, your perspective on things is a little different. Yes, there are things that feed the system or there are things that disrupt the system, but **you think of them as a whole**. When you act with this thought, you have a slightly different perspective.
Modeling relationships between concepts	C	As a teacher, I define systems thinking as follows: The topics I am trying to explain are actually all connected to a network of systems and it can be very difficult to visualize them in the minds of students. In most of our lessons we actually create a concept map. At the end **we need to create a framework to connect the concepts**, or at the beginning we need to create a framework for the children to understand, and this framework helps to connect the pieces that the children have learned. Actually, I have seen that when systems thinking in education is learned and applied, it is more useful than concept maps and it is useful for students to see the whole and to combine those parts. Especially, I mean, I was able to reduce a subject that I taught in 4-5 lessons or 6-7 lessons to 3-4 lessons by using systems thinking.

Table 4.2. Teachers' statements for defining systems thinking (cont.).

	G	I can model any situation when I define the event as a system. There can be many variables. We are science teachers now and we usually try to do experiments using one independent variable in our experiments. But life is not like that. Systems in life are not like that. There are many independent variables. There are many different causes affecting a situation. **I can place all of these variables in a meaningful way that I can see and solve the relationship between them. I can say that modeling contributes to me in this sense.**
	F	It is actually an idea that shows **the interrelatedness of systems**, where we can actually **concretize everything very clearly**, especially abstract events, and we can observe them very clearly with their graphics, and **what will happen in the future.**
A way of thinking & commu-nication	D	Systems thinking to better understand an existing system, to create a common language. To become aware of non-linear behaviors in the system. It is also **a way of thinking and a method of communication** in which we realize the relationships that we cannot realize with human intuition by using different tools.

The responses to the question "Explain the tools of systems thinking? " asked to see the teachers' knowledge of systems thinking in their implementations. Teachers B, C, D, E and F mentioned stock-and-flows, Teachers B, C, and D explained behavior over time and only Teacher D explained causal-loops. Table 4.3 shows some examples of teachers' explanations for stock-and-flows, behavior over time and causal-loops, which are emphasized as a bold font in the table.

Table 4.3. Teachers' explanation for systems thinking tools.

Categories	Teachers	Sample Teacher Explanations
Stock-flow	E	I think the system thinking tools explain the **stock-flow diagram**. The **stock flow diagram** is actually a diagram that shows that there is more data in it and that there is an **input and an output and that these accumulate in a stock**. Of course, factors also affect this. Apart from that, there is the iceberg model, we haven't used **the iceberg model much**, there is the ladder of inference. They come into play in the parts that are mostly used by social science groups or where there are more social science topics, we were dealing with emotions in the inference ladder.

Table 4.3. Teachers' explanation for systems thinking tools (cont.).

Stock-flow Behavior over time	B	In **the stock-flow** we find the concepts that increase and decrease the system. In the **stock-flow** there is a main stock, there are increasing and decreasing concepts and there are influencing factors. There are side links. We find out what are the situations that cause the accumulation of what accumulates in the system and what are the actions that will reduce the accumulation and what are the factors affecting these actions. **Behavior over time**, on the other hand, when I say stock-flow in the system, how the system will behave according to the state of the input and output flows over time, how the system will behave will increase, decrease, remain constant, and how it will continue, both inferences and mathematical expressions.

Table 4.3. Teachers' explanation for systems thinking tools (cont.).

Stock-flow Behavior over time Causal-loops	D	**Graphs of behavior over time**, where the x-axis is always time and the y-axis is what is changing. **Causal-loop diagrams** are about writing the elements and showing the causal relationships between them in the form of an increase in one and an increase in another, or an increase in one and a decrease in another, and then extracting **the balancing and reinforcing loops** from there and summarizing them a little more. But you cannot enter very numerical values in these, or the mechanics of the work cannot be shown much. It is not possible to understand the dynamics very much. In the stock-and-flow diagrams, there may be factors that we call connectors or converters. These can also be numerical. It can be done without using anything numerical at all, just to describe the situation, that is, this **accumulation and flow**. When it is done numerically, it may be necessary to pay a little more attention to the units, to actually use that converter to convert one to another. I think stock flow diagrams make you ask more questions because they are simpler. You need to get down to the simplest to explain it.

4.1.3. Teachers' Example of System

In addition, the examples given by the teachers to the question "Can you give an example of the system?" were shown in Figure 4.1 together with their percentage rates (Question number 2 in the first section of the interview). The examples given cover fifth, sixth, and eighth grade subjects which were food pyramid, matter cycles, human body systems, circulatory system, digestive system, heat and temperature, environment, solar system and ecosystem.

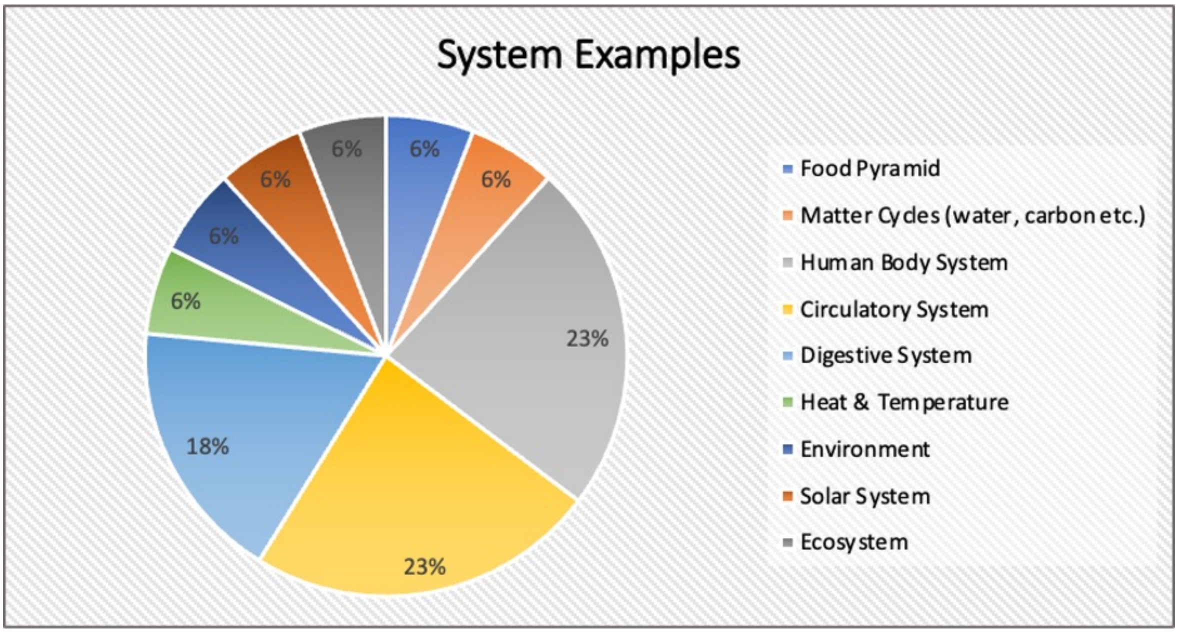


Figure 4.1. The system examples given by teachers.

The responses to the question about what are the characteristics of the mentioned system (Question number 3 in the first part of the interview), which is asked in order to better understand the system and the approach of systems thinking, show that the most common characteristics teachers mentioned were: the existence of components, the existence of relations between the components, the components forming a whole, the disruption of the system when a component is removed from the system. Table 4.4 shows examples of teachers' statements for these characteristics. The characteristics of the system in statements are emphasized as a bold font.

Table 4.4. Teachers' statements for systems characteristics.

Categories	Teachers	Sample Teacher Explanations
Existence of components	E	The characteristics of this system are to take all objects, living or non-living, that interact with the environment.**Components are all actually.**
Existence of relationships between components	D	There are elements. **There are** connections **between the elements** and there is a behaviour through time.
Existence of parts that make up a whole	A	I think the most important feature is that **the parts form a whole,** and when they come together, they fulfill the task of that whole.
Ripple of System Malfunction	F	In fact, there are many structures and parts in this system, but they are all interrelated. They are interconnected and affect each other. In other words, **when there is a somewhere in the system, it affects not only itself, but actually each step, the whole, positively or negatively.**

According to the responses to the question about whether the water cycle is a system, all teachers stated that the water cycle is a system. The teachers' reasons for why the water cycle is a system are given in Table 4.5. Teachers A, C, E, and F emphasized that the water cycle system is composed of interrelated parts, whereas Teachers B, D, and H emphasized that the system is a cycle. Teacher G emphasized that the water cycle consists of stocks and flows and that the amount of water will not change.

Table 4.5. Teachers' statements on the water cycle as a system.

Categories	Teachers	Teachers' Statements
Existence of interrelated parts	A	Yes, I think it is a system because **they are interrelated.** So an increase in one affects the other. If I think of one of them as the increase in evaporation affects something else . . . . because it will have to come back somehow.
	C	The water cycle is a system where the presence or decrease or increase of water in an environment **depends on various factors. . .** If evaporation is high, then the amount of water in the lake will decrease. So the water cycle can be likened to a system.
	E	It is a system because it is **always interacting.** And when you remove a part from that system, the system breaks down.
	F	The water cycle is a system because, you know, there are sub-headings that affect it as well, such as if this increases, this decreases, if this happens, this happens, so there are also related situations.

Table 4.5. Teachers' statements on the water cycle as a system (cont.).

Existence of a continuous cycle	B	The water cycle is a system because we have flows again, so we can actually count water as a stock in a certain amount, if we do not count the surface flows that are lost, **there is always a cycle that continues** within each other as evaporation and precipitation.
	D	**The water cycle is a cycle.** It shows water going from one place to another. So I can look at it as a water system. When it's a water cycle, I'm only focusing on one part of it, but there's no feedback in it, but there is a cycle there. It shows the discharge of water from one place to another, there is no feedback, but I think I would still say it's a system.
	H	I think yes, because there are things that increase the water content in that system. There are things that decrease it and **it's a continuous cycle.**

Table 4.5. Teachers' statements on the water cycle as a system (cont.).

Existence of stock & flows	G	Yes, because water can actually be thought of as a reservoir if we look at the water we have in the world in general, and in the idea of the system. There was the flow and the stock. **So if we think of water as a stock, we can make a lot of flows. The amount of water there always remains constant. Maybe the amount of usable water changes, but the amount of water that is available always remains constant.** Anything I can put in that stock flow diagram I define exactly.

4.2. Results of The Second Research Question

RQ.2: What are science teachers' systems thinking skill levels?

Three questions were asked to determine the level of teachers' systems thinking skills. These questions related to the three skills: stock-and-flow thinking, dynamic thinking, and causal-loop/closed-loop thinking. The responses to the three questions were analyzed according to the revised Systems Thinking Rubric (Appendix F) and the teachers' systems thinking levels were determined on the basis of each skill. The teachers' responses were analyzed by examining how much the questions covered the total components and processes in the possible answers developed in the STELLA program using system dynamics.

4.2.1. Results for the Teachers' Stock-and-Flow Thinking Skills

The answers given by the teachers to the first scenario-based question, which refers to the stock-and-flow thinking skills, were first transcribed and modeled on STELLA using system dynamics. The scenario-based question is given below:

"A new problem was emerging in the city of Izmir, which was always overflowing with tourists: Rats! The city was slowly filling up with rats that were eating everything. The kindly mayor who worried about his citizens and the city's tourists called in his assistant to find a solution to the rat problem. The assistant worked hard to find a poison that most rats, except for a few, were attracted to the smell of, and found a poison that the rats died shortly after eating it. The number of rats increased so much that the mayor immediately approved the idea. The rats ate the poison and soon died. When people got rid of the dead rats in their city, they organized a big celebration and thanked the kind mayor for his efforts. But even though no more rats entered the city from outside and the problem seemed to be solved, it wasn't long before the city was full of rats again. So why did the number of rats increase again?". (Dorani et al., 2015).

Figure 4.2 showed the possible model of the given scenario for the Stock-and-Flow Diagram developed using system dynamics in the STELLA program. Six components and twelve processes/relations were determined in this scenario. The total number of elements was taken as eighteen. Stocks were represented with rectangles, flows were represented with taps, and connectors were represented with circles. The arrows in the model were connectors that show the relations.

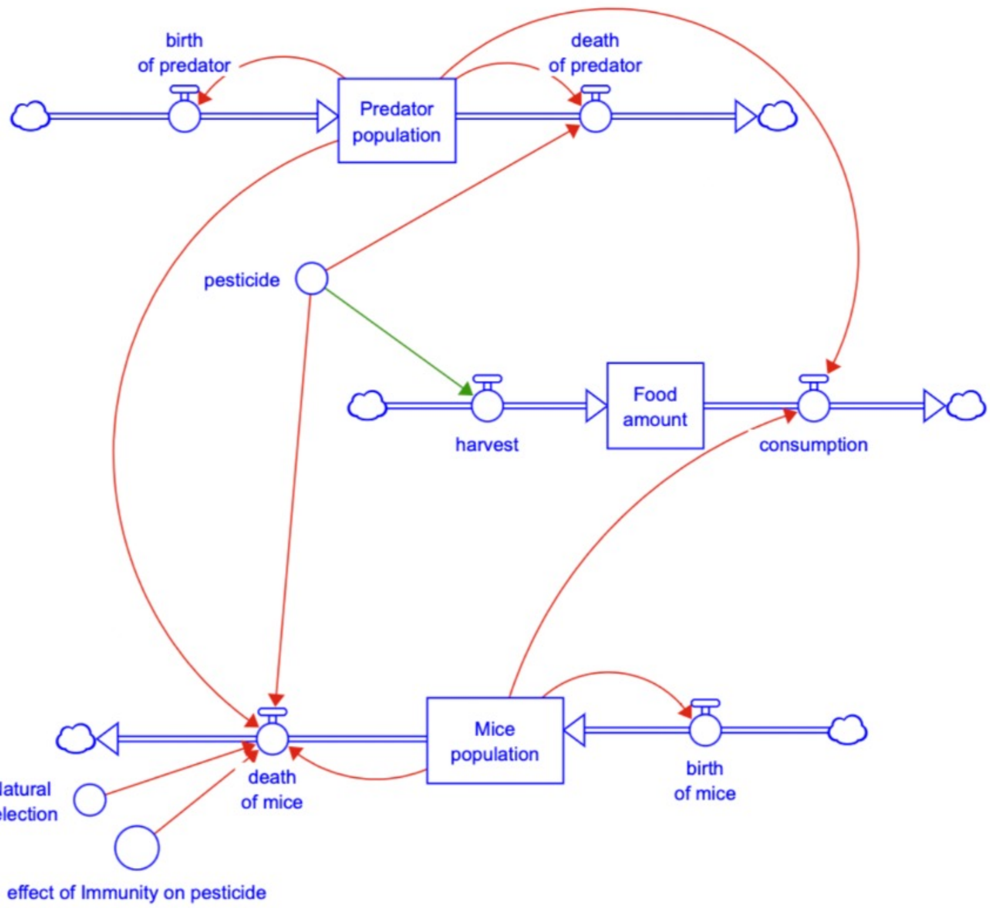


Figure 4.2. Stock-and-flow diagram of first scenario by system dynamics at STELLA.

Table 4.6 showed the teachers' statements, their possible stock-and-flow diagrams, the number of highlighted components and processes/relations in the diagram, and their systems thinking levels. The teachers' stock-and-flow models were created at STELLA by the researcher based on their responses. The teachers' systems thinking levels were determined using the revised Systems Thinking Rubric according to the number of components and processes in their models. In the statements of the teachers, while stocks were analyzed as a component; flows were taken as relations and processes according to the rubric. According to the results, Teachers B, E, and G were at level 0 (novice) and Teachers A, C, F, and H were at level 1 (recognition) in terms of the ability to think with stock and flows. There was one teacher reaching level 2 (beginning) which was Teacher D and there were no teachers reaching level 3 (intermediate) regarding the revised Systems Thinking Rubric.

Table 4.6. Teachers' stock-and-flow diagram and their thinking skills levels.

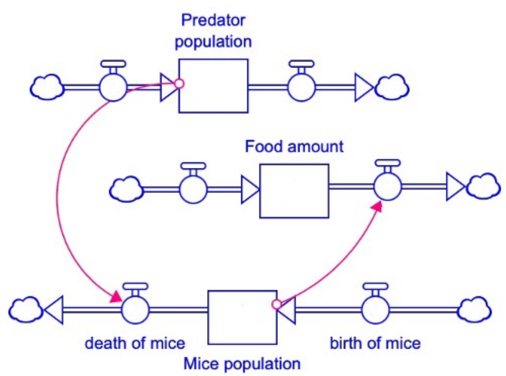
Teachers	Teacher's Statement	Teacher's Model using System Dynamics (Stock-and-Flow Diagram)	# of Com-ponents	# of Process/ Relati-onship	Total/ % Value	ST Level
A	I think that as long as that food is there, there will be creatures that will consume that food... It would have been better if he had brought a creature there to use the mouse as food. He had to add something to eat the rat because pesticide is a quick solution and not a permanent solution.		3	2	5 (%28)	Recog-nition Level (Level 1)

Table 4.6. Teachers' stock-and-flow diagram and their thinking skills levels (cont.).

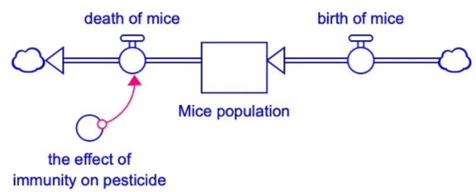
B	He had to find the main factor that was causing the rats to increase. So what was the cause? Why are the mice being supported and the number of repetitions is increasing... Maybe that's why I only found a temporary solution because I didn't go down there. There could be mice whose sense of smell didn't work well. There may have been mice where the pesticide didn't work. There are mice that are resistant, resistant to the extra pesticide.		2	1	3 (%17)	Novice Level (Level 0)

Table 4.6. Teachers' stock-and-flow diagram and their thinking skills levels (cont.).

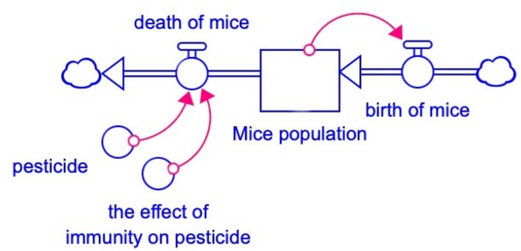
C	If we define the number of mice as a stock, we can think of the part that will reduce the number of mice as an outflow. Here pesticide can be used as an outflow. The reproduction of mice can be used as an input flow. The fact that there are a few mice left means that the pesticide is not effective. And because it doesn't work, or it can be like this, it can show that half of them are full of genes that are resistant to it.		3	3	6 (%33)	Recog-nition Level (Level 1)

Table 4.6. Teachers' stock-and-flow diagram and their thinking skills levels (cont.).

	When the mice reproduce again, the pesticide will no longer be effective because there are genes that are resistant to the pesticide. So there will be a problem in the outflow. As the inflow flow continues to reproduce, the number of mice will increase again.					

Table 4.6. Teachers' stock-and-flow diagram and their thinking skills levels (cont.).

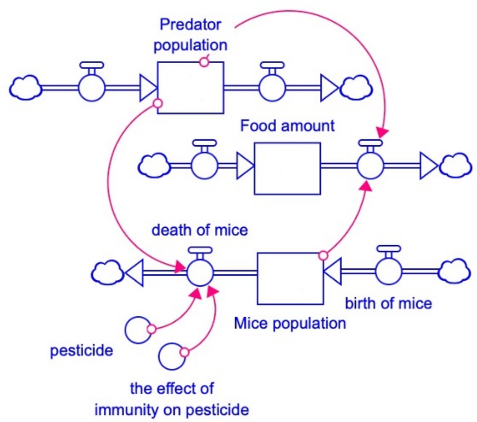
D	When we kill mice with pesticide, let's imagine that there is something as a species that feeds on mice. If this species also feeds on what the mice feed on, and when what the mice feed on increases, instead of eating the mice, they eat that food, the predator of the mice has decreased. That's why the mice have increased. Can mice become immune in such a short time? That might be another reason.		5	5	10 (%56)	Beginning Level (Level 2)

Table 4.6. Teachers' stock-and-flow diagram and their thinking skills levels (cont.).

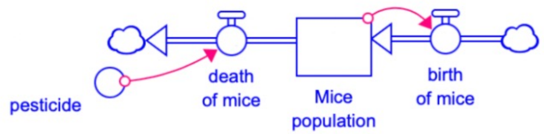
E	There are actually a few mice living there. And because they're alive, they can reproduce by walking again. So a few mice were added again and again and again. I call the number of mice a stock. The stock is already at the upper limit. I would call the inflow the reproduction of mice and the outflow the poisoning of mice. Even if we equalize the inflow flow with the outflow flow, the number of rats has always continued to increase because there are still rats in the stock.		2	2	4 (%22)	Novice Level (Level 0)

Table 4.6. Teachers' stock-and-flow diagram and their thinking skills levels (cont.).

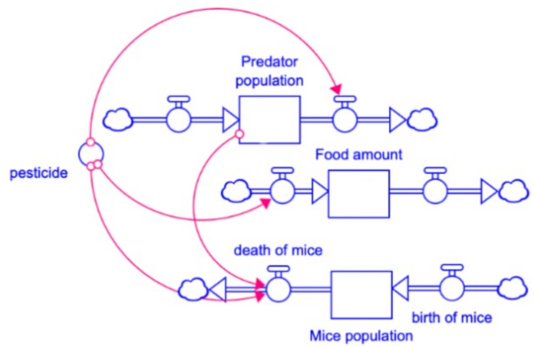
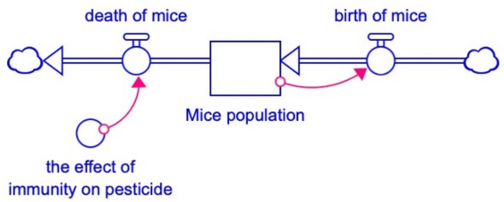
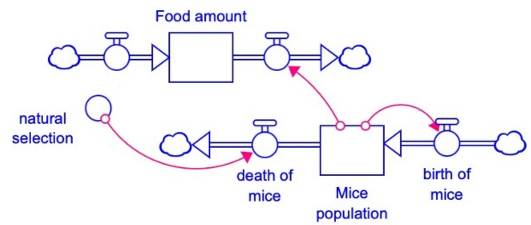
F	The pesticide actually affected other living things there. You know, it poisoned the creatures that fed on the rats, or not only the rats, but if it was thrown into the field there, it also caused the food there to run out, it affected the soil.		4	4	8 (%44)	Recog-nition Level (Level 1)
G	They may be reproducing very fast, they may have developed immunity. Those few mice were not affected, they may have reproduced very fast and may not have been affected by that pesticide.		2	2	4 (%22)	Novice Level (Level 0)

Table 4.6. Teachers' stock-and-flow diagram and their thinking skills levels (cont.).

H	Here, first, natural selection comes to my mind. Since not all living things have the same genetic structure, perhaps not all of them are affected by the pesticide, and after the affected ones diminish, that is, disappear, the remaining ones can reproduce rapidly. I will even make a comment that maybe they can find more food and increase their numbers more, but then again, the number of mice may have increased genetically stronger.		3	3	6 (%33)	Recog-nition Level (Level 1)

4.2.2. Results of the Teachers' Dynamic Thinking Skills

The answers given by the teachers to the second scenario-based question, which referred to the dynamic thinking skill were analyzed according to the dynamic thinking skills rubric given in Table 3.3. The scenario-based question is given below:

"Mert was looking for some real estate options to invest in. Two of the real estate agent's offers seemed interesting to him: the first offer was a small house near the heart of the city visited by tourists, where real estate is valuable, and the other offer was a large house in a less expensive but developing neighborhood. Which one would you choose if you were Mert? Explain your answer with reasons."(Dorani et al., 2015).

Table 4.7 shows the responses of the teachers to the question, the description of the responses, and the teachers' dynamic thinking levels according to the rubric in Table 3.3. According to the results, Teachers B, F, and H were at level 0, Teachers C and E were at level 1 and Teachers A, D, and G were at level 2 in terms of dynamic thinking skills. It was found that the teachers could not reach levels 3 and 4 in terms of dynamic thinking skills.

Table 4.7. Teachers' answers and their levels for dynamic thinking skills.

Teachers	Teachers' Answers	Description of the Response	Teachers' Dynamic Thinking Levels
A	I would prefer the house that tourists visit, because if my goal is investment, I would prefer the money flow, and naturally the house with tourists because tourists can rent it. And when they rent it, there is money flow… **You need to think long term..** Bigger house in a developing area can provide this: **markets, artisans, shopping malls, maybe such places can be opened there**, so it can be a house that will be valued exponentially in the process. He can then sell the house when he wants to get money in bulk. The purpose is very important here.	The participant demonstrates an understanding of considering long-term factors and the behavior of tourists in making his investment decision. The response also includes the potential for future development in the area and the importance of understanding the projects and timeline for development.	Beginning Level (Level 2)

Table 4.7. Teachers' answers and their levels for dynamic thinking skills (cont.).

	There may be two options with their justifications. For which purpose will I prefer this? Both are actually investments. The region chosen by tourists may shift towards another developing region in the future. **Time is important here.** How long will the investment take? Will it be a 10-year investment?... What is there in the developing neighborhood? For example, is there a shopping mall? I need to know what development is and how long it will take to develop.		

Table 4.7. Teachers' answers and their levels for dynamic thinking skills (cont.).

B	I would choose the first offer. Since it is a place visited by tourists, I would turn it back into profit from there. I buy it to invest. Since it is a place with a high density of tourists, **I would find factors to transform it in the same way, even if it is a small place, and turn it back into cash.** Maybe I will pay more money at the beginning, but the other one will be a house that will be spread over a longer period of time and it will be a developing neighborhood. I would choose the first one and cash out more quickly.	The participant focuses solely on immediate factors such as the presence of tourists and the potential for quick profit without considering behavior patterns, long-term trends, or the dynamic nature of the system. The participant prioritizes cashing out quickly without considering the potential future value or development of the neighborhood.	Novice Level (Level 0)

Table 4.7. Teachers' answers and their levels for dynamic thinking skills (cont.).

C	I would choose a house in a developing neighborhood that is less expensive, because if we think of the price of this house as a stock, in the first option, the input flow should be like this, popularity, being in the heart of the city etc. These are already completed in the first option. So the inflow has slowed down. **But in the second option, there is a possibility that the inflow will continue to increase.** It may be more possible that the value of the house he buys in the less expensive place may increase, it may make more sense from an economic point of view, because the flow of entry is accelerating and the flow of entry is slower in the other option, the more entry there is, the more the value will naturally increase.	The participant considers the behavior patterns related to the inflow of popularity and factors such as being in the heart of the city in the first option. He recognizes that the inflow has slowed down in that option. In contrast, the participant identify the possibility of the inflow continuing to increase in the second option, which is located in a developing neighborhood and is less expensive. The participant considers the potential economic sense of choosing the less expensive option based on the acceleration of the inflow and the potential for increased value.	Recognition Level (Level 1)

Table 4.7. Teachers' answers and their levels for dynamic thinking skills (cont.).

D	The first thing that comes to people's minds is that they can buy far away and this is a place that is developing, so they can multiply their money. You know, it will develop over time so its capital will increase. If its return will continue to increase and increase in the same way over the years… I would definitely buy the one in the distance… After all, the developing one is an investment, but how much money am I going to spend on it? How much do I expect the rent increases in the developing neighborhood to be? I divide that rent by the money I buy. I'll look at it over the years.	The participant considers the concept of buying a property in a developing area with the expectation that its value will increase over time. He also discusses the potential for higher rental returns in the city center and tries to project the rental income in both scenarios. He framed the problem in terms of the behavior of the properties and their potential returns over the years. The individual weighs factors such as affordability, potential rental income, and expected growth in value to make their decision.	Beginning Level (Level 2)

Table 4.7. Teachers' answers and their levels for dynamic thinking skills (cont.).

	What will be the rental return of the money I invested in the city center over the years? If the one in the developing area will double, for example, if the city center will be a much more vibrant place and it will increase 4 times, maybe I will buy it. I try to project the rental income. I divide it by the total amount of money I will give and look to the future.		

Table 4.7. Teachers' answers and their levels for dynamic thinking skills (cont.).

E	I would say it depends on how many people there are. **In terms of the number of individuals, if I am going to live on my own, I would still choose a big house because it is a developing neighborhood and I would choose a big house that is not included in the immediate investment but in a process that is developing over time because the neighborhood is developing.** As the neighborhood develops, my house will actually increase in value. I would choose a developing neighborhood because the big house I bought would be more valuable than the small house. Because it would be a behavior that I would look at for years over time, not instantaneously.	The response acknowledges the concept of a developing neighborhood and how it can impact the value of a big house over time. However, it lacks deeper analysis of specific behavior patterns and their implications. It primarily focuses on the immediate preference for a big house and does not demonstrate a comprehensive understanding of the dynamic nature of the real estate market or consider long-term trends.	Recognition Level (Level 1)

Table 4.7. Teachers' answers and their levels for dynamic thinking skills (cont.).

F	I would choose the first offer, the one in the heart of the city. **I would prefer it, even if it is small, because it is a place where I can reach everywhere very easily,** I can go to the center whenever I want, and it is also a valuable place. Thinking about the life of a working person, since we only use houses as hotels, I would prefer to be in the center and have easy access to everything. If I think about investing, I would also prefer it in the same way, because nowadays time is valuable, preciousand we want to reach everything very easily. The profile of people living in a developed area also affects you. **You are together with people you feel closer to yourself.** I would definitely choose there again.	The response primarily focuses on immediate factors such as easy access to the city center and personal convenience. It does not demonstrate a comprehensive understanding of behavior patterns, long-term trends, or the dynamic nature of the real estate market. The answer lacks deeper analysis and fails to consider factors beyond personal preference and convenience.	Novice Level (Level 0)

Table 4.7. Teachers' answers and their levels for dynamic thinking skills (cont.).

G	I would buy the big house in the developing area because I think it will develop, because it says it is developing. **The total population is already increasing. City centers are starting to shift to different areas.** At least I would have a big house and it will develop in the future.	The response demonstrates an understanding of the potential for development in the chosen area and considers the shifting of city centers to different regions. The answer acknowledges the importance of choosing a big house in a developing area, anticipating future growth and value appreciation. However, it does not delve into specific behavior patterns or provide detailed analysis beyond the general expectation of development.	Beginning Level (Level 2)

Table 4.7. Teachers' answers and their levels for dynamic thinking skills (cont.).

H	I would choose the place that is directly close to the heart of the city because **that's how I like to live.** The value of the real estate is not a big issue for me there or that's not the important part for me. The important thing is a little bit closer to the center of the city. **A place where everything can be found and I think it is more comfortable for me.** So if I were Mert, I would choose that place.	The response primarily focuses on personal preferences without considering dynamic factors or behavior patterns. It does not demonstrate an understanding of the potential impact on value appreciation, investment opportunities, or long-term trends in the real estate market. The answer lacks analysis and critical thinking beyond personal comfort and proximity to the city center.	Novice Level (Level 0)

4.2.3. Results of the Teachers' Causal/Closed-loop Thinking Skills

Teachers' responses to the third scenario-based question, which included the skill of causal-loop thinking, were modelled in STELLA using system dynamics. The scenario-based question was:

"A farming village was facing a pest problem due to two different insects: green and red bugs. The green bugs fed on the crops as well as the red bugs, and so the population of green bugs exceeded the number of the red bugs and was the main cause of crop loss. Villagers gathered to protect their crops against green bugs and find a solution. They used a special pesticide to destroy the green bugs, but after a while their crops were still disappearing. Why do you think this happened? Can you explain in writing or drawing?".(Dorani et al., 2015).

Figure 4.3 showed the possible model of the given scenario for causal-loop thinking developed using system dynamics in STELLA. Causal links were represented with arrows, nouns were variables, and +/- signs showed the direction of each link and the letter within the loop showed that the cycle is reinforcing or balancing. Four stocks and seven processes/relations as flows were identified in the scenario. The total number of elements was taken as eleven. Table 4.8 reveals the teachers' statements, the components, and processes highlighted by the teachers in the possible causal-loop diagram and their systems thinking levels. The teachers' causal-loop models were created at STELLA by the researcher based on their responses. In the teachers' statements, stocks were analyzed as a component; relationships were taken as a process according to the rubric. According to the results, Teacher H was at the recognition level; Teachers A, B, C, D, E, F, and G were at the beginning level in terms of the ability to think with causal loops. Regarding the findings, the teachers could not reach level 3. According to the model of possible answers in Figure 4.3, it was found that the teachers did not mention the relationships seen with the red arrow, i.e. positive relationships.

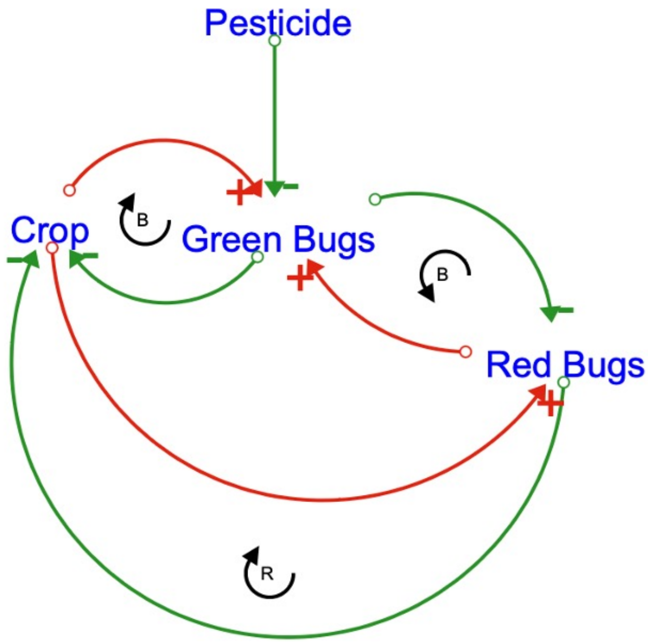


Figure 4.3. Causal-loop diagram of second scenario by system dynamics at STELLA.

Table 4.8. Teachers' causal-loop/closed-loop thinking skills levels.

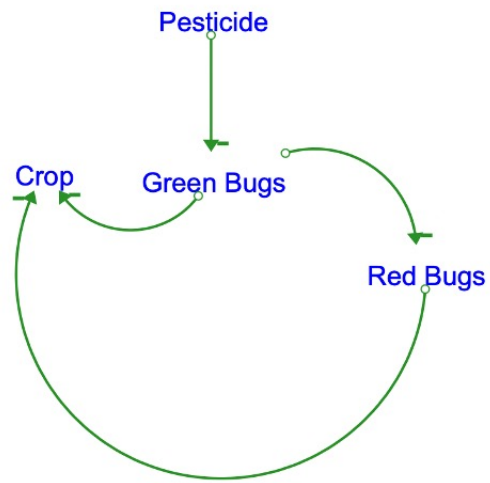
Teachers	Teacher's Statement	Teacher's referrals in System Dynamics Model (Causal-loop Diagram)	# of Compo-nents	# of Process/ Relati-onship	Total/ % Value	ST Level
A	Green insects also eat crops. They used a special pesticide but the greens were still disappearing.This time the red bugs will increase. They will also eat crops. Now you kill the green insects, then the red insects will survive. If the red bugs are also consuming the crop, then the red bugs will eat the crop.		4	4	8 (%73)	Beginning Level (Level 2)

Table 4.8. Teachers' causal-loop/closed-loop thinking skills levels (cont.).

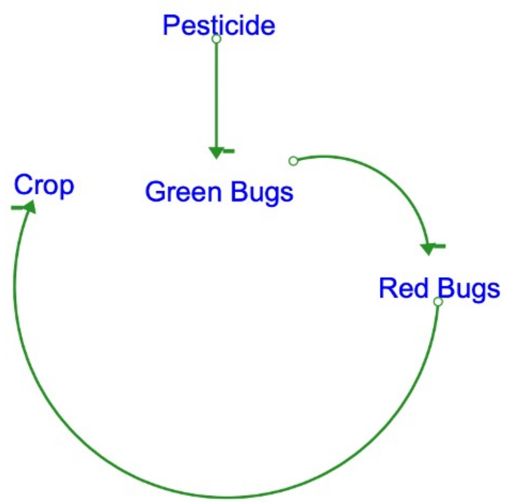
B	Their spraying may also be damaging their own harvest. Or, red bugs were causing serious damage to the crops, but they were not visible because the green bugs were eating them, but with the pesticide given to the green bugs, the system of red bugs damaging the harvests may have started.		4	3	7 (%64)	Beginning Level (Level 2)

Table 4.8. Teachers' causal-loop/closed-loop thinking skills levels (cont.).

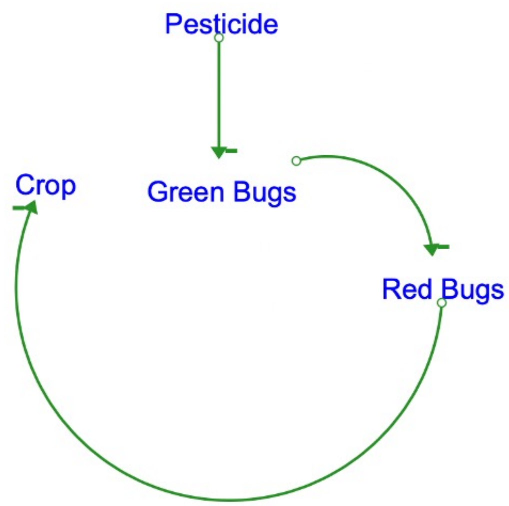
C	Since only green bugs were seen as the main cause of crop loss, green bugs were killed, but red bugs are still alive because they are not extinct. Since there is no formula to kill them, the number of red bugs will increase. In the future, the red bugs will still eat the crops.		4	3	7 (%64)	Beginning Level (Level 2)

Table 4.8. Teachers' causal-loop/closed-loop thinking skills levels (cont.).

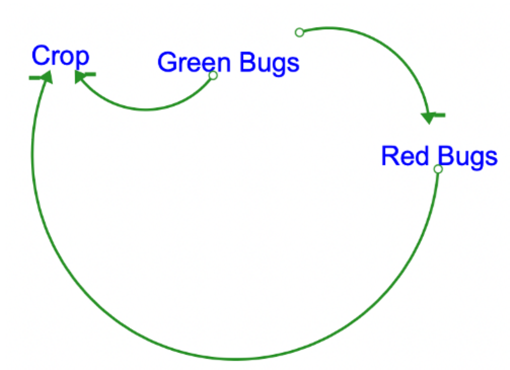
D	Because the reds here also feed on crops, right? The greens won't be able to eat the reds, so the red population will increase. The increase in the red population will increase the decline of crops. That's why I drew a line like this.		3	3	6 (%55)	Beginning Level (Level 2)

Table 4.8. Teachers' causal-loop/closed-loop thinking skills levels (cont.).

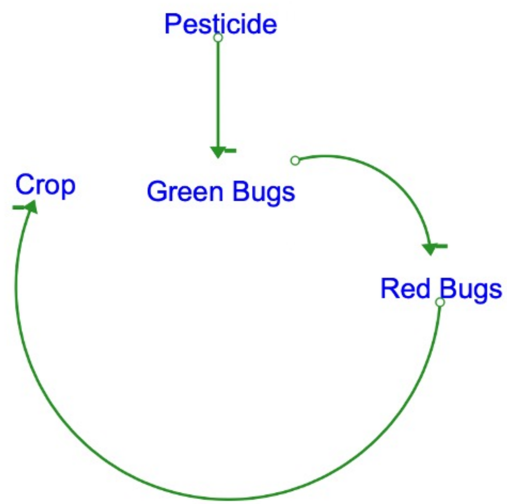
E	Now the green bugs are out of that system here, but the red bugs are still there. Red bugs can also eat crops. Since the green bugs disappeared, it was a creature that fed on red bugs. Since we separated the upper creature from the lower creature, the red bugs started not to be eaten. When the red ones were no longer eaten, their population increased. As the population increased, red beetles started to eat more crops.		4	3	7 (%64)	Beginning Level (Level 2)

Table 4.8. Teachers' causal-loop/closed-loop thinking skills levels (cont.).

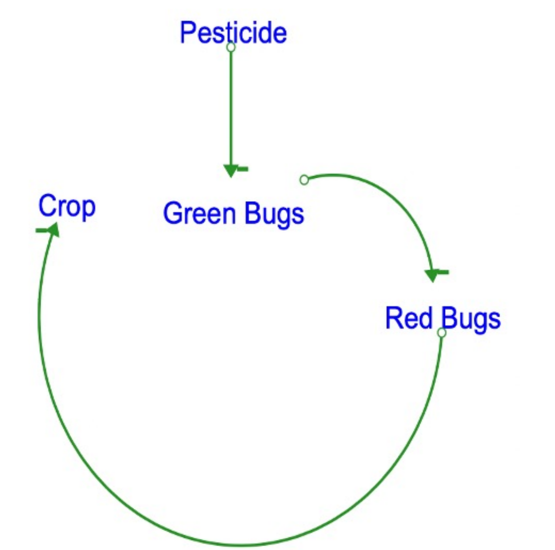
F	When the number of green bugs decreased, the number of red bugs increased. Well, this situation harmed both him and the crop in that area at the same time. There were still red bugs. They also damaged the crops and other living things.		4	3	7 (%64)	Beginning Level (Level 2)

Table 4.8. Teachers' causal-loop/closed-loop thinking skills levels (cont.).

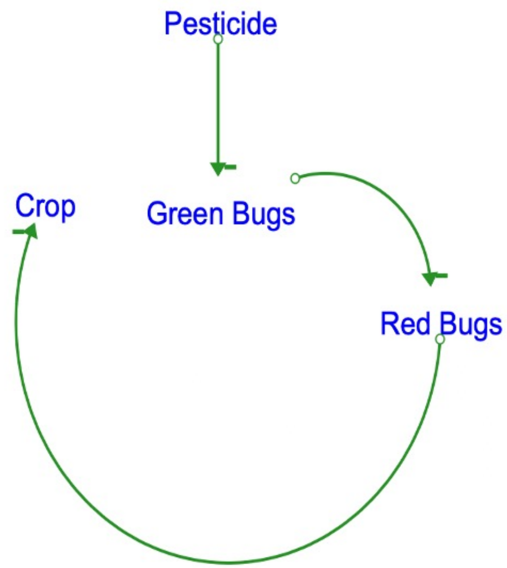
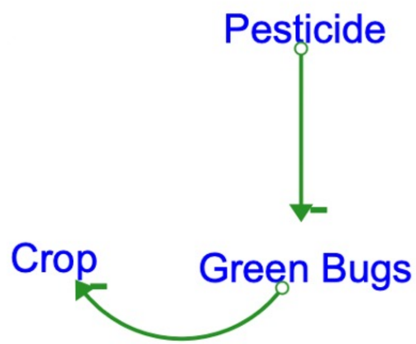
G	After the green bugs died, the number of red bugs may have increased. The red bugs may have eaten it. This time the crops may have suffered from the pesticide they used. There is another type of insect that green and red bugs feed on together. Maybe when the green bugs died in the environment, the number of those bugs may have increased.		4	3	7 (%64)	Beginning Level (Level 2)

Table 4.8. Teachers' causal-loop/closed-loop thinking skills levels (cont.).

H	The wrong pesticide is used and the green bugs do not disappear. The green bugs continue to multiply, or there is a third bug that they don't see. It could be something like that in addition to green and red. In the end, or the pesticides they are using may be destroying the insects, but they may also be destroying the plants. The crops may have been damaged.		3	2	5 (%45)	Recognition Level (Level 1)

4.2.4. Results for the Teachers' STS on the Context of Water Cycle

In the first section of the interview form, the responses given to the questions (Question number: 6, 7, and 8) about the water cycle process, which were asked to determine the teachers' understanding of the system and systems thinking, were analyzed according to the number of components and processes included in revised Systems Thinking Rubric (Appendix F). First of all, the numbers of components as stocks and processes as flows in the water cycle were determined as presented in Table 4.9. The total number of elements was identified as twelve, consisting of four stocks and eight processes as flows.

Table 4.9. The components and process in the water cycle.

Components	Process
1. Ocean, sea	1. Evaporation
2. Surface water (streams, lakes)	2. Transpiration
3. Groundwater	3. Sublimation
4. Water in the atmosphere	4. Condensation
	5. Precipitation
	6. Deposition
	7. Infiltration
	8. Surface runoff

As presented in Figure 4.4, a model of the water cycle, including the components and processes mentioned in Table 4.9, was developed using system dynamics on STELLA. This water cycle model can be expanded with more components and processes. However, this model was built by taking into account the components and processes that have a greater quantitative impact on the water cycle (Marshall & Mineau, 2013) and are included in the Turkish Science Curriculum. The teachers' systems thinking levels were determined by determining how many of these twelve components and processes the teachers' responses included by considering the relevant questions (Question number 5, 6, 7, and 8 in the first section of the interview).

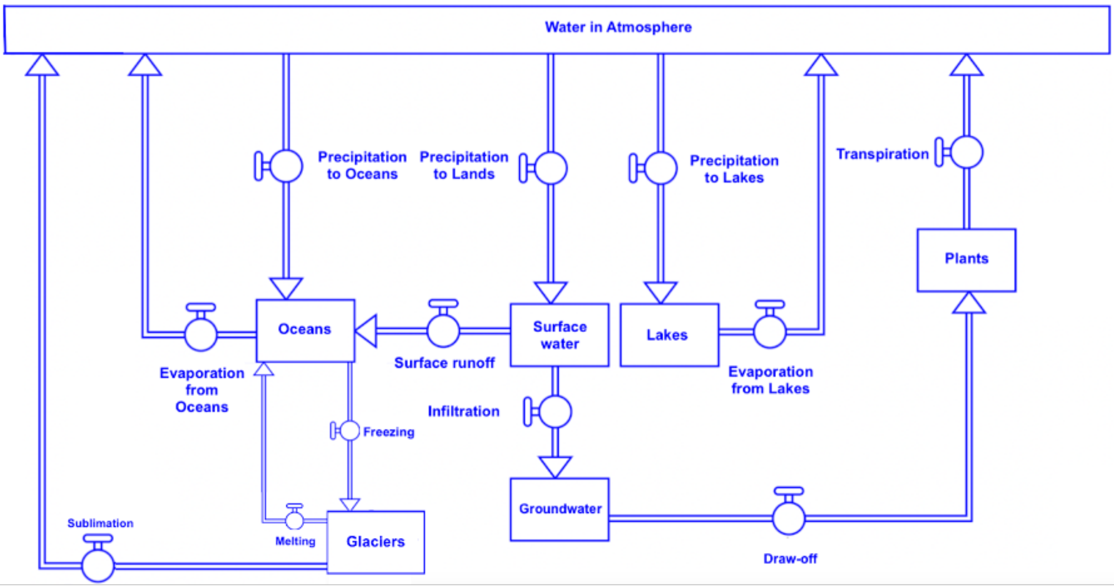


Figure 4.4. Water cycle model prepared using system dynamics at STELLA.

Table 4.10 presented the teachers' responses to the questions about the water cycle (Question number: 5, 6, 7, and 8 in the first section of the interview), including the components and processes, and the teachers' systems thinking levels. Words and phrases referring to components in teachers' answers were highlighted in red; words and word groups referring to processes were highlighted in blue as in Table 4.10. According to the revised Systems Thinking Rubric, Teacher G was at level 1 (recognition), Teachers B, C, D, E, F, and H were at level 2 (beginning), and Teacher A was at level 3 (intermediate) in terms of the use of the systems thinking approach in the context of water cycle.

Table 4.10. Teachers' systems thinking levels in the context of water cycle.

Teachers	Teacher's Statement	# of Compo-nents	# of Process	Total/ % Value	ST Level
A	Okay, you're asking about the components, and there I have to talk about water sources. I need to talk about state changes. I think the components of water sources are sea, lake, ocean, groundwater, surface water, evaporation, and condensation. Respiration is also water originating from living things, that is, giving water to the air in respiration, that is, exemplifying the events that increase the water vapor in the atmosphere in the air, these are evaporation, respiration, and transpiration. I can talk about the exemplification of decreasing events, condensation, and freezing.	4	5	9 (%75)	Intermediate Level (Level 3)

Table 4.10. Teachers' systems thinking levels in the context of water cycle (cont.).

	I can talk about weather phenomena, that is, precipitation types. These are all components. So when evaporation increases, I will say that the water level in the lakes and seas, that is, the amount of water decreases. When evaporation increases, condensation will also increase. When condensation increases, it will increase as precipitation. Then it will come back again. What I mean is that we can understand these processes with inversely proportional, directly proportional relationships.				

Table 4.10. Teachers' systems thinking levels in the context of water cycle (cont.).

B	The water cycle is a system because we have flows. We can actually count water as a certain amount of stock if we don't include surface flows and what is lost. They always have a cycle that continues within each other as evaporation and precipitation. For each cycle, we made the students infer the water sources. We made them find the flows coming from plants, mixing with the soil, finding the flows in the clouds, then finding the flows coming from the surface and oceans. We made the students comprehend themselves to whom each flow goes. We drew arrows on the flows and gave numerical values. In this way, we examined the parts of the water cycle in the system, such as evaporation after precipitation, and mixing with the soil. Oceans can be a main stock. There is evaporation coming up from the oceans. There's a runoff that comes from the trees or from the soil on the surface. Within itself, there is both evaporation and a cycle from evaporation to clouds. The clouds become a stock here. There is an ongoing flow from the clouds. It turns into precipitation again. There is surface runoff that mixes into the soil with precipitation and comes back to the oceans.	2	5	7 (%58)	Beginning Level (Level 2)

Table 4.10. Teachers' systems thinking levels in the context of water cycle (cont.).

C	The water cycle is a system. The presence or decrease or increase of water in an environment depends on various factors. For example, when we think of a lake, if it rains a lot, the amount of water in the lake will increase that year. But if it didn't rain, that is, the inflow flow decreased, and this is one of the things that caused the water in the system to decrease. If evaporation is high, the amount of water in the lake will decrease. So the water cycle can be likened to a system. The basic part is that we can think of water on the earth and water in the atmosphere as water vapor. This water comes down to the earth with the rains and the amount of water on the earth increases. On the other hand, with evaporation, the water on the earth decreases, and the water in the sky increases. If we give an example of evaporation, it can be an input flow for the water in the sky and an output flow for the water on the earth. There are other factors than evaporation or rain. We can add the input and output flows of these factors.	2	4	6 (%50)	Beginning Level (Level 2)

Table 4.10. Teachers' systems thinking levels in the context of water cycle (cont.).

	For example, the amount of population there can change the amount of water. Too much water use will reduce the amount of water there. We can add this to the output part. In a system, there can actually be an input flow and an output flow alone, so there can be a lot of factors instead of thinking about it. The important part is to create the main line while the students are explaining and then discussing what those factors can be. That's why we always try to talk about the main line. Then, after the children understand the event, we try to move on to the factors. Thereis a lake fed by a stream. We can use that lake on the right as a stock. From this stock, we will have inflows and outflowsthat will affect the amount of water in the lake. We can show evaporation as an outflow. We can show rainfall as an input flow. We can show the flow of the river into that lake or groundwater.We can think of these as factors that affect the amount of water in that lake. In terms of systems thinking, we can use the amount of water in the lake as a stock, evaporation as an outflow, rain, river, and groundwater as inflows.				

Table 4.10. Teachers' systems thinking levels in the context of water cycle (cont.).

D	First of all, we will show where the water circulates. But here, it may be difficult to show this situation as a cause-and-effect relationship. For example, it would be good to show water sources. Clouds, rivers, lakes, seas, those parts. We also need to focus on events and show events as a flow. Show evaporation, condensation, and rain. It is necessary to show the places where the water is located as a stock and the parts of the event where the water moves as a flow. Water flows from one place to another. It is constantly changing from one place to another. Water changes its place, but as I said, this is not done as a cause-and-effect relationship. Because when we try to write this example as a causal loop diagram, something is wrong. For example, it comes to the conclusion that the amount of water in the clouds must increase continuously. When we do cause and effect, that's why I get a bit stuck there. There is always displacement.	3	3	6 (%50)	Beginning Level (Level 2)

Table 4.10. Teachers' systems thinking levels in the context of water cycle (cont.).

	Here we can talk about water in clouds. We can talk about water in rivers . We can talk about water in the lake, let these be 3 stocks. There is a flow from the lake to the clouds and from the rivers to the clouds. We will call this flow evaporation. There is one flow from the river to the lake, we will call this flow from the river to the lake. There is also a flow from the clouds to the rivers and from some of the clouds to the lake again, maybe more to the river, I don't know if it happens more in terms of surface angle, I don't know in terms of surface area, but there are two flows again. There is a normal cloud and a rain cloud. It might be good to show that part as water vapor and rain clouds as condensation because there is a difference.				

Table 4.10. Teachers' systems thinking levels in the context of water cycle (cont.).

E	The water cycle is the process by which water from lakes and seas evaporate into the sky, condense, and returns through precipitation. Apart from this, we can also include transpiration and the respiration of living things. The fact that all of these work together already creates the water cycle. When one of them doesn't work, the water cycle starts to slowly disappear. That's why they should all work together like a machine. When we break or remove a part from the machine, the water cycle is affected in the same way as the machine starts to break down. When we take the precipitation from there, there is no water to go back down to the earth, so the water cycle is also affected.	3	4	7 (%58)	Beginning Level (Level 2)

Table 4.10. Teachers' systems thinking levels in the context of water cycle (cont.).

	In addition, this cycle ensures that the water on the earth evaporates and goes up to the sky, condenses in the sky, and comes down again as precipitation. In addition to the water on the surface of the earth, that water also goes underground, and both surface and underground water evaporates again, ensuring that this water cycle continues continuously. This cycle represents a system. Apart from this, of course, the water cycle is also served through perspiration and respiration. All of these are elements and since the idea of a system consists of elements, that is, the system consists of elements when we eliminate an element, we actually destroy this system.				

Table 4.10. Teachers' systems thinking levels in the context of water cycle (cont.).

F	We can say that transpiration, evaporation, and condensation are related to the fifth grade. The water in the earth combines with groundwater under the soil. Then the sea and lake, oceans are formed. Plants take these waters. With this, it provides development. Animals both take it directly, and the food they eat can take this water thanks to the plants. In other words, plants and animals remove this water from their bodies through various methods, such as the excretory system and sweating. Underground, above-ground systems in our bodies, each of them forms the whole of a system. It forms a part of it. For example, if there is no rainfall and the amount of water decreases, this will affect the condition of plants. The condition of the animals and people who feed on them is negatively affected, and the species of plants may disappear. They all affect each other. This also affects the amount of oxygen.	3	4	7 (%58)	Beginning Level (Level 2)

Table 4.10. Teachers' systems thinking levels in the context of water cycle (cont.).

G	If we look at the water we have on earth, we can think of it as a storehouse. If we think of water as a stock, we can make a lot of flows. The amount of water there always remains constant. Maybe the amount of usable water is changing, but the amount of water available is always constant. Water can be divided into usable water and potable water. As components, we can also talk about water pollution. Connections can be made between how usable water or potable water is decreasing, why it is decreasing, and so on. I show the available water as a stock. These state changes will be on the water. I write the state changes in the flow. First I write flows that will reduce it.	2	3	5 (%42)	Recognition Level (Level 1)

Table 4.10. Teachers' systems thinking levels in the context of water cycle (cont.).

	Secondly, I write flows that will allow it to return to the system. The evaporation of water in the sea is a flow that will reduce the water in the sea if we take it as a stock. Pollution of water is a flow that will reduce it. In the water cycle, the return of water to the seas and lakes after it has gone through some processes and been treated can be shown as a flow that will contribute to the stock again. If the lake is determined as a stock, the water vapor that evaporates from here and rises to the sky represents a flow. Then it descends again as rain also representing a flow. If we explain the water cycle, it evaporates from the lake, mixes with the atmosphere as water vapor, then condenses again and descends to the earth as rain.				

Table 4.10. Teachers' systems thinking levels in the context of water cycle (cont.).

H	Yes, it is a system because there are things that increase and decrease the water ratio in that system and this is a continuous cycle. First, we explain the basis of the water cycle as heat from the sun. In the components, we talk about the elements that increase and decrease the proportion of water on earth and we talk about the continuity of this. The total amount of water does not change. We explain that only its existing state changes. There is evaporation, there is condensation, there is precipitation.The water on the earth, the water under the ground, the proportion of water in the sky, humidity, cloud formation. The amount of water in the atmosphere and on the earth are the elements that change for us. What can reduce the proportion of water on the earth? Evaporation, as evaporation increases, the amount of water on the earth decreases, but this time the amount of water in the sky will increase. Cloud formation will increase and with condensation the water ratio in the clouds will decrease. But the amount of water on the earth will increase, this will create the cycle.	3	3	6 (%50)	Beginning Level (Level 2)

According to the summary results of research question two, each teacher's level of stock-and-flow thinking, dynamic thinking, and causal-loop thinking and their level of systems thinking skills in the context of the water cycle are shown in Table 4.11. In the table, each level is coded with a color to see the skill levels holistically. According to the color codes, it is seen that the number of teachers reaching level 3 is low, while level 2 is more common among the levels. Only teacher D was at level 2 in all contexts. As seen on Table 4.11, the teachers were found to have a higher level of systems thinking skills in the context of the water cycle.

Table 4.11. Teachers' systems thinking skills levels.

Teachers	Teachers' Systems Thinking Skill Levels			
	Stock-and-Flow Thinking	Dynamic Thinking	Causal-Loop Thinking	ST Skills Levels on Water Cycle
A	Level 1	Level 2	Level 2	Level 3
B	Level 0	Level 0	Level 2	Level 2
C	Level 1	Level 1	Level 2	Level 2
D	Level 2	Level 2	Level 2	Level 2
E	Level 0	Level 1	Level 2	Level 2
F	Level 1	Level 0	Level 2	Level 2
G	Level 0	Level 2	Level 2	Level 1
H	Level 1	Level 0	Level 1	Level 2

4.3. Results of The Third Research Question

RQ.3: What are science teachers' views on teaching systems and implementing systems thinking approaches in the classroom?

In this section, teachers' views on their practices will be presented in detail in terms of the methods and tools they use, the subjects covered, the implementation practices, the difficulties encountered and the measurement and evaluation approaches. For the answer to the third research question, the questions in the first section (Question number 4 and 9) and the third section (Question number 2, 3, 4, 6, 7, 8, and 9) of the interview were analyzed.

4.3.1. Teachers' Views on Teaching Systems

In response to the question "How does a secondary science teacher enable students to understand systems?", which was posed to understand the teachers' teaching practices, the teachers noted a variety of points and teaching methods. Nineteen different approaches were identified from the responses of the eight teachers. These nineteen codes from the teachers' statements were indicated as subcategories. Then, these subcategories were then grouped into seven major categories according to teaching and learning approaches.

These major categories were identified as: (1) Logical Reasoning and Analysis, including describing the relationships between parts, induction, and deduction, (2) Systems Thinking and Analysis, including questioning the concepts that increase and decrease stocks, finding the factors that affect the flows, and stock-and-flow diagrams, (3) Comparative Analysis and Pattern Recognition, including making an analogy, questioning how a behavior changes over time, and showing the similarities of the underlying behavior pattern when seen in different environments, (4) Understanding Systems and Concepts, including comprehending the definition of a system and holistic approach, (5) Visual and Interactive Learning, including visualization, modeling and gamification, (6) Step-by-Step Process and Application, including step by step processing and station works, and (7) Active Learning and Exploration, including more exposure, investigation and concretization. Categories, subcategories, and sample teacher examples were given in Table 4.12.

Table 4.12. Teachers' views on teaching systems.

Categories	Subcategories	Teachers	Sample Teacher Explanations
1. Logical Reasoning & Analysis	Describing the relationships between parts	A & B	Teacher A: The important thing is to explain how those parts affect each other. Teacher B: We will look at the part-whole relationship again... We are made to question the concepts that increase and decrease stocks.
	Induction	A & F	Teacher A: They need to explain the relationship between the parts. They need to do activities that will help them understand this relation. They need to summarize at the end and approach it inductively. Teacher F: It is explained by going from part to whole.
	Deduction	A & F	Teacher A: Explaining the relationship between the parts can also be done deductively, it depends on the topic or the learner profile. Teacher F: It is explained by breaking it down from the whole. It gives a whole without directly saying that this is the system, then it goes into details. It depends on the context.
2. Systems Thinking & Analysis	Question the concepts that increase & decrease stocks	B & C	Teacher B: By mentioning that everything is a stock, we make students question the concepts that increase and decrease these stocks by examples. Teacher C: The student understands the factors that will cause the money in his/her piggy bank to decrease or increase.

Table 4.12. Teachers' views on teaching systems (cont.).

	Find the factors affecting the flows	B	Teacher B: ... Then we can connect them to stocks and find the connectors that increase and decrease the flows.
	Stock-and-flow diagrams	C	Teacher C: Students should have knowledge about stock and flow diagrams. Before the content of the subject, in order to connect the subject to this, they should know that there is a stock and that it has an input and output flow.
3. Comparative Analysis & Pattern Recognition	Making an analogy	C	Teacher C: ... they think over it. After getting their ideas, we want them to at least simulate that initial example.
	Question how a behavior changes over time	D	Teacher D: by allowing them to examine any behavior over time, showing whether they understand how something changes over time, or whether they can describe it.
	Show the similarities of the underlying behavior pattern when seen in different environments	D & E	Teacher D: by trying to establish the structure that generates these behavioral patterns, and whether this pattern can be replicated in a different event, or whether they can make a connection between the two.

Table 4.12. Teachers' views on teaching systems (cont.).

4. Understanding Systems & Concepts	Comprehend the def. of a system	E	Teacher E: We need to make students understand what the system is.
	Holistic approach	E	Teacher E: by giving examples about this system and then teaching a holistic approach.
5. Visual & Interactive Learning	Visualization	G	Teacher G: I think visualization is very important.
	Make modeling	G	Teacher G: It's good that we provide the visual space and we give students the opportunity to make a model at the end or to create their own visuals.
	Gamification	G	Teacher G: Gamification is important.
6. Step-by-Step Process & Application	Process step by step	G	Teacher G: If we are talking about the human body, there are certain stations. There are structural organs. Games about them can be organized in which they can work step by step.
	Station work	G	Teacher G: The students work in stations and understand the structural tasks.
7. Active Learning & Exploration	More exposure	G	Teacher G: Needs to be done over and over. The more exposure students are exposed to, the better they learn.
	Investigate	G	Teacher G: It is important to provide opportunities for students to discover themselves through research.
	Concretize	H	Teacher H: It is more meaningful for them to see what is happening in their own bodies and it is meaningful for them to be able to apply it.

4.3.2. Teachers' Views on Challenges of Teaching Systems

Teachers' responses on the challenges associated with teaching systems. The teachers stated various challenges that affect the teaching systems in terms of students and practices. These are listed from most to least frequently: difficulty in understanding/interpreting how components affect each other and the process (Teacher A, D, F and G), unfamiliarity with system definition, topic and concept (Teacher E, G and H), interpreting graphs (Teacher A and C), using STELLA (Teacher B and C), an abstract concept (Teacher E and H), and limited time (Teacher B and C). Table 4.13 shows the teachers' statements and challenges they highlighted.

In addition, Teacher H stated that the systems thinking approach should be applied in a holistic and follow-up manner at all grade levels and that there are difficulties when it cannot be applied with the following words by saying these words: *"If the child does not see this in the fifth and sixth grades, you still have difficulty in trying to apply it to him in the seventh grade, but if you meet in the fifth grade, continue in the sixth grade, and continue in the seventh and eighth grades, it is a great convenience to you."*.

Table 4.13. Challenges on systems teaching posed by teachers.

Categories	Teachers	Sample Teacher Statements
Interpreting how components are related	A, D, F & G	Teacher D: The things they will have the most difficulty in explaining the systems are **if there is no linear relationship, they can see that the result of 1 is 2. The result of 2 is also 3, it is comfortable to explain this, but when we go back to 3 and say change 1, that is, when we break that linear relationship there, they may have difficulty in understanding it.** That's why it might be good to pass stock flow diagrams right there and show those feedbacks there.
Unfamiliarity with system terms	E, G & H	Teacher E: **Students do not know what the system is.** This is our problem at first, that is, students need to comprehend the system. **First we need to give the definition of what a system is, then we need to give the definition of the concept of system.** It is necessary to get ideas from the students about what the systems are and then talk about these ideas. Because as I said, since it is an abstract concept, children do not have a structure that can understand and comprehend them at first.

Table 4.13. Challenges on systems teaching posed by teachers (cont.).

Interpreting mathematical aspects	A & C	Teacher A: In order to understand how the system works, **we need to understand the direct proportion, inverse proportion, increase and decrease relationship between the components, and the best way to explain this is actually the graph. But students have difficulty in interpreting the graph.** Naturally, there is a deficiency in the infrastructure of this, they cannot interpret it because they cannot understand the relationship between the parts.
Using STELLA	B & C	Teacher C: **One of the difficulties we have in teaching the systems is that the most used program can be a bit high-level for children,especially in young age groups. we use the STELLA program.** In fact, if a certain amount of time can be allocated, children can learn this very easily. Because children at this age are really good with technology. But because of the concern of meeting curriculum on time, it will take a lot of our time to teach this or it will take our class hours, we cannot teach the program fully.

Table 4.13. Challenges on systems teaching posed by teachers (cont.).

Understanding abstract concepts	E & H	Teacher H: When we talk about systems thinking, they find **it very difficult to understand because we are talking about something abstract. They look at what you are saying.** But for example, when we teach it in the fifth and sixth grades and move on to higher grades, for example in the eighth grade, we have no difficulty in applying it. They understand more easily at that age.
Limited time	B & C	Teacher B: The difficulties related to teaching systems, first of all, I think it is necessary to make them use the system tools. It is necessary to teach them. **I define this as a difficulty as follows: we need extra time within the MoNE curriculum and the anxiety of completing the curriculum at a certain time can put us in a lot of trouble.** But since it is something that speeds up the process after learning the process quickly, I think that it is worth it, that is, I gain more than the time I lost again, and I think it raises the level of scientific and question interpretation of the students.

4.3.3. Teachers' Views on the Use of Systems Thinking in Education

All eight teachers responded 'yes' to the question if they think that systems thinking approaches and skills should be used in education. Teachers gave many reasons why system dynamics should be used in education. The most common reasons the teachers listed were: to develop students' ability to understand/make sense of issues or concepts (Teacher A, D, F, and H), to enable students to embody abstract concepts (Teacher A, E, and F), to facilitate tasks for both teachers and students (Teacher A, F, and H), to gain a different perspective (D and H) and to save time (Teacher B and E). Table 4.14 shows examples of teachers' statements about these reasons. The sentences highlighted in red referred to the reasons teachers listed for the use of systems thinking.

Table 4.14. Teachers' statements for the use of systems thinking and skills in education.

Categories	Teachers	Sample Teacher Statements
Developing students' ability to understand	A, D, F, & H	Teacher A: There was a work that I was prejudiced against or that I thought was not appropriate for the age level... I have seen that children make more sense and learn very quickly from this. So I think this is useful... **I saw that when they put the relationship together and see how it affects each other, they can make sense of it much more accurately.** I realized that they can see the background more.

Table 4.14. Teachers' statements for the use of systems thinking and skills in education (cont.).

Embodying abstract concepts	A, E, & F	Teacher F: In particular, it allows students **to understand abstract concepts such as work or Corona.** Even when solving a problem or calculating the money in a piggy bank in the future, it makes it easier for students to establish a tiny relationship to see how much they can collect in how many years, and to see what they will increase and what they will decrease, and to graph it. At the same time, they can see the state of a whole even years later in a very clear way.
Facilitating teaching and learning	A, F, & H	Teacher H: You create an environment in which students can learn in a different way, in a much more comfortable way, by having fun or by applying some of the subjects that you have traditionally taught in the same way, which have not been unusual until today. Therefore, the child learns in a different way and does not get bored because his/her perspective changes. He does not approach with prejudice. **Therefore, it both facilitates our work and makes learning more permanent and they remember it afterwards.**

Table 4.14. Teachers' statements for the use of systems thinking and skills in education (cont.).

Developing different perspectives	D & H	Teacher D: When we look at the behavior of the system, I think it can be good because it will make it easier for the students to see that everything affects each other and that something like external factors cannot be in question, and that an intervention from outside will grow or shrink due to the relationships within the elements of the system. **I think they can have different perspectives because I think they will realize that when a model is created, it is not the absolute truth, that this model is the mental model of that person, and that they can understand it and then develop it from their own perspective.** Because at school we are very focused on telling the absolute truth.
Saving time	B & E	Teacher E: **The idea of systems thinking in education allows students to reach a level by understanding a topic that I can explain in four or five hours in two lesson hours.** I think it is an approach that allows students to understand how to draw a line graph by giving the input and output to the students in a more comfortable way. it actually turns abstract into concrete for us.

4.3.4. Teachers' Views on the Topics Can Be Taught Using the STA

Teachers responded to the question which topics in the science curriculum they think can be taught using the systems thinking approach and at which grade level are these topics., Teachers identified many subjects and units in grades five to eight in which systems thinking could be used. Figures 4.5, 4.6, 4.7 and 4.8 list the subjects in fifth, sixth, seventh and eighth grade respectively. The eighth grade curriculum contains the largest number of subjects, while the seventh grade curriculum contains the smallest number of subjects. Also, teacher D claimed that the systems thinking approach could be applied to all subjects.

As shown in Figure 4.5, teachers mentioned four topics in 5th grade, which were heat and temperature, force, human and environment, and biodiversity. The topic of heat and temperature was mentioned by 6 teachers (%40); force by 5 teachers (%34); human and environment by 2 teachers (%13) and biodiversity by 2 teachers (%13). Also, Teacher A mentioned teaching graphs and stated "It is nice to use system tools to develop graphic reading skills in students without them knowing how to use them." Also, Teacher A mentioned teaching graphs and stated *"It is nice to use system tools to develop graphic reading skills in students without them knowing how to use them."*

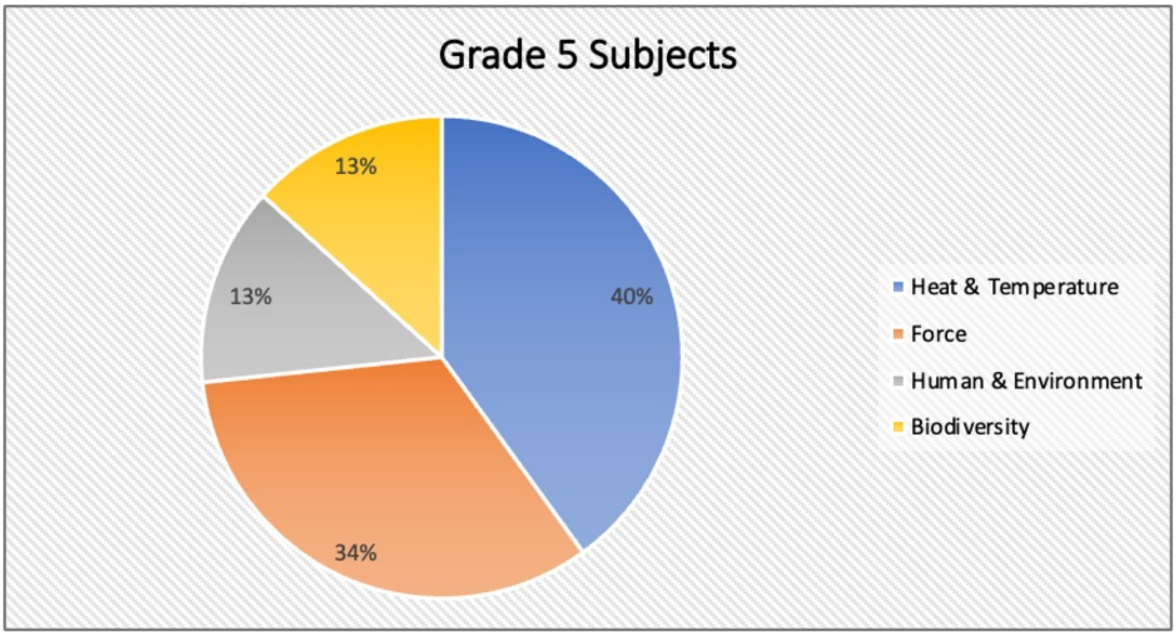


Figure 4.5. Fifth grade subjects that can be taught with systems thinking.

As shown in Figure 4.6, teachers mentioned about six topics in 6th grade, which were human body systems, constant velocity motion, resultant force, electricity, solar system and sound. The topic of human body systems was mentioned by 6 teachers (%35); constant velocity motion by 5 teachers (%29); resultant force by 3 teachers (%18) and electricity, solar system and sound by 1 teacher each (%6).

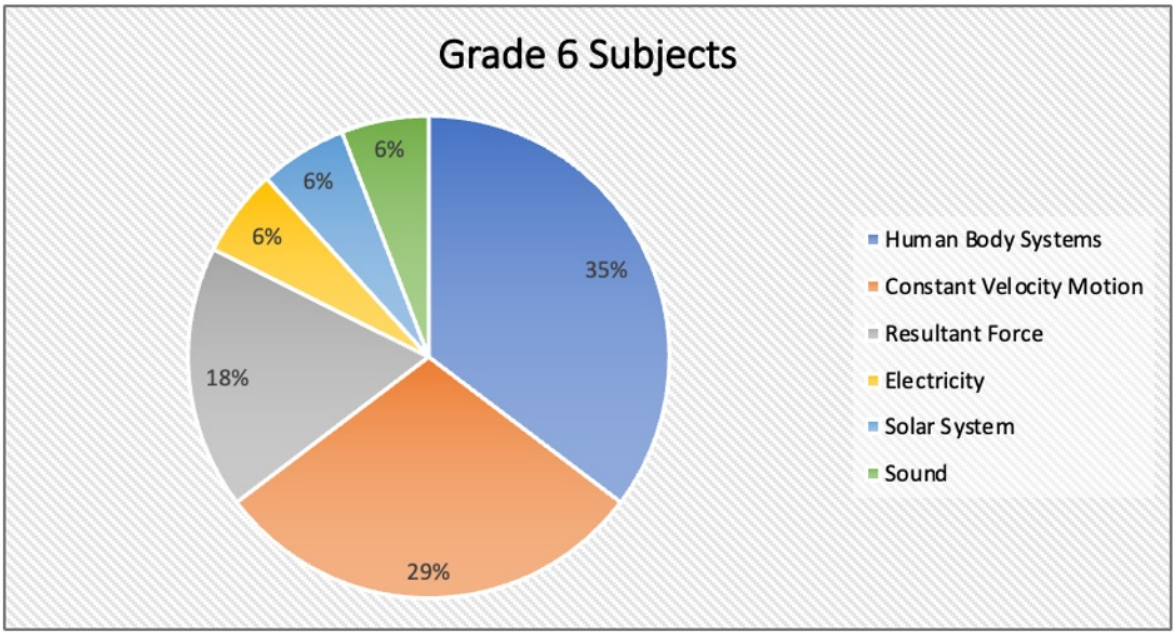


Figure 4.6. Sixth grade subjects that can be taught with systems thinking.

As shown in Figure 4.7, teachers mentioned only two topics in 7th grade, which were work and energy, and household waste and recycling. The topic of work and energy was mentioned by 7 teachers (%78) and household and recycling by 2 teachers (%22).

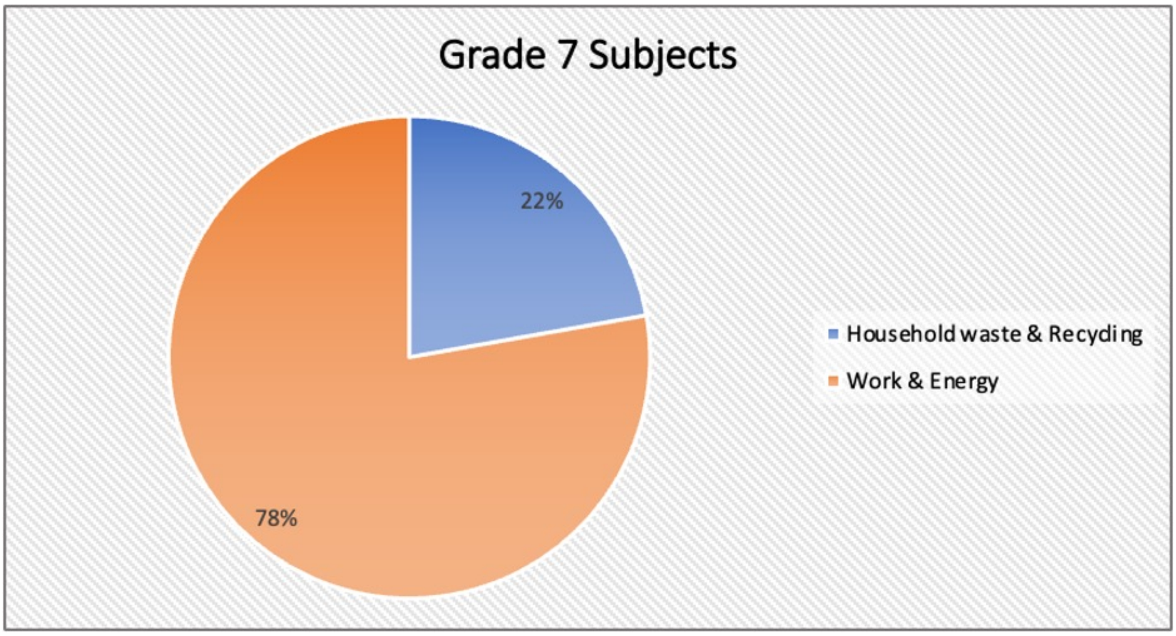


Figure 4.7. Seventh grade subjects that can be taught with systems thinking.

As shown in Figure 4.8, teachers mentioned six topics in 8th grade, which were cycles, energy flow, heat and temperature, pressure, simple machines, seasons and climate, sustainable development, DNA and genetic code, genetic engineering and biotechnology, and periodic table. The topic of cycles, energy flow, heat and temperature, and pressure was mentioned by 3 teachers each (%16), seasons and climate by 2 teachers (%11), and sustainable development, DNA and genetic code, genetic engineering and biotechnology, and periodic table by 1 teacher each (%5).

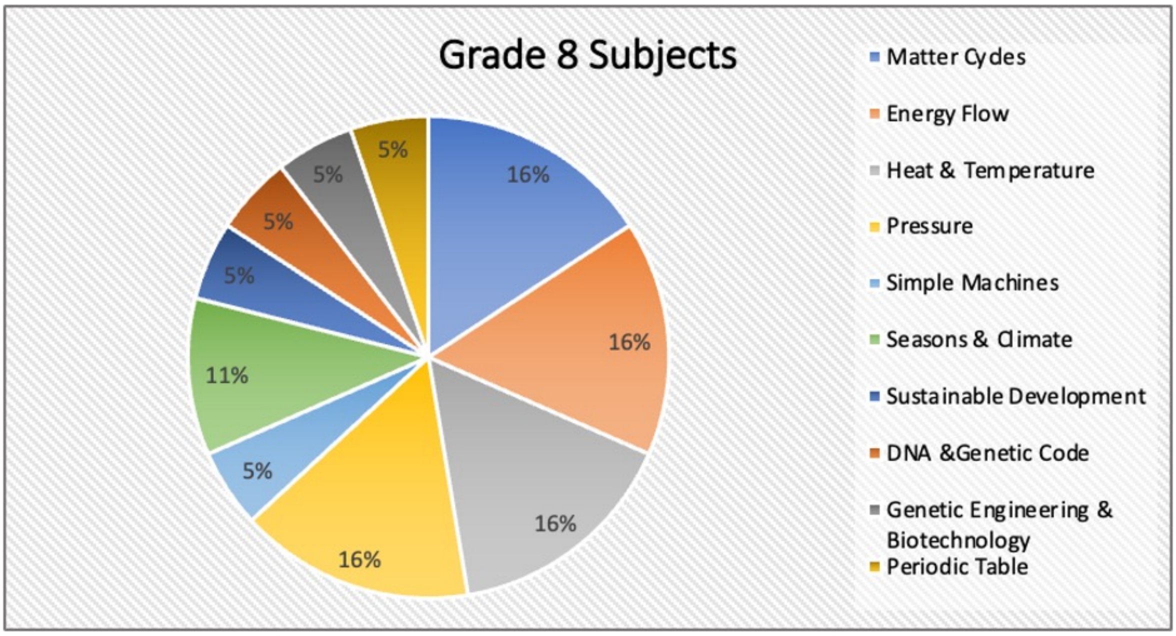


Figure 4.8. Eighth grade subjects that can be taught with systems thinking.

4.3.5. Teachers' Views on Methods and Tools as Teaching with STA

In order to get more detailed information about the teachers' practices, they were asked which methods and tools they use when teaching a subject in their classrooms. Teachers A, B, C, D, E, and G mentioned stock-flow diagrams, and Teachers B, C, and D mentioned behavior over time graphs as a tool among the system dynamics tools mentioned in the literature. Teacher D also mentioned the ladder of inference and causal-loop diagrams, but stated that she did not use them in her classes. Also, teacher E mentioned the iceberg model and the ladder of inference as a tool, but he also stated that they did not use it much. It is reached that teachers generally use stock-and-flow diagrams and behavior over time graphs. Table 4.15 shows the teachers' sample statements about the systems thinking tools they used in their practices.

Apart from the system dynamics tools mentioned above, Teachers A, C, E, F, G, and H mentioned the STELLA program as a tool. Teacher G mentioned the use of the STELLA program according to the needs of the students by saying these words:

"STELLA is very good, but it is important how the practicing teacher handles it. It would be good to see the needs of his/her own students. I think not every student can start at the same level.". IPads, worksheets, games, concept maps, smart boards, and experiments were also mentioned as tools when teaching a subject with systems thinking approach.

Table 4.15. Teachers' views on tools when teaching a subject with systems thinking approach.

Categories	Teachers	Sample Teacher Statements
Stock-and-Flow Diagrams	B	We taught stock flow diagrams. The students themselves set up the stocks and flows in a problem and solved the problem themselves from there.
	C	Right now we are basically using stocks, flows and models where children also use factors.
	D	I applied stock flow diagrams as soon as I said I was applying systems thinking.
	E	We apply it with a stock flow diagram. Since we work mostly with numerical data, we try to make at least one application at all levels.
	G	We give a problem. After giving this problem, we are now talking about the variables here. They determined what the stock could be, what the flow could be.
Behavior over time graphs	B	They saw the behavior over time and then they started to draw graphs themselves or they started to interpret the given graph accordingly. The behavior over time was also constructed by themselves after the stock flow.

Table 4.15. Teachers' views on tools when teaching a subject with systems thinking approach (cont.).

	C	The graphs created related to these factors are the part of the behavior over time when you press the run button, so they can observe them.
	D	We already use behavior over time graphs all the time to explore the structure that generates this behavior by examining behavior over time.

The teachers' responses on how often they refer to the systems thinking skills/tools in their classrooms were presented in Table 4.16. According to Table 4.16, the teachers comprise the stock-and-flow and dynamic thinking skills frequently in their classrooms, while they use causal-loop thinking skills the least. This result shows consistency with the systems thinking tools that teachers indicated that they used in the previous question.

Table 4.16. Frequency of use of the systems thinking skills.

		Teachers							
		A	B	C	D	E	F	G	H
Stock-and-Flow Thinking Skills	Never								
	Rarely								
	Sometimes								
	Often			1		1			
	Always	1	1		1		1	1	1
Dynamic Thinking Skills	Never	1							
	Rarely								
	Sometimes						1		
	Often		1	1		1			
	Always				1			1	1
Causal-loop Thinking Skills	Never	1							
	Rarely		1	1			1		
	Sometimes				1	1			
	Often							1	
	Always								1

4.3.6. Teachers' Views on Their Teaching Practices with STA

Teachers' responses to the question "How would you implement a systems thinking approach in your classroom? Can you explain with an example?", what kind of learning environment the teachers create in their teaching practices was examined.

Ten different teaching practices were identified from the responses of the eight teachers. These ten teaching practices from the teachers' statements were indicated as subcategories. These subcategories were then grouped into five major categories according to teaching and learning approaches. These are: (1) Visualization and Representation, (2) Analysis and Interpretation, (3) Practical Application, (4) Knowledge

Building and Conceptual Understanding, and (5) Critical and Creative Thinking. Categories, subcategories, and sample teacher examples were given in Table 4.17.

According to Table 4.17, among the system dynamics tools, the use of stock-and-flow diagrams and behavior over time graphs were emphasized by more teachers. However, even if Teacher B and D did not call it behavior over time graphs, they emphasized reading and drawing graphics in their practice. Similarly, Teacher C emphasized discussing the components in stock flows, while Teachers C, D, E & F emphasized using stock flow diagrams from system dynamics tools. The use of the causal-loop diagram, one of the system dynamics tools, was mentioned by only Teacher D.

Table 4.17. Teachers' views on their teaching practices.

Categories	Subcategories	Teachers	Sample Teacher Explanations
1. Visualization & Representation	Using causal-loop diagrams	A	Teacher A: I think the ecology pyramid with causal loops can be studied very well.
	Reading & drawing graphs	B & D	Teacher B: I would like to implement it for reading graphs in fifth grade as I have seen that students can solve line graphs very easily. Ask the students directly what you would expect if the money in your piggy bank was zero... It is useful to show the general outlines of the graph to the students through such situations and to show them the systems thinking. Afterwards, they can easily draw a line graph themselves. Teacher D: ... First of all, I would like them to draw the graph of the change of state of ice with an experiment.

Table 4.17. Teachers' views on their teaching practices (cont.).

	Using stock-flow diagrams	C, D, E & F	Teacher C: I start with stock flow diagrams at heat and temperature. I tell them what the flows of the stocks could be. Teacher D: ... Is temperature a stock, an accumulation or is temperature an indicator, here heat will be an accumulation. I created a stock flow diagram by discussing them like temperature will be an indicator. Teacher E: We can give the carbon cycle and say what could have been added here so that the amount of atmospheric carbon increases, and we can show the stocks and flows there and climate change. Teacher F: We would definitely use a stock flow diagram after using Phet simulation. For example, we would give a coefficient, we would increase the amount of roughness, and then we would observe the velocity, and from there we would interpret the friction force.
	Creating a concept map	F	Teacher F: We did it about household waste and recycling. We completed it as a concept map through the story. They were extracting all the concepts related to the solid waste management scheme. We gave a story in which these concepts such as raw material processing, production, recycling and reuse of waste were extracted one by one.

Table 4.17. Teachers' views on their teaching practices (cont.).

2. Analysis & Interpretation	Interpreting behavior over time	A, C & E	Teacher A: Behavior over time is the ideal for the carbon cycle. Because it's something that is very clear when you talk to children about the reasons for these things, and also constant velocity movement, for example, behavior over time, I think both of these can be applied. Teacher C: . . . How will the behavior graph change over time, will it increase or not? Or how will it be if this happens, will it increase if this happens, will it decrease if that happens? With such questions or examples, I make students see how those flows affect the stock. Teacher E: We can talk about climate change. We can divide it into two, before and after the industrial revolution, and in this way we can look at the graph of the behavior of carbon in the atmosphere over time and talk about why it was actually flat at first and then suddenly started to rise.
	Discussing the factors	C	Teacher C: I would like to brainstorm with the kids without making a stock flow diagram...I ask what the stocks and flows might be. I ask what other f actors might be involved in the inflow and outflow flows. Then I can have them do research to reach data about those factors.

Table 4.17. Teachers' views on their teaching practices (cont.).

3. Practical Application	Giving daily life problems	B	Teacher B: I added 100 TL to my piggy bank every month… After 3 months I started to pay a certain installment. It is useful to show the general outlines of the graph to students through small daily life problems with systems thinking.
4. Knowledge Building & Conceptual Understanding	Giving preliminary information about terms and concepts	C	Teacher C: I don't start by applying systems thinking directly. Obviously, I would like to make a lesson on that subject at least about terms and concepts so that they have a preliminary knowledge before using systems thinking. I don't start by applying systems thinking directly. Obviously, I would like to make a lesson on that subject at least about terms and concepts so that they have a preliminary knowledge before using systems thinking.
5. Critical & Creative Thinking	Brainstorming	C & E	Teacher C: I would like to brainstorm with the children without making a stock flow diagram and using STELLA... This could increase, this could decrease. Teacher E: Talking about the amount of carbon in the atmosphere and discussing with students the fossil fuels that emerged after the industrial revolution and why fossil fuels did not exist before.
	Using simulations	G	Teacher G: I thought it would be nice to apply kinetic and potential energy in energy transformations. It can be explained through a roller coaster system.

4.3.7. Teachers' Views on Assessment and Evaluation for STA

The responses given to the question of "What kind of assessment & evaluation would you do for Systems Thinking? What would you want to measure?" asked to see how they interpret their applications in terms of measurement and evaluation, the input from eight teachers revealed several prominent approaches and areas of focus. Among these, the most frequently mentioned methods emphasized by teachers E, F, G, H, and B was the use of building stock-and-flow & causal-loop diagrams. Open-ended questions (Teachers A, C, and F), reading/interpreting graphics (Teachers C, D, and F), transfer and interpretation skills (Teachers A, F, and D), and process-oriented evaluation (Teachers A, B and F) were all equally highlighted by three teachers. Categories and sample teacher statements are given in Table 4.18.

Table 4.18. Teachers' views on assessment and evaluation.

Categories	Teachers	Sample Teacher Statements
Building Diagrams	E	We asked questions about the stock and flow diagram. What can be the stock and what can be the flow? We gave a problem. We asked questions such as you draw the stock flow diagram of this, and then we scored it.
	F	We expected them to give the graphs and from there to connect the stock to the flow, in other words, to interpret it going from general to specific.
	G	I would ask them to model a system that they feel most comfortable with by establishing a cause and effect relationship using system dynamics, with at least one stock, at least 2-3 flows, increasing and decreasing flows.

Table 4.18. Teachers' views on assessment and evaluation (cont.).

	H	We could make a simple measurement where they could make the stock flow diagram themselves. For example, in a constant speed movement, we could ask them to create something like this much time will pass, the distance traveled will increase.
	B	I would like to measure the causal loop with systems thinking. I would like to measure how much students can see the big picture and whether they can make connections between events.
Using Open-ended Questions	A	What I mean by an open-ended question is more like these new generation style questions. It will give an event and require them to interpret it. And while interpreting, he will use what he has already done.
	C	It can be an open-ended question, it can be a new generation question. It can be a test question. I can ask a question related to this and ask a question that will test whether the subject has been learned with the system in mind.
	F	In the final evaluation, it was like a test. There were open-ended questions, there were questions based on interpretation... We focused on the individual, where everyone was, what they learned, how much they learned, so we preferred an application in that way.
Using Graphs	C	We gave a case over STELLA or we gave two different cases in two questions and asked how the graph could be.

Table 4.18. Teachers' views on assessment and evaluation (cont.).

	D	I'll probably try to figure out how they are at reading graphics.
	F	This time we didn't make them draw graphs, we gave them graphs and expected them to connect to the stock flow and interpret it from general to specific.
Measurement on Transfering & Interpretation Skills	A	I would like to measure students' interpretation and transfer skills. They can transfer what they have learned with their studies in daily life. I would definitely use experiments
	F	By giving problems similar to the problems we do in our lessons, we actually measured how much the students have learned and gained this.
	D	. . . Instead of a room, I would ask them to describe the heat exchange between two objects. I would try to measure whether they can change the variables and still interpret them in the same way.
Process-oriented Evaluation	A	I need to make it process-oriented. There may be tasks that I give them 10-15 days and they will progress gradually, not things that I expect an instant answer.
	B	We measured how the systems thinking approach can influence the graphical work. We did this with the line graph measurements given to the 5th graders during the process.

Table 4.18. Teachers' views on assessment and evaluation (cont.).

	F	We gave group work to the students. After the systems thinking lectures, we asked them how they solved the problems in these group works, what they thought, and then we thought about them in the next lecture for process evaluation purposes.

4.4. Summary of Results of Research Questions

4.4.1. Summary Results of First Research Question

- Teachers defined the system as a part-whole relationship, cause-effect relationship and dynamic relations with concepts.
- Teachers defined the systems thinking as a holistic thinking, modeling relationships between concepts, and a way of thinking & communication.
- Teachers were able to explain stock-and-flows, behavior over time and causal-loops of the systems thinking tools.
- Teachers gave different system examples from fifth to eighth grade including food pyramid, matter cycles, human body systems, circulatory system, digestive system, heat and temperature, environment, solar system and ecosystem.
- Teachers identified the characteristics of the system according to the existence of components, the existence of relationships between components, the existence of parts that make up a whole, and the ripple of system malfunction.
- Teachers defined the water cycle as a system in terms of the existence of interrelated parts, a continuous cycle and the stocks and flows.

4.4.2. Summary Results of Second Research Question

- Teachers were at the Novice, Recognition, and Beginning levels in terms of their ability to think in stock-and-flow.
- Teachers were at Novice, Recognition, and Beginning levels in their ability to think dynamically.
- Teachers were at Recognition and Beginning levels in their ability to think in causal- loops.
- Teachers were mostly at Beginning level in terms of systems thinking skills in the context of the water cycle system.
- Teachers could not reach a high level in terms of systems thinking skills.

4.4.3. Summary Results of Third Research Question

- Teaching methods stated by teachers for students' understanding of systems were grouped into 7 categories which are (1) Logical Reasoning and Analysis, (2) Systems Thinking and Analysis, (3) Comparative Analysis and Pattern Recognition, (4) Understanding Systems and Concepts, (5) Visual and Interactive Learning, (6) Step-by-Step Process and Application, and (7) Active Learning and Exploration.
- Teachers identified the challenges they face in teaching the systems as: Interpreting how components are related, unfamiliarity with system terms, interpreting mathematical aspects, using STELLA, understanding abstract concepts and restricted time.
- Teachers stated that systems thinking approaches and skills should be used in education for the following reasons: Developing students' ability to understand, embodying abstract concepts, facilitating teaching and learning, developing different perspectives, and saving time.
- Teachers identified many subjects and units in grades five to eight in which systems thinking could be used. The eighth grade curriculum contains the largest number of subjects, while the seventh grade curriculum contains the smallest

number of subjects.

- Teachers indicated that they use stock-flow diagrams and behavior over time graphs more than causal-loop diagrams in their classrooms when teaching a topic using the systems thinking approach.
- The learning environments created by teachers were grouped into 5 categories which are (1) Visualization and Representation, (2) Analysis and Interpretation, (3) Practical Application, (4) Knowledge Building and Conceptual Understanding, and (5) Critical and Creative Thinking.
- Teachers identified a varied assessment and evaluation approach for systems thinking approach which are building diagrams, using open-ended questions, using graphs, measurement on transfering & interpretation skills, and process-oriented evaluation.

5. DISCUSSION

5.1. Discussion of the Results

The goal of this study was to examine the understanding of science teachers about a system and the systems thinking skills and how they reflect their understanding and skills into their teaching practices. Therefore, in this study, three research questions were asked to investigate science teachers' knowledge, skills and their views on implementing systems thinking approaches in the classroom. The discussion of these questions is given in the following sections respectively.

5.1.1. Discussion of the First Research Question

Assaraf and Orion (2005) stated that although the teachers have content knowledge about the human body systems, they are not competent and have not received general training on how to teach these topics using a systems thinking approach. It was also noted that students are unlikely to develop higher-level systems by thinking on their own (Assaraf & Orion, 2005). Therefore, it is important to determine the status and needs of teachers who scaffold students to acquire a trendy and needed learning approach.

There are many different system definitions in the literature. Meadows (2008) defined a system as interconnectedness among the elements of a system and an integrated whole. In this study, most of the teachers defined it as a whole. The teachers also gave examples of systems such as the energy pyramid, cycles (water, carbon), human body systems, heat-temperature, solar system and ecosystem. Although the term system applies to a wide range of topics, including social systems, ecological systems and technological systems (Assaraf & Orion, 2005), the teachers' examples may have been limited to science due to their teaching field. It is essential that individuals understand a system and its components. For example, in order to understand the ecosystem, individuals need to first understand the living and nonliving components as a system.

On the other hand, the definitions of systems thinking in the literature varied, but they all shared elements like a knowledge of relationships, interactions, and patterns as well as the interconnectedness and complexity of the world (Karaaslan, 2016). In Arnold and Wade's (2015) research on the definition of systems thinking, a few key points for the definition of systems thinking have been extracted from the literature. Three key components make up systems thinking: elements, relationships, and a purpose. In the current research, when it is examined how the teachers defined the system and systems thinking, some teachers defined systems thinking too broadly by saying *"a way of thinking and a method of communication and a framework to connect the concepts", while others simplified it by saying "part-whole relationship and holistic approach".*

Although the teachers clearly emphasized the part-whole relationships in a system, they did not mention the third component of systems thinking, which is purpose. This finding is consistent with Senge's (1990) definition. According to Senge (1990), systems thinking is a discipline that seeks to reveal interrelationships and wholes rather than components. Teachers' emphasis on part-whole relationships are based on Senge's (1990) definition. Also, this result is similar to Assaraf et al. (2013) study in which the students emphasized the whole formed by the parts coming together and rarely mention how the parts interact within the system because the latter was more difficult to grasp. This shows that teachers and students have similar knowledge and interpretations about the system, systems thinking and its characteristics. It may be crucial to explain systems by identifying the purpose of a system and then detailing both its elements and the connections between them (Arnold & Wade, 2015).

Furthermore, in Assaraf and Orion's (2005; 2010) study with students, it was reported that despite students' inadequate systems thinking skills, their ability to analyze the hydrological world system according to its components and processes had improved. They had difficulty in perceiving the ”water cycle” as a set of relevant information. Although the students were aware of a number of hydro-biogeological processes, they did not have a dynamic, cyclical, or systemic understanding of the system. In the current study, by examining the stock-and-flow diagram models of the teachers, it was seen that they were also at different levels when their levels of component and process identification in the water cycle were examined. Some teachers did not fully identify the hydro-biological processes of the water cycle and did not mention its dynamic and cyclic nature. In addition, students had a tendency to concentrate on structural rather than procedural consequences in earth science, which led to a low degree of systems thinking (Mambrey et al., 2020). Therefore, the level of teachers' identification of the components and processes of the water cycle has an important role in students' achievements in this subject. In the study of Skaza et al. (2013), the teachers showed a weak understanding of stock-and-flow models, whereas the teachers in the current study had different understanding of stock-and-flows from recognition level to intermediate level in the context of water cycle. This result may be caused by the purposeful selection of the participants.

5.1.2. Discussion of the Second Research Question

Recently, systems thinking has been focused on by researchers in education and has been studied in education from primary to university level (Verhoef et al., 2018). In the literature, there are fewer studies investigating teachers' system skills (Ateskan & Lane, 2018). In addition to the scarcity of studies measuring teachers' systems thinking skills in this field, there are also few measurement instruments for systems thinking skills (Brandstadter et al., 2012). Interviews have been used quantitatively and qualitatively in combination with questionnaires, drawings or concept maps to capture participants' systems thinking skills (Ateskan & Lane, 2018; Karaarslan & Teksöz, 2020). In this research, three open-ended questions was used to evaluate the systems thinking skills of teachers extensively regardless of the content because in the literature it is emphasized although it appears to be about comprehending complex systems beyond of particular contexts, it is still not apparent if or how to categorize domain-general levels of systems thinking (Mambrey et al., 2020). In the research of Karaman (2013), in teacher education, the need for studies that enable pre-service teachers to think about social, ecological and cognitive systems to develop their interdisciplinary approaches and systems thinking skills has been emphasized. The results of the current study on teachers' levels of thinking skills with stock-flows, dynamic thinking skills and causal-loop/closed-loop thinking skills support the need of systems thinking and system dynamics approaches.

In the study of Hmelo-Silver et al. (2004; 2007), novice teachers were better at understanding the structures than causal behaviors and functions of the system in the context of biology education because understanding the behavior and functions of a system goes beyond seeing the relationships between components. However, when this result is compared with the current research results, the teachers have lower skills in identifying stocks and flows, being at the novice, recognition and beginning levels. Teachers were also most likely to be at the beginning level in the context of the water cycle, which includes identifying stocks and flows. In the literature, it was reported that individuals failed to solve stock-flow problems and that the failure to understand stock-flows was caused by decision-making processes rather than lack of contextual knowledge about the tasks (Asık & Doganca Kucuk, 2021). In addition, it was emphasized that stock-flow problems are new and non-routine problems for most of the participants. The difference in the current study may be due to the fact that water cycle is a context dependent topic and participants in this study have content knowledge about the water cycle because of their expertise in the science field. Hmelo-Silver et al. (2007) stated that this situation may be due to the fact that teachers did not receive significant science training in understanding complex systems in their university education.

Although stock-and-flow diagrams contain causal-loops, and determining the reinforcing and balancing cycles requires more understanding in causal-loop diagrams, in the current study the teachers were found to be better in determining causal-loops than in terms of components and processes although they stated that they use it less in their classrooms. In terms of determining dynamic behaviors, teachers again have low levels of dynamic thinking skills. However, in the study of Hmelo-Silver (2004; 2007) expert teachers were better in causal behaviors of the system. In summary, teachers' systems thinking skill levels were not very different from each other when the results were compared in terms of new and experienced teachers as in Hmelo-Silver's study (2007). Seeing the multilevel relationships between different levels of a system, interpreting how emergent properties arise, and applying this knowledge to the properties of an entire system over time requires the development of systems thinking skills. The differences between the levels of the teachers may be due to the differences in the theoretical training process of the teachers and the duration of the classroom implementations.

In Karaarslan Semiz, & Teksöz's research (2020) on the systems thinking skills of teachers in the field of Education for Sustainable Development, it was concluded that the systems thinking skills of the pre-service science teachers were found to be at low levels in the beginning, and after the intervention most of the teachers improved their skills to the developing or mastery level in the skills of identifying the aspects, analyzing the interconnections between these aspects and recognizing hidden dimensions of a system. In the current study, it was found that teachers were also better at these skills of systems thinking than dynamic thinking without considering recognizing hidden dimensions of a system in the current research.

Dutton-Lee (2015) investigated the systems thinking skills of elementary science teachers in pre-service and in-service in the context of the water cycle. He exhibited that these teachers' abilities were at a low level (novice or recognition). The teachers had difficulty in identifying components and processes, identifying multiple relationships and hidden dimensions of the system and recognizing the human impact on the system. Additionally, teachers were unable to recognize the numerous interactions between the hydrosphere, geosphere, biosphere, and atmosphere. Moreover, the teachers lacked knowledge of how humans affect complex systems, such as the water cycle, and they were unable to recognize unseen system components such as processes which take place under the surface or plants attract water with their roots and perform photosynthesis (Dutton-Lee, 2015). In the current study, the teachers were not adequate in terms of their ability to think in stocks and flows, and to think in causal-loops.

In the current research, only two science teachers mentioned human influence in the following words: *"There are other factors in the water cycle than evaporation or rainfall. We can also add the input and output flows of these factors. For example, the amount of population there can change the amount of water. Too much water use will reduce the amount of water there."* and *"The components of the water cycle can be divided into usable and potable water. In addition, water pollution can be mentioned. I think that connections can be established between how usable water or potable water is decreasing, why it is decreasing and so on."*. Similar to this, Palmberg et al. (2017) investigated the level of systems thinking abilities pre-service teachers possess in sustainability context and the findings showed that pre-service teachers have limited systems thinking abilities. None of the participants in Palmberg et al (2017) study attained an intermediate or advanced level, but they all had a basic level with connections, feedback, and behavioral aspects. In the current research, the teachers also did not have an intermediate or advanced level for systems thinking skills.

5.1.3. Discussion of the Third Research Question

Hmelo-Silver (2007) emphasized that unless teachers understand the nature of complex systems, it will be difficult for them to provide appropriate learning experiences. For these reasons, examining teachers' views and practices is important for the dissemination of the systems thinking approach in education. Firstly, all of the teachers in this study argued that systems thinking approaches should be used in education. In the research of Benson (2007), it was emphasized by teachers that the visual nature of systems thinking tools helps students to organize their thoughts, keep them motivated towards the lesson and to gain different perspectives. In the current study, the teachers emphasized similarly that the students gained different perspectives and one teacher stated that systems thinking motivated the students by saying these words *"You direct students to a different field from a different perspective. In other words, you create an environment where they can learn some of the subjects that you traditionally* *teach them in a different way, in a much more comfortable way, by having fun or by applying them at work. Therefore, the child learns in a different way and does not get bored because their perspective changes.".* On the other hand, Skala et al. (2013), on their study about teachers' barriers to implementing system dynamics in K-12 STEM curricula, found that teachers' self-efficacy, professional development aimed at understanding systems and system models, and providing materials for model building and the simulation STELLA use were effective in these barriers. This finding is consistent with the results of the current research. In the current study, in terms of the difficulties encountered by teachers in teaching systems, teachers reported difficulties in using the STELLA application and not being familiar with the definition, subject and concept of systems and systems thinking approach.

Also, one teacher in the current study emphasized an important point about applying system dynamics in terms of self-efficacy and professional development by saying these words *"I have been explaining the subject for years, but it was difficult for me to associate the subject I was explaining with the idea of this system and to apply it. I couldn't establish myself very well in my head so that I could make the child apply it well. This was problematic for me.".* The teachers in Skaza et al. (2013) also mentioned that the use of simulations caused classroom management problems and required different forms of instruction and management as well as additional supervision, whereas the teachers in this study did not mention such a challenge, and despite all the difficulties, they all stated that systems thinking should be used in education.

Moreover, Skaza et al. (2013) concluded from teachers' responses that a system dynamics model provides useful scaffolding for classroom discussions that start with variables and move on to more complex concepts, and that simulations of system dynamics have benefits. A similar conclusion was reached in this study. As presented in the results section, teachers stated that discussing factors and using simulations can be used in classrooms when teaching a topic with systems thinking. In the same study, the participants stated that they did not use stock-and-flow diagrams and system dynamics simulations, which are currently part of their curriculum, while the teachers in this study stated that they used stock-and-flow diagrams very often. Also, the teachers emphasized that the many subjects in the science curriculum can be covered with the systems thinking and systems dynamics approach.

Furthermore, Gilissen et al. (2020) conducted a research with biology teachers to examine how systems thinking has been integrated in biology education, they reached that teachers rarely incorporate systems thinking in their practice because they do not have enough time for complex subjects. Similarly, the teachers in this study stated that they needed enough time to implement systems thinking and that they could not focus on it sufficiently due to the concerns about meeting the curriculum on time. One of the teachers stated that *"But because of the concern of meeting curriculum on time, it will take a lot of our time to teach this or it will take our class hours, we cannot teach the program fully."*. The literature emphasizes the need to provide professional development opportunities in terms of pedagogical content knowledge for teachers to apply systems thinking and system dynamics to improve students' understanding and skills in systems thinking (Fisher & Systems Thinking Association, 2023; Gilissen et al., 2020; Skaza et al., 2013; Schuler et al., 2018). The results also emphasize the need for more research and initiatives to bridge the gap between research, curriculum development, teacher education and teaching practices.

Complex systems in various domains or contexts have been described in the literature, such as natural systems (Assaraf & Orion, 2005; 2010; Batzri et al., 2015; Dutton-Lee, 2015), geographical systems (Mehren et al., 2018), chemical systems and biological systems (Evagorou et al., 2009; Hmelo-Silver et al., 2000; 2007), climate change and sustainability education (Ferguson et al., 2021; Meilinda et al., 2018; Shepardson et al., 2014). Similarly, as a result of this research, teachers gave examples of middle school subjects from many different domains such as biology, chemistry, physics, etc. in which systems thinking and system dynamics were used.

Many studies in the literature have attempted to assess systems thinking skills using concept maps frequently (Assaraf & Orion, 2005; Brandstadter et al., 2012; Raved

& Yarden, 2014; Tripto et al., 2013). The use of stable tools such as concept maps in the evaluation of dynamic systems is not sufficient for the dynamic nature of systems thinking because a concept map includes concepts and relationships doesn't show the cyclic and dynamic relations adequately in the system. They can be used for identifying components in the system and simple relationships between the system components because they do not show behavior throughout time. In the current research, in the question of what kind of assessment and evaluation would you use for systems thinking, the teachers did not mention concept maps. However, one teacher stated that concept maps can be utilized in classroom activities. Also, another teacher emphasized the significance of using systems thinking in teaching practices by saying this *"Actually, I have seen that when systems thinking in education is learned and applied, it is more useful than concept maps and it is useful for students to see the whole and to combine those parts."*. In this study, in addition to systems thinking methods and tools, the teachers mentioned methods such as concept maps, experiments, games, brainstorming, station works, problem solving, and different tools such as smart boards and iPads.

5.2. Implications

Systems thinking skills have been determined to seal the gap between today's complex problems and their solutions. The findings of this research contributed to the research and practices of the systems thinking and system dynamics in science education. Two main conclusions were drawn from our study. The first is that science teachers have a limited understanding of and skills in systems thinking and systems dynamics. They didn't reach the higher levels of systems thinking skills. These results are valid for the context of this study. Therefore, there is a need to develop science teachers' systems thinking skills, so that they can support the students to develop these skills. Second, there is a need for professional development opportunities and curriculum enrichments for teachers to acquire systems thinking and systems dynamics skills in order to make them more qualified in this area because they are involved in implementing the curriculum that includes systems. From the research aspect, the current research findings suggest that systems thinking and system dynamics should be placed more in educational research to enrich teachers' understanding, skills, and teaching practices in systems thinking with evaluation and discussion. For this reason, qualitative & quantitative question sets and rubrics should be added to the literature for both students, candidates and teachers as a content dependent and independent.

5.3. Limitations

There are several notable limitations to this research. First, the selection of participants was not random, but was conducted with teachers trained in and known to practice systems thinking. The participants in the study therefore do not faithfully represent teachers, which limits the extent to which the results can be generalized. Second, this research is limited to qualitative research in terms of methodology and accordingly the participants were limited to eight and middle school science teachers in the 2022-2023 academic year. Therefore, the obtained data was limited with these participants. Third, this study was conducted online with participants and, due to the nature of online interviews, there may be differences in participants' performance compared to face-to-face interviews. Finally, the interview questions have been found to be a useful and reliable tool for investigating science teachers' understanding of a system, the systems thinking skills and their teaching practices. In the current study, although the interview questions were developed in accordance with the literature and expert opinion, they may have some limitations in terms of the appropriateness of the interview questions. Therefore, question sets based on measuring systems thinking skills can be improved in terms of content, language and context of the questions.

5.4. Recommendations for Further Research

The current literature reveals a noticeable lack of research on the study of systems thinking and systems approach among in-service and pre-service teachers. In this research, the question sets used to measure teachers' systems thinking skills as a content-independent or dependent can be expanded beyond the skills being researched and added to the literature for systems thinking skills of in-service and pre-service teachers in different fields. Furthermore, the number of rubrics found in the literature for the assessment of systems thinking skills is quite low. For this reason, the development of rubrics that can measure systems thinking skills as a content independent measure will make significant contributions to the literature. In addition, examining teachers' systems thinking skills by having them prepare their own models based on the given question sets may provide a meaningful and holistic representation for teachers' systems thinking skills. Teachers' verbal responses to the questions may have influenced their level of demonstration of systems thinking skills. Some teachers may show their skills better by writing, drawing, or creating models. Moreover, it will be significant to understand how teachers deal with the concepts of "systems and systems models" that aiming new science standards and to investigate how system dynamics and systems thinking inform their practice. In accordance with the findings of this research, the systems thinking and system dynamics approach inherent in science education can be incorporated into teacher training curricula and workshops to improve teachers' competencies in terms of knowledge, skills, and practices and to spread them out in this era. Making the diffusion of system dynamics in education more dynamic over time is important for a sustainable future.

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APPENDIX A: INTERVIEW QUESTIONS

Cinsiyetiniz: Kadın / Erkek

Eğitim Durumuz: Lisans / Yüksek Lisans / Doktora

Çalıştığınız Kurum: Özel / Devlet

Mesleki Kıdeminiz: 0-5 yıl / 6-10 yıl / 11-15 yıl /16-20 yıl /21 yıl ve üzeri

Sistem düşüncesi hakkında daha önce eğitim aldınız mı? Evet/ Hayır

Bu eğitimi nereden aldınız?

Bu eğitimi ne zaman aldınız?

Kaç senedir uyguluyorsunuz?

Bu eğitimlerde kaç uygulamaya katıldınız? Eğitimin içeriği hakkında bilgi verir misiniz?

Sınıfınızda sistem düşüncesi yaklaşımını uyguluyor musunuz? Uyguladınız mı? Uygulama hakkında bilgi verir misiniz? (kaçıncı sınıf, hangi üniteler, kaç ders saati, içeriği vs.)

BÖLÜM 1

1. Bilimde bir sistemi nasıl tanımlarsınız?
2. Bir sistem örneği verebilir misiniz?
3. Bu sistemin özellikleri nelerdir?
4. Bir ortaokul fen öğretmeni öğrencilerin sistemleri anlamasını nasıl sağlar?
5. Su döngüsü bir sistem midir? Eğer öyleyse, neden? Değilse açıklayınız.
6. 8. sınıf öğrencilerine öğretilmesi gereken su döngüsünün tüm bileşenleri ve süreçleri nelerdir? Anlatınız.

7.Bu bileşenlerin ve süreçlerin birlikte çalışmasıyla ilgili başka eklemek istediğiniz bir şey var mı?

8. (Su döngüsü şeması gösterilir.) Bu şemanın su döngüsü ile nasıl ilişkili olduğunu açıklar mısınız? Bu şema sistem fikrini temsil ediyor mu? Nasıl?
9. Bir ortaokul fen öğretmeni olarak sistemleri öğretmekle ilgili zorluklar nelerdir?

BÖLÜM 2

Aşağıda senaryolarla verilmiş soruları cevaplayınız. Cevabınızı çizerek veya yazarak açıklayabilirsiniz.

1. Her zaman turistlerle dolup taşan İzmir şehrinde yeni bir sorun ortaya çıkıyordu: Fareler! Şehir, yavaş yavaş her şeyi yiyen farelerle doluyordu. Vatandaşları ve şehrin turistleri için endişelenen şehrin kibar belediye başkanı, fare sorununa bir çözüm bulması için yardımcısını çağırdı. Asistan, birkaç fare hariç çoğu farenin kokusuna çekildiği bir zehir veya böcek ilacı bulmak için çok çalıştı ve farelerin yedikten kısa bir süre sonra öldükleri bir zehir buldu. Farelerin sayısı o kadar artmıştı ki, belediye başkanı bu fikri anında onayladı.

Fareler verilen zehri yediler ve kısa süre sonra öldüler. İnsanlar şehirlerindeki ölü farelerden kurtulunca büyük bir kutlama düzenlediler ve nazik belediye başkanına çabaları için teşekkür ettiler. Fakat şehre dışarıdan başka fare girmemiş ve sorun çözülmüş gibi görünse de, şehrin yeniden farelerle dolması çok uzun sürmedi. Bu durumda farelerin sayısı neden tekrar arttı?

Cevap: Farelerin doğum oranını ve bu durum değişkenini yöneten oran nedeniyle fare sayısının hızla artacağı gerçeğini dikkate alınır.

2. Mert, yatırım yapmak için bazı gayrimenkul seçenekleri arıyordu. Emlakçının tekliflerinden ikisi ona ilginç geldi: ilk teklif, turistlerin ziyaret ettiği şehrin kalbine yakın, gayrimenkulün değerli olduğu küçük bir evdi, diğer teklif ise daha az pahalı ama gelişmekte olan bir mahallede büyük bir evdi. Siz Mert'in yerinde olsaydınız hangisini seçerdiniz? Yanıtınızı gerekçeleriyle birlikte açıklayınız.

Cevap: Zaman içindeki değişikliklerin dikkate alınmasını ve farklı seçeneklerin değerinin zaman geçtikçe farklı şekilde değişebileceğini içerir.

3. Bir çiftçi köyü, iki farklı böcek nedeniyle bir haşere sorunuyla karşı karşıyaydı: yeşil ve kırmızı böcekler. Yeşil böcekler, mahsullerin yanı sıra kırmızı böceklerle de beslendi ve böylece yeşil böceklerin popülasyonu kırmızı böcekleri aştı ve buna bağlı olarak da mahsul kaybının ana nedeni oldu. Köylüler, ekinlerini yeşil böceklere karşı korumak ve bir çözüm bulmak için toplandılar. Yeşil böcekleri yok etmek için özel bir böcek ilacı kullandılar; ancak bir süre sonra ekinleri hala yok oluyordu. Sizce bu

durumun gerçekleşme sebebi nedir? Yazarak veya çizerek anlatabilir misiniz?
Cevap: Çiftçilerin yeşil böcekleri öldürme kararının sorunun gelecekteki durumunu, yani kırmızı böceklerin sayısını etkileyeceğini içerir.

BÖLÜM 3

Fen bilgisi öğretmenlerine göre sistem düşüncesinin anlamını eksiksiz ve güvenilir elde edebilmek için aşağıdaki soruları mümkün olduğunca dürüstçe doldurmanızı rica ediyorum.

1. Sistem düşüncesini nasıl tanımlıyorsunuz?
2. Eğitimde sistem düşüncesi yaklaşımının ve sistem düşüncesi becerilerinin kullanılması gerektiğini düşünüyor musunuz? Nedenini açıklar mısınız? Neden kullanılması/kullanılmaması gerektiğini düşünüyorsunuz?
3. Sistem düşüncesi yaklaşımıyla bir konuyu öğretirken kullanılan yöntemler nelerdir? Açıklayınız.
4. Sınıflarınızda sistem düşüncesi yaklaşımını uyguluyor musunuz? Cevabınız evetse, hangi araçlarla nasıl uyguluyorsunuz? Açıklayınız.
5. Sistem düşüncesi araçlarını açıklayınız? Sistem düşüncesini nasıl öğretebiliriz?
6. Sınıflarınızda sistem düşüncesi araçları ile geliştirilmesi hedeflenen aşağıdaki becerileri hangi sıklıkla kullanıyorsunuz? Aşağıda belirtip nasıl uyguladığınıza örnek verebilir misiniz?

	Hiçbir zaman	Nadiren	Bazen	Sık Sık	Her zaman
Stok ve Akışlarla Düşünme Becerisi					
Dinamiklerle Düşünme Becerisi					
Nedensel Döngülerle Düşünme Becerisi					

7. Fen bilimleri dersi öğretim programında yer alan hangi konular sistem düşüncesi yaklaşımıyla öğretilebilir? Bu konular kaçıncı sınıf düzeyinde yer alıyor?
8. Bir konuyu sınıflarınızda sistem düşüncesi yaklaşımıyla nasıl uygulardınız? Bir örnek ile anlatabilir misiniz?
9. Sistem Düşüncesi için nasıl bir ölçme değerlendirme yapardınız? Neyi ölçmek isterdiniz?
Cevapladığınız için teşekkürler.

APPENDIX B: ANALYSIS OF INTERVIEW QUESTIONS ACCORDING TO RESEARCH QUESTIONS

	Interview Section 1
RQ.1	Q1
	Q2
	Q3
RQ.3	Q4
RQ.1	Q5
RQ.2	Q6
	Q7
	Q8
RQ.3	Q9
	Interview Section 2
RQ.2	Q1
	Q2
	Q3
	Interview Section 3
RQ.1	Q1
RQ.3	Q2
RQ.3	Q3
RQ.3	Q4
RQ.1	Q5
RQ.3	Q6
RQ.3	Q7
RQ.3	Q8
RQ.3	Q9

APPENDIX C: ETHICS COMMITTEE APPROVAL

Evrak Tarih ve Sayısı: 13.09.2022-86196

T.C.
BOĞAZİÇİ ÜNİVERSİTESİ REKTÖRLÜĞÜ
Fen Bilimleri ve Mühendislik Alanları İnsan Araştırmaları Etik Kurulu
(FMİNAREK)

Sayı : E-84391427-050.01.04-86196 13.09.2022
Konu : 2022/24 Kayıt no'lu başvurunuz hakkında

Sayın Dr. Öğr. Üyesi Gaye Defne CEYHAN
Matematik ve Fen Bilimleri Eğitimi Bölüm Başkanlığı - Öğretim Üyesi

"Science Teachers' Understanding of Systems and The Systems Thinking Skills and Their Teaching Practices" başlıklı projeniz ile Boğaziçi Üniversitesi Fen Bilimleri ve Mühendislik Alanları İnsan Araştırmaları Etik Kurulu (FMİNAREK)'e yaptığınız 2022/24 kayıt numaralı başvuru 05.09.2022 tarihli ve 2022/09 No.lu kurul toplantısında incelenerek etik onay verilmesi uygun bulunmuştur.

Bu karar tüm üyelerin toplantıya on-line olarak katılımıyla ve oybirliği ile alınmıştır. Onam mektubu tüm üyeler adına Komisyon Başkanı tarafından e-imzalanmıştır.

Saygılarımızla bilginize sunarız.

Prof. Dr. Tınaz EKİM AŞICI
Başkan

Bu belge, güvenli elektronik İmza ile imzalanmıştır.

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APPENDIX D: MoNE APPROVAL

T.C.
İSTANBUL VALİLİĞİ
İl Millî Eğitim Müdürlüğü

GÜNLÜDÜR

Sayı : E-59090411-44-62656174 03.11.2022
Konu : Anket ve Araştırma İzni (Büşra KARGA)

BOĞAZİÇİ ÜNİVERSİTESİ REKTÖRLÜĞÜNE
(Yazı İşleri Müdürlüğü)

İlgi : a) Yenilik ve Eğitim Teknolojileri Genel Müdürlüğünün 21.02.2020 tarihli ve 2020/2 sayılı genelgesi.
b) Valilik Makamının 01.11.2022 tarihli ve 62387432 sayılı oluru.

Valilik Makamının Anket ve Araştırma İzni konulu ilgi (b) oluru ve kullanılması uygun görülen ölçme araçlarının Müdürlüğümüzce mühürlenen örnekleri ekte gönderilmiştir.

İlgi (a) genelgenin 28. maddesinde; "Araştırma uygulama izni alan kamu kurum ve kuruluşları, uluslararası kuruluşlar, üniversiteler, sivil toplum kuruluşları ve araştırmacılar tamamladıkları bilimsel araştırma ile ilgili sonuç raporlarını, izni aldıkları ilgili birime çalışma bitiminden itibaren 30 gün içerisinde göndereceklerdir." ifadesi yer almaktadır.

Olur gereğince işlem yapılması ve araştırma sonuç raporunun ekte sunulan örneğe göre Müdürlüğümüz Strateji Geliştirme Şubesine gönderilmesi hususlarında gereğini arz ederim.

Ahmet BÜRLÜKKARA
İl Millî Eğitim Müdürü a.
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APPENDIX E: INFORMED CONSENT FORM

Öğretmen Bilgi ve Onam Formu

Araştırmayı destekleyen kurum: Boğaziçi Üniversitesi
Araştırmanın adı: Fen Bilgisi Öğretmenlerinin Sistem Anlayışı, Sistem Düşüncesi Becerileri ve Öğretim Uygulamaları
Proje Yürütücüsü/Araştırmacının adı: Assist. Prof. Gaye Defne Ceyhan**,** Büşra Karga
Adresi:
E-mail adresi:
Telefonu:
Sayın Fen Bilimleri Öğretmenleri,

Bu bilimsel araştırma Boğaziçi Üniversitesi Matematik ve Fen Bilimleri Eğitimi Bölümü Dr. Öğretim Üyesi Gaye Defne Ceyhan danışmanlığında ve yüksek lisans öğrencisi Büşra Karga tarafından "Fen Bilgisi Öğretmenlerinin Sistem Anlayışı, Sistem Düşüncesi Becerileri ve Öğretim Uygulamaları" adı altında yürütülmektedir. Bu araştırmanın amacı, yarı yapılandırılmış görüşme soruları ile fen bilimleri öğretmenlerinin bir sistemi ve sistem düşüncesi yaklaşımını nasıl tamamladıklarını ve ortaokul fen bağlamlarında sistem düşüncesi öğretimi için uygulamalarını nasıl açıkladıklarını incelemektir. Bu araştırmaya yardımcı olmanız için siz öğretmenlerimizi araştırmamıza davet ediyoruz. Kararınızdan önce araştırma hakkında sizi bilgilendirmek istiyoruz.

Bu araştırmaya katılmayı kabul ettiğiniz takdirde bireysel görüşme yapacağız. Araştırmanın hiçbir aşamasında sizden kimlik bilgileriniz istenmeyecektir. Bireysel görüşmeler 01.10.2022 ile 01.01.2023 tarihleri arasında yüz yüze gerçekleştirilecek ve onay veren katılımcılardan ses kaydı alınacaktır.

Bu araştırma bilimsel bir amaçla yapılmaktadır ve katılımcı bilgilerinin gizliliği esas tutulmaktadır. Bu araştırmaya katılmak tamamen isteğe bağlıdır. Katıldığınız takdirde çalışmanın herhangi bir aşamasında herhangi bir sebep göstermeden onayınızı çekmek hakkına da sahipsiniz. Araştırmadan çekildiğiniz takdirde tüm veriler silinecek ve herhangi bir araştırmada kullanılmayacaktır. Araştırmanın size bir risk oluşturması beklenmemektedir. Sizden ücret talep etmiyoruz ve size herhangi bir ödeme yapmayacağız/ödül vermeyeceğiz.

Bilimsel araştırma hakkında ek bilgi almak istediğiniz takdirde lütfen Boğaziçi Üniversitesi Matematik ve Fen Bilimleri Eğitimi Bölümü Dr. Öğretim Üyesi Gaye Defne Ceyhan (e-mail:) veya araştırma yürütücüsü Büşra Karga iletişime geçiniz (e-mail:). Ayrıca bu araştırmadaki haklarınız ile ilgili daha fazla bilgi almak için Boğaziçi Üniversitesi Fen Bilimleri ve Mühendislik Alanları İnsan Araştırmaları Etik Kurulu'na (FMINAREK) fminarek@boun.edu.tr mail adresinden danışabilirsiniz.

Eğer bu bilimsel araştırma çalışmasına katılmayı kabul ediyorsanız, lütfen bu formu imzalayıp kapalı size verilen zarf içerisinde bize geri verin.

Ben, (katılımcının adı) ...., yukarıdaki metni okudum ve katılmam istenen çalışmanın kapsamını ve amacını, gönüllü olarak üzerime düşen sorumlulukları tamamen anladım. Çalışma hakkında soru sorma imkânı buldum. Bu çalışmayı istediğim zaman ve herhangi bir neden belirtmek zorunda kalmadan bırakabileceğimi ve bıraktığım takdirde herhangi bir ters tutum ve olumsuzluk ile karşılaşmayacağımı anladım.

Bu koşullarda söz konusu araştırmaya kendi isteğimle, hiçbir baskı ve zorlama olmaksızın katılmayı kabul ediyorum.

Bu koşullarda söz konusu araştırmada gerçekleştirilen bireysel görüşmede ses kaydı alınmasını kabul ediyorum.

Formun bir örneğini aldım / almak istemiyorum (bu durumda araştırmacı bu kopyayı saklar).
Katılımcının Adı-Soyadı:...
İmzası:...
Adresi (varsa Telefon No, Faks No):...
Tarih (gün/ay/yıl):...../......./.............

APPENDIX F: REVISED SYSTEMS THINKING RUBRIC

Levels	% over the total number of components & processes/relations	Description	Examples
Novice Level (Level 0)	0-24%	No response OR indication of not knowing. Components/processes/relations not identified. 0-24 % of component or process may be included, but indicates not knowing (i.e. "I don't know about global warming")	I have no clue or it seems it should be that way
Recognition Level (Level 1)	25-49%	identification of 25-49 % of component or a process/relations -OR identification of a pattern in the system -AND no explanation of relationship between components or processes	There is no beginning or end to the water cycle a cycle constantly flows or continuous cycle Always the same amount of water on earth (none is gained or lost)
Beginning Level (Level 2)	50-74%	identification of 50-74 % of components or processes/relations of the system -BUT there is only an indication of one directional cause and effect relationships between components or processes (A causes B) -OR recognition of an interaction between only two components	(A) evaporation is constantly going, therefore there is no increase in the amount of (B) water acquired (A causes B) Example (A) polar ice caps are melting due to (B) global warming B causes A (one directional) Example of recognition of an interaction between two components Water seeps into ground
Intermediate Level (Level 3)	75-100%	identification of 75-100 % of components or processes/relations of the system -AND interaction involves at least two or more components -OR recognition of an multiple interaction between more than two components	The (A) water (B) evaporates (C) ocean water is rising due to (D) global warming Example (A) rivers do flow into the (C) ocean but because of (D) evaporation the levels are mainly constant