EXPLORING THE INCLUSION OF THE SYSTEMS THINKING APPROACH IN THE TURKISH MIDDLE SCHOOL SCIENCE CURRICULUM AND TEXTBOOKS

by

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ABSTRACT

EXPLORING THE INCLUSION OF THE SYSTEMS THINKING APPROACH IN THE TURKISH MIDDLE SCHOOL SCIENCE CURRICULUM AND TEXTBOOKS

The comprehension of intricate systems, encompassing their behavioral and structural intricacies, represents a significant challenge for both educators and students. To cope with this complexity, the systems thinking (ST) approach, which facilitates an understanding of interdependencies and effective problem-solving, emerges as a pivotal element. In the science education, ST fosters problem-solving abilities, which are of paramount importance in overcoming contemporary challenges. Therefore, it is of paramount importance to emphasize the ST integration into formal education. This study examines the extent to which systems thinking (ST) is included in the Turkish middle school science curriculum and textbooks from fifth to eighth grade. A rubric was developed to examine the curriculum and textbooks in terms of their explicit emphasis on ST. The findings of the study revealed that ST lacks explicit emphasis and a comprehensive integration is needed. Although interconnections between ST components are emphasized in the curricula and textbooks, it is evident that further integration with ST tools, particularly in relation to feedback mechanisms and system structures, is required. Additionally, there are deficiencies in the representation of stocks and flows and an incomplete understanding of hierarchical systems. Although not currently included, the study demonstrates the potential for practical ST integration in science education. The study offers guidance for policy makers and curriculum developers and contributes to the existing literature on the integration of ST.

ÖZET

TÜRK ORTAOKULU FEN MÜFREDATI VE DERS KİTAPLARINDA SİSTEM DÜŞÜNCESİ YAKLAŞIMININ YER ALMASININ İNCELENMESİ

Davranışsal ve yapısal incelikleriyle karmaşık sistemleri anlamak, hem öğretmenler hem de öğrenciler için bir zorluk teşkil etmektedir. Bu karmaşıklığın üstesinden gelmede, karşılıklı bağımlılıkların anlaşılmasını ve etkili problem çözmeyi sağlayan sistem düşüncesi (SD) yaklaşımı önemli bir unsur olarak ortaya çıkmaktadır. Fen eğitimi bağlamında ise SD, çağdaş zorlukların üstesinden gelmek için hayati önem taşıyan yaratıcılık ve problem çözme becerilerini geliştirir. Bu sebeple, SD'nin örgün eğitime entegrasyonunu vurgulamak önemlidir. Bu çalışma, beşinci sınıftan sekizinci sınıfa kadar Türkiye'deki ortaokul fen müfredatında ve ders kitaplarında SD'ye yer verilip verilmediğini incelemektedir. Çalışma, SD'nin müfredat ve ders kitaplarına ne ölçüde dahil edildiğini incelemek için bir dereceli puanlama anahtarı geliştirilmiştir. Çalışma bulguları, müfredat ve ders kitaplarında SD'ye yönelik açık bir vurgu bulunmadığını ve kapsamlı bir entegrasyonun gerekliliğini ortaya çıkarmıştır. SD bileşenlerinden ara bağlantılar vurgulanırken, özellikle geri bildirim mekanizmaları ve sistem yapıları ile ilgili olarak SD araçlarıyla daha fazla entegrasyona ihtiyaç olduğu açıktır. Ayrıca, stok ve akışların gösterilmesi ve hiyerarşik sistemlerin anlaşılması konusunda eksiklikler bulunmaktadır. SD'nin entegrasyonu, analitik becerilerin ve disiplinler arası düşüncenin geliştirilmesi açısından büyük önem taşımaktadır. Şu anda dahil edilmemiş olsa da, çalışma fen eğitiminde pratik SD entegrasyonu potansiyelini göstermektedir. Çalışma, politika yapıcılar ve müfredat geliştiriciler için rehberlik sunmakta ve SD"nin entegrasyonuna ilişkin mevcut literatüre katkıda bulunmaktadır.

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LIST OF ACRONYMS/ABBREVIATIONS

ACARA	Australian Curriculum, Assessment and Reporting Authority
BOTG	Behavior over Time Graph
CM	Concept Map
MoNE	Ministry of National Education of Turkey
NGSS	Next Generation Science Standards
NRC	National Research Council
OECD	Organisation for Economic, Co-operation and Development
SDG	Sustainable Development Goal
SERC	Science Education Resource Center at Carleton College
SFD	Stock-flow Diagram

1. INTRODUCTION

In the changing and developing world, especially in recent years, rapid economic, social, and technological changes have been experienced. Changes also bring complex thoughts and ideas. Many events and situations that we encounter in our daily lives are interrelated and complex. Complexities based on cause-effect relationships are highly dynamic. It requires considering numerous variables and progressing with a broad perspective to understand the problems holistically. For example, environmental issues, including the climate change crisis, problems such as traffic and pollution, and various economic, social, and political difficulties, are not issues that we can make sense of and solve from a single point of view. To cope with the complex and difficult-to-solve problems encountered in our lives, it is necessary to look at the picture that is lived in from afar, not from a close one, and to embody the big picture (Senge, 1990). It is also critical to have high-level thinking skills to embody abstract concepts.

In addition, there is a need for a more comprehensive framework of thought for solving the problems around us. At this point of need, the systems thinking (ST) approach provides a broad perspective in contrast to insufficient foresight from a narrow point of view and difficulties in problem-solving (Daellenbach *et al.*, 2012). The concept of a system, which has been extensively explored across various disciplines, emphasises the interdependence of its elements in producing a coherent whole. The concept of system is sustained through interactions, as noted by Pratt (1978), O'Connor and McDermott (1997), Kim (1999), Penner (2000), Assaraf and Orion (2005b), and Arnold and Wade (2015). The ST approach aligns with the concept of a system, emphasizing the dynamic interaction between individuals and their environment. It contributes to the understanding of systems as interconnected entities producing coherent wholes (Fischer and Yan, 1998).

As modern science advances, there is an increasing amount to be taught and learned (Verhoeff *et al.*, 2018). Rapid developments also require the presentation of

interrelated concepts and skills that will guide lifelong learning as a whole (National Research Council, 2012; 2013). By providing a holistic perspective on requirements, ST makes sense of complex processes and focuses on relationships within complexity by considering differences (Assaraf and Orion, 2005b; Daellenbach *et al.*, 2012; Mahaffy *et al.*, 2019; Meadows, 2008). Examining a whole's behavior by considering the parts' interactions is critical since focusing only on parts or a part of the whole may overlook essential relationships and connections between parts (Orgill *et al.*, 2019). ST's complementary stance on understanding the behavior of complexity is a guide to the challenges that future generations will face today and in the future (Meadows, 2008). ST also provides a framework for knowledge-building on scientific concepts to examine the complex world around us (Caulfield and Maj, 2001). ST provides a new perspective on scientific concepts (Hammond, 1997) and influences the ways of doing science by depicting the problem and how science is used to construct a solution (Edson *et al.*, 2016). ST is a source of motivation for individuals to develop coping skills by emphasizing awareness and sustainable solutions instead of uncertainties about the future in our world, where every moment becomes more complex than the previous one (Blatti *et al.*, 2019). ST makes the invisible visible by supporting different ways of thinking and bringing the unexamined focus to light, allowing looking at current problems from afar (Assaraf and Orion, 2005b; Mahaffy *et al.*, 2019).

In this context, ST is a critical focus for topics frequently encountered in science education. For instance, socioscientific issues such as climate change, genetically modified foods (GMFs), genetic engineering, COVID-19, and vaccines are, by their nature, intensely discussed in society and contain opposing views. There are difficulties in the knowledge-building process of students' learning in these subjects (Ceyhan *et al.*, 2021). ST facilitates interdisciplinary thinking and enables students to negotiate more productively on issues that create dilemmas (Delaney *et al.*, 2021). In this regard, the importance of having a basic understanding of ST cannot be underestimated. It is said that the inclusion of ST in different curricula in terms of seeking sustainable solutions to problems by developing a holistic perspective and having abstract thinking skills of students makes learning stronger, and there is a need for the integration of ST into the

education and curriculum (Aubrecht *et al.*, 2019; MacDonald *et al.*, 2022; Richmond, 1990).

The formal curriculum that aims to raise scientifically literate students relies heavily on school science (Hernthaisong *et al.*, 2015; Smart *et al.*, 2020). In science education, ST emerges as an approach that can integrate many subjects into the science curriculum (Blatti *et al.*, 2019; Verhoeff *et al.*, 2018; Yoon, 2018). Framing science education with the ST approach helps developing scientifically literate individuals who can think productively and solutions-oriented by encouraging lifelong learning and allowing individuals to apply their problem-solving skills to current problems (Blatti *et al.*, 2019). Considering the science curriculum in many countries, the curriculum does not explicitly aim to provide skills for ST (Finnish National Board of Education, 2016; Ministry of National Education of Turkey (MoNE), 2018; Ministry of Education, 2015; Ministry of Education, Singapore, 2015a; Organisation for Economic Co-operation and Development (OECD), 2018; The New Zealand Curriculum, 2007). On the other hand, the document published by the National Research Council (NRC) in 2015 on the vision of the K-12 science education framework stated that systems thinking and modeling should be further integrated into science education to explain concepts and provide a context for new ideas (NRC, 2015).

In this context, there are many studies in the literature that aim to provide students with ST skills and include the integration of subjects in the science curriculum with ST (Ateskan and Lane, 2018; Eilam, 2012; Gilissen *et al.*, 2020; Ke *et al.*, 2020; Ormancı *et al.*, 2018; Roychoudhury *et al.*, 2017; Sterman and Sweeney, 2002; Sweeney and Sterman, 2007).

In this context, both quantitative and qualitative studies on ST conducted with different groups revealed parallels that students and science teachers have a conclusion that there is a lack of understanding and integration of ST in different aspects, such as understanding the structure of a system and its dynamic behavior (Ateskan and Lane, 2018; Eilam, 2018; Gilissen *et al.*, 2020; Roychoudhury *et al.*, 2017), identifying

stock-flow relationships (Sterman and Sweeney, 2002; Sweeney and Sterman, 2007), recognizing feedback mechanisms (Eilam, 2012; Roychoudhury *et al.*, 2017), and making generalizations (Ormancı *et al.*, 2018).

It is vital for students to be able to detail the complex systems that exist in various contexts in their lives, reveal the relationships, and understand the systems' behavior in developing high-level skills. For students to develop a holistic perspective, it is also essential for teachers to see the whole by combining the parts (Delaney *et al.*, 2021). ST strengthens the ability to see the big picture and think and act multidimensionally for any problem encountered in learning and our daily lives (Hernthaisong *et al.*, 2015). Therefore, it is also a significant issue for science teachers to include the ST in the classroom and curriculum to be studied.

Additionally, textbooks play a significant role in integrating the curriculum into lessons and are learning resources actively used to support and advance the learning process (Torkar *et al.*, 2022). While textbooks are the books that teachers use as the main source of information, they also play an essential role in transferring the curriculum to the students in an appropriate way (King, 2010). Considering the importance of using textbooks, it is crucial that the ST approach is adequately included in science textbooks. There are many studies in the existing literature on the extent to which science teachers, pre-service teachers, and students adopt the ST approach and to what extent they have developed ST skills (Ateskan and Lane, 2018; Eilam, 2012; Gilissen *et al.*, 2020; Ke *et al.*, 2020; Ormancı *et al.*, 2018; Roychoudhury *et al.*, 2017; Sterman and Sweeney, 2002; Sweeney and Sterman, 2007).

On the other hand, studies on the extent to which the current science curriculum and science textbooks in Turkey include the ST are also of great importance in revealing the implemented science curriculum and the contents of the science textbooks (Chiu *et al.*, 2019; Karaarslan Semiz and Teksöz, 2023; Skamp and Green, 2022; Şahingöz, 2021). Regarding the importance of raising systems thinkers and the role of curriculum and textbooks in education, as mentioned above, it is crucial to reveal how ST is addressed

in the curriculum and textbook. In this context, this study aimed to shed light on the ST inclusion of the science education curriculum and the aims, objectives, and content of science textbooks.

1.1. The Purpose of the Study

The study aims to examine how systems thinking is included in the Turkish middle school science curricula and science textbooks.

1.2. The Research Questions

(i) How is the systems thinking (ST) approach included in Turkish middle school science curricula and textbooks?

To what extent does a fifth-grade science curriculum and textbook include the ST approach?

To what extent does a sixth-grade science curriculum and textbook include the ST approach?

To what extent does a seventh-grade science curriculum and textbook include the ST approach?

To what extent does an eighth-grade science curriculum and textbook include the ST approach?

1.3. Significance of the Study

The world is complex; situations or events we may encounter at any time in our daily lives have an invisible and visible side. The systems thinking (ST) approach, which can make the complexity and abstraction solvable and concrete, enables the development of a deep and holistic understanding of a particular subject, ensuring the integration of information with each other and interpreting the subjects with their dynamics. ST approach is based on the realization that the study of system components and their behavior in isolation is insufficient; instead, the dynamic interaction of

parts must be considered in solving problems (Lynch *et al.*, 2021). A comprehensive understanding necessitates the mastery of the higher-order cognitive processes (Hung, 2008).

Being a systems thinker and having ST skills is essential not only in education but also in our everyday lives. The ST approach is structured to reduce complexity by supporting new and deeper insights (Forrest, 2008). Reducing complexity is important in making sense of the uncertainty that may exist in the nature of complexity and making it simpler and more accessible by assimilating complexity (Senge, 1990). On this Earth, where we have evolved and changed since the Big Bang, many authors agree that we need the ST approach to increase the applicability and cope with the complexity of the future (Arnold and Wade, 2015; Meadows, 2008; Plate, 2010; Richmond, 1990; Senge, 1990). The need for ST and systems thinkers is increasing to overcome the growing problems surrounding all areas of life (Arnold and Wade, 2015).

In science education, ST increases students' creativity and productivity by supporting various skills such as analytical, abstract, and critical thinking for problem-solving (Blatti *et al.*, 2019). The ST approach searches for sustainable solutions, one of its goals (Arnold and Wade, 2015), and facilitates student learning by making the arguments presented and discussions concrete in the search for solutions (Fisher and Systems Thinking Association, 2023; Potash, 1994). In addition, the ability to make sense of complex systems and the development of ST skills are crucial to strengthening scientific literacy (Assaraf and Orion, 2005b; Sabelli, 2006). Nevertheless, it has been demonstrated that by the conclusion of the K-12 educational programme, the majority of students have not attained the level of comprehension necessary to comprehend complex phenomena (Assaraf and Orion, 2005a; Eilam, 2012; Fortus *et al.*, 2019; Gilissen *et al.*, 2020; Ke *et al.*, 2020; Roychoudhury *et al.*, 2017; Sterman and Sweeney, 2002; Sweeney and Sterman, 2007).

Studies of middle school and high school science teachers' understanding of ST have also found similar results, indicating that teachers lack sufficient knowledge about

ST and encounter difficulties in incorporating it into their teaching (Ateskan and Lane, 2018; Karaarslan Semiz and Teksöz, 2020; Kim and Lee, 2019; Lavi and Dori, 2019). ST is a method of analysis that enables students and teachers alike to develop a holistic view of complex and systematically evolving problems. Therefore, it is recommended that ST be included in the learning and teaching process and continuously integrated throughout the learning environment (Assaraf and Orion, 2005b; Fisher and Systems Thinking Association, 2023).

One of the key elements for ST integration is the curriculum and textbooks. For teachers to develop a deep understanding of the ST approach and incorporate it into their teaching, the curriculum content they use as a source and the textbooks they use in the classroom should reflect ST appropriately. A curriculum is a tool that provides content for educational policies and allows them to be consistent (Tedesco *et al.*, 2014). The inclusion of ST, especially in the science curriculum, allows students to establish a closer relationship with the scientific method by revealing interdisciplinary thinking (Blatti *et al.*, 2019).

Textbooks, on the other hand, are tools used extensively in learning and teaching, helping students build a solid foundation for further learning (Oates, 2014). Therefore, it is necessary to examine the curriculum and science books for all middle school levels to get a general and big picture of the inclusion of ST in middle school science curricula and textbooks. The studies on the presence of ST characteristics in the science curriculum revealed that ST is only partially integrated into the curriculum, and the improvements are needed to facilitate ST integration (Chiu *et al.*, 2019; Karaarslan Semiz and Teksöz, 2023; Şahingöz, 2021).In addition, studies of ST are progressing more context-based from a domain-specific point of view (Assaraf and Orion, 2005a; Assaraf and Orion, 2005b; Doganca Kucuk and Saysel, 2018; Eilam, 2012; Lammi, 2011; Roychoudhury *et al.*, 2017; Sterman and Sweeney, 2002; Yoon, 2008). This study was conducted as a domain-general study because it revealed the extent to which ST was integrated into the currently implemented middle school science curricula and textbooks by examining all middle school curricula and textbooks. The reason why

the study was chosen as domain-general rather than domain-specific is that it aims to reveal ST inclusion as a whole by examining the entire content of middle school science curricula and textbooks. Therefore, this study contributes to the literature by providing a picture of ST inclusion for policymakers and stakeholders. It examines the ST inclusion and provides necessary recommendations, if any.

Additionally, a rubric was developed for the analysis, which may provide a framework for reviewing textbooks for different subjects and grade levels. The findings and recommendations of this study contribute to curriculum developers, authors, and publishers who prepare textbooks to include ST in the textbook preparation process.

1.4. The Operational Definitions of the Key Terms

- Systems Thinking; Systems thinking is the art and science of making reliable inferences about system behavior by developing an increasingly deep understanding of the underlying structure (Richmond, 1994, p.6). In this study, considering the reflections of ST in education, ST is defined as a holistic approach that gains different perspectives to benefit students' learning and reduces the complexity of the world by thinking abstractly.
- Curriculum; National Research Council (1999) defines a curriculum as a programme comprising the subject matter to be taught, its organization, balance, and delivery in the classroom over time. The curriculum is a purposeful and methodical selection of values, knowledge, and abilities that establishes the structure of teaching, learning, and evaluation processes by providing answers to concerns about what, why, when, and how students should learn (National Research Council, 1999).
- Textbook; A textbook is a tool that is used in the study of a subject (Merriam-Webster's online dictionary, 2023). Textbooks used for learning and teaching purposes are a source of information used to create effective learning (Gak, 2011). In this study, the textbook is defined as a resource that enables teachers and students to follow the curriculum and plays an effective role in learning.

- Content Analysis; In this study, content analysis is operationally defined as the examination of how Turkish middle school science curricula and textbooks include systems thinking.

2. LITERATURE REVIEW

This chapter includes the study's theoretical background and existing studies in the literature. In the first part, systems and ST are defined in detail. In the second part, ST tools are described. The frameworks and models in the literature for ST and ST skills are explained in the third part. In the last part, the place of ST in science education is included.

2.1. System and Systems Thinking

To elaborate on ST, it is necessary to identify the system first. A system is a group of items that interact or are interdependent regularly to produce a coherent whole (Merriam-Webster's online dictionary, 2022). The concept of a system has been studied from a variety of perspectives because of its wide range of applications (Kim, 1999; O'Connor and McDermott, 1997; Penner, 2000) and has implications for a wide range of disciplines, including biology, management, communication, planning, philosophy, geography, economics, psychology, sociology, and politics (Pratt, 1978). The common point of the studies is that the system as a whole is a concept that continues to exist through the interactions of the parts (Assaraf and Orion, 2005b). The system and its components must serve a specific purpose for the interactive and interrelated components to be found (Assaraf and Orion, 2005b). Thus, the system consists of the elements, the specific purposes of the elements, the interconnections of these elements, and constant change (Arnold and Wade, 2015; Karnopp *et al.*, 2012). Starting from the universe, galaxies, stars, planets, the Earth, and every situation that is lived on the Earth contains different systems. A car, a house, a school, an ecosystem, or various organizations can be examples of systems that contain complex interconnections and consist of components that come together for a specific purpose. Systems are everywhere; every event, starting from the family and extending to society, consists of parts of a different system that have come together for a particular purpose. As a result of dynamic relationships, constant change is observed.

In addition to the system itself being a whole, the components of the system are also sub-wholes, i.e., each of the parts that depend on the system within the hierarchical structure of the system also forms a system in itself (Kresh, 2006). Different but interrelated systems interact to form a coherent whole in a single extensive system, creating the system's dynamics (Hmelo *et al.*, 2000). Being aware of the system's dynamics and understanding the system's mechanism makes it possible to predict the interaction between the elements that make up the system and the changes in the system (Tripto *et al.*, 2016).

Mastering system dynamics also helps to reveal system behavior (Hmelo *et al.*, 2020). System behavior expresses the dynamic mechanism of the system by revealing the functionality of the components in the system (Hmelo *et al.*, 2020). On the other hand, system behavior is much more than individuals can see easily (Hmelo *et al.*, 2020). The connection and interaction between some system components are invisible; therefore, it has an effect that makes it difficult to understand (Feltovich *et al.*, 1994). These invisible variables without concrete lines require the ability to explain the causality between these variables to understand the system's behavior (Hmelo *et al.*, 2020). To cite an instance, considering the systems in our body, each system has a specific task, and systems contain different organs and structures that perform these tasks. Suppose we remove one of these organs or structures from the system. In that case, that system cannot continue functioning for its intended purpose, and there will be problems in performing many different tasks, including other systems. Additionally, there are behaviors of the systems in our body that cannot be seen with the naked eye but whose effects we can feel, such as the substances circulating in our blood and veins, the levels of our hormones, and their effects on the body.

For this reason, it is necessary to examine in detail the parts of systems that develop in a complex and dynamic way and the connections between them. An attempt to comprehend the system by disregarding its constituent elements will result in a superficial understanding of the process (Arnold and Wade, 2015; Meadows, 2008). In order to focus on the functions and behaviors of the system, it is crucial to concretise

abstract concepts and to be aware of how the functions are performed (Meadows, 2008). At this point, ST is the ability to understand the working mechanism of systems and how changes within the system affect the system (NRC, 2010). It is an approach that uses abstract thinking skills to understand the interaction of different elements (NRC, 2010).

ST allows the problem to be examined in detail to facilitate the complex process of focusing on the problem, addresses the different nature of each problem and the individual from all levels, and helps develop thoughts specific to each perspective (Senge, 1990). Comprehending the structure of systems and the components of the system within the context of a holistic framework by analyzing the associations of feedback mechanisms and considering the dynamic changes in systems is defined as ST (Arnold and Wade, 2017; Meadows, 2008; Sweeney and Sterman, 2000). Sweeney and Sterman (2000) defined ST as "the ability to assess and represent dynamic complexity" (p. 2). Senge (1990) described ST as an approach that considers mutual relations instead of seeing the whole and allows one to see changes as a model. Senge (1990) stated that the approach of ST is a school of thought that teaches us to recognize the relations between system parts and integrate these relations into a whole.

Senge proposed ST as a framework that determines the constantly changing phenomena around us in a changing world and can observe the relationships between concepts (Senge, 1990). Similar to the example of the systems in the human body, it is necessary to focus on the interconnections of the systems and see the sum of the parts as a whole instead of observing the situations we encounter all around us from a limited perspective. Each piece is like a domino; when an element, a point, or a part of the system is overlooked, such as when a stone falls, the whole domino is destroyed and causes the entire system to fail to function. Therefore, ST has a critical role in understanding complex problems. ST provides a framework for multi-directional relations and making sense of complexities in conjunction with higher-order thinking skills (Assaraf and Onion, 2005b; Behl and Ferreira, 2014).

Individuals have difficulty making sense of the complex structure and dynamism of systems (Hmelo *et al.*, 2000; Assaraf and Orion, 2005a). This difficulty manifests itself in young children and adults (Assaraf and Orion, 2005a; Kali *et al.*, 2003; Sweeney and Sterman, 2000). One of the reasons for the difficulty of learning complex systems is that individuals experience the learning process of systems starting with isolated concepts, and the whole system is emphasized before the mutual relations are introduced (Feltovich *et al.*, 1993). Understanding the intricate effects of systems in all areas of our lives is a critical step in what science is about understanding science, doing scientific analysis, and applying scientific practices (Assaraf and Orion, 2005b; Hmelo *et al.*, 2000). Furthermore, although understanding a system's dynamics is a challenging process for all ages, it has been observed that a deep understanding can be achieved even in young children (Penner, 1997).

Individuals' processes of perceiving systems as coherent wholes and understanding their interrelationships with other systems are also based on scientific knowledge and cognitive skills (Assaraf and Orion, 2005a; Kali *et al.*, 2003). For this reason, Penner (2000) stated that science educators should organize their teaching about systems to strengthen their students' ability to apply what they have learned in a real-world context. Penner (2000) also emphasized that domain-specific knowledge should guide teaching about systems. Kali *et al.* (2003) also pointed out that ST is required to provide a deep understanding of systems in a real-world context.

In conclusion, ST elucidates the intricate dynamics of interconnected systems, highlighting their interdependence and the necessity of viewing them as coherent wholes. The insights gained through ST facilitate a deeper understanding of the complex behaviors and interactions within systems, thereby enabling the identification of solutions to real-world challenges. The integration of ST into educational curricula enables individuals to navigate and comprehend the complexities of our interconnected world. It equips them with the analytical, adaptive, and innovative skills necessary to thrive in an ever-changing environment. As it continues to explore the intricacies of systemic understanding, ST emerges as a crucial framework for navigating the multifaceted nature

of our reality. It provides a foundation for adopting holistic approaches to problem-solving and decision-making in diverse domains.

2.2. Curriculum and Textbooks

Many studies have been conducted on the definition of education from past to present (Chazan, 2022; Curtis *et al.*, 2013; Marshall, 2006; Matheson, 2014; Peters, 1967). Most of these studies agree that education aims to gain certain skills, especially transferring knowledge, developing various characteristics, and achieving different goals according to the field (Marples, 1999; Peters, 1967). The curriculum is a deliberate and systematic selection of knowledge, skills, and values that determines how teaching, learning, and evaluation procedures are organized by answering questions like what, why, when, and how students should learn (National Research Council, 1999). Within the scope of the curriculum, one of the fundamental elements that form the basis of education is the textbook. Textbooks are essential learning materials, especially for individuals studying in disadvantaged urban areas with limited resources (Smart *et al.*, 2020). Improvements in textbooks can remove barriers to learning, improve practice, guide teachers, and strengthen their teaching (Ensor *et al.*, 2002; Smart, 2019).

Especially in the 21st century, education, like all other fields, is highly affected by a rapidly developing and changing world. To adapt to rapid development and change, many different educational reforms and arrangements were made, and the most comprehensive version of these reforms may be seen in curricula (Gouëdard *et al.*, 2020). For example, New Zealand's recent curriculum reform aims developing individuals who make connections, participate in active learning, and are committed to lifelong learning (The New Zealand Curriculum, 2007). Estonia's latest curriculum reform includes a textbook revision on critical thinking, self-assessment skills, and lifelong learning (Ministry of Education and Research, Estonia, 2014). Singapore has adopted a participatory approach that progresses in line with the feedback and suggestions of stakeholders such as teachers, principals, and department heads (Ministry of Education, Singapore, 2012). In this reform, schools develop curricula aligned with national guidelines to

promote lifelong development, develop cognitive and metacognitive skills, continuously continue active learning, and advance critical thinking and creativity skills (Ministry of Education, Singapore, 2012). Finland implemented a curriculum reform in 2016 and adopted a bottom-up approach in which everyone, from students to policymakers, could have a say (Finnish National Board of Education, 2016). The reform aims to strengthen meaningful learning and raise individuals who can solve problems and evaluate themselves in the solution process (Finnish National Board of Education, 2016). South Korea has developed a curriculum emphasizing creative and critical thinking, collaboration, and communication (Ministry of Education, 2015). The reform, which supports teachers in terms of their professional development, a standardized curriculum aimed at improving scientific literacy is discussed (Ministry of Education, 2015). The Japanese curriculum reform involves teachers determining and updating teaching methods by collaborating with academic literature. By emphasizing self-reflection, it is aimed to shape students' differences in a way that allows them to develop (OECD, 2018).

Although curriculum reforms vary depending on the social, cultural, and economic situation of each country, changes in contexts, such as adapting students to 21st-century skills, developing the ability to solve problems, and adapting to an uncertain world that is constantly changing, appear as common points (Gouëdard *et al.*, 2020). To remain relevant in the modern era, educational curricula must be flexible and responsive to the rapid changes that occur in society; traditional approaches to teaching are no longer sufficient (Ogburn, 2022). Curriculum reforms, especially for the 21st century, aim to ensure that students have specific skills that will make it easier for them to navigate a constantly changing and uncertain world (Gouëdard *et al.*, 2020).

The most current global regulation is included in the OECD Learning Compass 2030. The framework offers a holistic and comprehensive approach to addressing the challenges associated with the development of the curriculum (OECD, 2020). The OECD Learning Compass 2030 includes multiple nested systems within this framework. These systems refer to the changing and developing multiple systems that directly and

indirectly affect individuals throughout their lives (OECD, 2020). This system was prepared with a unifying perspective, considering the student, teachers, family, and all other stakeholders to strengthen learning (OECD, 2020).

In connection with curricula, incorporating ST into learning and teaching is essential for schools as the formal educational setting, although learning develops everywhere and in all forms. Schools should include components such as curriculum, teachers, teaching, textbooks, assessment and evaluation, and classroom management to implement the ST approach (Hernthaisong *et al.*, 2015). The curriculum, one of the components, is one of the comprehensive versions of the reforms made to keep up with the rapid changes and developments (Hernthaisong *et al.*, 2015; Smart *et al.*, 2020). The significant impact of curriculum and textbooks on learning and teaching is a point to consider when integrating ST into education. In a framework developed by Orion to understand world systems for science curriculum, it was emphasized that understanding the existing subsystems in the world as a whole is essential for humanity to understand the level of influence on people's daily lives (Orion, 2002). Although the ST approach is not explicitly integrated in different countries curricula today, in a document published by Next Generation Science Standards (NGSS) in 2015 on how science education will change, ST and modeling are included in the K-12 science education framework vision to create a context for the ideas while explaining the phenomenon of science education (NGSS, 2015). It is stated in the document that ST and modeling will take more place in science education (NGSS, 2015). In a study examining the United Kingdom National secondary school biology curriculum, it is stated that subjects such as living things and ecosystems, biological diversity, matter cycles, cells, and organisms consist of complex systems that are intertwined with each other, and ST develops the ability to reason about systems by organizing these systems (Moore-Anderson, 2023). The study also states that the physiological subjects and biology curriculum in secondary school should be integrated with the ST approach and that ST is an approach that should be taken as a basis for the curriculum content (Moore-Anderson, 2023).

The Australian Curriculum for Science, as outlined by the Australian Curriculum, Assessment and Reporting Authority (ACARA), emphasizes the importance of interdisciplinary thinking and understanding system interactions to analyze complex systems (ACARA, 2017). The application of ST in this context is also highlighted (ACARA, 2017). It is stated that it is necessary for students to understand feedback loops that arise from cause-effect relationships and to comprehend systems at both macro and micro levels to solve problems within these systems (ACARA, 2017).

Assaraf and Orion stated that activities emphasizing knowledge integration throughout the learning process of complex systems should be included in science teaching. They also underlined that the framework for ST should be arranged in early childhood and primary education curricula, as the components of ST and related skills are considered high-level thinking skills (Assaraf and Orion, 2005b). Assaraf and Orion (2005b), further, mentioned that a comprehensive curriculum plan should be prepared as a basis and preparation for the following years since students who can have ST abilities in their early years can reach higher levels of ST as the grade levels progress. Science education is closely related to ST in the context of developing the capacity of individuals to produce solutions to cope with unforeseen challenges in the future on controversial issues that require society to make decisions, such as socioscientific issues and sustainable development (Aubrecht *et al.*, 2019; Chiu *et al.*, 2009; Roychoudhury *et al.*, 2017; Tümay, 2023). On the other hand, not integrating ST into education causes difficulty in assimilating and displaying ST skills in students (Budak and Ceyhan, 2023; Semiz and Teksöz, 2019).

Considering the importance of the curriculum and the reflection of textbooks on science education, revealing the ST inclusion of the science curriculum and science textbooks may be a guide for integrating ST into science education. The integration of ST into science education enables individuals to focus on complex problems by emphasizing how and in what way different parts are integrated and the interactions between the parts (Orion, 2002; Plate and Monroe, 2014). In connection with this, science education content emerges as an area where ST skills should be acquired (Armstrong

et al., 2009; Hurst, 2020; Moore-Anderson, 2023). Therefore, it is remarkable that ST is integrated into the curriculum and textbooks used in science learning and teaching. The following section presents the ST tools to be used to examine the representation of ST in the curriculum and textbooks.

2.3. Systems Thinking Tools and the Iceberg Analogy

ST tools refer to the instruments utilized to implement the ST approach (Blokland and Reniers, 2020; Nuhoğlu *et al.*, 2021). Therefore, an integrated analysis of the Turkish middle school science curricula and textbooks for ST inclusion with a rubric containing ST tools allows for a clear indication of the extent to which the curriculum and textbooks represent ST. Below, the ST tools used in the literature are detailed about the iceberg analogy, which is used to reveal systems thinking (ST) characteristics and to make sense of complex events in our environment by guiding individuals (Blokland and Reniers, 2020; Nuhoğlu *et al.*, 2021).

2.3.1. Behavior over Time Graph (BOTG)

Some of the observed and perceived events are concretely similar to the visible part of the iceberg above the water (Blokland and Reniers, 2020). The invisible part of the iceberg, which forms the bulk of the iceberg and remains below the water's surface, corresponds to the tools provided by ST. As it goes deeper into the water, the first element encountered is behavior over time graphs (Göktepe, 2022; Nuhoğlu *et al.*, 2021). The dynamics of changing elements in the system are captured by the time graph along the behavior (Fisher and Systems Thinking Association, 2023). Behavior over time graphs represent the change caused by events. It provides information about the patterns of events that change over time and the behavior of the change. Change over time refers to the change of the elements of the system over time. Considering their relations, the elements affect each other and constantly change. This change can be visualized with line charts and generated by increase or decrease (Göktepe, 2022). The graph's horizontal axis must represent the time, and the vertical axis must represent

the variable with its degree (Fisher and Systems Thinking Association, 2023). Graphs of behavior over time must be quantified to be plottable (Göktepe, 2022).

The systems thinker must have the ability to understand and interpret system behavior graphically in order to make sense of dynamic complexity (Sweeney and Sterman, 2000). In this context, BOTG helps to understand the system dynamics and linear and nonlinear relationships of system variables and to predict future situations related to the system by digitizing and visualizing the change of system variables over time (Monat and Gannon, 2015). For example, Turkey's population change in certain years can be taken as an example. The behavior over time graph of the population is determined by changes in birth and death rates over the years at different rates for various reasons.

2.3.2. Stock-Flow Diagrams (SFD)

As going deeper into the iceberg, the reasons for the changes begin to make sense. At this stage, individuals use their beliefs and assumptions, called mental models, to perceive changes and cause-and-effect relationships (Blokland *et al.*, 2020). Senge (1990) emphasized the relationship between individuals' mental models and ST and stated that those who think systemically can control the problem-solving process by organizing their mental models and managing their thinking processes. Forrester (2009) stated that students should use their mental models to ensure precision in analyzing system problems, and simulation models should be created to test their mental models. In perceiving changing concepts and making sense of their causes, mental models, which are a visual representation of cause-effect relationships, begin to emerge (Blokland *et al.*, 2020). Cause-effect relationships become more visible by making sense of the system's stocks, flows, and variables. For this reason, stock-flow diagrams, which allow individuals to see their mental models, shed light on this step (Fisher and Systems Thinking Association, 2023).

Mental models are the representations or cognitive frameworks that individuals use to make sense of and comprehend the world around them, particularly in the context of complex systems (Meadow, 2008). Mental models influence individuals' perceptions of and interactions with systems, as well as their choices, actions, and methods for addressing problems. The ST method posits that mental models are crucial for comprehending how individuals perceive systems, identify patterns, and forecast outcomes (Meadows, 2008). The degree to which these models align with the fundamental principles of ST determines whether they facilitate or impede the comprehension of complex systems.

Mental models are created using stock-flow diagrams; stock refers to a variable that accumulates and changes, and the level of stock changes over time as the activity of flows increases or decreases (Fisher and Systems Thinking Association, 2023; Göktepe, 2022; Richmond and Peterson, 2001). Stock-flow diagrams are also influenced by factors and relate changing behavior to the dependence of one variable on another (Fisher and Systems Thinking Association, 2023; Göktepe, 2022). Modeling a dynamic system requires creating stock-flow diagrams by defining variable types (Cavana and Maani, 2000). Stock-flow diagrams contribute to the development of mental model representations (Richmond and Peterson, 2001). When creating a solution to a complex problem, a systems thinker should be able to use a stock-flow diagram to determine the variables of the problem and thus determine system behavior patterns (Monat and Gannon, 2015). When the example of a population is considered again, the birth and death rates that make up the population can be included as the elements used in the stock-flow diagrams. Each element is interrelated, and birth and death rates can be described as two different flows that change the population. Population changes over time and is affected by birth-death rates. That is, stocks change with flows and factors.

2.3.3. Causal Loop Diagram (CLD)

Loops control the system's behavior when stocks and flows affect each other (Fisher and Systems Thinking Association, 2023). The relationships between system components and their effects on each other form a causal feedback mechanism (Hopper and Stave, 2008; Richmond and Peterson, 2001). To make sense of the causal loop, it is necessary to understand the linear and nonlinear cause-effect relationships (Göktepe, 2022; Haraldsson, 2004). Causal loop diagrams based on the cause-effect relationship help make the relationships of the flows concrete. One type of causal loop is the reinforcing loop that continues in the same direction of change within the loop (Fisher and Systems Thinking Association, 2023). A change in a particular direction within the loop continues to move in the same direction, combining with other changes. For example, births increase population; population also increases births.

The balancing loop, the other type, refers to balancing the system by neutralizing the increases and decreases (Fisher and Systems Thinking Association, 2023). The effort of our body cells to stabilize their balance against the negativities occurring in our environment; Homeostasis is an example of a balancing loop. The feedback mechanism that occurs with the continuation of the loops may include positive or negative loops; they may affect each other positively or negatively (Richmond and Peterson, 2001). Using CLD to understand causal loops makes it clear how and in what way the system behavior manifests itself (Haraldsson, 2004).

When we get to the bottom of the iceberg, we encounter mental models that express perceptions, habits, and beliefs (Assaraf and Orion, 2005b; Göktepe, 2022; Richmond, 2010). After the causal loop diagrams, the fundamental structure that causes the behavior is determined. This section uses the ladder of inference to visualize the path from perception to behavior. The ladder of inference is a tool for understanding observations, feelings and behaviors, and their relationship (Göktepe, 2022).

With the iceberg analogy, the structure of the systems becomes more understandable to better see the unexpected results by descending into the dynamics of an event that can be seen as static from the outside (Nuhoğlu *et al.*, 2021). Today's and future citizens, the new millennials, need tools to understand and contribute to human knowledge in the interconnected complex world (Jakobsson, 1999). ST tools each emerge from the other. The behavior graph over time is used in conjunction with stock-flow diagrams to detail change. Causal loop diagrams dig deeper into the variation within stock-flow diagrams and define feedback mechanisms. Using the ladder of inference, mental models are created, and a concrete picture of the change is tried to be captured.

2.3.4. Concept Map (CM)

A concept map is a tool that shows the relationships between concepts by arranging and organizing information (Novak, 1990; Novak and Gowin, 1984). Concept maps enable knowledge to be structured hierarchically and observe connections (Baxter *et al.*, 1996; Edmondson, 2005; Novak, 1990). Another tool that has recently been used as an effective tool to measure individuals' systems thinking skills is the concept map (Assaraf and Orion, 2005a; Brandstädter *et al.*, 2012; Khajeloo and Siegel, 2022; Sommar and Lücken, 2010).

Concept maps appear to represent the relationships between concepts in mental models and enable the visualization of individuals' cognitive structures (Brandstädter *et al.*, 2012; Nesbit and Adesope, 2006; Yin *et al.*, 2005). Since it has been described as an effective tool for interpreting mental models (Assaraf and Orion, 2010; Evagorou *et al.*, 2009; Mintzes *et al.*, 1998; Ruiz-Primo *et al.*, 1996), it is used to reveal the basic structure of system behavior. CMs, also encountered in science learning, are related to the fact that many complex systems around us are the subject of science lessons. These complex phenomena require systemic thinking in science learning (Evagorou *et al.*, 2009).

In the literature, CM was used as an evaluation tool in studies on students' ST skills (Assaraf *et al.*, 2013; McCarthy *et al.*, 2011; Tripto *et al.*, 2016, 2017, 2018). CMs have been cited as an effective tool for individuals to evaluate multilevel structures in complex systems (Buckley and Boulter, 2000). Additionally, in conjunction with CM, scaffolding has been shown to contribute to students' development of higher-order thinking skills in their search for solutions to potentially complex problems (Eggert *et al.*, 2017; Belland *et al.*, 2017; Sawyer, 2006). Since ST includes the ability to explain and interpret the behavior of a system (Arnold and Wade, 2015; Meadows, 2008; Sweeney and Sterman, 2000), CM in this context helps organize the individual's knowledge in order to explain their behavior and functions (Khajeloo, and Siegel, 2022).

2.3.5. Other Tools

Existing literature has shown that apart from the BOTG, SFD, CLD, and CM, ST skills and characteristics are evaluated using different tools such as computer programming environments, videotaped classroom discussions, and paper-and-pencil tools (Assaraf and Orion, 2010; Evagorou *et al.*, 2009). Tools such as video analyses, interviews, student drawings, repertory grids, word associations, and observations are also among the tools used to measure students' ST skills (Assaraf and Orion, 2005b; Brandstädter *et al.*, 2012; Lammi, 2011; Sweeney and Sterman, 2007). In addition, studies are conducted with specially designed courses or workshops to measure ST skill levels and encourage ST (Ateşkan and Lane, 2018; Doganca Kucuk and Saysel, 2018; Gilissen *et al.*, 2000; Yoon, 2008). The following section aims to present the models and frameworks of ST that have been developed so far and the theoretical framework to be used in this study.

2.4. Systems Thinking Frameworks

Many researchers have studied the definition, components, characteristics, and skills of systems thinking (ST) (Arnold and Wade, 2015; Assaraf and Orion, 2005a; 2005b; Dorani *et al.*, 2015; Plate and Monroe, 2014; Richmond, 1987; 1990; 2000;

Senge,1990; Stave and Hopper, 2007; Sweeney and Sterman, 2000). To fully understand a system, many researchers have associated ST with a set of skills such as identifying the elements of the system and their connections, understanding the causal loops and nonlinearity in the system, and using modelling (Arnold and Wade, 2015; 2017; Assaraf and Orion, 2005a; 2005b; Behl and Ferreira, 2014; Dorani *et al.*, 2015; Richmond 1990; 1997; Stave and Hopper, 2007; Sweeney and Sterman, 2000).

The development and understanding of ST skills have evolved through various studies and models proposed by researchers. In 1987, Richmond introduced the term systems thinking and subsequently delineated ST skills in his studies in 1990 and 2000 (Richmond, 1990; Richmond, 2000). The core skills, such as dynamic thinking and scientific thinking, persisted, but there were refinements, such as replacing generic thinking with forest thinking in 2000, which reflects a more holistic perspective (Richmond, 1990). Operational and structural thinking has been expanded to include quantitative, system-as-cause, and closed-loop thinking (Richmond, 1990). Senge (1990) emphasized the systemic nature of ST, highlighting the significance of interconnections, viewing the bigger picture, feedback loops, and mental models.

Sweeney and Sterman (2000) defined the ST skills similarly to Richmond's (1990) definitions. However, they do not explain the policies for modeling and creating sustainable solutions, which are critical to ST. Subsequent studies by Assaraf and Orion (2005; 2010) focused on ST skills in middle school education, emphasizing hierarchical skill development from system component analysis to implementation. Stave and Hopper (2007; 2008) integrated ST components with Bloom's Taxonomy, emphasizing understanding dynamic behavior, feedback loops, and policy testing. Plate and Monroe (2014) extended this approach to assess students' ST skill proficiency, similar to measuring literacy levels. Dorani *et al.* (2015) developed an assessment scale for ST skills, presented separately rather than holistically.

In this regard, there are many common points regarding explaining ST skills in the studies. A systems thinker should have multiple perspectives, identify and un-

derstand feedback loops, define the stock flow and variables in the system, determine linear relationships as well as nonlinear relationships, describe the interconnections between system components, and analyze the system both conceptually and numerically (Arnold and Wade, 2015;2017; Assaraf and Orion, 2005a; 2005b; Stave and Hopper, 2007; Sweeney and Sterman, 2000). Having these skills, a systems thinker understands the structure and dynamic behavior of the system, applies the system's structure to different contexts, and develops sustainable solutions to the problems in the system (Arnold and Wade, 2015).

Arnold and Wade (2015) offered a different perspective on the ST characteristics and skills, based the definition of ST on a perspective that integrates specific system components by reviewing it individually and holistically. Arnold and Wade (2015) established the characteristics of the relationship of ST with different disciplines. They stated that ST skills are intertwined as a system and reviewed the components individually and holistically.

The systemic essence of ST has been overlooked in studies on the definition of ST (Arnold and Wade, 2015). Systemic essence refers to what makes a system a system and is defined as the system aspect of ST (Arnold and Wade, 2015). In creating a complete ST definition, Arnold and Wade (2015) developed a System Test that addresses the requirements of the ST definition and tests whether the ST is defined as a system with a systemigram. Systemigram is a tool that visualizes the structure of the system by structuring complex systems and helps to understand its operation (Melher *et al.*, 2010; Sauser and Boardman, 2014). Later, Arnold and Wade (2015) redefined ST as a group of skills used to recognize systems, predict their behavior, and design changes to produce the desired behavior by making sense of the dynamic behaviors.

The systemigram depicts the eight main characteristics of the ST and their interrelationships. Systemigram constantly runs with feedback loops. This is a sign that ST is constantly changing and developing according to change, development, and improvements (Arnold and Wade, 2015). Arnold and Wade (2015) also subjected their

systemigram to a system test designed to test if the characteristics determined to define ST as a system. They tested whether each characteristic in the systemigram contains a clear purpose, elements, and interconnections (Arnold and Wade, 2015). It was emphasized that the systemigram passed the system test as it contained a clear purpose, a detailed description of the characteristics, and explained the connections in the characteristics (Arnold and Wade, 2015). In addition, Arnold and Wade (2015) stated that this definition and systemigram can be used in different disciplines.

ST should express the change over time with various models based on causality, generating sustainable solutions by adopting these models and creating holistic thinking (Göktepe, 2020). Creating various models by gaining different perspectives plays a mediator role in forming holistic thinking (Arnold and Wade, 2015).

In summary, many researchers have conducted studies on the definition and characteristics of ST (Arnold and Wade,2015; 2017; Assaraf and Orion, 2005a; 2005b; Behl and Ferreira, 2014; Plate and Monroe, 2014; Richmond, 1990; 2000; Serge, 1990; Stave and Hopper, 2007; Sweeney and Sterman, 2000). However, compared to other frameworks, the systemigram reveals ST's dynamic nature (Arnold and Wade, 2015). Since more emphasis is placed on modeling, nonlinear relationships, and policy development, and every step of the development phase is tested before being maintained, the ST systemigram was used as the theoretical framework for this study (Arnold and Wade, 2015). The following section aims to detail the place of ST in science education about the science curriculum and textbooks to be examined.

2.5. Systems Thinking in Science Education

Science is the systematic knowledge gained from observations, studies, and experiments to determine the nature or principles of what is being studied (Clough and Olson, 2004). Science is a body of knowledge; it refers to a process conducted using testable explanations and predictions of phenomena and, throughout the process, using evidence to construct scientific knowledge (Clough and Olson, 2004).

In the context of science education, systems thinking (ST) aims to make sense of the nature of science while making sense of the world (Assaraf and Orion, 2005a). It also serves as a tool to solve the problems that students encounter in their daily lives in connection with the characteristic features of the nature of science. Students need to be able to organize the knowledge construction and problem-solving process in detail from beginning to end to gain an integrated perspective on complex ideas. Researchers have expressed skills such as understanding the dynamics and complexity of system behavior, identifying feedback processes in the system, determining stock and flow relationships, being aware of delays in the system and interpreting their effects, understanding nonlinear relationships, and creating models by digitizing relationships as ST skills (Assaraf and Orion, 2005b; Draper, 1993; Frank, 2000). These determined skills are also directly related to the ability to organize and high-level thinking while solving daily problems (Frank, 2000; Sweeney and Sterman, 2000).

ST catalyzes students' critical thinking and problem-solving abilities (Hernthaisong *et al.*, 2015; Senge, 1990). Achieving results in complex systems by analyzing how the parts of a whole interact with each other requires adopting an ST approach (Trilling and Fadel 2009). The reflection of this complexity on daily life, especially in the new millennium, requires students to have skills such as creativity in knowledge building, innovative thinking, and productivity. One objective in raising individuals who can adapt to today's age is to use the ST approach (Trilling and Fadel, 2009). ST, which provides tools that can adapt to every problem, is closely related to the aims and content of science education. Analytical and abstract thinking skills are regulated in the Next Generation Science Standards (NGSS, 2013). The Framework for K-12 Science Education report (National Research Council (NRC), 2012) defines the main dimensions as scientific and engineering applications, crosscutting concepts, and key ideas. Especially crosscutting concepts have characteristics associated with the ST approach. It includes crosscutting concepts, systems and systems models, structure and function, stability, and change (NRC, 2012). Concepts are included in every disciplinary core idea and are related to the ST approach in terms of the definition and application of the concepts (NRC, 2012).

Additionally, NGSS (2013) identified scientific practices such as asking questions and defining problems, developing and using models, constructing explanations and designing solutions, and planning and carrying out investigations (NRC, 2013). Scientific practices help students to be adaptable and flexible by enabling them to think critically. Interdisciplinary learning and teaching support critical thinking and cognitive ability (Science Education Resource Center at Carleton College (SERC), 2021). ST promotes interdisciplinary thinking (Delaney *et al.*, 2021) and helps strengthen students' learning outcomes to better cope with difficulties (SERC, 2021).

The difficulty of understanding complex systems' structure and behavioral aspects involving multiple perspectives is becoming more challenging for scientists and students today (Hmelo *et al.*, 2000; Jacobson, 2001; Jacobson and Wilensky, 2006). It has been shown that the ST approach is still a major challenge for students at different grade levels (Jacobson and Wilensky, 2006). Since understanding complex systems is one of the critical components of understanding science, the representation of dynamic systems and their interactions in different ways should be made more explicit (Hmelo-Silver *et al.*, 2007).

The significance of system-oriented thinking is evident in numerous international documents. For instance, the United Nations' 2030 Agenda for Sustainable Development, titled Transforming Our World, incorporates a system-oriented approach in its all-encompassing plan for worldwide advancement (United Nations, 2015). The document outlines the 17 Sustainable Development Goals (SDGs), highlighting their interconnectedness and the fact that progress in one area depends on progress in others (United Nations, 2015). The document emphasizes the need for solutions that address multiple dimensions of global problems in an integrated manner to promote sustainability. It also stresses the importance of developing policies with the collaboration of stakeholders and a sense of responsibility rather than focusing on issues from a single perspective and seeking solutions.

In addition, the Global Sustainable Development Report, published by the United Nations in 2019, is a guide for the ways that can be drawn to achieve sustainable development (United Nations, 2019). This action-oriented report is prepared to bridge the gap between science and policy to accelerate sustainable development in the fight against climate change (United Nations, 2019). The report mentions a significant gap and the need for students to acquire skills in cooperation and communication in coping with the climate change crisis, quality education, especially in mathematics and natural sciences, and ST skills (United Nations, 2019). The fact that ST is included in the report indicates that the need for this approach in raising literate individuals is increasing day by day in the face of global crises that are increasingly difficult to cope with (United Nations, 2019).

Since dealing with complex systems also requires retrospective and predictive thinking skills related to science education (Assaraf and Orion, 2005b; Orion, 2002), science teaching shifts its focus to learning complex systems to make sense of phenomena (Assaraf and Orion, 2005b). Achieving results in complex systems by analyzing how the parts of a whole interact with each other requires adopting an ST approach (Trilling and Fadel 2009). One of the goals to be achieved in raising students who can adapt to today's age is to use the ST approach (Trilling and Fadel, 2009). In this context, Liu and Hmelo-Silver (2009) suggested that the learning natural systems of our lives should be included in science teaching to illustrate complexity (Liu and Hmelo-Silver, 2009). When we look at the big picture of the ST approach in science education, studies in existing literature have come up with similar results. Studies have shown that students have a superficial knowledge of the characteristics of dynamic systems, cannot explain ST components, and cannot use ST tools effectively (Assaraf and Orion, 2005a; Gilissen *et al.*, 2020; Ke *et al.*, 2020; Ormancı *et al.*, 2018; Penner, 2000; Sterman and Sweeney, 2002; Sweeney and Sterman, 2007).

When the focus is switched to the science teachers, the notions outlined above appear similarly. The current lack of students' ability to view complexity with the ST approach is similar to the lack of science teachers' ability to incorporate the ST

approach into their teaching and classroom (Ateskan and Lane, 2018; Karaarslan Semiz and Teksöz, 2020; Kim and Lee, 2019; Lavi and Dori, 2019). In addition, it has been revealed that teachers' limited access to tools and methods for assessing in-class ST development creates difficulties in assessing students (Kim and Lee, 2019). In this context, it is also stated that various changes should be made in the curriculum during the integration of ST into the classroom to provide appropriate resources and sufficient time, and they need more support for vocational education (Delaney *et al.*, 2021). On the other hand, not including ST in the education system limits the display and development of ST skills among students and teachers (Budak and Ceyhan, 2023; Semiz and Teksöz, 2019).

Moreover, it is stated that in the courses designed with the ST approach or implemented in simulation-based or system-based environments that support ST, students' learning about the subject is strengthened, and they make progress in having higher-order thinking skills and problem-solving (Assaraf and Orion, 2005b; 2009; 2010; Doganca Kucuk and Saysel, 2018; Evagorou *et al.*, 2009; Yoon, 2018). It has also been revealed that students can embody abstract concepts more easily with inquiry-based learning and begin to develop ST skills (Assaraf and Onion, 2005b; Lammi, 2011). In the studies carried out on the courses containing the ST approach, it is also stated that students need to be more knowledgeable about ST and its components, and more focus should be placed on the relationship between students' learning and the ST approach (Eilam, 2012; Roychoudhury *et al.*, 2017).

Considering the students' and teachers' deficiencies towards the ST approach, the need for the ST approach can be underlined for students to have metacognitive skills such as concretizing events and ideas by thinking within the framework of the system and making sense of the relationships between systems (Assaraf and Orion, 2005b). To understand and analyze complex systems, individuals need to be system thinkers (Arnold and Wade, 2015). Regarding the literature, there is a lack of knowledge about the ST approach among students and teachers (Ateskan and Lane, 2018; Assaraf and Orion, 2005a; 2005b; Eilam, 2012; Gilissen *et al.*, 2020; Ke *et al.*, 2020; Ormancı *et al.*,

2018; Roychoudhury *et al.*, 2017; Sterman and Sweeney, 2002; Sweeney and Sterman, 2007). Research also revealed that the integration of ST creates a positive difference in learning the related subject, especially in science (Assaraf and Onion, 2005b; Karaarslan Semiz and Teksöz, 2020; Lamm, 2011; Yoon, 2008). ST should be used regularly to support making systemic problems concrete and producing sustainable solutions (Fisher and Systems Thinking Association, 2023).

On the other hand, the development and demonstration of ST skills are limited since ST is not explicitly included in the educational system (Budak and Ceyhan, 2023; Semiz and Teksöz, 2019). Therefore, it is a significant step to examine the inclusion of ST by examining the Turkish middle school science curriculum and middle school science textbooks since curriculum and textbooks are critical elements in education. In this context, there are various studies in the literature examining the science curriculum regarding the ST approach (Chiu *et al.*, 2019; Karaarslan Semiz and Teksöz, 2023; Skamp and Green, 2022; Şahingöz, 2021).

Chiu *et al.* (2009) investigated the integration of ST components, such as comprehending system structure and system behavior, into high school chemistry curricula in Israel, the Netherlands, the United States, and Taiwan. The authors emphasized the significance of ST in promoting sustainable living and identified the implicit inclusion of ST principles within the curriculum (Chiu *et al.*, 2009). Similarly, Skamp and Green (2022) investigated the alignment of the Australian Earth system science curriculum with ST principles. They found that while the curriculum indirectly refers to ST concepts such as complex systems and feedback loops, it lacks explicit integration (Skamp and Green, 2022). The study emphasized the significance of ST in comprehending Earth systems and addressing global challenges (Skamp and Green, 2022).

Karaarslan Semiz and Teksöz (2023) analyzed sustainability-related units in the K-8 science curriculum and found that while nine out of eleven ST components were present, they were only at a basic level. The curriculum fell short of fully expressing ST in aspects such as dynamic system behaviors and comprehensive cause-effect relation-

ships, indicating a need for improvement in problem-solving approaches (Karaarslan Semiz and Teksöz, 2023). Şahingöz (2021) examined the integration of spatial and systems thinking skills in Turkey's primary and middle school science curricula. The study found that while ST was partially included across grades, there was a lack of explicit instruction in acquiring these skills. It is stated that there is a need for curriculum refinement and development regarding ST (Şahingöz, 2021).

Although there are various studies on integrating ST into education and curriculum, these studies were conducted on a subject-specific basis (Karaarslan Semiz and Teksöz, 2023; Şahingöz, 2021) or were studied on a single grade level (Karaarslan Semiz and Teksöz, 2023), or conducted with high school or higher grade levels (Chiu *et al.*, 2009; McCarthy *et al.*, 2011; Skamp and Green, 2022). There is a lack of studies on ST integration in middle school grade-level science curricula and textbooks in the literature. For this reason, this study aims to examine the entire content of fifth-, sixth-, seventh-, and eighth-grade Turkish science curricula and textbooks. The study contributes to the literature, providing insight to curriculum developers and policymakers regarding ST inclusion.

3. METHODOLOGY

This chapter includes the methodological details of the study with the following sections: the research design, data sources, and sampling.

3.1. Research Design

The study aims to examine how the systems thinking (ST) approach is included in Turkish fifth-, sixth-, seventh-, and eighth-grade science curricula and textbooks. The first part of the study identifies the objectives related to ST in the science curriculum prepared and currently implemented by the Ministry of National Education. The second part of the study includes an analysis of the inclusion of the ST approach in science textbooks distributed to students in the fifth, sixth, seventh, and eighth-grades by the Ministry of National Education. The qualitative content analysis method was chosen for both study parts.

According to Lune and Berg (2017), "Qualitative research, thus, refers to the meanings, concepts, definitions, characteristics, metaphors, symbols, and descriptions of things." (p. 12). Qualitative research evaluates the quality of things using words, images, descriptions, experiences, and documents and develops a detailed understanding of a phenomenon (Creswell, 2008). Meaning-making is critical in qualitative research, where a situation, phenomenon, or phenomenon is dealt with in great detail. This type of research expresses concepts, meanings, definitions, and properties (Creswell and Poth, 2018). It differs from investigating a single phenomenon by going beyond understanding the theories embodied in the research; it seeks meaning while seeking truth. The social meaning that individuals ascribe to their experiences, conditions, and lives and their meanings on concepts are the focus of qualitative research (Creswell and Poth, 2018). Content analysis, a type of qualitative research, is used to draw objective conclusions in a systematic order from the characteristics determined in the text or any document (Stone *et al.*, 1966). Content analysis is a basis for interpreting latent con-

tent (Stone *et al.*, 1966) and replicable from texts to contexts to draw valid inferences (Krippendorff, 2004). The qualitative content analysis method was chosen to analyze the contents of the Turkish middle school science curriculum and textbooks to see to what extent they include ST. Content analysis can be carried out with an inductive or deductive approach.

While the inductive approach is a bottom-up process that proceeds from inferences to generalizations, the deductive approach is a top-down process that proceeds from generalizations to inferences (Krippendorff, 2004). While the inductive approach refers to the construction of the categories to be formed based on data, the deductive approach refers to the construction of the categories according to the analysis structure determined based on previous studies in the literature (Kynga s and Vanhanen, 1999). The study was followed with a deductive approach, as it was carried out with data analysis that includes codes created based on a theoretical framework.

3.2. Data Sources

In this study, two data sources were used to collect data. The Turkish middle school science curricula and science textbooks of fifth, sixth, seventh, and eighth-grades were used to investigate the inclusion of ST.

3.2.1. The Turkish Middle School Science Curriculum

The current 2018 Science Curriculum was used as the first data source in the study. The science curriculum, piloted as a draft in 2017, was re-evaluated and revised after the pilot application and updated again in January 2018 (MoNE, 2018). The curriculum, which was put into practice under the name of the 2018 Turkish Middle School Science Curriculum, is currently applied to third to eighth-grade students studying in Turkey. The science curriculum, which has been implemented since 2018, is prepared with the aim of raising individuals who can adapt to rapid changes in science and technology, produce knowledge and use it functionally in daily life, solve problems, think

critically, and are self-confident (Ministry of National Education (MoNE), 2018). It considers individual differences and is prepared to gain values and skills. It was created in a way that helps to gain a progressive and holistic perspective by integrating and complementing previous knowledge on subjects at different grade levels (MoNE, 2018). Besides, at the middle school level, which is from fifth to eighth-grades, it is aimed that students who have completed primary school should be scientifically literate individuals sensitive to various scientific reasoning skills and other social skills following their development levels and individual differences and apply them effectively in their daily lives.

A summary of the main objectives of the science curriculum, which aims to educate all individuals as science literate, is to educate students who have basic knowledge about different branches of science who can produce solutions to the problems they encounter by adopting scientific research approaches, and who have sustainable development awareness (MoNE, 2018). In addition, it aims to guide the raising of scientifically literate individuals involved in decision-making processes by developing arguments through discussion (MoNE, 2018). The field-specific skills in the 2018 science curriculum are expressed as scientific process skills, life skills, including analytical and creative thinking, communication, collaboration, entrepreneurship and decision-making, and engineering and design skills, including innovative thinking (MoNE, 2018). In the science curriculum, which took its final form in 2018, the engineering and design skills title under the field-specific skills was arranged to highlight the STEM context. In this context, students are expected to develop themselves in producing alternative solutions to the problem by defining a need or a problem encountered in daily life for the subjects covered in the units within the scope of Science, Engineering, and Entrepreneurship Practices. Students are expected to develop a product and present it in the school environment by developing their organizational skills by considering criteria such as material, time, and cost for the solution of the problem and planning. In addition, in the product development process, it is among the curriculum objectives to record the data obtained by observation or experiment and to reach a conclusion by comparing them.

The 2018 Turkish middle school science curriculum consists of 305 objectives in its final form. While eighty-two objectives cover the third and fourth grades, the other 223 objectives are designed for the fifth-, sixth-, seventh-, and eighth-grades. Each grade level is based on seven units and four learning areas: living things and life, earth and universe, physical events, and matter and its nature (MoNE, 2018).

3.2.2. Turkish Middle School Science Textbooks

The fifth-, sixth-, seventh-, and eighth-grade science textbooks were used as the second data source in the study. The primary school science curriculum in Turkey includes third grade through fourth grade, and this study focused on middle school levels from fifth-grade to eighth-grade. The Turkish middle school science curriculum has progressive knowledge content at each grade level (i.e., spiral curriculum design), but the topics are the same for all grade levels. In other words, although there are changes in their content, the same subjects are taught in science textbooks in a way that is arranged according to the grade levels of the students. The table below contains the contents of the fifth, sixth, seventh, and eighth-grade science textbooks Table 3.1.

Table 3.1. Content of middle school science textbooks.

Unit	**Content of Fifth-Grade Science Textbook**	**Content of Sixth-Grade Science Textbook**	**Content of Seventh-Grade Science Textbook**	**Content of Eighth-Grade Science Textbook**
1st **Unit**	Sun, Earth, and Moon	Solar System and Eclipses	Solar System and Beyond	Seasons and Climate
2nd **Unit**	The World of Living Things	Systems in Our Body	Cells and Divisions	DNA and Genetic Code
3rd **Unit**	Measurement of Force	Force and Movement	Force and Energy	Pressure

Table 3.1 Content of middle school science textbooks. (cont.)

Unit	**Content of Fifth-Grade Science Textbook**	**Content of Sixth-Grade Science Textbook**	**Content of Seventh-Grade Science Textbook**	**Content of Eighth-Grade Science Textbook**
4th **Unit**	Matter and Change	Matter and Heat	Pure Substances and Mixtures	Matter and Industry
5th **Unit**	Propagation of Light	Sound and Features	Interaction of Light with Matter	Simple Machines
6th **Unit**	Human and Environment	Systems in Our Body and Health of Systems	Reproduction, Growth, and Development in Living Things	Energy Conversions and Environmental Science
7th **Unit**	Electrical Circuit Components	Transmission of Electricity	Electrical Circuits	Electrical Charges and Electrical Energy

The fifth, sixth, seventh, and eighth-grade science textbooks, approved by the Ministry of National Education (MoNE) and distributed free of charge to all schools in Turkey, were used to reflect the representation of ST in science textbooks.

3.3. Sampling

3.3.1. Sampling of Curriculum

The Turkish middle school science curriculum was one of the study samples. This curriculum was selected using a purposive sampling method. This method refers to selecting the subject of interest with the selection principles determined for a specific purpose rather than randomly (Palys, 2008). This method, widely used in qualitative

research, is chosen for the criteria determined based on the research questions. The main criterion determined in the selection of the curriculum is that the curriculum is the current science curriculum published by the Ministry of National Education in 2018. The Turkish science curriculum includes primary and middle school objectives, units, and subunits from third to eighth-grade.

This study focused on middle school from fifth to eighth-grade. In the middle school curriculum, in addition to the emphasis on the scientific process and scientific research steps, the emphasis is on creative, innovative, and entrepreneurial thinking skills under the heading of engineering and design skills. These skills, also defined as 21st-century skills, include the competencies students have to adapt to the rapid changes in recent years. The curriculum, prepared for students trained as science literate following the changing needs of the age, aims to raise individuals who seek solutions to problems that may be encountered in daily life. The curriculum mentions the importance of producing sustainable products. Also, it emphasizes the ability to think abstractly and to create models from the obtained data on the way to scientific knowledge.

Since ST adopts a new perspective on adaptation to the rapidly changing and developing world and produces sustainable solutions with holistic thinking by modeling these perspectives, it has similar aims to those indicated in the 2018 science curriculum (MoNE, 2018). For this reason, the 2018 Turkish middle school science curriculum overlaps to examine the inclusion of ST in the curriculum. Curriculums were accessed from the website (http://ttkb.meb.gov.tr/) published by the Ministry of National Education Board of Education and Discipline.

3.3.2. Sampling of Science Textbooks

The four different science textbooks, fifth-, sixth-, seventh-, and eighth-grade science textbooks, were another group of the study samples. The textbooks were also selected using a purposive sampling method. The main criterion determined in the

study is that the textbooks to be examined are science textbooks, and only one textbook is selected from each middle school grade, including the fifth, sixth, seventh, and eighth-grades of science textbooks. These science textbooks are distributed free of charge to students by the Ministry of National Education. Some of these books, which the Ministry of National Education copyrights, were prepared by private publishers, and the Ministry of National Education Publishing prepared some of the textbooks. The books are chosen by the Ministry of National Education to be used in middle schools for five years among the science textbooks sent to students by different publishing houses, and the publishers have purchased the copyrights. For this reason, middle school students at the same grade level can use science textbooks from different publishers according to the regulation policies of their city or school. Science textbooks used in middle schools all contain the same objectives and a very similar set of content.

When the published fifth, sixth, seventh, and eighth-grade science textbooks were examined, it was found that there were books belonging to different copyrighted publishers for each grade level besides the books published by the Ministry of National Education Publishing. In line with the opinions received from science teachers currently working in public schools, it was concluded that some schools only use textbooks published by the Ministry of National Education Publishing, and the use of books published by different publishers is not allowed. For this reason, priority was given to selecting fifth, sixth, seventh, and eighth-grade science textbooks published by the Ministry of National Education Publishing and distributed free of charge to all public schools in Turkey.

While science textbooks published by the Ministry of National Education Publishing were selected for the fifth, sixth, and seventh-grades, no current textbook published by the Ministry of National Education Publishing could be found for the eighth-grade. For this reason, the book published by ATA Publishing, a private publisher that purchases the copyright, was chosen as the eighth-grade science textbook. The criteria for choosing ATA publishing is that it has a five-year copyright from the 2023-2024 academic year by the Ministry of National Education and that the book content is

more up-to-date than the science textbooks published by other private publishers. In addition to textbooks, there are workbooks for middle school grades. However, this study only focuses on examining to what extent fifth, sixth, seventh, and eighth-grade science textbooks include ST.

3.4. Data Analysis

Qualitative research is learned by doing and moving with analytical loops instead of presenting a linear approach (Creswell, 2008). All data analysis steps are interconnected, and qualitative data analysis, an iterative process, involves a concurrent process rather than steps that progress separately.

3.4.1. Unit of Analysis

Units are functions of the empirical stability of the observed phenomenon (Krippendorf, 2004). Recoding/coding units are a specific segment of the content that is characterized (Holsti, 1969). Recoding/coding units are distinguished for coding, transcription, and detailed explanation (Krippendorf, 2004). Since the science curriculum has relatively small content, it was not divided into units for analysis. In this study, the middle school science curriculum, which includes fifth to eighth-grade, was included in the analysis following the components of Arnold and Wade (2015) systemigram.

Science textbooks have a large content, and they are divided into coding units. In content analysis, dividing large samples into smaller units to provide reliable explanations that increase the reliability of the study's results and reduce the conflict among coders (Krippendorf, 2004). Dividing texts into small units is important for the reliability of the analysis in content analysis (Kriffendorff, 2004). To determine the unit of analysis for the textbooks, the textbooks were scanned before the analysis. In the scanning stage, some keywords were found that are likely to reflect ST, such as system, component, connection, relationship, cause-effect, variable, accumulation, decrease, and increase (Arnold and Wade, 2015) in the textbooks. However, as a re-

sult of the examination of the units in a holistic view, it was determined that these keywords only partially reflected the ST approach. Analyzing words, sentences, figures, paragraphs, or activities may not completely reveal the representation of the ST approach. Since the ST approach is a holistic framework and provides a broad perspective (Arnold and Wade, 2017; Meadows, 2008; Ramage and Shipp, 2009; Sweeney and Sterman, 2000), the coding unit of science textbooks was determined as a chapter. Therefore, science textbooks were analyzed according to the chapters, including the chapters subheadings to establish meaningful connections.

The Science, Engineering, and Entrepreneurship Applications (SEEA) section was also considered in textbook analyses. This section provides examples from daily life related to relevant topics and concepts, offers solutions and projects for problems that may arise in daily life, integrates technology into the subject, and provides interesting information and explanations on the subject (MoNE, 2018). Additionally, the activity and assessment sections of the chapter contain experiments, observations, research, and evaluation questions related to the subject were also considered in textbook analyses. During the analysis of the textbooks, all chapters, including SEEA, activity, and assessment sections in grades five through eight, were examined for ST inclusion.

3.4.2. Analytical Framework

The analytical framework of this study was based on Arnold and Wade's study (2015). Systems thinking was defined as "A system of thinking about systems" (Arnold and Wade, 2015, p. 670). Based on the definition, ST includes a clear goal, elements of systems thinking, and the interconnections between these elements (Arnold and Wade, 2015).

By comparing ST definitions in the literature (Forrester, 2014; Kopainsky *et al.*, 2011; Richmond, 1994; Senge, 1990; Squires *et al.*, 2011; Stave and Hopper, 2007; Sweeney and Sterman, 2000), Arnold and Wade (2015) created a systemigram describing ST characteristics based on the objectives of maintaining the system's function

regularly and containing a continuous feedback loop. Systemigram allows for clear visualization of the interaction between each ST element based on their determined characteristics (Arnold and Wade, 2015). Arnold and Wade (2015) stated that as the elements in the system develop and affect the development of the elements they are connected to, the ST will be in constant development.

Systemigram consists of eight main components: recognizing interconnections, identifying and understanding feedback, understanding system structure, differentiating types of stocks, flows, and variables, identifying and understanding nonlinear relationships, understanding dynamic behavior, reducing complexity by modeling systems conceptually, and understanding systems at different scales (Arnold and Wade, 2015). Among the components in systemigram, there are strong and weak connections, and each component interacts, and the systemigram components combine to form another component (Arnold and Wade, 2015). For example, recognizing interconnections and identifying and understanding feedback components combine to form the understanding system structure component. Similarly, differentiating types of stocks, flows, and variables and identifying and understanding nonlinear relationship components combine to form the understanding of dynamic behavior components (Arnold and Wade, 2015).

The aim, which is based on the interaction of eight components with each other, is "The capability of identifying and understanding systems, predicting their behaviors, and devising modifications to them in order to produce desired effects" (Arnold and Wade, 2015, p. 676). Arnold and Wade (2015) stated that understanding the system and dynamic behaviors and making changes to create the desired effects when it is necessary to change the system's behavior is one of the characteristics of ST. Eight components in the systemigram interact strongly with this component, although it is not explicitly stated as the ninth component. In another study, Arnold and Wade (2017) conducted on skills that support the four basic principles of ST as referring to the systemigram they developed in 2015: identifying systems, understanding systems, predicting system behavior, and devising modifications to systems to produce desired

effects. Additionally, Arnold and Wade (2017) also said that a systems thinker should have a perspective on whether the changes produce the desired result. Therefore, devising modifications to produce the desired effects were included as a component in the characteristics of ST, and the rubric developed for data analysis was created based on the nine components included in the systemigram. The definitions and explanations of the nine components are given below.

- Recognizing Interconnections; The concept is defined as the basic level of ST, which includes recognizing the basic connections between the system parts (Arnold and Wade, 2015). Recognizing interconnections requires seeing the system as a whole and understanding how and to what extent the parts of the system are related to the whole (Stave and Hopper, 2007).
- Identifying and Understanding Feedback; Feedback refers to an environment where a part of a system's output is returned to the system that generated that output (Doherty and Balzer, 1988). It includes the ability to identify feedback loops to determine causal relationships by bringing together interconnections (Arnold and Wade, 2015). The ST approach also involves determining how system behaviors are created by identifying feedback loops (Plate and Monroe, 2014).
- Understanding System Structure; To take a holistic view of the system, it is necessary to be aware that the structure of the system consists of elements and the interconnections between these elements (Arnold and Wade, 2015; Richmond, 1994). Understanding the system structure requires and is highly influenced by recognizing interconnections and identifying and understanding feedback (Arnold and Wade, 2015). Arnold and Wade (2015) expressed the strong connection between recognizing interconnections and understanding feedback components in their systemigram. They showed that understanding the system structure component emerged from the combination of these two components.
- Differentiating Types of Stocks, Flows, and Variables; Stocks refer to resource pools in the system, while flows represent stock changes, variables are changeable parts that affect stocks and flows (Arnold and Wade, 2015). Identifying stocks,

flows, and variables in the system is one of the critical qualities a systems thinker must possess. It is necessary to go beyond defining causal relationships superficially to distinguish stocks, flows, and different variables and to understand their functioning (Arnold and Wade, 2015; Stave and Hopper, 2007).

- Identifying and Understanding Nonlinear Relationships; The concept includes nonlinear stocks and flows (Arnold and Wade, 2015; Hopper and Stave, 2008; Plate and Monroe, 2014). Arnold and Wade (2015) stated that this characteristic can also be specified under the differentiating types of stocks, flows, and variables. On the other hand, it is used as a separate element to avoid possible confusion caused by the concept of nonlinearity (Arnold and Wade, 2015). Using only linear causal relationships such as X causes Y; Y causes Z (Raia, 2005) is limited in learning complex systems so that individuals can interpret information (Plate, 2010; Webb and Boltt, 1990). The perception that a cause has only one effect should be developed through a causal loop, where one cause can lead to more than one effect (or vice versa). Causal loops should include nonlinear and linear relationships, and systems dynamics should be interpreted by developing non-unidirectional cause-effect maps (Lagnado *et al.*, 2007; Plate, 2010). In this context, understanding feedback, the second element of the model developed by Arnold and Wade (2015) to adopt causal loops, also helps to assimilate the dynamic behavior of complex systems (Plate, 2010).
- Understanding Dynamic Behavior; The dynamic behavior of the system includes defined interconnections, feedback loops, stocks, flows, and variables (Arnold and Wade, 2015). Understanding different mechanisms and their effects, placing them in the causal loop, distinguishing flows, stocks, and variables, and creating nonlinear relationships are critical elements in understanding the system's dynamic behavior. As with the understanding system structure component, Arnold and Wade (2015) stated that the understanding dynamic behavior component has a strong connection with the differentiating types of stocks, flows, and variables, and identifying and understanding nonlinear relationships components and consists of these two components.

- Reducing Complexity by Modeling Systems Conceptually; It includes viewing the system from different perspectives by developing conceptual modeling of different system parts (Arnold and Wade, 2015). This ability, which provides the opportunity to examine the system in more detail by reducing the complexity, refers to facilitating the view of the system by using concepts such as reduction, abstraction, homogenization, or transformation. This element refers to the non-numerical modeling (Arnold and Wade, 2015).
- Understanding Systems at Different Scales; It refers to determining different system scales (Arnold and Wade, 2015). It includes being able to define and understand systems at different scales. The component also requires explaining the connections from a broader scale by interpreting the system behavior with its interactions and variables, rather than superficially describing the system behavior with a single scale, to understand the system's functioning (Plate and Monroe, 2014).
- Devising Modifications to Produce Desired Effects; For the system to work together with all its components, it is necessary to design and use changes in the system to produce effects when necessary (Arnold and Wade, 2015). The eight components specified in systemigram come together and serve the purpose of raising system thinker individuals who can more consciously understand the behavior of complex systems and master the decision-making process by interpreting the inferences obtained from the system (Arnold and Wade, 2015; Plate and Monroe, 2014). A systems thinker must have the ability to create broad policies and make inferences about the problem he encounters by using systems thinking and systems (Plate and Monroe, 2014).

3.4.3. Rubric Development

A rubric is a document that contains a definition, criteria, and explanations about what is required and quality levels for the phenomenon being evaluated and expresses expectations for the phenomenon (Andrade, 2000; Arter and Chappuis, 2007; Reddy and Andrade, 2010). Rubrics also reveal transparency regarding the evaluated

criteria, minimizing the uncertainties that may occur in the evaluation (Andrade, 2000; Arter and Chappuis, 2006). Rubrics are also effective in evaluating ST (Karaarslan-Semiz and Teksöz, 2020; Lavi and Dori, 2019). For consistent data analysis, a rubric was developed for the Turkish middle school science curricula and textbook analysis according to systemigram, which is the analytical framework to be followed (Arnold and Wade, 2015). The rubric was associated with the systemigram and ST tools, such as behavior over time graph, stock-flow diagram, and causal loop diagram. The rubric was also associated with the concept map, which is frequently used as the ST tool in the literature (Assaraf and Orion, 2005a; Brandstädter *et al.*, 2012; Khajeloo and Siegel, 2022; Sommar and Lücken, 2010); therefore, four main tools were included in the rubric to examine ST inclusion.

Apart from ST tools, tools such as video analyses, interviews, student drawings, repertory grids, word associations, and classroom discussions are operationally defined as other tools that evaluate skills for ST (Assaraf and Orion, 2005b; Brandstädter *et al.*, 2012; Lammi, 2011; Sweeney and Sterman, 2007), were also included in the rubric. Additionally, in science teaching and learning, evaluation tools such as experiments, observations, visuals, graphics, and tables are frequently used (Eddy *et al.*, 2015; Hart *et al.*, 2000; Jewitt *et al.*, 2011; Palincsar *et al.*, 2011). These tools were also included in the rubric to deepen the analysis and be able to compare the inclusion of ST in curricula and textbooks although they were not used as an assessment tool for the inclusion of ST.

Since qualitative research involves iterative processes (Creswell and Poth, 2018), expert opinions were obtained in regular meetings held once a week during the rubric development process. At the weekly meetings, the systemigram of Arnold and Wade (2015), which was selected for the analytical framework, was initially examined. Once it had been confirmed as an analytical framework, the components in the systemigram were reviewed with the ST expert.

According to the ST components included in the analytical framework, the rubric criteria and the explanations for scoring were discussed and determined. The content and the structure of the rubric were discussed with the expert, and any necessary edits were made.

Content validity is defined as the degree to which a test is utilized to measure an intended content area (Gay *et al.*, 2012). To ensure content validity, throughout the six-month period, weekly meetings were conducted with the ST expert. The opinions, suggestions, comments, and concerns of this expert were considered for the content validity.

As a result of the meetings with the expert, the rubric was edited and finalized, and detailed explanations were created for each of the nine components according to the four criteria of the rubric for the analysis. The final version of the rubrics created for Turkish middle school science curricula and textbooks consists of nine components based on the systemigram developed by Arnold and Wade (2015).

While the middle school science curricula were analyzed as a whole, the science textbooks were divided into units of analysis determined as chapters, given the extensive content. For the analysis of the textbooks, the chapters determined as units of analysis were analyzed together with all their subheadings. In the analysis of the textbooks, the contents of all chapters in the book were included in the analysis, including the evaluation and SEEA sections.

3.4.3.1. Rubric for Turkish Middle School Science Curricula. The rubric which was created for Turkish middle school science curricula included four scoring criteria in the form of 0-1-2-3 for each of the nine components in Arnold and Wade's systemigram (Arnold and Wade, 2015) is shown in Table 3.2.

Table 3.2. Rubric for Turkish middle school science curricula.

Components	Rubric level	Rubric criteria
Recognizing Interconnections	3	The objective is applicable for recognizing interconnections and is fully included.
	2	The objective is applicable for recognizing interconnections but is partially included.
	1	The objective is applicable for recognizing interconnections but is not included.
	0	The objective is not applicable for recognizing interconnections.
Identifying and Understanding Feedback	3	The objective is applicable for identifying and understanding feedback and is fully included.
	2	The objective is applicable for identifying and understanding feedback but is partially included.
	1	The objective is applicable for identifying and understanding feedback but is not included.
	0	The objective is not applicable for identifying and understanding feedback.
Understanding System Structure	3	The objective is applicable and fully included for recognizing interconnections, and identifying and understanding feedback.
	2	The scoring was based on the matrix created for the understanding of the system structure component. *
	1	The scoring was based on the matrix created for the understanding of the system structure component. *
	0	The objective is not applicable for recognizing interconnections and identifying and understanding feedback.
Differentiating Types of stocks, flows, and variables	3	The objective is applicable for the differentiating types of stocks, flows, and variables, and is fully included.
	2	The objective is applicable for the differentiating types of stocks, flows, and variables but is partially included.
	1	The objective is applicable for the differentiating types of stocks, flows, and variables but is not included.
	0	The objective is not applicable for the differentiating types of stocks, flows, and variables.

Table 3.2 Rubric for Turkish middle school science curricula. (cont.)

Components	**Rubric level**	**Rubric criteria**
Identifying and Understanding Nonlinear Relationships	3	The objective is applicable for identifying and understanding nonlinear relationships and is fully included.
	2	The objective is applicable for identifying and understanding nonlinear relationships but is partially included.
	1	The objective is applicable for identifying and understanding nonlinear relationships but is not included.
	0	The objective is not applicable for identifying and understanding nonlinear relationships.
Understanding Dynamic Behavior	3	The objective is applicable and fully included for differentiating types of stocks, flows, and variables, and identifying and understanding nonlinear relationships.
	2	The scoring was based on the matrix created for the understanding of dynamic behavior components. *
	1	The scoring was based on the matrix created for the understanding of dynamic behavior components. *
	0	The objective is not applicable for differentiating types of stocks, flows, and variables, and identifying and understanding nonlinear relationships.
Reducing Complexity by Modeling Systems Conceptually	3	The objective is applicable for reducing complexity by modeling systems conceptually and is fully included.
	2	The objective is applicable for reducing complexity by modeling systems conceptually but is partially included.
	1	The objective is applicable for reducing complexity by modeling systems conceptually but is not included.
	0	The objective is not applicable for reducing complexity by modeling systems conceptually.

Table 3.2 Rubric for Turkish middle school science curricula. (cont.)

Components	**Rubric level**	**Rubric criteria**
Understanding Systems at Different Scales	3	The objective is applicable for understanding systems at different scales and is fully included.
	2	The objective is applicable for understanding systems at different scales but is partially included.
	1	The objective is applicable for understanding systems at different scales but is not included.
	0	The objective is not applicable for understanding systems at different scales.
Devising Modifications to Produce Desired Effect (Policy making)	3	The objective is applicable for devising modifications to produce desired effect and is fully included.
	2	The objective is applicable for devising modifications to produce desired effect but is partially included.
	1	The objective is applicable for devising modifications to produce desired effect but is not included.
	0	The objective is not applicable for devising modifications to produce desired effect.

In the rubric, the operational definition of each level (0-1-2-3) for each component was explained as:

- Recognizing Interconnections; Recognizing interconnections involves completely identifying the parts of the systems and the connections between these parts (Arnold and Wade, 2015). Turkish middle school curricula were examined by considering the extent to which the objectives in the curriculum included relationships and connections.

  Objectives that cannot be applied to recognizing interconnections or are written for purposes other than recognizing connections and showing relationships between parts, received zero points on the rubric. Objectives that can be applied to

the recognizing interconnections component but do not include establishing relationships or showing connections where relationships exist and can be integrated in a specific subject received one point from the rubric.

Objectives that can be applied to the recognizing interconnections component but are partially included to define the relationship and interconnections received two points from the rubric. While the objectives that receive two points from the rubric may include methods that can show the relationship between concepts, such as comparison and classification, the objectives are not written directly for recognizing relationships or the ability to establish relationships, and the word relationship is not included in the objective.

An objective that can be applied and aims to explain the relationship and connections, and includes the direction of the relationship received three points from the rubric. In addition, since the interaction is a situation arising from the relationship of two or more concepts with each other, if the objective was aimed at defining the interaction of two or more concepts, it received three points from the rubric.

- Identifying and Understanding Feedback; Identifying and understanding feedback involves understanding that interconnections come together to form cause-effect loops, identifying the loops, and gaining information about the functioning of the loops (Arnold and Wade, 2015).

  Objectives that cannot be applied to identifying and understanding feedback or are written for purposes other than identifying and understanding feedback loops received zero points on the rubric. Objectives that can be applied to the identifying and understanding feedback component but do not include demonstrating cause and effect relationships where cause and effect relationships exist and can be integrated into a specific subject received one point from the rubric.

  Objectives that can be applied to the identifying and understanding component but are partially included to define and show the cause-and-effect relationships received two points from the rubric. Objectives that aim to explain the cause-and-effect relationship and also include the details of the relationship received three points from the rubric.

- Understanding System Structure; Since understanding system structure interacts strongly with recognizing interconnections and identifying and understanding feedback components and is a combination of two components (Arnold and Wade, 2015), a matrix was created for this component in the rubric definition. Considering the matrix, the understanding system structure component was scored according to the total score received from recognizing interconnections and identifying and understanding feedback components. The matrix created for scoring objectives for understanding system structure is shown in Table 3.3.

Table 3.3. Calculation matrix of objectives for understanding system structure.

		Identifying and Understanding Feedback Level			
		3	2	1	0
Recognizing	3	3	2	2	2
Interconnections	2	999*	2	2	1
Level	1	999*	999*	1	1
	0	999*	999*	999*	0
999* = Error code, the scoring should be revised.					

As seen in Table 3, an objective cannot receive more points from the identifying and understanding component than it does from the recognizing interconnections component, it can only receive the same score or less than its score from the rubric. Since the interconnections in the system combine to form cause-effect loops, it is not possible to understand how the feedback loop arising from the relationships affects the system behavior without defining the relationship and connections between the system elements (Plate and Monroe, 2014). If an objective is not applicable for recognizing interconnections and identifying and understanding feedback, it is also not applicable for understanding system structure and will receive zero points for this component.

If the objective received one point from the understanding structure component, this has three meanings. First, the objective is applicable for recognizing interconnection but not included, and the objective is not applicable for identifying and understanding feedback component. Second, the objective is applicable for both recognizing interconnection but not included and identifying and understanding feedback component. Third, the objective is applicable for recognizing interconnection but partially included, and it is not applicable for identifying and understanding feedback component.

If the objective received has a score of two from understanding system structure component, this has several meanings. If the objective is applicable for recognizing interconnection but partially included, and the objective is applicable for identifying and understanding feedback but not included or partially included, it receives two points from the understanding system structure component. If the objective is applicable for recognizing interconnection and fully included, it receives two points from the understanding system structure component unless it is also fully included in the identifying and understanding component. If an objective is applicable for recognizing interconnections, and identifying and understanding feedback, it is also applicable for understanding system structure and will receive three points.

- Differentiating Types of stocks, flows, and variables; Being able to assimilate working mechanisms by differentiating stocks, flows, and variables within the system is a very important characteristic of systems thinker skills (Arnold and Wade, 2015). Objectives that are not applicable to differentiating types of stocks, flows, and variables or are written for purposes other than differentiating types of stocks, flows, and variables, received zero points on the rubric.

  Objectives that can be applied to differentiating types of stocks, flows, and variables but do not include recognizing and distinguishing stocks, flows, and variables while stocks, flows, and variables can be included and integrated into a specific subject received one point from the rubric. Objectives that can be applicable to the differentiating types of stocks, flows, and variables but are partially included

to define and show the stocks, flows, and variables in a system received two points from the rubric. Objectives that aim to show and explain how the stocks, flows, and variables of the systems operate received three points from the rubric.

- Identifying and Understanding Nonlinear Relationships; Identifying and understanding nonlinear relationships refers to identifying and understanding system components and system behaviors that have nonlinear properties as well as linear relationships (Arnold and Wade, 2015; Plate and Monroe, 2014; Stave and Hopper, 2007). It also includes the nonlinear nature of stocks and flows (Arnold and Wade, 2015).

  Objectives that cannot be applied to identifying and understanding nonlinear relationships, or do not include the nonlinear relationships in a specific subject, or are written for purposes other than defining and showing the nonlinear relationships in the system received zero points on the rubric. Objectives that can be applied to identifying and understanding nonlinear relationships but do not include establishing or showing nonlinear relationships where nonlinear relationships exist and can be integrated into a specific subject received one point from the rubric. Objectives that can be applied to identifying and understanding nonlinear relationships but are partially included to define and show the nonlinear relationship within the system received two points from the rubric. An objective that can be applied and aims to explain and show the nonlinear relationship in the system received three points from the rubric.
- Understanding Dynamic Behavior; The component of understanding dynamic behavior is formed by the combination of differentiating types of stocks, flows, and variables and identifying and understanding nonlinear relationships, as described in Arnold and Wade's systemigram (2015). It is very difficult to observe the dynamic movement of the system without understanding the stocks, flows, and variables in the loops of the system and the behaviors that do not proceed linearly in the system (Plate and Monroe, 2014). For this reason, a matrix was created for this component in the rubric definition. Considering the matrix, the understanding dynamic behaviors component was scored according to the total score obtained from differentiating types of stocks, flows, and variables and iden-

tifying and understanding nonlinear relationships. The matrix created for scoring objectives for understanding system structure is shown in Table 3.4.

Table 3.4. Calculation matrix of objectives for understanding dynamic behavior.

		Identifying and Understanding Nonlinear Relationship Level			
		3	2	1	0
Differentiating	3	3	3	3	3
Types of	2	999*	2	2	2
stocks, flows, and	1	999*	999*	1	1
variables Level	0	999*	999*	999*	0
999* = Error code, the scoring should be revised.					

As seen in Table 3.4, an objective cannot receive more points from the identifying and understanding nonlinear relationships component than it does from the differentiating types of stocks, flows, and variables component, it can only receive the same score or less than its score from the rubric. If an objective is not applicable for differentiating types of stocks, flows, and variables, and identifying and understanding nonlinear relationships, it is also not applicable for understanding dynamic behavior and will receive zero points for this component.

If the objective received one point from the understanding dynamic behavior component, this has two meanings. First, the objective is applicable for differentiating types of stocks, flows, and variables but not included, and the objective is not applicable for identifying and understanding nonlinear relationship component. Second, the objective is applicable for both differentiating types of stocks, flows, and variables and identifying and understanding nonlinear relationships components but not included.

If the objective received has a score of two from understanding dynamic behavior component, this has three meanings. First, the objective is applicable for differentiating types of stocks, flows, and variables but partially included, and the objective is not applicable for identifying and understanding nonlinear relationships. Second, the objective is applicable for recognizing interconnection but partially included, and the objective is applicable for identifying and understanding nonlinear relationships but not included. Third, the objective is applicable and partially included for both differentiating types of stocks, flows, and variables, and identifying and understanding nonlinear relationships.

If the objective is applicable for recognizing interconnections and fully included, no matter how many points the objective receives from the identifying and understanding nonlinear relationship component, it will receive three points from the understanding dynamic behavior component.

- Reducing Complexity by Modeling Systems Conceptually; The reducing complexity by modeling systems conceptually component enables the system to be seen as a whole under different situations by conceptually modeling the system parts (Arnold and Wade, 2015). Arnold and Wade (2015) stated that it allows interpreting dynamic systems in their entirety by helping to understand complexity by reducing and simplifying complexity about the system. To develop the ability to interpret system behavior, models created by defining the relationships in the system with numerical or verbal terms and data are among the critical attributes a systems thinker must possess (Stave and Hopper, 2007). Therefore, while scoring the rubric, non-numerical modeling containing both quantitative and qualitative data and terms was taken into account.

  The rubric assigned zero points to objectives that could not be applied to reducing complexity by modeling conceptually, i.e., those that were unsuitable for modeling. Objectives that are applicable to reducing complexity by modeling conceptually component but were not included for the component received one point on the rubric. The rubric scored two points for objectives that can be ap-

plied and partially included reducing complexity by conceptually modeling components, either numerically or conceptually, in the outcome content. Objectives that incorporated both numerical and non-numerical modeling, in accordance with the subject's nature, received three points from the rubric.

- Understanding Systems at Different Scales; Understanding systems at different scales allows us to look at the big picture by expressing systems within systems (Arnold and Wade, 2015). In order to fully understand the functioning of the system, it is necessary to interpret the system behavior from a larger scale and to recognize the connections and interactions between the system and another system with which it is connected (Plate and Monroe, 2014).

  Objectives that cannot be applied to understanding systems at different scales, or have limited relationships in a specific subject, or are written for purposes other than showing the behavior of the system from a broader perspective received zero points on the rubric. Objectives that can be applied to understanding systems at different scales but do not include showing systems at different scales that can be integrated into a specific subject received one point from the rubric. Objectives that can be applied to the understanding systems at different scales but are partially included to define and show systems at a broader perspective two points from the rubric. An objective that can be applied and aims to show the system's behavior and interactions from a different and wider angle received three points from the rubric.

- Devising Modifications to Produce Desired Effect; ST refers to creating desired effects by changing system behavior when necessary (Arnold and Wade, 2015). A systems thinker must have the ability to make changes to the data obtained from system behaviors to test systemic effects and seek solutions to problems that may arise (Arnold and Wade, 2015; Stave and Hopper, 2007). Therefore, in rubric scoring, objectives that emphasize the capacity to produce solutions to problems and aim to develop solution-oriented suggestions are considered. Objectives that cannot be applied to devising modifications to produce a desired effect or are written for purposes other than seeking a solution to the problems in a specific subject received zero points on the rubric. Objectives that can be applied to

the devising modifications to produce the desired effect component but do not include demonstrating changes with details that can be made to create solutions that can be integrated into a specific subject received one point from the rubric. Objectives that can be applied to the devising modifications to produce the desired effect component but are partially included, giving details such as the purpose and method of the change to be designed, received two points from the rubric. An objective that can be applied and aims to solve problems by changing system behavior received three points from the rubric.

3.4.3.2. Rubric for Turkish Middle School Science Textbooks. The rubric, which was created for Turkish middle school science textbooks, included four scoring criteria in the form of 0-1-2-3 for each of the nine components in Arnold and Wade's systemigram (2015) is shown in Table 3.5.

Table 3.5. Rubric for Turkish middle school science textbooks.

Components	**Rubric Level**	**Rubric Criteria**
Recognizing Interconnections	3	ST tools are used in the chapter for recognizing interconnections.
	2	ST tools can be used in the chapter but not used; instead, other tools are used for recognizing interconnections.
	1	ST tools can be used in the chapter but not used, nor is any tool are used instead for recognizing interconnections.
	0	The chapter is not applicable for recognizing interconnections.
Identifying and Understanding Feedback	3	CLDs are used in the chapter for identifying and understanding feedback.
	2	CLD can be used in the chapter but not used; instead, other tools are used for identifying and understanding feedback.

Table 3.5 Rubric for Turkish middle school science textbooks. (cont.)

Components	**Rubric Level**	**Rubric Criteria**
	1	CLD can be used in the chapter but not used, nor is any tool used instead for identifying and understanding feedback.
	0	The chapter is not applicable for identifying and understanding feedback.
Understanding system structure	3	ST tools are used in the chapter for understanding system structure.
	2	The scoring was based on the matrix created for the understanding of the system structure component. *
	1	The scoring was based on the matrix created for the understanding of the system structure component. *
	0	The chapter is not applicable for understanding system structure.
Differentiating types of stocks, flows, variables	3	SFDs are used in the chapter for differentiating types of stocks, flows, and variables.
	2	SFD can be used in the chapter but not used; instead, other tools are used for differentiating types of stocks, flows, and variables.
	1	SFD can be used in the chapter but not used, nor is any tool used instead for differentiating types of stocks, flows, and variables.
	0	The chapter is not applicable for the differentiating types of stocks, flows, and variables.
Identifying and Understanding Nonlinear Relationships	3	BOTGs are used in the chapter for identifying and understanding nonlinear relationships.
	2	BOTG can be used in the chapter but not used; instead, other tools

Table 3.5 Rubric for Turkish middle school science textbooks. (cont.)

Components	**Rubric Level**	**Rubric Criteria**
		are used for identifying and understanding nonlinear relationships.
	1	BOTG can be used in the chapter but not used, nor is any tool used instead for identifying and understanding nonlinear relationships.
	0	The chapter is not applicable for identifying and understanding nonlinear relationships.
Understanding Dynamic Behavior	3	ST tools are used in the chapter for understanding of dynamic behavior.
	2	The scoring was based on the matrix created for the understanding of dynamic behavior components. *
	1	The scoring was based on the matrix created for the understanding of dynamic behavior components. *
	0	The chapter is not applicable for understanding of dynamic behavior.
Reducing Complexity by Modeling Systems Conceptually	3	ST tools are used in the chapter for reducing complexity by modeling systems conceptually.
	2	ST tools can be used in the chapter but not used; instead, other tools are used for reducing complexity by modeling systems conceptually.
	1	ST tools can be used in the chapter but not used, nor is any tool are used instead for reducing complexity by modeling systems conceptually.
	0	The chapter is not applicable for reducing complexity by modeling systems conceptually.
Understanding **Systems at**	3	ST tools are used in the chapter for understanding systems at different scales.

Table 3.5 Rubric for Turkish middle school science textbooks. (cont.)

Components	**Rubric Level**	**Rubric Criteria**
Different Scales	2	ST tools can be used in the chapter but not used; instead, other tools are used for understanding systems at different scales.
	1	ST tools can be used in the chapter but not used, nor is any tool used instead for understanding systems at different scales.
	0	The chapter is not applicable for understanding systems at different scales.
Devising Modifications to Produce Desired Effect (Policy Making)	3	ST tools are used in the chapter for devising modifications to produce desired effect.
	2	ST tools can be used in the chapter but not used; instead, other tools are used for devising modifications to produce desired effect.
	1	ST tools can be used in the chapter but not used, nor is any tool are used instead for devising modifications to produce desired effect.
	0	The chapter is not applicable for devising modifications to produce desired effect.
ST tools = Systems Thinking tools (BOTG = Behavior over time graph, SFD = Stock-flow diagram, CLD = Causal loop diagram, CM= Concept map), Other tools = Video analyses, interviews, student drawings, repertory grids, word associations, classroom discussions, visual, experiment, observation, graphic, table **Later in the chapter, the scoring was explained in detail.*		

In the rubric, the operational definition of each level (0-1-2-3) for each component was explained as:

- Recognizing Interconnections; Comprehending the system's components and their relationships is necessary to recognize interconnections (Arnold and Wade, 2015).

Therefore, the degree to which relationships and connections were included in the textbook with ST tools was considered in the examination of Turkish middle school textbooks.

On the rubric, chapters that cannot be applicable or are created for goals other than identifying connections and illustrating relationships between parts received zero points from the rubric. Chapters in which ST tools can be used but not used or where no tools are used instead to recognize interconnections received one point from the rubric. Chapters in which ST tools can be used but not used; instead, other tools are used to recognize interconnections received two points from the rubric. Chapters in which ST tools are used for recognizing interconnections received three points from the rubric.

- Identifying and Understanding Feedback; Identifying and understanding feedback requires recognizing that interconnections combine to form cause-effect loops, comprehending the loops, and learning how the feedback loops work (Arnold and Wade, 2015). The identifying and understanding feedback component is associated with the causal-loop diagram (CLD), an ST tool that is used to show feedback loops (Fisher and Systems Thinking Association, 2023).

  On the rubric, chapters that cannot be applicable or are created for goals other than identifying the feedback loops and showing CLD received zero points from the rubric. Chapters in which CLD can be used but not used or where no tools are used instead to identify and understand feedback received one point from the rubric.

  Chapters in which CLD can be used but not used; instead, other tools are used to identify and understand received two points from the rubric. Chapters in which CLDs are used for identifying and understanding feedback received three points from the rubric.

- Understanding System Structure; Since understanding system structure is a combination of recognizing interconnections and identifying and understanding feedback components (Arnold and Wade, 2015), a matrix was created for this component in the textbook rubric definition as in the curricula rubric definition. Similar to the matrix in the curriculum, the component of the understanding system

structure was scored according to the total score obtained from the components of recognizing interconnections and identifying and understanding feedback. The matrix created for the scoring of objectives for understanding system structure is shown in Table 3.6.

Table 3.6. Calculation matrix of chapters for understanding system structure.

		Identifying and Understanding Feedback Level			
		3	2	1	0
Recognizing	3	3	2	2	2
Interconnections	2	999*	2	2	1
Level	1	999*	999*	1	1
	0	999*	999*	999*	0
999* = Error code, the scoring should be revised.					

As seen in Table 3.6, a chapter cannot score more points in the identifying and understanding component than it does in the recognizing interconnections component, it can only score the same or less than it scores in the rubric. To comprehend how the feedback loop resulting from the relationships affects the system behavior, it is necessary to define the interconnections between the system elements (Plate and Monroe, 2014). If a chapter is not applicable for recognizing interconnections and identifying and understanding feedback, it is also not applicable for understanding system structure and will receive zero points for this component.

If the objective received one point from the understanding structure component, this has three meanings. First, if ST tools can be used in the chapter but not used, nor is any tool are used instead for recognizing interconnections, and the chapter is not applicable for identifying and understanding feedback. Second, ST tools can be

used in the chapter but not used, nor is any tool are used instead for both recognizing interconnections, and identifying and understanding feedback. Third, ST tools can be used in the chapter but not used; instead, other tools are used for recognizing interconnections, and the chapter is not applicable for identifying and understanding feedback.

If the objective received two points from the understanding structure component, this has several meanings. If ST tools can be used in the chapter but not used; instead, other tools are used for recognizing interconnections, and if the chapter is applicable for identifying and understanding feedback, unless ST tools are used for this component, the chapter receives two points from the understanding system structure component. In addition, if ST tools are used in the chapter for recognizing interconnections, unless ST tools are used for identifying and understanding feedback, the chapter also receives two points from the understanding system structure component.

If ST tools are used for recognizing interconnections in the chapter, it means that CLD is also used, so it scored three points in both components. Because system interconnections combine to form cause-and-effect (feedback) loops, it is not possible to understand how feedback loops resulting from relationships affect system behavior without defining the relationships and connections between system elements (Plate and Monroe, 2014).

- Differentiating Types of Stocks, Flows, and Variables; One crucial aspect of systems thinking skills is the ability to absorb operating mechanisms by differentiating stocks, flows, and variables inside the system (Arnold and Wade, 2015). Therefore, differentiating types of stocks, flows, and variables is associated with the stock-flow diagram (SFD), which is a tool that allows individuals to review the structure of systems in detail (Fisher and Systems Thinking Association, 2023). (Fisher and Systems Thinking Association, 2023).

  On the rubric, chapters that are not applicable or are formed for aims other than differentiating types of stocks, flows, and variables and showing SFD received

zero points from the rubric. Chapters in which SFD can be used but not used or where no tools are used instead to differentiate types of stocks, flows, and variables received one point from the rubric. Chapters in which SFD can be used but not used; instead, other tools are used to differentiate types of stocks, flows, and variables received two points from the rubric. Chapters in which CLD are used for differentiating types of stocks, flows, and variables received three points from the rubric.

- Identifying and Understanding Nonlinear Relationships; Identifying and understanding nonlinear relationships involves recognizing and comprehending linear and nonlinear system behaviors and components (Arnold and Wade, 2015; Stave and Hopper, 2007; Plate and Monroe, 2014). This component is associated with the behavior over time graph (BOTG), an ST tool for visualizing the dynamic behavior of parts changing within the system, including linear and nonlinear relationships (Fisher and Systems Thinking Association, 2023).

  On the rubric, chapters that cannot be applied or are created for aims other than identifying and understanding nonlinear relationships and showing BOTG received zero points from the rubric. Chapters in which BOTG can be used but not used or where no tools are used instead to identify and understand nonlinear relationships received one point from the rubric. Chapters in which BOTG can be used but not used; instead, other tools are used to identify and understand nonlinear relationships received two points from the rubric. Chapters in which BOTG is used for identifying and understanding nonlinear relationships received three points from the rubric.
- Understanding Dynamic Behavior; According to the systemigram, differentiating types of stocks, flows variables, and identifying and understanding nonlinear interactions combine to form the component of understanding dynamic behavior (Arnold and Wade, 2015). It is difficult to comprehend the dynamic behavior of a system without identifying its stocks, flows, and variables in the loops, as well as the behaviors that do not follow a linear path (Plate and Monroe, 2014). For this reason, a matrix was created for this component in the rubric definition. Considering the matrix, the understanding dynamic behaviors component was

scored according to the total score obtained from differentiating types of stocks, flows, and variables and identifying and understanding nonlinear relationships. The matrix created for scoring objectives for understanding system structure is shown in Table 3.7.

Table 3.7. Calculator matrix of chapters for understanding dynamic behavior.

		Identifying and Understanding Nonlinear Relationship Level			
Differentiating		3	2	1	0
Types of	3	3	3	3	3
stocks, flows, and	2	999*	2	2	2
variables Level	1	999*	999*	1	1
	0	999*	999*	999*	0
999* = Error code, the scoring should be revised.					

As seen in Table 3.7, a chapter cannot receive more points from the identifying and understanding nonlinear relationships component than it does from the differentiating types of stocks, flows, and variables, it can only receive the same score or less than its score from the rubric. That is, a chapter that can be represented by stocks and flows does not need to have a nonlinear relationship. For this reason, a chapter that does not have a nonlinear relationship can be represented by stocks and flows. If the objective received one point from the understanding dynamic behavior, this has two meanings. First, SFD can be used in the chapter but not used, nor is any tool used instead for differentiating types of stocks, flows, and variables, and identifying and understanding nonlinear relationships. Second, SFD can be used in the chapter but not used, nor is any tool used instead for differentiating types of stocks, flows, and variables, and the chapter is not applicable for identifying and understanding nonlinear relationships.

If the objective received two points from the understanding dynamic behavior, it means that SFD can be used in the chapter but not used; instead, other tools are used for differentiating types of stocks, flows, and variables. Regarding the identifying and understanding nonlinear relationships, chapter may not applicable, SFD may be used in the chapter but not used, nor is any tool used instead, or SFD may be used in the chapter but not used; instead, other tools are used.

Additionally, if a chapter is not applicable for SFD, it is also not applicable for BOTG. Since stocks reveal nonlinear relationships in the system and flows in the system, it is not possible to identify nonlinear relationships in the system without defining stock-flow relationships and their interactions (Arnold and Wade, 2015).

- Reducing Complexity by Modeling Systems Conceptually; The system's complexity can be reduced, and the system can be viewed as a whole in various contexts by conceptually modeling the system's elements (Arnold and Wade, 2015). According to Arnold and Wade, this component makes it possible to interpret dynamic systems as a whole by reducing and simplifying complexity related to the system. One of the most important skills a systems thinker must have is the capacity to generate models by describing the relationships in the system using data and numerical or verbal terminology. Modeling helps individuals to develop the ability to comprehend system behavior (Stave and Hopper, 2007). As a result, non-numerical modeling that included qualitative and quantitative concepts and data was considered for the rubric. On the rubric, chapters that cannot be applicable or are created for aims other than reducing complexity by modeling systems conceptually received zero points from the rubric. Chapters in which ST tools can be used but not used or where no tools are used instead of reducing complexity by modeling systems conceptually received one point from the rubric.
  Chapters in which ST tools can be used but not used; instead, other tools are used to reduce complexity by modeling systems conceptually received two points from the rubric. Chapters in which ST tools are used for reducing complexity by modeling systems conceptually component received three points from the rubric.

- Understanding Systems at Different Scales; Understanding systems at different scales allows for a broader view by representing systems within systems (Arnold and Wade, 2015). Understanding the behavior of the system at larger scales and the relationships and interactions between the system and other systems it is connected to is essential to gaining a complete understanding of how the system operates (Plate and Monroe, 2014).

  On the rubric, chapters that cannot be applied or are created for goals other than understanding systems at different scales received zero points from the rubric. Chapters in which ST tools can be used but not used or where no tools are used instead to understand systems at different scales received one point from the rubric. Chapters in which ST tools can be used but not used; instead, other tools are used to understand systems at different scales, and two points were received from the rubric. Chapters in which ST tools are used for understanding systems at different scales component received three points from the rubric.
- Devising Modifications to Produce Desired Effect; According to Arnold and Wade, systems thinking is achieving desired outcomes by changing system behaviors as needed (Arnold and Wade, 2015). To assess systemic effects and search for potential solutions, a systems thinker must be able to modify data gathered from system behavior (Arnold and Wade, 2015; Stave and Hopper, 2007). As a result, objectives that emphasize the ability to solve problems and seek to formulate solution-oriented proposals were considered in the rubric.

  On the rubric, chapters that cannot be applicable or are created for aims other than devising modifications to produce desired effect received zero points from the rubric. Chapters in which ST tools can be used but not used or where no tools are used instead of devising modifications to produce the desired effect received one point from the rubric.

  Chapters in which ST tools can be used but not used; instead, other tools are used to devise modifications to produce the desired effect received two points from the rubric. Chapters in which ST tools are used for devising modifications to produce the desired effect component received three points from the rubric.

3.5. Analysis Procedures

The qualitative research process for developing rubrics for analyzing Turkish middle school science curricula and textbooks involved a series of iterative steps and expert consultation. Regular weekly meetings were held to obtain expert opinions and refine the rubric. Initially, the Arnold and Wade's systemigram (2015) that was followed as an analytical framework was reviewed with the expert to determine its suitability. The criteria and detailed scoring explanations of the rubric were established based on the systemigram components. These were refined through ongoing discussions and edits in collaboration with the expert, who is knowledgeable about the field. Content validity was ensured through six months of continuous meetings with a subject matter expert, during which their feedback was incorporated into refining the rubric. The middle school science curricula and textbooks were analyzed with all their contents according to the final rubric, comprising nine components aligned with the analytical framework. Firstly, the objectives in the middle school science curricula and the chapters with subheadings in the middle school science textbooks were identified and analyzed by the researcher. Secondly, another coder independently analyzed the chapters with subheadings in the fifth, sixth, seventh, and eighth-grade science curricula and textbooks. Finally, the interrater reliability level was calculated with the agreement between researchers regarding the rubric analysis, once the rubric had been fully analyzed by two coders. The reliability between the two coders was found to be 91%, which is considered to be almost perfect agreement (Miles and Huberman, 1994).

3.6. Trustworthiness

Trustworthiness means readers have confidence in the researchers' conclusion and the essence readers report when reading and interpreting the study. Guba and Lincoln (1981) stated that research should be consistent and reliable to be worthwhile (Guba and Lincoln, 1981). Lincoln and Cuba (1986) emphasized the concept of rigor, which is essential in qualitative research, and stated that concepts such as credibility, transferability, and dependability are criteria for presenting a rigor study (Lincoln and Guba,

1986). Lincoln and Guba (1986) stated that the concept of trustworthiness strengthens the value of research. Trustworthiness is also vital for the study to be worth considering (Lincoln and Guba, 1986). These criteria determined for trustworthiness also assume the position of indicator of the concepts of internal and external validity, reliability, objectivity, and generalizability in qualitative studies (Lincoln and Guba, 1986).

3.6.1. Credibility

Credibility is confidence in the findings' validity by revealing whether or not the study results reflect reality (Lincoln and Guba, 1985). Lincoln and Guba (1985) presented some techniques for providing credibility: "prolonged engagement, persistent observation, triangulation, peer debriefing, negative case analysis, referential adequacy, and member-checking" (Lincoln and Guba, 1985, p. 77). An audit trail can strengthen credibility to confirm the researcher's findings (Cope, 1969). Additionally, Lincoln and Cuba (1985) argued that among the helpful techniques, member-checking is one of the most essential techniques for providing credibility. In the current study, triangulation is considered a credibility technique. Lather (1991) defined triangulation as using multiple data sources and methods. Triangulation means using multiple data sources instead of a single method or technique to achieve the goal of clear and comprehensive findings (Creswell, 2008).

Triangulation has four types: method triangulation, in which more than one method is used in the research; investigator triangulation, in which two or more researchers participate in the same study to strengthen the results, theory triangulation, in which different theories are used for data analysis and data source triangulation, in which more than one data source is used in terms of validation of the data (Carter *et al.*, 2014, p. 545).

In the study, data source triangulation was applied to strengthen credibility. The study aims to examine how ST is included in the Turkish middle school science curricula and textbooks. Following the purpose, the curriculum and science textbooks

were determined as data sources. In addition, investigator triangulation was used to reflect ST representation in the Turkish middle school science curriculum and science textbooks. Two researchers evaluated the coding process and content analysis results.

3.6.2. Dependability

Dependability is the consistency of the findings to show that the study can be repeated (Lincoln and Guba, 1985). In qualitative research, dependability and confirmability are determined by an audit of the research process (Creswell, 2018). A study is considered reliable when the researcher's findings agree with findings in repeated studies with similar conditions and participants (Koch, 2006). In other words, the stability of the data provides dependability and reliability for qualitative study (Tobin and Begley, 2004). The inquiry audit is a technique proposed by Lincoln and Guba (1985) to provide the dependability required for the reproducibility of the study. In addition, code-recoding, interrater comparisons, and triangulation techniques are also specified (Ary *et al.*, 2010). In the present study, two triangulation methods were followed, as mentioned before. After the two researchers conducted the coding process independently, the existing codes were recorded, and the reliability coefficient for inter-reliability was calculated. In addition, the rubric development process was carried out simultaneously with expert opinion and feedback.

3.6.3. Transferability

Transferability refers to the applicability of findings in different contexts (Creswell, 2008; Lincoln and Guba, 1985). Transferability requires the author to describe the studied phenomenon (Creswell, 2008; Erlandson *et al.*, 1993; Lincoln and Guba, 1985). A strategy that can be used to ensure transferability is thick description (Amankwaa, 2016; Creswell, 2000). Lincoln and Guba (1985) also referred to the thick description to provide external validity. Detailed descriptions and explanations allow researchers to draw a picture of the findings and transfer the results to other situations, times, environments, and people (Amankwaa, 2016; Creswell, 2000). A thick description gives

details regarding providing a rich description from general to specific (Creswell, 2008). To ensure transferability, details of the sources, information, and explanations of all data from the beginning to the end of the research were taken into account. For example, detailed explanations based on the rubric were given to examine the extent to which the content of the Turkish middle school science curriculum reflects ST. To see the reflection of the ST components in the curriculum, the components of ST in the rubric were defined in detail, and the analysis results were presented in detail. To illuminate the extent to which science textbooks reflect ST, the relevant chapters and pages in the book were also shown based on the rubric developed.

3.6.4. Confirmability

Confirmability requires the research steps to be carried out transparently and expresses the degree of confirmation of the study's results (Lincoln and Guba, 1985; Tobin and Begley, 2014). The researcher can demonstrate the confirmability of the study by explaining how the data and results were generated and interpreted with rich quotes (Cope, 1969). In addition, confirmability is an indicator of the reflexivity of the study; it is also very critical in creating the findings without prejudice of the researcher and reflecting the truth (Amankwaa, 2016). Lincoln and Guba (1985) suggested audit trail, triangulation, and reflexivity techniques provide confirmability (Guba and Lincoln, 1981). The current study was conducted with two types of triangulation, as stated in the previous section, to ensure confirmability and include a data analysis conducted by two coders.

4. RESULTS

This chapter includes four sections containing the content analysis results of fifth, sixth, seventh and eighth-grade science curricula and science textbooks, according to the rubric created based on the definitions of the nine components in systemigram (Arnold and Wade, 2015), which is used as the analytical framework. First, the examination of the science curricula for fifth, sixth, seventh and eighth grades, followed by an investigation of the textbooks for each grade is presented. Then, a comparative analysis of each chapter in the fifth, sixth, seventh and eighth-grade science textbooks with the curriculum objectives is presented. Finally, a summary of the results is presented.

4.1. The Results of the Fifth-grade Curriculum and Textbook Analysis

First, this section contains the content analysis of the fifth-grade science curriculum and textbook, respectively. Finally, the section presents an integrated content analysis of the results of the fifth-grade curriculum and textbooks.

4.1.1. Inclusion of ST in the Fifth-grade Science Curriculum

This subsection covers ST inclusion in the fifth-grade science curriculum. There are a total of thirty-six objectives in the fifth-grade science curriculum. Figure 1 shows the scores obtained regarding the extent to which the fifth-grade science curriculum includes ST according to the rubric (Table 3.2).

4.1.1.1. Recognizing Interconnections. All objectives in the curriculum received at least one point for the recognizing interconnections component. A score of zero indicates the objective is not applicable for recognizing interconnections, therefore, these results show that all objectives in the fifth-grade science curriculum are applicable to the recognizing interconnections component.

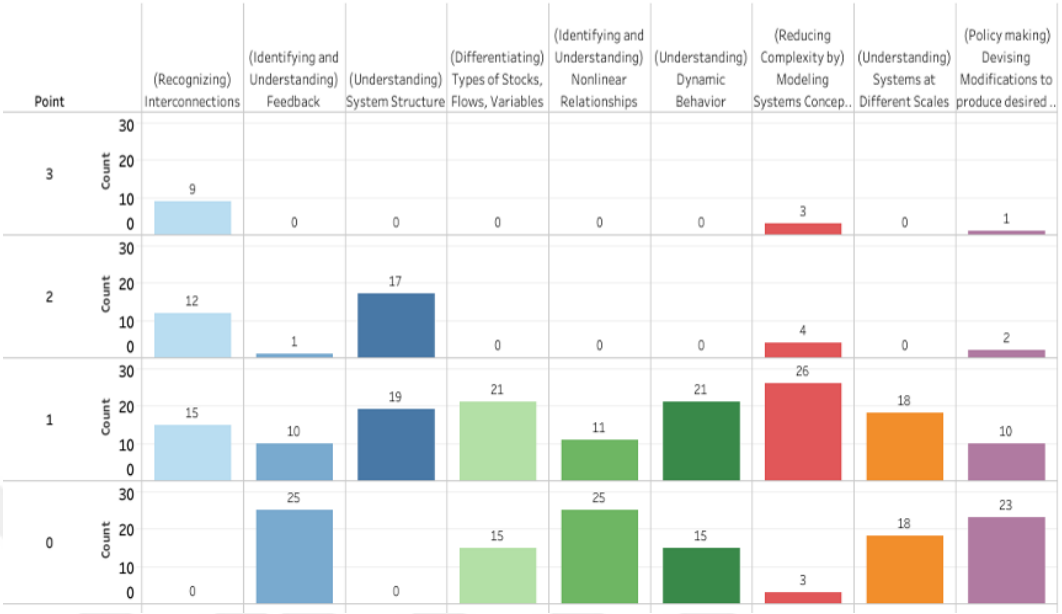

Figure 4.1. Inclusion of ST in the fifth-grade science curriculum.

Fifteen curriculum objectives received one point, indicating the objective is applicable for recognizing interconnections but is not included (Figure 4.1). An example of an objective that meets this criterion is "Explain the properties of the Sun" (MoNE, 2018, p. 25). The objective was not designed to explain the cause-and-effect relationship or the components of the Solar System. On the other hand, there is a relationship between the Sun, Moon, Earth, and other planets in the Solar System.

Twelve objectives received two points, indicating the objective is applicable for recognizing interconnections but is partially included (Figure 1). An example of an objective that meets this criterion is "Give examples of living things and classify them according to their similarities and differences" (MoNE, 2018, p. 26). Classification is not intended to demonstrate the cause-effect relationship within a living system fully but can partially illustrate it. Nine objectives received three points, indicating the objective is applicable for recognizing interconnections and is fully included in this component (Figure 1). An example of an objective that meets this criterion is "Describe the relationship between the Moon's phases and its orbit around the Earth" (MoNE, 2018, p. 26). This objective clearly aims to explain the relationship between the Moon's rotation around the Earth.

4.1.1.2. Identifying and Understanding Feedback. Twenty-five objectives received zero points, indicating the objective is not applicable to identifying and understanding feedback (Figure 4.1). An example of an objective that meets this criterion is "Provide examples of frictional force in everyday life" (MoNE, 2018, p. 27). The objective does not aim to identify the feedback that exists in the friction force but rather to offer examples.

Ten objectives received one point, indicating the objective is applicable for identifying and understanding feedback but is not included (Figure 4.1). An example of an objective that meets this criterion is "Interpret the results of experiments on heat exchange as a result of mixing liquids with different temperatures" (MoNE, 2018, p. 28). Heat exchange is a process that involves feedback loops, but the objective does not mention feedback loops. The objective is only about interpreting the results of an experiment on heat exchange, while it may aim to explain the feedback mechanisms involved in the experiment.

One objective received two points for the identifying and understanding feedback component indicating that the objective is applicable for identifying and understanding feedback but is partially included (Figure 4.1). An example of an objective that meets this criterion is "Make inferences based on the data obtained from the experiments that substances can change state under the influence of heat" (MoNE, 2018, p. 27). The objective includes the expression of a changing state under the influence of heat. Since changing the state under the influence of heat may indicate feedback loops in the objective, it differs from the objective that gets one point. However, the objective did not score three points because the demonstration of the existing feedback loop was not clearly stated. No objective received three points indicating that neither objective includes a clear definition and understanding of feedback loops as an objective.

4.1.1.3. Understanding System Structure. The understanding system structure component was scored depending on the scoring of the recognizing interconnections and identifying and understanding feedback components. No objective received zero points

for understanding the system structure component, indicating the objective is not applicable for recognizing interconnections and identifying and understanding feedback (Figure 4.1). These results show that all of the objectives in the fifth-grade science curriculum are applicable to the understanding system structure.

Nineteen objectives received one point on the understanding of the system structure component (Figure 4.1). The criteria for receiving one point from the understanding system structure component were scored according to the matrix created for recognizing interconnections and identifying and understanding feedback components criteria. An example of an objective that receives one point from this component is "Prepare a model representing the movements of the Sun, Earth, and Moon relative to each other" (MoNE, 2018, p. 26). This objective received one point for the recognizing interconnections component since it is applicable to show the interconnections between the Sun, Earth, and Moon. However, it does not define the relationship between them, which was the intended purpose of ST. It also received zero points for identifying and understanding the feedback component because the feedback loop between the Sun, Earth, and Moon is required to know Newton's Law of Gravity (Born, 1962) to define feedback loops. However, the Law of Gravity is not included in the fifth-grade science curriculum objectives, so it is not applicable to including feedback loops. Therefore, it received one point from the matrix created for the understanding of the system structure component. Since the interconnections in the system come together to form feedback loops, an objective that is applicable to the recognizing interconnections component but does not include a purpose for displaying feedback loops is not sufficient to understand the system structure.

Seventeen objectives received two points from this component (Figure 4.1). The criteria for receiving two points for the understanding system structure component were scored based on the matrix created for the recognizing interconnections, and identifying and understanding feedback components criteria. An example of an objective that receives two points from this component is "Explain the relationship between the phases of the Moon and the Moon's orbital motion around the Earth" (MoNE, 2018,

p. 26). This objective received three points from the recognizing interconnections component, as it aims to explain a relationship fully. However, the objective does not apply to feedback loops due to the knowledge of Newton's Law of Gravity (Born, 1962), as mentioned previously. Therefore, it received zero points for identifying and understanding feedback. In this case, two points were given for understanding the system structure component due to its clear purpose in comprehending system elements despite the absence of a feedback loop. No objective received three points on the understanding system structure component, which indicates that no objectives aim to recognize and understand interconnections and feedback loops fully.

4.1.1.4. Differentiating Types of Stocks, Flows, and Variables. Fifteen objectives received a score of zero, indicating the objective is not applicable for the differentiating types of stocks, flows, and variables (Figure 4.1). An example of an objective that meets this criterion is "Explain the rotation and circulation movements of the Moon" (MoNE, 2018, p. 26). This objective aims to explain only the movements of the Moon, which does not include stock and flow.

Twenty-one objectives received a score of one from this component, indicating the objective is applicable for the differentiating types of stocks, flows, and variables but is not included (Figure 4.1). An example of an objective that meets this criterion is "Express the importance of interaction between human and environment" (MoNE, 2018, p. 29). The relationship between humans and the environment can be highlighted through the use of stocks and flows in this objective. Still, the purpose of the objective is to emphasize the importance of the relationship between humans and the environment rather than showing with stocks and flows. No objective was found that received two or three points, indicating that the objectives in the fifth-grade science curriculum are not aimed at showing stocks, flows, and variables.

4.1.1.5. Identifying, Understanding Nonlinear Relationship. Twenty-five objectives received a score of zero for identifying and understanding nonlinear relationships, in-

dicating the objective is not applicable for identifying and understanding nonlinear relationships (Figure 4.1). An example of an objective that meets this criterion is "Generate new ideas to increase or decrease friction in daily life" (MoNE, 2018, p. 27). The objective does not aim to show relationships that have nonlinearity.

Eleven objectives received a score of one from this component, indicating the objective is applicable for identifying and understanding nonlinear relationships but is not included (Figure 4.1). An example of an objective that meets this criterion is "Interpret the results of experiments on heat exchange as a result of mixing liquids with different temperatures" (MoNE, 2018, p. 28). While the objective is applicable to demonstrate the nonlinear relationships that exist in heat exchange through experiment, the focus is on interpreting the experimental results regarding heat exchange, rather than showing nonlinear relationships. No objective was found to receive two or three points indicating that the fifth-grade science curriculum lacks objectives that demonstrate nonlinear relationships.

4.1.1.6. Understanding Dynamic Behavior. The understanding dynamic behavior component was scored depending on the scoring of the differentiating stocks, flows, and variables, and identifying and understanding nonlinear relationships components (Table 3.4). Fifteen objectives received a score of zero on understanding dynamic behavior component indicating that the objective is not applicable for differentiating types of stocks, flows, and variables, and identifying and understanding nonlinear relationships (Figure 4.1). An example of an objective that meets this criterion is "Observe the reflections of light on smooth and rough surfaces and shows them in drawing" (MoNE, 2018, p. 28). This objective aims to observe the reflections of light and do not have stock, flow or nonlinear relationships. Therefore, it is also not applicable to understanding dynamic behavior. Twenty-one objectives received one point on the understanding dynamic behavior component (Figure 4.1). The criteria for receiving one point from the understanding dynamic behavior component were scored according to the matrix created for the differentiating stocks, flows, and variables, and identifying and understanding nonlinear relationships components criteria. An example of an objective that

receives one point from this component is “Discuss the results of the experiments by conducting experiments on the expansion and contraction of substances under the influence of heat” (MoNE, 2018, p. 28). Since the objective mentions the state of the matter under the influence of heat, it is applicable to the differentiating stocks, flows, and variables component because the changes in the matter under the influence of heat can be shown with stocks and flows.

On the other hand, since the objective does not aim to show stocks and flows, so it received one point from this component. In addition, it received zero points for the identifying and understanding nonlinear relationships component. Expansion and contraction due to heat do not have a nonlinear relationship; therefore, the objective is not applicable to this component. However, since the objective is applicable to show stock, flow, and variables, it is also applicable to understanding the dynamic behavior component. A concept represented by stock, flow, and variables will help reveal the dynamic behavior of the system. However, a concept that can be represented with stocks and flows does not necessarily contain nonlinear relationships. Therefore, the understanding dynamic behavior component scored one point on this component.

No objective was found that received two points from the understanding dynamic behavior component according to the matrix. These results indicate that no objective received two points from both differentiating types of stocks, flows, and variables, and identifying and understanding nonlinear relationship components. An objective that receives two points from both components means that it partially includes these two components in its content. Another case, receiving two points from the understanding dynamic behavior means that the objective received two points from the differentiating types of stocks, flows, and variables component while received one point from the identifying and understanding component. This indicates that the objective partially includes stock, flow and variables, while it may include nonlinear relationships but does not.

In another case, receiving two points from the understanding dynamic behavior also means that the objective received two points from the differentiating types of stocks, flows, and variables component while receiving zero points from the identifying and understanding component. This indicates that the objective partially includes stock, flow, and variables, but it is not applicable to show nonlinear relationships. Not every representation that can be expressed through the stock and flows needs to have a nonlinear relationship. If a topic that does not involve a nonlinear relationship can be demonstrated with stocks and flows, it can be mentioned as a means to understand the dynamic behavior of the system. Therefore, while the objective received zero points of identifying and understanding nonlinear relationships, two points can be scored from the understanding dynamic behavior component regarding the differentiating types of stocks, flows, and variables component. No objective was found that received three points, indicating that the fifth-grade science curriculum does not include an objective that includes stock, flow, and fully representing variables and nonlinear relationships.

4.1.1.7. Reducing Complexity by Modeling Systems. Three objectives received a score of zero for reducing complexity by modeling systems conceptually, indicating the objective is applicable for reducing complexity by modeling systems conceptually but is not included (Figure 4.1). An example of an objective that meets this criterion is "Classify materials according to their light transmission" (MoNE, 2018, p. 28). The objective does not aim to model the topic.

Twenty-six objectives received a score of one for this component indicating the objective is applicable for reducing complexity by modeling systems conceptually but is not included (Figure 4.1). An example of an objective that meets this criterion is "Predict the variables affecting the brightness of a light bulb in an electrical circuit and tests the predictions" (MoNE, 2018, p. 30). While the objective may be aimed at testing the bulb brightness by modeling the electrical circuit, it is not focused on the modeling part.

Four objectives received a score of two, indicating the objective is applicable for reducing complexity by modeling systems conceptually but are partially included (Figure 4.1). An example of an objective that meets this criterion is "Observe how a full shadow is formed and shows it with simple ray drawings" (MoNE, 2018, p. 28). Since the objective aims to draw a simple ray, it partially includes modeling.

Three objectives received a score of three on this component indicating the objective is applicable for reducing complexity by modeling systems conceptually and is fully included (Figure 4.1). An example of an objective that meets this criterion is "Prepare a model representing the movements of the Sun, Earth, and Moon relative to each other" (MoNE, 2018, p. 25). Since the objective involves modeling the movements of the Sun, Earth, and Moon, it received three points from this component.

4.1.1.8. Understanding Systems at Different Scales. For the understanding of systems at different scales component, eighteen objectives received a score of zero, indicating the objective is not applicable for understanding systems at different scales (Figure 4.1). An example of an objective that meets this criterion is "Design a dynamometer model using simple tools" (MoNE, 2018, p. 27). The objective is not applicable to showing systems from different perspectives in a hierarchical manner, its purpose includes designing a thermometer.

Eighteen objectives received a score of one, indicating the objective is applicable for understanding systems at different scales but is not included (Figure 4.1). An example of an objective that meets this criterion is "Discuss the ideas that living things can live on the Moon" (MoNE, 2018, p. 25). While the objective may include being able to compare different systems of living things on Earth considering the conditions necessary for living things to live on the Moon, it does not include such an aim. No objective was found to receive two or three points on this component, indicating no objective in the fifth-grade science curriculum objectives that aim to interpret at different scales and show the hierarchy, if any, between systems.

4.1.1.9. Devising Modifications to Produce the Desired Effect. Twenty- three objectives received zero points on the devising modifications to produce the desired effect component indicating the objective is not applicable for devising modifications to produce the desired effect (Figure 4.1). An example of an objective that meets this criterion is "Observe that the light from a source follows a linear path in all directions and shows it with a drawing" (MoNE, 2018, p. 28). The objective is not applicable to making changes to seek a policy-making solution to the problems.

Ten objectives received one point on this component, indicating that the objective is applicable for devising modifications to produce the desired effect but is not included (Figure 4.1). An example of an objective that meets this criterion is "Discuss the factors threatening biodiversity based on research data" (MoNE, 2018, p. 29). The objective does not aim to seek solutions to problems that may be encountered regarding the impact of factors that threaten biodiversity while researching them. It only aims to identify those factors.

Two objectives received two points from this component, indicating the objective is applicable for devising modifications to produce the desired effect but is partially included (Figure 4.1). An example of an objective that meets this criterion is "Discuss the ideas that living things can live on the Moon" (MoNE, 2018, p. 25). While the objective could have aimed to produce a solution to a problem that might be encountered while discussing life on the Moon, its aim was solely to discuss the subject.

One objective received three points, indicating the objective is applicable for devising modifications to produce the desired effect and is fully included (Figure 4.1). An example of an objective that meets this criterion is "Offer suggestions for solving an environmental problem in the immediate environment or in our country" (MoNE, 2018, p. 29). Since the objective aims to provide suggestions for solving an environmental problem, it clearly emphasizes the component of devising modifications to produce the desired effect.

4.1.2. Inclusion of ST in the Fifth-grade Science Textbook

This subsection covers ST inclusion in the fifth-grade science textbook. The fifth-grade science textbook contains seven units and twenty chapters. Figure 4.2 shows the scores obtained regarding the extent to which the fifth-grade science textbook includes ST according to the rubric (Table 3.5).

4.1.2.1. Recognizing Interconnections. All chapters received two points on the recognizing interconnections component, indicating ST tools can be used in the chapter but not used; instead, other tools are used for recognizing interconnections (Figure 4.2). The results indicate that all chapters in the fifth-grade science textbook focus on recognizing and understanding interconnections. However, there is no content explained with ST tools.

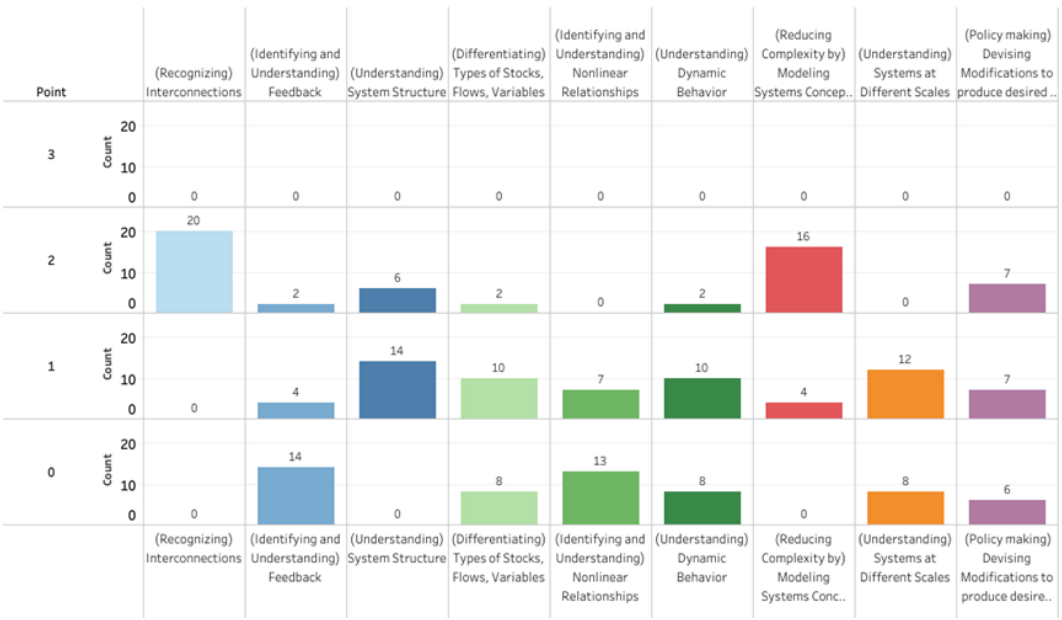

Figure 4.2. Inclusion of ST in the fifth-grade science textbook.

4.1.2.2. Identifying and Understanding Feedback. Fourteen chapters received zero points on the identifying and understanding feedback indicating the chapter is not applicable for identifying and understanding feedback (Figure 4.2). An example of a chapter that meets this criterion is the Measurement of Force. This chapter only includes the

characteristics of the force, the fact that force is measured with a dynamometer, and a definition of frictional force, without going into detail regarding the age group.

Four chapters received one point on this component indicating CLD can be used in the chapter but not used, nor is any tool used instead for identifying and understanding feedback (Figure 4.2). An example of a chapter that meets this criterion is the Living Things. In this chapter, feedback loops arising from interactions between living things are not mentioned.

Two chapters received two points on this component, indicating CLD can be used in the chapter but not used; instead, other tools are used for identifying and understanding feedback (Figure 4.2). An example of a chapter that meets this criterion is Biodiversity. In this chapter, the human-environment relationship can be shown with CLD but is explained with visuals and written explanations. Although feedback loops are not explicitly included in the textbook, concepts about Biodiversity that constantly influence each other are mentioned in the textbook. No chapter received three points on the identifying and understanding feedback component, indicating that that the chapters in the fifth-grade textbook do not contain CLD.

4.1.2.3. Understanding System Structure. The understanding system structure component was scored depending on the points received from recognizing interconnections and identifying and understanding feedback components. No chapter received zero points for understanding the system structure component, which indicates the chapter is not applicable for recognizing interconnections and identifying and understanding feedback (Figure 4.2). These results show that all of the chapters in the fifth-grade science textbook are applicable to the understanding system structure.

Fourteen chapters received one point on this component (Figure 4.2). The criteria for receiving one point from the understanding system structure component were scored according to the matrix created for recognizing interconnections, and identifying and understanding feedback components criteria (Table 3.6). An example of a chapter

that receives one point from this component is Friction Force. This chapter received two points for the recognizing interconnections component and zero points for the identifying and understanding feedback component.

Interconnections are present in the chapter, although not with ST tools, while the chapter is not applicable for demonstrating feedback loops. To comprehend the system structure, it is crucial to understand the feedback loops generated by the interconnections. However, this chapter lacks a feedback mechanism. Nevertheless, the interconnections within the chapter are supported by visual and written explanations. As a result, the chapter received one point for the understanding system structure component. Since the chapter has no causal loops, it received one point instead of two.

Six chapters received two points from the understanding system structure component (Figure 4.2). The criteria for receiving two points from the understanding system structure component were scored according to the matrix created for recognizing interconnections, and identifying and understanding feedback components criteria (Table 3.6). An example of a chapter that receives two points from this component is Living Things. This chapter received two points for the recognizing interconnections component and one point for the identifying and understanding feedback component. The chapter demonstrates interconnections, although not with ST tools, and contains feedback loops that are not explicitly shown.

The distinction from the chapter that receives one point for the understanding system structure component is that this chapter covers a topic that involves causal loops. Interconnections are showed by visual and written explanations. Feedback mechanisms are not included, although can be shown, resulting in the chapter receiving two points instead of one in the understanding system structure component. No chapter received three points on understanding the system structure component, which indicates that no chapter in the fifth-grade science textbook is explained with ST tools for understanding system structure.

4.1.2.4. Differentiating Types of Stocks, Flows, and Variables. For the differentiating types of stocks, flows, and variables component, eight chapters received a score of zero, indicating the chapter is not applicable for the differentiating types of stocks, flows, and variables (Figure 4.2). An example of a chapter that meets this criterion is Earth and Moon. In this chapter, it is aimed to show the properties and movements of the Earth and the Moon. There is no purpose in chapter objectives to show stock, flow and variables about Earth and Moon.

Ten chapters received a score of one, indicating SFD can be used in the chapter but not used, nor is any tool used instead for differentiating types of stocks, flows, and variables (Figure 4.2). An example of a chapter that meets this criterion is Friction Force. While stocks and flows that exist in the friction force can be shown in this chapter, they are not included in the chapter.

Two chapters received two points indicating SFD can be used in the chapter but not used; instead, other tools are used for differentiating types of stocks, flows, and variables (Figure 4.2). An example of a chapter that meets this criterion is Change of State of Matter. This chapter covers the change between states of matter resulting from heat exchange. The representation used in the textbook is similar to SFD, although it is not explicitly referred to as stock and flow. No chapter was found that received three points indicating that SFD was not used in the fifth-grade science textbook.

4.1.2.5. Identifying, Understanding Nonlinear Relationship. Thirteen chapters received a score of zero from the identifying and understanding nonlinear relationships component indicating the chapter is not applicable for identifying and understanding nonlinear relationships (Figure 4.2). An example of a chapter that meets this criterion is the Propagation of Light, as there are no nonlinear relationships in the Propagation of Light. Seven chapters received a score of one from this component indicating BOTG can be used in the chapter but not used, nor is any tool used instead for identifying and understanding nonlinear relationships (Figure 4.2). An example of a chapter that meets this criterion is Heat and Temperature. The heat exchange in this chapter in-

volves nonlinear relationships, but these relationships are not mentioned in the chapter content. No chapter received two or three points indicating that nonlinear relationships are not explained in all the chapters in the fifth-grade science textbooks.

4.1.2.6. Understanding Dynamic Behavior. Depending on the scores obtained on differentiating stocks, flows, and variables, and identifying and understanding nonlinear relationships components, understanding dynamic behavior was scored (Table 3.7). Eight chapters received zero points, indicating the chapter is not applicable for differentiating stocks, flows, and variables, and identifying and understanding nonlinear relationships components (Figure 4.2). An example of a chapter that meets this criterion is Propagation of Light. Light propagation is not a subject that can be represented by stocks and flows and has nonlinear relationships, therefore it is not applicable to understanding dynamic behavior. Ten chapters received one point on this component (Figure 4.2). The criteria for receiving one point from the understanding dynamic behavior component were scored according to the matrix created for the differentiating stocks, flows, and variables, and identifying and understanding nonlinear relationships components criteria (Table 3.7). An example of a chapter that receives one point from this component is Representation of Circuit Elements with Symbols and Circuit Diagrams. This chapter can present electrical circuit elements and electrical flow using stocks and flows. However, the textbook does not mention stocks and flows, resulting chapter receiving only one point for the differentiating types of stocks, flows, and variables component.

Additionally, the chapter does not contain a nonlinear relationship, so it is not applicable to the identifying and understanding nonlinear relationship component and received zero points. To comprehend the system's dynamic behavior, it is crucial to depict concepts with nonlinear relationships using stocks and flows. However, this chapter lacks nonlinear relationships, and although stocks and flows could be illustrated, they are not. As a result, the chapter received only one point for understanding the dynamic behavior component (Figure 4.2). If the textbook included stocks and flows, although not with ST tools, the chapter could have received two points instead of one.

Two chapters received two points on the understanding dynamic behavior component (Figure 4.2). The criteria for receiving two points from the understanding dynamic behavior component were scored according to the matrix created for the differentiating stocks, flows, and variables, and identifying and understanding nonlinear relationships components criteria (Table 3.7). An example of a chapter that receives one point from this component is Change of State of Matter. In this chapter, the state change with heat flow presents a similarity to SFD, although not with SFD itself. Therefore, it received two points in the differentiating types of stocks, flows, and variables component.

Additionally, while the chapter may demonstrate the nonlinearity that occurs in the state change of matter, the textbook does not include this nonlinear relationship. Due to the lack of representation of nonlinear relationships using any tools, the identifying and understanding nonlinear relationship component only scored one point. While Chapter stocks and flows were depicted, they were not shown using ST tools. As a result, the chapter received two points on the understanding dynamic behavior component. No chapter was found to receive three points on this component which indicates that no chapter in the fifth-grade science textbook is explained with ST tools for understanding dynamic behavior.

4.1.2.7. Reducing Complexity by Modeling Systems. No chapter received zero points on this component indicating the chapter is not applicable for reducing complexity by modeling systems conceptually. These results show that all chapters in the fifth-grade science textbook are applicable to reducing complexity by modeling systems conceptually (Figure 4.2). Four chapters received one point indicating ST tools can

be used in the chapter but not used, nor is any tool are used instead for reducing complexity by modeling systems conceptually (Figure 2). An example of a chapter that meets this criterion is Heat and Temperature. This chapter is applicable to modeling with ST tools such as SFD and CLD, but is not included in the textbook content. Sixteen chapters received two points indicating ST tools can be used in the chapter but not used; instead, other tools are used for reducing complexity by modeling systems conceptually (Figure 4.2). An example of a chapter that meets this criterion is Shadow. There is modeling for the relevant topic in the chapter, but ST tools are not integrated into the modeling. No chapter received three points for this component indicating that none of the models presented in the fifth-grade science textbook were created or displayed using ST tools.

4.1.2.8. Understanding Systems at Different Scales. Eight chapters received zero points for understanding systems at different scale component indicating the chapter is not applicable for understanding systems at different scales (Figure 4.2). An example of a chapter that meets this criterion is Reflection of Light. This chapter describes the properties of light and is not applicable for understanding systems at different scales component. Twelve chapters received one point on this component, indicating that ST tools can be used in the chapter but are not used, and no tool is used instead for understanding systems at different scales (Figure 4.2). An example of a chapter that meets this criterion is Natural Phenomenon. The chapter discusses the formation processes of natural disasters. As natural disasters are complex systems that affect various other systems, it can provide insight into different scales of systems. However, there is no narrative integrated with ST tools, nor with any tools. No chapter received two or three points indicating that none of the chapters in the fifth-grade science textbook employ ST or other tools to understand systems at varying scales.

4.1.2.9. Devising Modifications to Produce Desired Effect. Six chapters received zero points for revising modifications to produce the desired effect component, indicating the chapter is not applicable for devising modifications to produce desired effect (Fig-

ure 4.2). An example of a chapter that meets this criterion is Distinctive Properties of Matter. This chapter aims to show the distinctive properties of matter, such as melting and freezing points, and is not applicable to the purpose of seeking a solution to a problem.

Seven chapters received one point indicating ST tools can be used in the chapter but not used, nor is any tool used instead for devising modifications to produce the desired effect (Figure 4.2). An example of a chapter that meets this criterion is the Human and the Environment. This chapter is applicable to finding solutions to problems that may arise as a result of human and environmental interactions, but there is no content regarding seeking a solution in the textbook.

Seven chapters received two points from this component, indicating ST tools can be used in the chapter but not used; instead, other tools are used for devising modifications to produce the desired effect (Figure 4.2). An example of a chapter that meets this criterion is Living Things. In this chapter, it is emphasized to produce solutions to the problems that occur in the natural flow of the living world, but there is no content related to ST tools. No chapter was found that received three points indicating that the chapters in the fifth-grade science textbook do not include an integrated explanation with ST tools to seek a solution or to solve a problem by making changes to create the desired effect.

4.1.3. ST Inclusion in the Fifth-grade Science Curriculum and Textbook by Units

In this subsection, a unit-based content analysis of ST inclusion in fifth-grade science curriculum and textbook are presented.

In the first unit, the Sun, Earth, and Moon, covers chapters on the Structure and properties of the Sun, the Structure and properties of the Moon, the Movements and Phases of the Moon, and the Sun, Earth, Moon. Although not using ST tools

for the recognizing interconnections component in the Sun, Earth, and Moon unit, there are objectives in the curriculum for the relationships between the Sun, Earth, and Moon and the relationships are included in the textbook content. In addition, there is a causal loop between the Sun, Earth, and Moon, which can be represented by nonlinear relationships and stock-flows. However, this causal loop requires knowledge of the variables in Newton's Law of Gravity (Born, 1962) since knowing the distance between the Sun, Earth, and Moon and their masses enables to recognize the dynamic relationship and nonlinear mechanism in the rotation and orbital motions of the Sun, Earth, and Moon.

The objectives in the fifth-grade curriculum are not targeted at knowing the law of gravity (MoNE, 2018), and the age group is not appropriate for understanding the variables in the law of gravity. Therefore, the objective and content in this unit are not applicable to identifying and understanding feedback, differentiating types of stocks, flows, and variables, identifying and understanding nonlinear relationships, and understanding dynamic behavior. On the other hand, the unit is applicable for recognizing the Sun, Earth, and Moon as a part of the Milky Way Galaxy, interpreting them at different scales, and creating modeling as stated in the objectives (MoNE, 2018). In this context, modeling is aimed and presented with visualization tools such as models and diagrams in the textbook, although not integrating ST tools. Although all the objectives in this unit are applicable to understanding systems at different scales component, the textbook does not include content related to this component.

The unit is also applicable for brainstorming about problems that may arise in the movements of the Sun, Earth, and Moon relative to each other in accordance with devising modifications to produce the desired effect component with an objective "Discuss the ideas that living things can live on the Moon" (MoNE, 2018, p. 25).

The activity and assessment sections do not provide any content on the use of ST tools. Additionally, in the science, engineering, and entrepreneurship applications (SEEA) section of the unit, even though it is not an activity that involves using ST

tools, there is an activity that encourages students to think and create ideas about life on the Moon, which is expressed as follows.

> Design a habitat on the moon where living things can live. First, express your design in a drawing. Then, you can turn your drawing into a three-dimensional model by getting the necessary tools and equipment (MoNE, 2023, p. 37).

The second unit, Living Things, includes classifications and similarities/differences of living things. As stated in the curriculum objectives, classifications and relationships between living things are included in the textbook in accordance with the recognizing interconnections component, although not with ST tools. The unit is applicable to identifying and understanding feedback and nonlinear relationships, because it has feedback loops that can be represented by stocks and flows within the Living Things and have nonlinear relationships. However, the curriculum objectives and the textbook contents do not include information on feedback mechanisms and stock-flow relationships within the living things system.

Furthermore, the concepts of genus and species are not included in the classifications of living things in the textbook. Living things can be considered complex systems with various subsystems, therefore, their hierarchical structure also needs to be introduced in fifth-grade textbooks for understanding systems at different scales component. The unit is also applicable to reducing complexity by conceptually modeling systems with their objectives. It is also applicable to devising modifications to produce desired effect components with its objectives. Although various visuals are used in the textbook content, these two components are not associated with ST tools. The activity and assessment sections do not provide any information on using ST tools. The SEEA section includes an activity that aims to solve the problems related to the living things given below, but it does not aim to make a design with ST tools.

> Identify a problem or need encountered in daily life related to the topics you learned in this unit. Prepare a research project to solve the problem or meet the need you have identified (MoNE, 2023, p. 60).

The third unit, Force Measurement and Friction Force, includes chapters on Force Measurement and Friction Force. The textbook content and curriculum objectives include the relationship between these two concepts, even though they do not utilize ST tools as part of the recognizing interconnections component. This unit and its objectives are not applicable to identifying and understanding feedback and nonlinear relationships components, as it lacks any mechanism that can create a causal loop with nonlinear relationships. Although the friction force can be depicted by SFD, which defines the force as a stock that increases as the friction force increases, no content related to SFD has been found in either the curriculum or the textbook.

The textbook includes modeling for reducing complexity by modeling system conceptually components, but it does not mention any content for model design in the objectives. For the understanding systems at different scales component, microscopic images of friction surfaces and their relationship to surface roughness could be included, but no content for this component is present in the curriculum or textbooks. The activity and assessment sections do not include any information on the use of ST tools. The SEEA section provides an activity that addresses issues related to friction force. However, it does not include ST integration; therefore, devising modifications to produce the desired effect component was not fully adapted. The guideline for the activity is shown below.

> Design a vehicle that reduces air and water resistance, similar to those engineered by professionals. Begin by drawing your design and then create a three-dimensional model using the appropriate tools and equipment (MoNE, 2023, p. 87).

The fourth unit, Matter and Change, covers chapters such as Change of State of Matter, Distinctive Properties of Matter, Heat Affects Substances, and, Heat and Temperature. The unit discusses the relationships between matter and changes in both curriculum objectives and textbook content in accordance with the recognizing interconnections component. Changes in the state of matter occur due to the influence of heat, making it a causal loop in the form of a balancing loop. When a substance

is subjected to a change in temperature, it undergoes a transformation from one state to another. It can be exemplified by the transition from a solid to a liquid or a liquid to a gas. However, the state of matter does not undergo a continuous and indefinite change, resulting in a balancing loop with nonlinear relationships. The objective in the curriculum and textbook aims to discuss the relationship between changes in state and heat change resulting from temperature differences, although it does not explicitly state a causal loop. Therefore, the components of identifying and understanding feedback and nonlinear relationships were not fully implemented in an integrated manner with ST.

The provided diagram in the fifth-grade science textbook (MEB, 2023, p. 106) illustrates the transitions of substances between solid, liquid, and gas states, but it was created without defining stock and flow. Similarly, the differentiating stocks, flows and variables component was not fully integrated with ST. Although the curriculum does not have a learning outcome for reducing complexity by modeling systems conceptually component, the textbook includes modeling in the unit. The activity and assessment sections do not contain any content related to ST. In the SEEA section, there is an activity on the subject that cannot be fully adapted to the devising modifications to produce the desired effect component because ST tools are not used. The guideline for the activity is expressed as follows.

> Design a product that utilizes the expansion and contraction properties of materials to simplify your daily life (MoNE, 2023, p.127).

The fifth unit, Light Propagation, includes chapters on Propagation of Light, Reflection of Light, Interaction of Light with Matter, and Shadow. The curriculum objectives and textbook content both emphasize the importance of recognizing interconnections between these concepts. The unit does not contain nonlinear relationships and causal loops in the propagation of light and, therefore, cannot be represented by stock flows with a SFD. As a result, identifying and understanding feedback, identifying and understanding nonlinear relationships, and differentiating stocks, flows, and variables are not applicable to the unit. The unit is also not applicable for under-

standing systems at different scales. The unit includes various models, as stated in the objectives. However, ST tools for reducing complexity by modeling systems conceptually component are not used. The activity and assessment sections do not contain any content related to ST tools, other than true/false, fill-in-the-blank, and multiple-choice questions. In the SEEA section, there is an activity that aims to develop a solution to a problem without the use of ST tools, which is shown below. Therefore, the activity does not involve any content related to the devising modifications to produce the desired effect component. The guideline for the activity is shown below.

> Design a product that uses light reflection to make your life easier (MoNE, 2023, p. 159).

The sixth unit, Human and the Environment, covers chapters such as Biodiversity, Human and the Environment, and Natural Disasters. These chapters are interconnected, and their connections are included in the curriculum objectives and textbook content in accordance with the recognizing interconnections component. Human-environment interaction involves a causal loop of interconnected parts that includes both nonlinear and linear relationships, since human activities impact the environment, ecosystems, biodiversity, and the formation of natural events.

The relationship between humans and the environment can also be described using stock and flows. Therefore, ST can be used to explain the dynamics of interaction between humans and the environment. However, this unit explains the objectives and content of the textbook using different tools instead of ST tools, in the context of the relationship between humans and the environment, as well as biodiversity. Although the component of reducing complexity by modeling systems conceptually can be used, it was not utilized both in the objectives and textbook. The activity and assessment sections include multiple-choice, fill-in-the-blank, and true/false questions. In the SEEA section, the activity focuses on human and environmental interaction or biodiversity, and ST tools are not used for devising modifications to produce the desired effects component to be applied. The guideline for the activity is provided as follows.

> Design a tool to mitigate the negative effects of natural disasters, similar to the tools engineers design to mitigate the harmful effects of earthquakes (MoNE, 2023, p. 191).

The seventh chapter, Electrical Circuit Elements, covers chapters on the Representation of Electrical Circuit Elements and Circuit Diagrams, and Variables Affecting Bulb Brightness. The unit is aligned with the recognizing interconnections in the curriculum objectives and textbook content, as it includes interconnections and the relationships related to the subject. Electrical circuit elements do not have causal loops or nonlinear relationships; therefore, identifying and understanding feedback and nonlinear relationships components are not applicable. Electric flow, which is a current formed by electric potential difference, can be represented by SFD according to the age level. However, the curriculum objectives and textbook contents did not utilize SFD in a manner that would allow for differentiating types of stocks, flows, and variables.

In accordance with the reducing complexity by modeling systems conceptually component, the chapter includes modeling but does not incorporate ST tools. In the objectives, there is only one objective for this component "Create a diagram of the electrical circuit" (MoNE, 2018, p. 30). Additionally, this chapter is not applicable to understanding systems at different scales both in the objectives and textbook content. The activity and assessment sections involve multiple choice, true/false, and fill-in-the-blank questions and lack ST tools, similar to the other chapters in the textbook. The SEEA section includes an activity that focuses on devising modifications to produce the desired effect component, but does not involve ST tools. The guideline for the activity is shown below.

> Design a product with a simple electrical circuit that will make daily life easier (MoNE, 2023, p. 213).

4.2. The Results of the Sixth-grade Curriculum and Textbook Analysis

Firstly, the content analysis of the science textbook and curriculum for sixth graders is presented in this section. Finally, the section presents an integrated content analysis of the results of the sixth-grade curriculum and textbooks.

4.2.1. Inclusion of ST, Sixth-grade Science Curriculum

This subsection covers ST inclusion in the sixth-grade science curriculum. The sixth-grade science curriculum comprises seven units and fifty-nine objectives. Figure 4.3 shows the scores obtained regarding the extent to which the sixth-grade science curriculum includes ST according to the rubric (Table 3.2).

4.2.1.1. Recognizing Interconnections. Out of fifty-nine objectives, six objectives received zero points indicating the objective is not applicable for recognizing interconnections (Figure 4.3). An example of an objective that meets this criterion is "Develop alternative thermal insulation materials" (MoNe, 2018, p. 25). This objective has a different purpose for the development of thermal insulation materials than explaining the components in thermal insulation, so it is not applicable to recognizing connections.

Sixteen objectives received one point, indicating the objective is applicable for recognizing interconnections but is not included (Figure 4.3). An example of an objective that meets this criterion is "Define speed and express its unit" (MoNE, 2018, p. 33). While defining the concept of speed, it would have been beneficial to include the components such as direction, magnitude, or orientation, but this was not done in an objective manner.

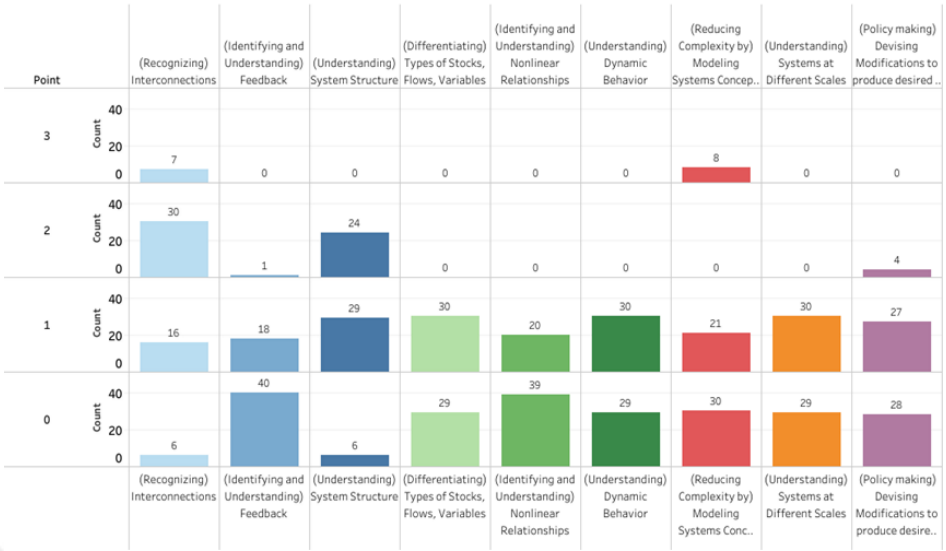

Figure 4.3. Inclusion of ST in the sixth-grade science curriculum.

Thirty objectives received two points, indicating the objective is applicable for recognizing interconnections but is partially included (Figure 4.3). An example of an objective that meets this criterion is "Compare the densities of liquids that are insoluble in each other through experimentation" (MoNE, 2018, p. 34). The objective aims to compare liquids with different densities, and the comparison also involves knowing the cause-effect relationship, whereas the cause-effect relationship is not explicitly included.

Seven objectives received three points from the recognizing interconnections component, indicating the objective is applicable for recognizing interconnections and is fully included (Figure 4.3). An example of an objective that meets this criterion is "Illustrate the relationship between distance, time, and speed using a graph" (MoNE, 2018, p. 34). The objective clearly aims to show the relationship between concepts such as speed, time, and distance, so recognizing interconnections is fully included in this objective.

4.2.1.2. Identifying and Understanding Feedback. Forty objectives received zero points from the identifying and understanding feedback component, indicating the objective is not applicable for identifying and understanding feedback component (Figure 4.3). An

example of an objective that meets this criterion is “Compare balanced and unbalanced forces by observing object motion” (MoNE, 2018, p. 34).

Balanced and unbalanced forces are not relevant for demonstrating feedback loops, as it does not involve feedback mechanisms.

Eighteen objectives received one point on this component, indicating the objective is applicable for identifying and understanding feedback but is not included (Figure 4.3). An example of an objective that meets this criterion is “Explain the functions of the structures and organs that make up the respiratory system using models” (MoNE, 2018, p. 33). The respiratory system contains ongoing feedback between respiratory system organs, but the objective does not aim to demonstrate these feedback mechanisms.

One objective received two points, indicating the objective is applicable for identifying and understanding feedback but is partially included (Figure 4.3). An example of an objective that meets this criterion is “Discuss the effect of controlling and regulating systems on the regular and coordinated functioning of other systems in our body” (MoNE, 2018, p. 37). The objective focuses on the interaction between control and regulation systems and other systems in the human body, including their effects. There is a feedback mechanism between control and regulation systems and other systems. However, the aim is not to demonstrate the feedback mechanism clearly. The objective indirectly alludes to feedback loops; therefore, it does not fully emphasize the identification and comprehension of the feedback component. No objective received three points from this component, indicating that the objectives in the sixth-grade science curriculum do not fully include the identifying and understanding feedback component.

4.2.1.3. Understanding System Structure. The understanding system structure component was scored depending on the scoring of the recognizing interconnections and identifying and understanding feedback components (Table 3.3). Six objectives received zero points on this component indicating the objective is not applicable for

recognizing interconnections and identifying and understanding feedback (Figure 4.3). An example of an objective that meets this criterion is "Determine the selection criteria of thermal insulation materials used in buildings" (MoNE, 2018, p. 35). The objective does not aim to recognize any concept related to thermal insulation. The objective aims to determine the selection criteria for thermal insulation materials; therefore, it received zero points for the recognizing interconnections component. Furthermore, thermal insulation does not involve feedback loops; therefore, it received zero points in the identifying and understanding feedback component as it is not applicable. Therefore, it also received zero points for the objective understanding of the system structure component.

Twenty-nine objectives received one point on the understanding of the system structure component (Figure 4.3). The criteria for receiving one point from the understanding system structure component were scored according to the matrix created for recognizing interconnections and identifying and understanding feedback components criteria (Table 3.3). An example of an objective that receives one point from this component is "Discuss the importance of this situation for living things by comparing the densities of solid and liquid states of water" (MoNE, 2018, p. 34). This objective received two points for the recognizing interconnections component since the objective involves comparison. Making comparisons is also related to knowing the cause-effect relationship, but there is no purpose to define the cause-effect relationship in the objective clearly, so it received two points on recognizing interconnections component. The objective received zero points for identifying and understanding the feedback component because it aims to compare the densities of water in different states and does not include a feedback loop. Therefore, the objective received one point from the matrix created for the understanding of the system structure component. Understanding the system structure requires showing feedback loops and the recognition of interconnections. This is because the interconnections in the system join together to produce feedback loops. Therefore, an objective that is not applicable to the identifying interconnections component and does not include a purpose for illustrating feedback loops is also not applicable to understanding the system structure.

Twenty-four objectives received two points from the understanding system structure component (Figure 4.3). The criteria for receiving two points for the understanding system structure component were scored based on the matrix created for recognizing interconnections, and identifying and understanding feedback components criteria (Table 3.3). An example of an objective that receives two points from this component is "Express the exchange of blood between blood groups" (MoNE, 2018, p. 33). This objective received two points from the recognizing interconnections component. While it does not indicate to identify a cause-effect relationship, it aims to recognize interconnections in blood exchange and received two points. Blood exchange involves feedback loops, but the objective is not to show these loops. The objective of identifying and understanding the feedback component scored one point for this reason. Additionally, the objective understanding system structure component scored two points as it partially aims to identify and understand the system elements and can include the feedback loops. No objective received three points from this component, indicating that no objective aims to recognize and understand interconnections and feedback loops of the system fully.

4.2.1.4. Differentiating Types of Stock, Flow, Variable. Twenty- nine objectives received a score of zero, indicating the objective is not applicable for the differentiating types of stocks, flows, and variables (Figure 4.3). An example of an objective that meets this criterion is "Show the direction, direction, and magnitude of the force acting on an object by drawing" (MoNE, 2018, p. 33).

Since the components of the force do not include stocks and flows, this objective is not applicable to differentiating stocks, flows, and variables component. Thirty objectives received a score of one from this component, indicating the objective is applicable for the differentiating types of stocks, flows, and variables but is not included (Figure 4.3). An example of an objective that meets this criterion is "Explain the functions of the structures and organs that make up the digestive system using models" (MoNE, 2018, p. 32). The digestive system is applicable for showing stocks, flows, and variables and can be represented by stocks and flows, but the objective does not aim

to show stocks and flows. No objective was found to receive two or three points, indicating that the objectives in the sixth-grade science curriculum are not aimed at showing stocks, flows, and variables.

4.2.1.5. Identifying, Understanding Nonlinear Relationship. Thirty-nine objectives received a score of zero from the identifying and understanding nonlinear relationships component, indicating the objective is not applicable for identifying and understanding nonlinear relationships (Figure 4.3). An example of an objective that meets this criterion is "Show the relationship between path, time and speed on a graph" (MoNE, 2018, p. 34). Since there is no nonlinear relationship between the concepts of speed, time, and distance, the objective is not applicable to identifying and understanding nonlinear relationships.

Twenty objectives received a score of one from this component, indicating the objective is applicable for identifying and understanding nonlinear relationships but is not included (Figure 4.3). An example of an objective that meets this criterion is "Explain the functions of the structures and organs that make up the respiratory system using models" (MoNE, 2018, p. 33). The respiratory system contains feedback loops, as well as nonlinear relationships in these feedback loops. For this reason, the objective is applicable to show nonlinear relationships, but the objective does not aim to show these relationships. No objective was found to receive two or three points, indicating that the objectives in the sixth-grade science curriculum are not included in identifying and understanding nonlinear relationships in the systems.

4.2.1.6. Understanding Dynamic Behavior. The understanding dynamic behavior component was scored depending on the scoring of the differentiating stocks, flows, and variables, and identifying and understanding nonlinear relationship components (Table 3.4). Twenty-nine objectives received a score of zero on understanding dynamic behavior components indicating that the objective is not applicable for differentiating types of stocks, flows, and variables, and identifying and understanding nonlinear rela-

tionships (Figure 4.3). An example of an objective that meets this criterion is "Create a model by sorting the planets in the solar system according to their proximity to the Sun" (MoNE, 2018, p. 31). The objective is to create a model of the planets. The model of planets does not contain a nonlinear relationship and is not a model that can be represented with stock and flows. The objective only aims to sort the planets according to their distance from the Sun. For this reason, it is not applicable to stock flow and nonlinear relationship representation. Therefore, the objective is also not applicable to the understanding of the dynamic behavior component.

Thirty objectives received one point from the understanding dynamic behavior component (Figure 4.3). The criteria for receiving one point from the understanding dynamic behavior component were scored according to the matrix created for the differentiating stocks, flows, and variables, and identifying and understanding nonlinear relationships components criteria (Table 3.4). An example of an objective that receives one point from this component is "Make inference about nutrients must undergo physical (mechanical) and chemical digestion in order to pass into the blood" (MoNE, 2018, p. 32). Physical and chemical digestion involves stocks and flows, as well as nonlinear relationships. On the other hand, the objective does not aim to show stock flows and nonlinear relationships. For this reason, it received one point for differentiating stocks, flows, and variables, and identifying and understanding nonlinear relationship components. Therefore, it also received one point from the understanding dynamic behavior component.

No objective received two points from the understanding dynamic behavior component (Figure 4.3). These results indicate that no objective received two points from both differentiating types of stocks, flows, and variables, and identifying and understanding nonlinear relationship components. An objective that received two points from both components is an objective that partially includes these two components in its content. In another case, receiving two points from the understanding dynamic behavior means that the objective received two points from the differentiating types of stocks, flows, and variables component while receiving one point from the identify-

ing and understanding component. This indicates that the objective partially includes stock, flow, and variables, while it may include nonlinear relationships but does not.

In another case, receiving two points from the understanding dynamic behavior also means that the objective received two points from the differentiating types of stocks, flows, and variables component while receiving zero points from the identifying and understanding component. This indicates that the objective partially includes stock, flow and variables, while it is not applicable to show nonlinear relationships. Not every representation that can be expressed through stock flows needs to have a nonlinear relationship. If a subject that does not involve a nonlinear relationship can be demonstrated with stocks and flows, it can be mentioned as a means to understand the dynamic behavior of the system. Therefore, while identifying and understanding nonlinear relations receives zero points, two points can be earned from the understanding system structure component. No objective received three points indicating that the sixth-grade science curriculum does not include an objective that includes stock, flow, and fully representing variables and nonlinear relationships.

4.2.1.7. Reducing Complexity by Modeling Systems. Thirty objectives received a score of zero for reducing complexity by modeling systems conceptually, indicating the objective is applicable for reducing complexity by modeling systems conceptually but is not included (Figure 4.3). An example of an objective that meets this criterion is "Define speed and expresses its unit" (MoNE, 2018, p. 33). The objective does not include modeling. Twenty-one objectives received a score of one point for this component indicating the objective is applicable for reducing complexity by modeling systems conceptually but is not included. An example of an objective that meets this criterion is "Explain the functions of organs that help digestion" (MoNE, 2018, p. 32). While the organs that help digestion can be shown with a model in the objective, it only aims to explain their functions and not focus on the modeling.

No objective received two points, indicating the objective is applicable for reducing complexity by modeling systems conceptually but is partially included (Figure 4.3).

These results show that the objectives in the sixth-grade science curriculum do not partially include modeling.

Eight objectives received three points from this component, indicating the objective is applicable for reducing complexity by modeling systems conceptually and is fully included (Figure 4.3). An example of an objective that meets this criterion is "Create a model representing the eclipse of the Sun and Moon" (MoNE, 2018, p.31). The objective is clearly aimed at modeling, so it received three points.

4.2.1.8. Understanding Systems at Different Scales. Twenty-nine objectives received zero points, indicating the objective is not applicable for understanding systems at different scales (Figure 4.3). An example of an objective that meets this criterion is "Develop alternative heat insulation materials" (MoNE, 2018, p. 35). The objective aims to develop materials for thermal insulation and is not applicable to understanding and interpreting systems from different perspectives.

Thirty objectives received one point, indicating that the objective is applicable for understanding systems at different scales but is not included (Figure 4.3). An example of an objective that meets this criterion is "Examine the large and small blood circulation on the diagram and explains their functions" (MoNE, 2018, p. 33). Blood circulation can be interpreted at different scales when other metabolic events occurring in the human body and the functions of organs in the human body are considered; however, the objective aims to examine and define blood circulation only. No objective received two or three points on this component, indicating there is no objective in the sixth-grade science curriculum objectives that aims to interpret at different scales and show the hierarchy, if any, between systems.

4.2.1.9. Devising Modifications to Produce Desired Effect. Twenty-eight objectives received zero points on the devising modifications to produce the desired effect component indicating the objective is not applicable for devising modifications to produce

the desired effect (Figure 4.3). An example of an objective that meets this criterion is "Predict the environments in which sound can propagate and tests their predictions" (MoNE, 2018, p. 35). The objective is aimed at focusing on and testing predictions about sound propagation, which is not applicable to devising modifications to produce the desired effect.

Twenty-seven objectives received one point on this component, indicating the objective is applicable for devising modifications to produce the desired effect but is not included (Figure 4.3). An example of an objective that meets this criterion is "Summarize the functions of the structures and organs that make up the excretory system by showing them on the model" (MoNE, 2018, p. 33).

The objective aims to show the excretory system organs and their functions. It does not aim to provide a solution to a problem that may occur in the system, while it could have pointed out excretion problems while explaining the structure and organs.

Four objectives received two points from this component, indicating the objective is applicable for devising modifications to produce the desired effect but is partially included (Figure 4.3). An example of an objective that meets this criterion is "Research and report the measures to be taken about stove and natural gas poisoning" (MoNE, 2018, p. 35).

While the objective could have identified natural gas and stove poisoning as a problem and aimed to produce solutions for this problem, it focused only on researching this problem. No objective received three points from this component, indicating that the objectives in the sixth-grade science curriculum do not explicitly include the aim of creating a solution to a specific problem.

4.2.2. Inclusion of ST in the Sixth-grade Science Textbook

This subsection covers ST inclusion in the sixth-grade science textbook. There are seven units and twenty-two chapters in the sixth-grade science textbook. Figure 4.4 shows the scores obtained regarding the extent to which the sixth-grade science textbook includes ST according to the rubric (Table 3.5).

4.2.2.1. Recognizing Interconnections. All chapters in the sixth-grade science textbook received two points on the recognizing interconnections component, indicating ST tools can be used in the chapter but not used; instead, other tools are used for recognizing interconnections (Figure 4.4). The results indicate that all chapters in the sixth-grade science textbook focus on recognizing and understanding interconnections. On the other hand, there is no content in the chapters explained with ST tools.

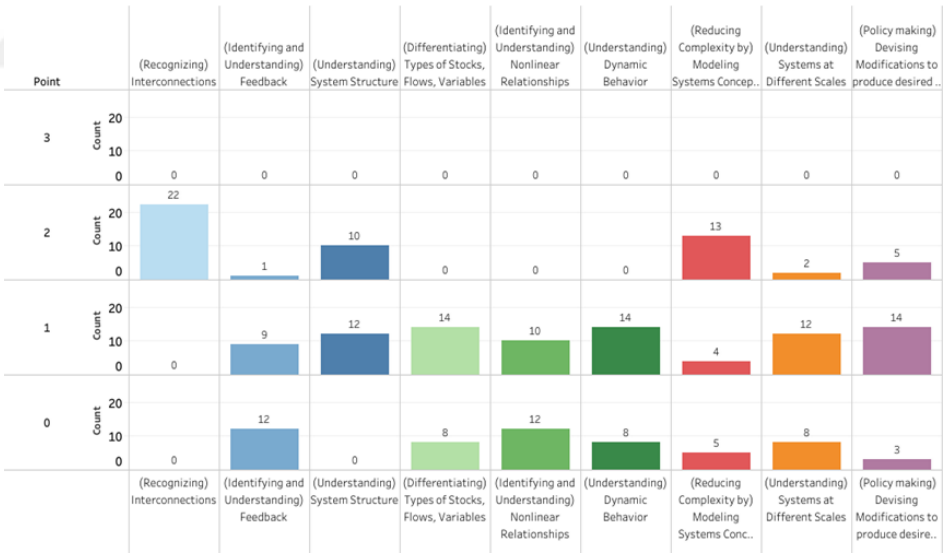

Figure 4.4. Inclusion of ST in the sixth-grade science textbook.

4.2.2.2. Identifying and Understanding Feedback. Twelve chapters received zero points for identifying and understanding feedback, indicating the chapter is not applicable for identifying and understanding feedback (Figure 4.4). An example of a chapter that meets this criterion is Resultant Force. This chapter includes the direction and magnitude of the force and the definitions of a balanced and unbalanced force. Since

the chapter does not contain a feedback mechanism, it is not applicable for displaying feedback loops.

Nine chapters received one point on this component, indicating that CLD can be used in the chapter but not used, nor is any tool used instead for identifying and understanding feedback. An example of a chapter that meets this criterion is the Respiratory System. The respiratory system contains feedback loops, but the textbook does not mention feedback mechanisms. One chapter received two points indicating CLD can be used in the chapter but not used; instead, other tools are used for identifying and understanding feedback. An example of a chapter that meets this criterion is the Circulatory System. In this chapter, large and small blood circulation is shown with other tools such as visuals (MoNE, 2023, p.61).

No chapter received three points on the identifying and understanding feedback component, indicating that the CLD was not used in the sixth-grade textbook (Figure 4.4). These results show that the chapters in the sixth-grade science textbook do not contain CLD.

4.2.2.3. Understanding System Structure. The understanding system structure component was scored depending on the points received from recognizing interconnections and identifying and understanding feedback components (Table 3.6). No chapter received zero points on understanding the system structure component, indicating the chapter is not applicable for recognizing interconnections and identifying and understanding feedback (Figure 4.4). These results show that all of the chapters in the sixth-grade science textbook are applicable to the understanding system structure.

Twelve chapters received one point on this component (Figure 4). The criteria for receiving one point from the understanding system structure component were scored according to the matrix created for recognizing interconnections and identifying and understanding feedback components criteria. Solar and Lunar Eclipses are an example of a chapter that receives one point from this component. This chapter received

two points for recognizing interconnections and zero points for identifying and understanding feedback components. This indicates that interconnections are present in the chapter, although not with ST tools, while the chapter is not applicable for showing feedback loops. To comprehend the system structure, it is crucial to understand the feedback loops created by the system's interconnections. However, this chapter lacks a feedback mechanism. Despite this, both written and visual explanations reinforce the connections made within the chapter. As a result, the chapter scored one point for the understanding of the system structure component. The chapter only received one point instead of two because it is not applicable to causal loops.

Ten chapters received two points from the understanding system structure component (Figure 4.4). The criteria for receiving two points from the understanding system structure component were scored according to the matrix created for recognizing interconnections and identifying and understanding feedback components criteria (Table 3.6). An example of a chapter that receives two points from this component is Musculoskeletal System. This chapter received two points for the recognizing interconnections component and one point for the identifying and understanding feedback component.

The chapter identifies and shows interconnections in the textbook, although not with ST tools, and contains feedback loops that are not explicitly shown. The distinction from the chapter that receives one point for the understanding system structure component is that this chapter involves causal loops. Visual and written explanations in the textbook show interconnections. Feedback mechanisms are not included, although they can be shown, resulting in the chapter receiving two points instead of one in the understanding system structure component. No chapter received three points on understanding system structure component, which indicates that no chapter in the sixth-grade science textbook is explained with ST tools for understanding system structure.

4.2.2.4. Differentiating Types of Stock, Flow, Variable. Eight chapters received a score of zero, indicating the chapter is not applicable for the differentiating types of stocks, flows, and variables (Figure 4.4). An example of a chapter that meets this criterion is Speed of Sound. This chapter aims to explain the speed of sound in different environments. The speed of sound is not applicable to representation by stocks and flows.

Fourteen chapters received a score of one, indicating that SFD can be used in the chapter but not used, and that no tool is used instead for differentiating types of stocks, flows, and variables (Figure 4.4). An example of a chapter that meets this criterion is Sensory Organs. While stocks and flows in the sensory organs can be presented in the content, they are not included in the chapter. No chapter received two or three points indicating that SFD was not used in the sixth-grade science textbook, even can be used.

4.2.2.5. Identifying, Understanding Nonlinear Relationship. Twelve chapters received a score of zero for the identifying and understanding nonlinear relationships component, indicating that the chapter is not applicable for identifying and understanding nonlinear relationships (Figure 4.4). An example of a chapter that meets this criterion is Propagation of Sound, as the chapter has no nonlinear relationships. Ten chapters received a score of one from this component, indicating BOTG can be used in the chapter but not used, nor is any tool used instead for identifying and understanding nonlinear relationships (Figure 4.4). An example of a chapter that meets this criterion is The Human Body Systems and Health. Although the Human Body Systems and Health chapter contains nonlinear relationships similar to the Human Body System chapter, but nonlinear relationships are not mentioned in the textbook. No chapter received two or three points indicating that nonlinear relationships are not explained in any of the chapters in the sixth-grade science textbooks.

4.2.2.6. Understanding Dynamic Behavior. Depending on the scores obtained on differentiating stocks, flows, and variables, and identifying and understanding nonlinear relationship components, understanding dynamic behavior was scored (Table 3.7). Eight chapters received zero points, indicating the chapter is not applicable for differentiating stocks, flows, and variables, and identifying and understanding nonlinear relationship components (Figure 4.4). An example of a chapter that meets this criterion is Propagation of Sound. Sound propagation is not a subject that can be represented by stocks and flows and has nonlinear relationships, therefore it is also not applicable to understanding dynamic behavior.

Fourteen chapters received one point on this component (Figure 4.4). The criteria for receiving one point from the understanding dynamic behavior component were scored according to the matrix created for the differentiating stocks, flows, and variables, and identifying and understanding nonlinear relationships components criteria (Table 3.7). An example of a chapter that receives one point from this component is Fuels. In this chapter, an SFD can be shown on renewable and non-renewable energy sources. However, the textbook does not mention stocks and flows, resulting chapter receiving only one point for the differentiating types of stocks, flows, and variables component. Likewise, human interaction with renewable and non-renewable energy sources has nonlinear relationships in this chapter. On the other hand, only the definition of energy resources is given in the textbook content, supported by visuals. Thus, it is applicable to identifying and understanding nonlinear relationship components, but BOTG is not included in the chapter. Therefore, the chapter also received one point for identifying and understanding nonlinear relationships. Depicting concepts using stocks and flows is crucial for understanding the dynamic behavior of a system. Nonlinear relationships should also be included in the expression if they exist. Although this chapter does not mention stock, flow variables, or nonlinear relationships, it received one point for understanding the dynamic behavior component since the chapter is applicable to showing SFD and BOTG. If the textbook included stocks and flows, although not with ST tools, the chapter could have received two points instead of one.

No objective received two points from the understanding dynamic behavior component (Figure 4.4). These results indicate that there was no chapter received two points from both differentiating types of stocks, flows, and variables, and identifying and understanding nonlinear relationship components. A chapter that receives two points from both components means that SFD and BOTG can be used in the chapter but not used; instead, other tools are used for differentiating types of stocks, flows, and variables, and identifying and understanding nonlinear relationship components.

In another case, receiving two points from the understanding dynamic behavior means that the chapter received two points from the differentiating types of stocks, flows, and variables component while receiving one point from the identifying and understanding component. This indicates that the SFD can be used in the chapter but not used; instead, other tools are used, while BOTG can be used in the chapter but not used, nor is any tool used for nonlinear relationships.

In another case, receiving two points from the understanding dynamic behavior also means that the chapter received two points from the differentiating types of stocks, flows, and variables component while receiving zero points from the identifying and understanding component. This indicates that SFD can be used in the chapter but not used; instead, other tools are used for differentiating types of stocks, flows, and variables, while it is not applicable to show nonlinear relationships.

Not every representation that can be described by stocks and flows requires a nonlinear relationship. Using stocks and flows is one way to understand the dynamic behavior of the system, even if there is no nonlinear relationship involved. Therefore, the comprehending dynamic behavior component can be scored two points by addressing the differentiating types of stocks, flows, and variables component, even though the chapter received zero points for identifying and understanding nonlinear relationships.

Similarly, no chapter received three points on this component, which indicates ST tools are used in the chapter for understanding dynamic behavior (Figure 4.4). Results

showed that no chapter in the sixth-grade science textbook is explained with BOTG for understanding dynamic behavior.

4.2.2.7. Reducing Complexity by Modeling Systems. Five chapters received zero points for reducing complexity by modeling systems conceptually component, indicating the chapter is not applicable for reducing complexity by modeling systems conceptually (Figure 4.4). An example of a chapter that meets this criterion is Hearing Sound Differently in Different Environments. This chapter explains that different sounds can be heard when the sound source or environment changes, and the chapter is not aimed at modeling.

Four chapters received one point indicating ST tools can be used in the chapter but not used, nor is any tool are used instead for reducing complexity by modeling systems conceptually (Figure 4.4). An example of a chapter that meets this criterion is the Resultant Force. This chapter is applicable to modeling with ST tools such as SFD, but is not included in the textbook content, supported only with visuals and graphics. Thirteen chapters received two points indicating ST tools can be used in the chapter but not used; instead, other tools are used for reducing complexity by modeling systems conceptually (Figure 4.4). An example of a chapter that meets this criterion is Matter and Heat. There is modeling for the relevant topic in the chapter, but ST tools are not integrated into the modeling. No chapter received three points for this component, indicating that none of the models presented in the fifth-grade science textbook were created or displayed using ST tools (Figure 4.4).

4.2.2.8. Understanding Systems at Different Scales. Eight chapters received zero points for understanding systems at different scale component indicating the chapter is not applicable for understanding systems at different scales (Figure 4.4). An example of a chapter that meets this criterion is Density. This chapter describes the density and includes the calculation about density, therefore, is not applicable for the understanding systems at different scales component.

Twelve chapters received one point on this component, indicating ST tools can be used in the chapter but not used, nor is any tool used instead for understanding systems at different scales (Figure 4.4). An example of a chapter that meets this criterion is Control and Regulatory Systems. This chapter covers the interaction of control and regulatory systems with other systems in the human body. For this reason, systems can be interpreted from different scales in this chapter. Each system in the human body creates a system within itself, and when all systems come together, they form a large system (i.e., the human organism). Therefore, in this chapter, ST tools can be used to highlight the understanding systems at different scales components, but they are not used. The chapter also does not contain any content that would indicate system-within-a-system.

Two chapters received two points indicating ST tools can be used in the chapter but not used; instead, other tools are used for understanding systems at different scales (Figure 4.4). An example of a chapter that meets this criterion is the Solar System. This chapter includes the location of the solar system in space, the features of the solar system, and the planets in the solar system. Although not explicitly with ST tools, it is explained in the textbook that the Solar system is a small system within a larger system (i.e., the Milky Way galaxy). No chapter received three points, indicating that none of the chapters in the sixth-grade science textbook employ any tools to understand systems at varying scales (Figure 4.4).

4.2.2.9. Devising Modifications to Produce Desired Effect. Three chapters received zero points for revising modifications to produce the desired effect component, indicating the chapter is not applicable for devising modifications to produce the desired effect (Figure 4.4). An example of a chapter that meets this criterion is Resultant Force. The chapter includes the definition and properties of the resultant force and is not applicable to produce a solution to a specific problem. Fourteen chapters received one point indicating ST tools can be used in the chapter but not used, nor is any tool used instead for devising modifications to produce the desired effect (Figure 4.4). An example of a chapter that meets this criterion is the Respiratory System. This chapter is

applicable to finding solutions to problems that may arise in the respiratory system or stem from the system's functions, but there is no content regarding seeking a solution in the textbook.

Five chapters received two points from this component, indicating ST tools can be used in the chapter but not used; instead, other tools are used for devising modifications to produce the desired effect (Figure 4.4).

An example of a chapter that meets this criterion is Fuels. Although it is not integrated with ST tools, the chapter includes activities related to finding solutions to the harmful effects of different types of fuels. No chapter received three points, indicating that the chapters in the sixth-grade science textbook do not include an integrated explanation with ST tools to seek a solution or to solve a problem by making changes to create the desired effect (Figure 4.4).

4.2.3. Inclusion of ST in the Sixth-Grade Science Curriculum and Textbook by Units

In this subsection, a unit-based content analysis of ST inclusion in sixth-grade science curriculum and textbooks are presented.

The first unit, Solar System and Eclipses, includes chapters on Solar System, and Lunar and Solar Eclipses. The planets in the Solar system are listed in the unit according to their characteristics and proximity to the Sun. Additionally, the unit provides information about solar and lunar eclipses. The features of these concepts are outlined in the curriculum objectives and textbook content in line with the recognizing interconnections component, even it is not fully included. It is important to note that there may be nonlinear relationships, causal loops, and stock flows between the planets due to the law of gravity. However, since the law of gravity is not included in the sixth-grade curriculum, it may not be appropriate to discuss it with this age group.

Besides, the Solar System can be viewed as a smaller system within the Milky Way Galaxy, which is a larger system for understanding systems at different scales component. However, the objectives and textbook contents do not include contents that can provide a comprehensive and hierarchical view of the Milky Way Galaxy, the Solar system, and its planets. The activity and assessment sections include true-false, fill-in-the-blank, and multiple-choice questions which do not utilize ST tools. The SEEA section does not include any activities aimed at adapting the component to devising modifications to produce the desired effect or finding solutions to problems related to the subject.

The Human Body Systems unit, the second unit, includes the Musculoskeletal, Digestive, Circulatory, Respiratory, and Excretory Systems chapters. The unit includes the structures and organs that make up the systems for all the systems, as well as their functions and relationships to each other. Although the relationships are in accordance with the recognizing interconnections component, they do not include ST tools integration. Additionally, although a feedback mechanism that can be represented by nonlinear relationships and stock flows is applicable to all systems, there is no CLD or SFD representation in the curriculum objectives and textbook contents. For example, for the musculoskeletal system, the chapter may include calcium and mineral balance in the bones, contraction and relaxation movements, how cartilage ossifies, areas that do not ossify (such as the trachea, auricle, tip of the nose), the relationship between Voluntary or involuntary movement of the muscles and organs, support and movement.

In the digestive system, the chapter may involve the effect of the amount of stomach acid on the system, systemic problems that can occur when enzymes do not do their job, and the relationship between hunger and satiety will help to understand the mechanism and dynamics of digestion. In addition, the blood flow in the large and small circulations of blood in the circulatory system is mentioned in the textbook content, but the stock and flow of blood, which affect each other, are not mentioned. The respiratory system model does not mention the relationship between oxygen and carbon

dioxide and the body's blood supply to a better comprehension of respiratory system behavior. In the excretory system, similar to the respiratory system, the relationship between excretion and the stock of blood is not mentioned.

All systems in our body have different system mechanisms, but they are parts of a larger system that work together. For this reason, to learn the mechanism of systems in our body from a holistic perspective, the subject of systems with causal loops containing stock-flow and nonlinear relationships should be included in the sixth-grade curriculum objectives and textbook contents. All systems in our body are located within a system, and all systems are applicable to be displayed in accordance with the understanding of systems at different scale components but were not found in the content of the curriculum and textbook. All chapters in the unit include reducing complexity by modeling systems conceptually adaptable and modeling components, but ST tools are not integrated. The content of the activity and assessment sections is similar to that of other chapters in the textbook, as multiple choice, true/false, and fill-in-the-blank questions are included. Although the SEEA section may be applicable to devising modifications to produce the desired effect component and include an activity aimed at producing a solution to a problem that may occur in our body, no activity was found.

The third unit, Force and Motion, covers chapters on Resultant Force and Constant Speed Motion. The unit details the relationship between force and motion for recognizing the interconnections component to be applied, but it does not utilize ST tools in the objectives and textbook content. This unit may contain a causal loop with nonlinear relationships, as force can be defined as a stock, and SFD can be used in this unit. However, it is found that they are not used. The unit is applicable for reducing complexity by modeling conceptually, and modeling is included, on the other hand, modeling that is integrated with ST tools is not found in the textbook content. In addition, the objectives in this unit do not contain any aim related to the modeling. This unit is not applicable to the component of understanding systems at different scales and there is no content for the component in the curriculum and textbook. Even

designing modifications to produce desired effect is applicable to the chapter, no content was found to be applied for this component. No objective was found related to this component either. In addition to the activity and assessment sections, the SEEA section also does not have an activity that includes ST tools.

The fourth unit, Matter and Heat, includes chapters on the Structure of Matter, Density, Matter and Heat, and Fuels. In the chapters, the changes in matter are under the influence of heat for recognizing interconnections in both the curriculum and the textbook, but ST tools are not utilized. While the feedback mechanism may be demonstrated in the chapter through the change in space between the particles of the substance and the mobility of the particles due to the change in state, no details of the causal loop were found in the curriculum objectives and textbook content.

The unit also contains nonlinear relationships within the state change under the influence of heat (i.e., when heat is applied, substances change their state, and a solid substance does not remain in the solid state but turns into a liquid or gas). In the content of the textbook, these relationships are included only through the concepts of heat load and heat loss. No objective was found to highlight nonlinear relationships. Matter structure is a modellable subject that reduces complexity, and modeling is included in the textbook, although not with ST tools and in the objectives.

Regarding understanding systems at different scale components, the social and economic dimensions of sustainability can be addressed by mentioning the use and impacts of renewable and non-renewable energy resources at the city, country, and world levels regarding fuels. However, the textbook only classifies fuels, and the objectives do not mention the impacts of fuel use at different levels. The fuels chapter can also be adapted to the devising modifications to produce the desired effect component, and an activity can be designed with ST tools to solve problems through the impact of renewable and non-renewable energy sources on human life. On the other hand, no activity or evaluation with integrated ST tools was found in the activity, assessment, and SEEA sections.

The fifth unit, Properties of Sound, includes chapters such as Propagation of Sound, Hearing Sound Differently in Different Environments, Speed of Sound, and Interaction of Sound with Matter. Although the objectives for this unit are not aimed at recognizing relationships, sound properties are mentioned with their existing relationships in the textbook without ST tools integration. In this unit, it is not applicable to other ST components except recognizing relationships, and there is no information, activity, evaluation or content related to the objectives in the curriculum and other components in the textbook.

The sixth unit, Human Body Systems and Health, covers chapters on Control and Regulatory Systems, Sensory Organs, and the Health of the Human Body Systems. The structure of the control and regulatory system, endocrine glands, sensory organs and their functions within the regulatory systems, childhood and adolescence, diseases in human body systems, and the relationships and connections of such systems are aimed at the objectives and given for the recognizing interconnections component, without ST tools integration. In the unit, nervous and endocrine systems and sensory organs contain causal loops with nonlinear relationships and stock-flows, as in the chapter on the human body system, but no explanation of feedback mechanisms was found in the curriculum objectives and textbook content.

To make sense of nonlinear relationships and produce solutions to the problems that behaviors in the system can create, the effect of different behaviors in the nervous system on other systems in the human body, the impact and importance of what can be done for the health of childhood and adolescence on an individual, social and global basis, the effect of drinking milk during childhood on bone development (i.e. Drinking milk after a certain age has no effect on bone development) may be included in the objectives as an aim and textbook content. These highlights may also be adapted to the understanding systems at different scales component since the nervous and endocrine systems are small systems within our body when our body is considered large systems, regarding the objectives and textbook content.

In addition, this unit is modellable to reduce complexity, and there are models related to the subject in the textbook content, even if they do not utilize ST tools. There is also an objective explicitly aimed at modeling "Explains the nervous system and the functions of the central and peripheral nervous system on a model" (MoNE, 2018, p. 36). Additionally, activity and assessment sections contain true-false, fill-in-the-blank, and multiple-choice questions, as in other chapters in the textbook. While there is no activity in the SEEA section that uses ST tools, there is an activity which is shown below for devising modifications to produce the desired effect component.

> Conduct research on the problems that disabled individuals may encounter in daily life. Choose one of the problems you discovered at the end of your research. Create a model for solving this problem (MoNE, 2023, p. 219).

The seventh unit, Transmission of Electricity, covers chapters such as Conductor and Insulator materials, and, Electrical Resistance and the Factors that Affect it. The objectives for this unit and textbook content contain the relationships between the conduction of electricity and electrical resistance in accordance with the recognizing interconnections component, although not with ST tools. The unit is not applicable to nonlinear relationships or causal loops. While Ohm's law is applicable for stocks and flows with SFD representation, it is not included in the curriculum objectives and textbook content. In addition, the unit is applicable for reducing complexity by modeling conceptually component and includes models in the textbook. On the other hand, no objective explicitly aims at modeling. The unit is also applicable to devising modifications to produce desired effect component, even though the objectives are not aimed to seek a solution for a specific problem. The activity and assessment sections contain multiple choice, true/false, and fill-in-the-blank questions, as in other chapters in the textbook. In the SEEA section, although ST tools are not integrated, there is an activity aimed at designing a solution for the relevant subject.

> Research the things that need to be considered to ensure our safety and the safety of those around us when using electrical energy. Based on your research, design a system model that can protect living things from electric shock in the event of an electrical leak (MoNE, 2023, p.226).

4.3. The Results of the Seventh-grade Curriculum and Textbook Analysis

First, this section shows the content analysis of the seventh-grade science curriculum and textbook, respectively. Finally, the section presents an integrated content analysis of the results of the seventh-grade curriculum and textbooks.

4.3.1. Inclusion of ST in the Seventh-grade Science Curriculum

This subsection covers ST inclusion in the seventh-grade science curriculum. The seventh-grade science curriculum comprises seven units and sixty-eight objectives. Figure 4.5 shows the scores obtained regarding the extent to which the seventh-grade science textbook includes ST according to the rubric (Table 3.5).

4.3.1.1. Recognizing Interconnections. Out of sixty-eight objectives, ten objectives received zero points, indicating the objective is not applicable for recognizing interconnections (Figure 4.5). An example of an objective that meets this criterion is "Prepare and present a simple telescope model" (MoNE, 2018, p. 39). This objective involves designing a telescope and is not aimed at describing the components of the objective telescope.

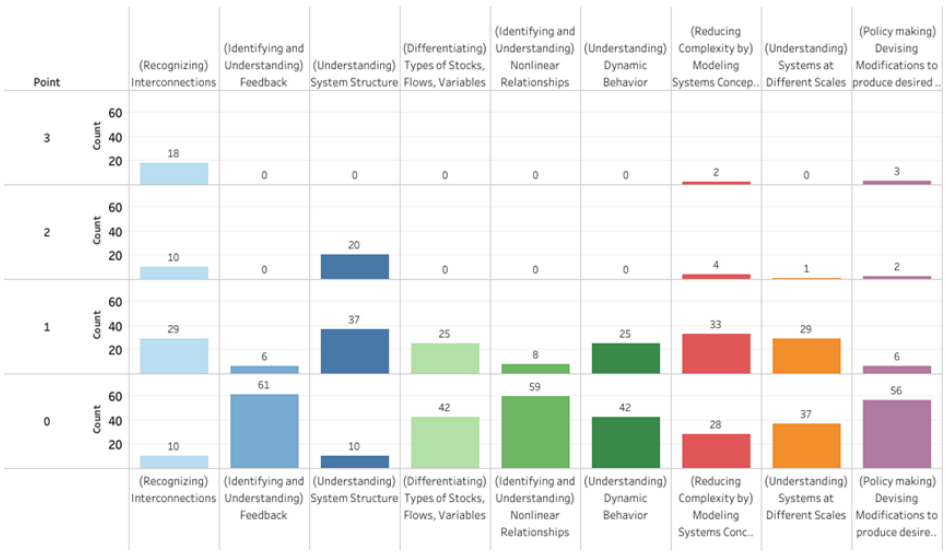

Figure 4.5. Inclusion of ST in the seventh-grade science curriculum.

Twenty-nine objectives received one point, indicating the objective is applicable for recognizing interconnections but is not included (Figure 4.5). An example of an objective that meets this criterion is "Explain the importance of mitosis for living things" (MoNE, 2018, p. 40). While explaining the importance of mitosis for living things in the objective, it can also be stated how and in what way which components of mitosis affect living things, the direction and focus of the importance of mitosis for living things is not given.

Ten objectives received two points, indicating the objective is applicable for recognizing interconnections but is partially included (Figure 4.5). An example of an objective that meets this criterion is "Conclude that energy is conserved based on the transformation of kinetic and potential energy types into each other" (MoNE, 2018, p. 42). In the objective, the relationship between energy transformations and conservation of energy is pointed out, although it is not given explicitly as a cause-effect relationship.

Eighteen objectives received three points from the recognizing interconnections component, indicating the objective is applicable for recognizing interconnections and is fully included (Figure 4.5). An example of an objective that meets this criterion is "Explain the relationship of cell, tissue, organ, system, organism" (MoNE, 2018, p.40). The objective explicitly aims to show the relationship between the cell, organ, system, and organism, so recognizing interconnections is fully included in this objective.

4.3.1.2. Identifying and Understanding Feedback. Sixty-two objectives received zero points from the identifying and understanding feedback component, indicating the objective is not applicable for identifying and understanding feedback component (Figure 4.5). An example of an objective that meets this criterion is "Explain the space technologies" (MoNE, 2018, p. 39). The objective aims to explain space technologies, which do not contain a causal loop. Six objectives received one point on this component, indicating the objective is applicable for identifying and understanding feedback but is not included (Figure 4.5). An example of an objective that meets this criterion

is “Explain the structures and organs that provide reproduction in humans by showing them on the diagram” (MoNE, 2018, p.45). Human reproduction, growth, and development contain feedback loops, but the objective does not contain a statement indicating the existence of these feedbacks. No objective was found to receive two or three points indicating that the objectives in the seventh-grade science curriculum do not partially include the identifying and understanding feedback component (Figure 5).

4.3.1.3. Understanding System Structure. The understanding system structure component was scored depending on the scoring of the recognizing interconnections and identifying and understanding feedback components (Table 3.3). Ten objectives received zero points on this component, which indicates the objective is not applicable for recognizing interconnections and identifying and understanding feedback (Figure 4.5). An example of an objective that meets this criterion is “Question how ideas about the concept of an atom have changed from the past to the present” (MoNE, 2018, p. 42). The objective aims to learn how the ideas about the concept of an atom have changed, it does not aim to mention about any interconnection related to the concept of atom. Therefore, it received zero points from the recognizing interconnections component. Furthermore, the objective is also not applicable to any feedback mechanism as the ideas about the atom do not involve feedback. Thus, it also received zero points in the identifying and understanding feedback component as it is not applicable. Therefore, it also received zero points for the objective understanding of system structure component.

Thirty-seven objectives received one point on the understanding of the system structure component (Figure 4.5). The criteria for receiving one point from the understanding system structure component were scored according to the matrix created for recognizing interconnections and identifying and understanding feedback components criteria (Table 3.3). An example of an objective that receives one point from this component is “Compare the images formed in flat, concave and convex mirrors” (MoNE, 2018, p. 44). This objective received two points for the recognizing intercon-

nections component. The objective involves comparing images formed in different types of mirrors, and although the cause-effect relationship is not explicitly mentioned, the comparison is also related to cause-effect. Thus, it received two points for recognizing the interconnections component. The objective received zero points for identifying and understanding the feedback component because the images formed in different mirror types do not include the feedback loop. Therefore, the objective is not applicable for identifying and understanding component. Thus, it received zero points from the matrix created for the understanding of the system structure component. Understanding the system structure requires recognizing the connections and interconnections, and the purpose of showing feedback loops that exist. In this case, interconnections with cause-effect relationship are not explicitly stated, and the objective does not include any feedback mechanism. For this reason, it received one point for understanding the system structure component.

Twenty objectives received two points from the understanding system structure component (Figure 4.5). The criteria for receiving two points for the understanding system structure component were scored based on the matrix created for recognizing interconnections, and identifying and understanding feedback components criteria (Table 3.3). An example of an objective that receives two points from this component is "Discuss the views on the structure of the cell from past to present, relating them to technological developments" (MoNE, 2018, p. 40). This objective received three points from the recognizing interconnections component. The objective indicates to identify a cause-effect relationship between technological developments and the structure of cell and received three points. On the other hand, it is not an applicable for showing feedback mechanisms. Thus, the objective scored zero points for identifying and understanding the feedback component. Additionally, the objective understanding system structure component scored two points as it aims to identify and understand the system elements explicitly, although it is not applicable to identifying and understanding feedback. No objective received three points from this component, indicating no objectives in the seventh-grade curriculum aim to recognize and understand interconnections and feedback loops of the system.

4.3.1.4. Differentiating Types of Stock, Flow, Variable. Forty-two objectives received a score of zero, indicating the objective is not applicable for the differentiating types of stocks, flows, and variables (Figure 4.5). An example of an objective that meets this criterion is "Design a vehicle to reduce the effect of air or water resistance" (MoNE, 2018, p. 42). Since the air and water resistance do not include stocks and flows, this objective is not applicable to differentiating stocks, flows, and variables component.

Twenty-five objectives received a score of one from this component, indicating the objective is applicable for the differentiating types of stocks, flows, and variables but is not included. An example of an objective that meets this criterion is "Explain the basic factors affecting growth and development in plants and animals" (MoNE, 2018, p. 45). Factors affecting growth and development in plants and animals can be explained by stocks and flows. However, there is no aim to show these stocks and flows in the objective. No objective was found to receive two or three points, indicating tthat the objectives in the seventh-grade science curriculum are not aimed at showing stocks, flows, and variables (Figure 4.5).

4.3.1.5. Identifying, Understanding Nonlinear Relationship. Fifty-nine objectives received a score of zero from the identifying and understanding nonlinear relationships component, indicating the objective is not applicable for identifying and understanding nonlinear relationships (Figure 4.5). An example of an objective that meets this criterion is "Compare animal and plant cells in terms of their basic parts and functions" (MoNE, 2018, p. 40). Since there is no nonlinear relationship in the structure of animal and plant cells, the objective received zero points for this component.

Eight objectives received a score of one from this component, indicating the objective is applicable for identifying and understanding nonlinear relationships but is not included (Figure 4.5). An example of an objective that meets this criterion is "Explain the growth and development processes in plants and animals by giving examples" (MoNE, 2018, p. 45). The objective consists of systems that contain feedback loops with nonlinear relationships in reproduction, growth, and development in plants and

animals, but the objective does not aim to show the nonlinearity. No objective was found to receive two or three points indicating that the objectives in the seventh-grade science curriculum are not aimed at identify and understand nonlinear relationships in the systems (Figure 4.5).

4.3.1.6. Understanding Dynamic Behavior. The understanding dynamic behavior component was scored depending on the scoring of the differentiating stocks, flows, and variables, and identifying and understanding nonlinear relationships components (Table 3.3). Forty-two objectives received a score of zero on understanding dynamic behavior component indicating that the objective is not applicable for differentiating types of stocks, flows, and variables, and identifying and understanding nonlinear relationships (Figure 4.5). An example of an objective that meets this criterion is "Explain the structure and function of the telescope" (MoNE, 2018, p. 39). The objective cannot be represented by stocks and flows or has a nonlinear relationship. Therefore, the objective is also not applicable to the understanding of dynamic behavior component.

Twenty-five objectives received one point from the understanding dynamic behavior component. The criteria for receiving one point from the understanding dynamic behavior component were scored according to the matrix created for the differentiating stocks, flows, and variables, and identifying and understanding nonlinear relationships components criteria (Table 3.4). An example of an objective that receives one point from this component is "Express the causes of space pollution and predicts the possible consequences of this pollution" (MoNE, 2018, p. 41). The causes and consequences of space pollution can be shown with stock flows, but such a purpose is not included in the objective. For this reason, it received one point from both differentiating stocks, flows, and variables. Additionally, the objective received zero points from the understanding dynamic behavior component as it does not have nonlinear relationships. Therefore, the objective is scored as one point for the understanding dynamic behavior component.

No objective was found that received two points from the understanding dynamic behavior component. These results indicate that no objective received two points from both differentiating types of stocks, flows, and variables, and identifying and understanding nonlinear relationship components. An objective that receives two points from both components is an objective that partially includes these two components in its content. In another case, receiving two points from the understanding dynamic behavior means that the objective received two points from the differentiating types of stocks, flows, and variables component while receiving one point from the identifying and understanding component. This indicates that the objective partially includes stock, flow, and variables, while it may include nonlinear relationships but does not. In another case, receiving two points from the understanding dynamic behavior also means that the objective received two points from the differentiating types of stocks, flows, and variables component while receiving zero points from the identifying and understanding component. This indicates that the objective partially includes stock, flow, and variables, but it is not applicable to show nonlinear relationships. A nonlinear relationship is not necessary for every representation that can be described by stocks and flows. One way to understand the dynamic behavior of the system is to use stocks and flows to illustrate an issue that does not involve a nonlinear relationship. Consequently, the understanding of the system structure component may receive two points, while the goal of identifying and understanding nonlinear relationships receives zero points.

4.3.1.7. Reducing Complexity by Modeling System. Twenty-eight objectives received a score of zero for reducing complexity by modeling systems conceptually, indicating the objective is applicable for reducing complexity by modeling systems conceptually but is not included (Figure 4.5). An example of an objective that meets this criterion is "Explain space technologies" (MoNE, 2018, p. 39) since the objective does not include modeling.

Thirty-three objectives received a score of one point for this component indicating that the objective is applicable for reducing complexity by modeling systems

conceptually but is not included (Figure 5). An example of an objective that meets this criterion is "Compare the differences between meiosis and mitosis" (MoNE, 2018, p. 41). While the comparison of mitosis and meiosis can be shown and supported by modeling, the objective is not focused on the modeling part. Four objectives received two points, indicating the objective is applicable for reducing complexity by modeling systems conceptually but is partially included (Figure 4.5). An example of an objective that meets this criterion is "Show on the model how meiosis takes place in reproductive mother cells. Cell names are not mentioned during gamete formation. Only sperm and egg are given" (MoNE, 2018, p. 41). Although the objective aims to model meiosis, it is stated that only sperm and egg will be involved in modeling how meiosis takes place. Since the model of meiosis does not include all its components, the modeling cannot be fully implemented. Therefore, the objective received two points from this component.

Two objectives received three points for this component, indicating the objective is applicable for reducing complexity by modeling systems conceptually and fully included. An example of tan objective that meets this criterion is "Create and present various molecule models" (MoNE, 2018, p. 42). Since the objective aims at modeling, it received three points.

4.3.1.8. Understanding Systems at Different Scales. Thirty-seven objectives received zero points, indicating that the objective is not applicable for understanding systems at different scales (Figure 4.5). An example of an objective that meets this criterion is "Define electric current" (MoNE, 2018, p. 46). The objective aims to identify the electric current that is not applicable to understand and interpret systems at different perspectives.

Twenty-nine objectives received one point, indicating that the objective is applicable for understanding systems at different scales but is not included (Figure 4.5). An example of an objective that meets this criterion is "Explain the relationship between sperm, egg, zygote, embryo, fetus and baby" (MoNE, 2018, p. 45). The concepts

of sperm, egg, zygote, embryo, and baby are interconnected and influenced by each other. Since each of them creates a system within itself, the objective is applicable to the component of understanding systems at different scales, but the objective does not aim to interpret the systems from different scales and perspectives.

One objective received two points, indicating the objective is applicable for understanding systems at different scales but partially included. An example of an objective that meets this criterion is "Explain the relationship between cell, tissue, organ, system, organism" (MoNE, 2018, p.40). Cells, tissues, organs, organisms and systems are concepts to which the understanding systems at different scales component can be applied, as each is a system in itself. While the objective explains the relationship between these concepts, it does not explicitly mention that each is a small and different system in a larger system such as the human body.

No objective received three points on this component, indicating no objective in the seventh-grade science curriculum objectives that aim to interpret at different scales and show the hierarchy, if any, between systems (Figure 4.5).

4.3.1.9. Devising Modifications to Produce Desired Effect. Fifty-six objectives received zero points on devising modifications to produce the desired effect component, indicating the objective is not applicable for devising modifications to produce the desired effect (Figure 4.5). An example of an objective that meets this criterion is "Classify pure substances as elements and compounds and give examples" (MoNE, 2018, p. 22). The objective aims to classify and exemplify pure substances and mixtures and is not applicable to produce a solution to a problem. Six objectives received one point on this component, indicating that the objective is applicable for devising modifications to produce the desired effect but is not included (Figure 4.5). An example of an objective that meets this criterion is "Give examples of innovative applications of solar energy in daily life and technology" (MoNE, 2018, p. 44). The objective aims to give only examples that can focus on the problems and solutions related to the applications of Solar energy in daily life.

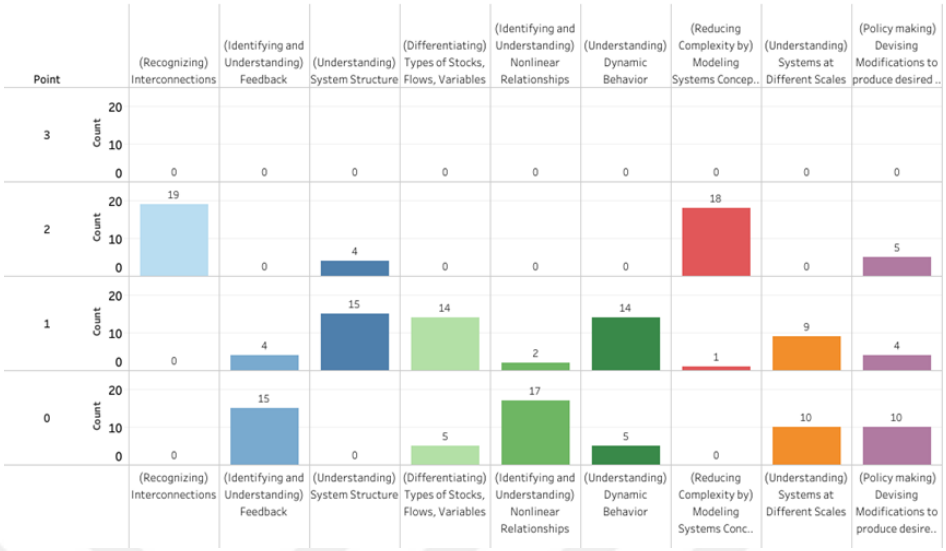

Figure 4.6. Inclusion of ST in the seventh-grade science textbook.

Two objectives received two points from this component, indicating the objective is applicable for devising modifications to produce the desired effect but is partially included. An example of an objective that meets this criterion is "Design an imaging tool using mirrors or lenses" (MoNE, 2018, p. 44). Objective received two points since it could include the aim of designing a tool as a solution to problems that may be encountered regarding imaging rather than just aiming to design an imaging tool.

Three objectives received three points from this component, indicating the objective is applicable for devising modifications to produce the desired effect and is fully included (Figure 4.5). An example of an objective that meets this criterion is "Design a tool to reduce the effect of air or water resistance" (MoNE, 2018, p. 42). The objective aims to design a tool that has the purpose of reducing air and water resistance by creating a solution to the negative effects of air and water resistance. Therefore, it received three points on this component.

4.3.2. Inclusion of ST in the Seventh-grade Science Textbook

This subsection represents ST inclusion of seventh-grade science textbook. There are a total of seven units and nineteen chapters in the seventh-grade science textbook.

Figure 4.6 shows the scores received regarding the extent to which the seventh-grade science textbook include ST according to the rubric (Table 3.5).

4.3.2.1. Recognizing Interconnections. All chapters in the seventh-grade science textbook received two points on the recognizing interconnections component, indicating ST tools can be used in the chapter but not used; instead, other tools are used for recognizing interconnections (Figure 4.6). The results indicate that all chapters in the seventh-grade science textbook focus on recognizing and understanding interconnections. On the other hand, there is no content in the chapters explained with ST tools.

4.3.2.2. Identifying and Understanding Feedback. Fifteen chapters received zero points for identifying and understanding feedback, and nine chapters received one point, indicating the chapter is not applicable for identifying and understanding feedback (Figure 4.6). An example of a chapter that meets this criterion is Pure Substances. Chapter includes the listing of pure substances as elements and compounds, the properties of the elements in the periodic table and the properties of compounds formed from these elements. Therefore, the chapter is not applicable to show feedback loops.

Four chapters received one point on this component, indicating that CLD can be used in the chapter but not used, nor is any tool used instead for identifying and understanding feedback (Figure 4.6). An example of a chapter that meets this criterion is Cell and Divisions. Cell divisions such as mitosis and meiosis occur. They create causal loops within themselves. On the other hand, these causal loops are not mentioned in the textbook content. No chapter received two or three points on this component, indicating that CLD is not included in the seventh-grade science textbook content (Figure 4.6).

4.3.2.3. Understanding System Structure. Depending on the points received from recognizing interconnections and identifying and understanding feedback components, the

understanding system structure component was scored. No chapter was found to receive zero points for understanding the system structure component, which indicates the chapter is not applicable for recognizing interconnections and identifying and understanding feedback (Figure 4.6). These results show that all of the chapters in the seventh-grade science textbook are applicable to the understanding system structure.

Fifteen chapters received one point on this component (Figure 4.6). The criteria for receiving one point from the understanding system structure component were scored according to the matrix created for recognizing interconnections and identifying and understanding feedback components criteria. An example of a chapter that receives one point from this component is Mirrors. This chapter received two points for the recognizing interconnections component and zero points for the identifying and understanding feedback component. This indicates that interconnections are present in the chapter, although not with ST tools, while the chapter is not applicable for showing feedback loops. It is essential to recognize the feedback loops that the system's interconnections create to understand the system structure. However, this chapter lacks a feedback mechanism. Despite this, both written and visual explanations for interconnections are included in the chapter. As a result, the chapter scored one point for the understanding of the system structure component. The chapter only received one point instead of two because it is not applicable to causal loops.

Four chapters received two points from the understanding system structure component (Figure 4.6). The criteria for receiving two points from the understanding system structure component were scored according to the matrix created for the recognizing interconnections, and identifying and understanding feedback components criteria. An example of a chapter that receives two points from this component is Reproduction, Growth, and Development in Plants and Animals. This chapter received two points for the recognizing interconnections component and one point for the identifying and understanding feedback component. The chapter identifies and shows interconnections related to the reproduction, growth, and development process of animals and plants in the textbook, although not with ST tools. The chapter also contains feedback loops

that are not explicitly shown. The distinction from the chapter that receives one point for the understanding system structure component is that this chapter has causal loops. Interconnections are shown by visual and written explanations in the textbook. Feedback mechanisms are not included, although they can be shown, resulting in the chapter receiving two points instead of one in the understanding system structure component.

No chapter received three points on understanding system structure component, which indicates that no chapter in the seventh-grade science textbook is explained with ST tools for understanding system structure (Figure 4.6).

4.3.2.4. Differentiating Types of Stocks, Flows, and Variables. For the differentiating stocks, flows, and variables component, five chapters received a score of zero, indicating the chapter is not applicable for the differentiating types of stocks, flows, and variables (Figure 4.6). An example of a chapter that meets this criterion is Mirrors. In this chapter, it is aimed to explain the speed of sound in different environments. In this chapter, types of mirrors and the images of objects formed in the mirror are explained. It does not include a feedback loop, nor is it a chapter applicable to showing stocks and flows.

Fourteen chapters received a score of one, indicating SFD can be used in the chapter but not used, nor is any tool used instead for differentiating types of stocks, flows, and variables (Figure 6). An example of a chapter that meets this criterion is Beyond the Solar System: Celestial Bodies. While the star formation process in the chapter can be illustrated with stocks and flows, they are not included in the textbook content. No chapter received two or three points, indicating that SFD was not used in the seventh-grade science textbook (Figure 4.6).

4.3.2.5. Identifying, Understanding Nonlinear Relationship. Seventeen chapters received a score of zero for the identifying and understanding nonlinear relationships component, indicating that the chapter is not applicable for identifying and understanding

nonlinear relationships (Figure 4.6). An example of a chapter that meets this criterion is Separation of Mixtures, as the chapter does not have nonlinear relationships.

Two chapters received a score of one from this component indicating BOTG can be used in the chapter but not used, nor is any tool used instead for identifying and understanding nonlinear relationships (Figure 4.6). An example of a chapter that meets this criterion is The Human Digestive System. Although the chapter contains nonlinear relationships similar to the other chapter in the human body system unit, nonlinear relationships are not mentioned in the textbook.No chapter was found to receive two or three points indicating that nonlinear relationships are not explained by using BOTGs in any of the chapters in the seventh-grade science textbooks (Figure 4.6).

4.3.2.6. Understanding Dynamic Behavior. Depending on the scores obtained on differentiating stocks, flows, and variables, and identifying and understanding nonlinear relationships components, understanding dynamic behavior was scored. Five chapters received zero points, indicating the chapter is not applicable for differentiating stocks, flows, and variables, and identifying and understanding nonlinear relationships components (Figure 4.6). An example of a chapter that meets this criterion is Refraction of Light and Lenses. The chapter explains the refraction of light and lens types, and the refraction of light cannot be represented with stocks and flows and has a nonlinear relationship. Therefore, it is also not applicable to understanding dynamic behavior.

Fourteen chapters received one point on this component (Figure 4.6). The criteria for receiving one point from the understanding dynamic behavior component were scored according to the matrix created for the differentiating stocks, flows, and variables, and identifying and understanding nonlinear relationships components criteria. An example of a chapter that receives one point from this component is the Relationship of Mass and Weight. In this chapter, an SFD can be shown in defining mass and weight. However, the textbook does not mention stocks and flows, resulting chapter receiving only one point for the differentiating types of stocks, flows, and variables component. On the other hand, the chapter does not have nonlinear relationships. Thus,

it is not applicable to identifying and understanding nonlinear relationship component. Therefore, the chapter received zero points for identifying and understanding nonlinear relationship. Using stocks and flows to illustrate ideas is essential to understanding the dynamic nature of a system. This chapter gets one point for understanding dynamic behavior even though it does not include SFD in its content. The chapter might have received two points instead of one if the textbook had covered stocks and flows even though it did not use ST tools.

No objective received two points from the understanding dynamic behavior component (Figure 4.6). These results indicate that there was no chapter received two points from both differentiating types of stocks, flows, and variables, and identifying and understanding nonlinear relationship components. A chapter that receives two points from both components means that SFD and BOTG can be used in the chapter but not used; instead, other tools are used for differentiating types of stocks, flows, and variables, and identifying and understanding nonlinear relationship components.

In another case, receiving two points from the understanding dynamic behavior means that the chapter received two points from the differentiating types of stocks, flows, and variables component while receiving one point from the identifying and understanding component. This indicates that the SFD can be used in the chapter but not used; instead, other tools are used, while BOTG can be used in the chapter but not used, nor is any tool used for nonlinear relationships. In another case, receiving two points from the understanding dynamic behavior also means that the chapter received two points from the differentiating types of stocks, flows, and variables component while receiving zero points from the identifying and understanding component. This indicates that SFD can be used in the chapter but not used; instead, other tools are used for differentiating types of stocks, flows, and variables, while it is not applicable to show nonlinear relationships. A representation that can be characterized by stocks and flows does not require a nonlinear relationship. Even without a nonlinear relationship, one way to understand the system's dynamic behavior is through the use of stocks and flows. Therefore, even if the chapter did not receive any points for detecting and

understanding nonlinear relationships, it can still score two points for comprehending dynamic behavior by addressing the various types of stocks, flows, and variables.

No chapter received three points on this component, which indicates that no chapter in the seventh-grade science textbook is explained with ST tools such as SFD and BOTG for understanding dynamic behavior.

4.3.2.7. Reducing Complexity by Modeling Systems. No chapter received zero points for this component, indicating the chapter is not applicable for reducing complexity by modeling systems conceptually. These results showed that all chapters in the seventh-grade science textbook are applicable to this component.

One chapter received one point indicating ST tools can be used in the chapter but not used, nor is any tool used instead for reducing complexity by modeling systems conceptually (Figure 4.6). An example of a chapter that meets this criterion is the Separation of Mixtures. This chapter is applicable to modeling but is not included in the textbook content, supported only with visuals and written explanations.

Eighteen chapters received two points indicating ST tools can be used in the chapter but not used; instead, other tools are used for reducing complexity by modeling systems conceptually (Figure 4.6). An example of a chapter that meets this criterion is Mitosis. There is modeling in the explanation of the phases of mitosis in the chapter, but ST tools are not integrated into the modeling. No chapter received three points for this component indicating ST tools are used in the chapter for reducing complexity by modeling systems conceptually. The results indicate that none of the models presented in the seventh-grade science textbook were created or displayed using ST tools.

No chapter received three points for this component, indicating ST tools are used in the chapter for reducing complexity by modeling systems conceptually. These results showed that no chapter used ST tools to create a solution to a problem.

4.3.2.8. Understanding Systems at Different Scales. Ten chapters received zero points for understanding systems at different scale component indicating the chapter is not applicable for understanding systems at different scales (Figure 4.6). An example of a chapter that meets this criterion is The Relationship of Force, Work, and Energy. This chapter does not include a system within a system, so it is not applicable to comprehend the different systems in a hierarchical manner.

Nine chapters received one point on this component, indicating ST tools can be used in the chapter but not used, nor is any tool used instead for understanding systems at different scales (Figure 4.6). An example of a chapter that meets this criterion is Reproduction, Growth, and Development in Humans. The chapter involves the interaction of different systems during the phases of reproduction, growth, and development. For this reason, systems can be interpreted from different scales in this chapter. All systems within the human body generate other systems. When these systems combine, they form a larger system, which is the human organism. Therefore, in this chapter, ST tools can be used to highlight the understanding systems at different scales component, but they are not used. No chapter was found to receive two or three points indicating that none of the chapters in the seventh-grade science textbook employ any tools to understand systems at varying scales (Figure 4.6).

4.3.2.9. Devising Modifications to Produce Desired Effect. Ten chapters received zero points for revising modifications to produce the desired effect component, indicating the chapter is not applicable for devising modifications to produce desired effect (Figure 4.6). An example of a chapter that meets this criterion is Pure Substances. Since the chapter only contains descriptions and examples of pure substances, it is not applicable to the purpose of creating a solution to a problem.

Four chapters received one point indicating ST tools can be used in the chapter but not used, nor is any tool are used instead for devising modifications to produce the desired effect (Figure 4.6). An example of a chapter that meets this criterion is Space Research. This chapter is applicable to finding solutions to problems that may arise

in space or stem from the concept related to space, but there is no content regarding seeking a solution in the textbook.

Five chapters received two points from this component, indicating ST tools can be used in the chapter but not used; instead, other tools are used for devising modifications to produce the desired effect (Figure 4.6). An example of a chapter that meets this criterion is Recycling. Although it is not integrated with ST tools, the chapter includes activities related to finding solutions to recycling. No chapter was found that received three points indicating that the chapters in the seventh-grade science textbook do not include an integrated explanation with ST tools to seek a solution or to solve a problem by making changes to create the desired effect (Figure 4.6).

4.3.3. Inclusion of ST in the Seventh-grade Science Curriculum and Textbook by Units

In this subsection, a unit-based content analysis of ST inclusion in seventh-grade science curriculum and textbook are presented.

The first unit, Solar System and Beyond, includes chapters on Space Research, and Beyond the Solar System: Celestial Bodies. The objectives of the unit aim to show the relationships within subtopics such as space technologies, the star formation process, and the structure of galaxies. These topics are included in the unit in accordance with the recognizing interconnections component. In the unit, the structure of galaxies and the star formation process has a feedback mechanism and stock flows (i.e., the life history of stars is determined and changes according to their mass), but the objectives and textbook contents do not include content for the causal loop of stars with nonlinear relationships and stock flow representation. There is modeling of celestial bodies in the unit; although the modeling is not aimed at the objective. On the other hand, the model does not show the celestial bodies as a small system within a large system like the universe has led to the understanding of systems at different scales component could not be applied. In addition, the lack of an activity that would trigger finding

a solution to space pollution and its consequences on Earth has led to the devising of modifications to produce the desired effect component not being implemented. In the activity and assessment sections, there are only multiple-choice, true/false, and fill-in-the-blank activities.

The second unit, Cell and Divisions, includes the Cell, Mitosis, and Meiosis chapters. The structure of animal and plant cells, cell, tissue, organ, system, and organism relationship, and the division stages of mitosis and meiosis are given respectively and in relation to each other in a way that reflects the recognizing interconnections component in both objective and textbook content. The cell, tissue, organ, system, and organism relationship have a feedback mechanism that does not contain nonlinear relationships but can be represented by stocks and flows. This hierarchy is mentioned in both the objectives and the textbook content, but ST tools are not used. The fact that small systems (i.e., cells) come together to form a large system (i.e., organism) is not included in the textbook content in connection with the concept of systems.

Animal and plant cells can be modeled, and modeling is included in the textbook but not aimed at the objectives. In addition, the stages of mitosis and meiosis follow each other sequentially, and exponential cell growth is observed in mitosis (i.e., the number of cells formed in mitosis is given by the formula 2n, where n = number of divisions). Therefore, there is a feedback mechanism in mitosis that does not involve a nonlinear relationship, but the causal loop (feedback loop) is not included in the curriculum and textbook content. Although mitosis and meiosis are types of cell division and can be related to the system within a system according to the component of understanding systems at different scales, they are not included in the curriculum and textbook content. Since mitosis and meiosis are not applicable to devising modifications to produce the desired effect component, there is no activity for this component in the curriculum and textbook content. The activity, assessment, and SEEA sections include multiple-choice, true/false, and fill-in-the-blank questions, similar to other chapters in the textbook.

The third unit, Force and Energy, covers chapters such as the Relationship of Mass and Weight, the Relationship of Force, Work and Energy, and Energy Conversions. Each chapter includes the curriculum objectives and the connections between concepts in the textbook content in accordance with the recognition interconnections component. This unit does not contain any causal loops with nonlinear relationships, but the concepts of force, work, and energy can be represented through stocks and flows. The curriculum objectives and textbook contents do not include any information on stock-flows. The objectives of the unit are not applicable to modeling, but the textbook content contains models related to the subject. The unit links energy types, such as kinetic and potential energy, with friction. Therefore, the fifth-grade activity related to friction, which includes a microscopic image of the friction force and surface relationship, can be included in the Friction Force chapter for understanding systems at different scales component. The activity and assessment sections do not integrate ST tools, as other units, and the SEEA section contains the problem-solving oriented activity provided below.

> Design a method to minimize the impact of air or water resistance (MoNE, 2021, p.100).

The fourth unit, Pure Substances and Mixtures, includes chapters such as the Structure of Matter, Pure Substances and Mixtures, the Separation of Mixtures, Domestic Waste, and Recycling. The textbook content covers the component of recognizing interconnections with existing relationships in all chapters. While some objectives in the unit are not applicable to the recognizing interconnections component (i.e., Question about how ideas about the concept of atom have changed from past to present (MoNE, 2018, p. 42), some objectives have partially included this component (i.e., Gives examples by classifying mixtures as homogeneous and heterogeneous (MoNE, 2018, p. 43). However, there are no feedback mechanisms with nonlinear relationships regarding the chapters. The objectives of this unit are also not applicable to identifying and understanding feedback and nonlinear relationships. Additionally, the curriculum objectives and textbook contents do not include any application related to stock flows, despite the fact that molecule formation, dissolution, and recycling can be explained

with stocks and flows. The textbook has models in all chapters, following the component of reducing complexity by modeling system components conceptually. However, there is one objective related to the modeling in the unit "Create and present various molecule models" (MoNE, 2018, p. 42).

In addition, the relationship between atoms, molecules, and matter may highlight the importance of understanding systems at different scales. Atoms, the smallest building blocks of matter, are systems composed of their particles, and the atomic system forms a larger system called matter. The hierarchy of these systems is not mentioned in the curriculum objectives or textbook contents. No objective aims to produce a solution for a problem regarding the devising modifications to produce desired effect component, except in the Recycling chapter "Develop a project to deliver reusable items to those in need" (MoNE, 2018, p. 43). The activity and assessment sections include all activities and evaluations without utilizing the ST tool. It also may design an activity that sheds light on a systemic problem for devising modifications to produce the desired effect component that could include a systemic situation regarding the impact of the effective use of world resources on the economy and social life. Activity and assessment sections do not have activities and evaluations that include ST tools, while in the SEEA section, there is an activity that does not use ST tools, but supports creating a solution to a problem in recycling. The guideline for the activity is provided as follows.

> Plan a project that will deliver your unused but reusable clothes and belongings to those in need (MoNE, 2021, p. 142).

The fifth unit, the Interaction of Light with Matter, includes chapters on Light Absorption, Mirrors, and Light Refraction and Lenses. Each chapter explains in detail the situations that may occur when light interacts with matter, in accordance with the recognizing interconnections component both in the curriculum and textbook. Nonlinear relationships and feedback mechanisms with stock-flows, as well as understanding systems at different scales, are not applicable. For this unit, only modelable concepts such as refraction, mirrors, and lenses are included; on the other hand, no objective

was found to aim for modeling this unit. For devising modifications to produce the desired effect component, there are two objectives "Design a viewing device using mirrors or lenses" (MoNE, 2018, p. 44) and "Discuss the ideas on how to benefit from solar energy in the future" (MoNE, 2018, p. 44).

The evaluation questions, such as multiple choice, true/false, and fill-in-the-blank questions in the activity and assessment sections, do not include ST tools, similar to other chapters in the textbook. Additionally, the SEEA section features a design activity that is shown below on the relevant topic that does not incorporate ST tools.

> Design a viewing device utilizing mirrors and lenses (MoNE, 2021, p. 178).

The sixth unit, Reproduction, Growth, and Development in Living Organisms, includes chapters such as Reproduction, Growth, and Development in Humans, and Reproduction, Growth, and Development in Plants and Animals. The curriculum objectives and textbook content are all aligned with the recognizing interconnections component. However, the textbook does not include any integration of ST tools. The unit involves a feedback mechanism that includes nonlinear relationships and stock flows. For instance, as the number of births increases, the population also increases, which in turn leads to an increase in the number of births, creating a reinforcing loop. However, the curriculum objectives do not cover this mechanism, and it is not included in the textbook content. This unit pertains to the hierarchical organization of living things, beginning with the cell as the fundamental unit, followed by humans and societies as systems at various scales. However, there is no objective or content regarding the application of understanding systems at different scales. The unit has modeling for reducing complexity by modeling systems conceptually, and there is one objective related to this component "Explain the structures and organs that enable human reproduction by showing them on a diagram" (MoNE, 2018, p. 45). The unit may but does not address solutions for potential health issues with the embryo or modifications to apply devising modifications to produce desired effects. Additionally, the sections on activity, assessment, and SEEA do not provide any activity or evaluation of ST tools.

The seventh unit, Electrical Circuit, includes a chapter on Connecting Light Bulbs and covers concepts such as series and parallel circuits, current, voltage, and the factors that affect them. These topics are included in the curriculum objectives and textbook content for recognizing interconnections. This unit does not have a feedback mechanism involving nonlinear relationships, and there is no content on this mechanism in both the objectives and the content of the textbook. While electric current can be explained using stocks and flows, there is no objective and textboom content related to the showing SFD. Furthermore, the unit is not applicable to systems of different scales that can be represented as a system within a system. The textbook provides electrical circuit models to reduce complexity by modeling conceptually, regarding the objective "Draws a circuit diagram consisting of series and parallel connected bulbs" (MoNE, 2018, p. 46). Activity and assessment sections includes multiple choice, true/false, and fill-in-the-blank questions, but do not include ST tools similar to the other chapters in the textbook. An activity in SEEA section involves creating a solution to a problem related to the devising modifications to produce desired effect component regarding the objective "Design a unique lighting tool" (MoNE, 2018, p. 46).

4.4. The Results of the Eighth-Grade Curriculum and Textbook Analysis

This section shows the content analysis of the eighth-grade science curriculum and textbook, respectively. Finally, the section presents an integrated content analysis of the results of the eighth-grade curriculum and textbooks.

4.4.1. Inclusion of ST in the Eighth-grade Science Curriculum

This subsection covers ST inclusion in the eighth-grade science curriculum. The eighth-grade science curriculum contains seven units and sixty-one objectives. Figure 4.7 shows the scores obtained regarding the extent to which the eighth-grade science curriculum includes ST according to the rubric.

4.4.1.1. Recognizing Interconnections. Out of sixty-one objectives, nine objectives received zero points, indicating the objective is not applicable for recognizing interconnections (Figure 4.7). An example of an objective that meets this criterion is "Provide examples of how the pressure properties of solids, liquids, and gases are applied in daily life and technology" (MoNE, 2018, p. 49). The objective aims to provide examples of solid, liquid, and gas pressure, and it is not applicable to recognizing interconnections.

Twenty-five objectives received one point, indicating the objective is applicable for recognizing interconnections but is not included (Figure 4.7). An example of an objective that meets this criterion is "Draw the state change and heating graphs of substances to interpret them" (MoNE, 2018, p. 51). While it can be focused on phase changes and heat interactions and aims to show interconnections in the graph, the objective only includes a graphical interpretation of the subject.

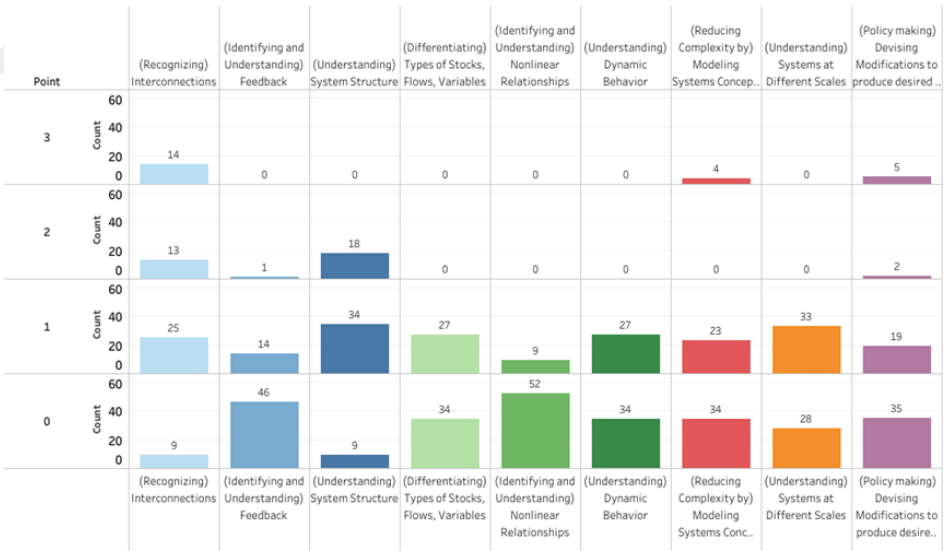

Figure 4.7. Inclusion of ST in the eighth-grade science curriculum.

Thirteen objectives received two points, indicating the objective is applicable for recognizing interconnections but is partially included (Figure 4.7). An example of an objective that meets this criterion is "Explain the differences between physical and chemical change by observing various events" (MoNE, 2018, p. 50). To explain the differences between physical and chemical change, it is necessary to know the

relationship between them. Objective includes a purpose that, although not explicit, may point to the relationship between physical and chemical change.

Fourteen objectives received three points from the recognizing interconnections component, indicating the objective is applicable for recognizing interconnections and is fully included (Figure 4.7). An example of an objective that meets this criterion is "Explain the concepts of nucleotide, gene, DNA, and chromosome and establishes a relationship between these concepts" (MoNE, 2018, p. 48). The objective explicitly aims to show the relationship between the nucleotide, gene, DNA and chromosome, so recognizing interconnections is fully included in this objective.

4.4.1.2. Identifying and Understanding Feedback. Forty-six objectives received zero points from the identifying and understanding feedback component, indicating the objective is not applicable for identifying and understanding feedback component (Figure 4.7). An example of an objective that meets this criterion is "Make inferences about the differences between mutation and modification" (MoNE, 2018, p. 39). The objective aims to interpret the differences between mutation and modification, and mutation and modification have no feedback loops.

Fourteen objectives received one point on this component, indicating the objective is applicable for identifying and understanding feedback but is not included (Figure 4.7). An example of an objective that meets this criterion is "Discover that heating depends on the type of matter, mass and/or temperature change by experimenting" (MoNE, 2018, p. 51). While the heating contains causal loops, the objective did not aim to recognize and show this.

One objective received two points, indicating the objective is applicable for identifying and understanding feedback but is partially included (Figure 4.7). An example of an objective that meets this criterion is "Explain the cycles of matter by showing them on the diagram" (MoNE, 2018, p. 52). A feedback loop is a process that involves changing the behavior of the system by influencing its components while the system

constantly affects itself (Trudeau, 2013). On the other hand, a cycle is a process that follows a path toward a goal in order to reach it in the next step (Trudeau, 2013). Not every cycle may contain feedback loops, as cycles may only indicate the sequential movement of components that do not affect each other (Trudeau, 2013). Although cycles of matter contain feedback mechanisms within themselves, the objective is to display only the elements inside the cycles of matter rather than the feedback mechanisms. The objective does not explicitly mention feedback loops, so it received two points. No objective received three points from this component, indicating that the eighth-grade science curriculum objectives do not include the identifying and understanding feedback component (Figure 4.7).

4.4.1.3. Understanding System Structure. The understanding system structure component was scored depending on the scoring of the recognizing interconnections and identifying and understanding feedback components (Table 3.3). Nine objectives received zero points on this component, which indicates the objective is not applicable for recognizing interconnections and identifying and understanding feedback (Figure 4.7). An example of an objective that meets this criterion is "Comprehend that climate science (climatology) is a branch of science and experts working in this field are called climate scientists (climatologists)" (MoNE, 2018, p. 45). The objective aims only to provide a definition of climate science. Therefore, it received zero points from the recognizing interconnections component. Furthermore, objective is also not applicable to any feedback mechanism, as it does not involve feedback. Thus, it also received zero points in the identifying and understanding feedback component as it is not applicable. Therefore, it also received zero points for the objective understanding of the system structure component.

Thirty-four objectives received one point on the understanding of the system structure component (Figure 4.7). The criteria for receiving one point from the understanding system structure component were scored according to the matrix created for recognizing interconnections and identifying and understanding feedback components criteria (Table 3.3). An example of an objective that receives one point from this

component is “Discuss the genetic consequences of consanguineous marriages” (MoNE, 2018, p. 48). This objective received two points for the recognizing interconnections component. The objective aims to reveal the consequences of consanguineous marriage. Although the reasons for consanguineous marriage are not explicitly mentioned, since it aims to show its consequences, the objective received two points on recognizing interconnections component. The objective received zero points for identifying and understanding the feedback component since consanguineous marriage does not include the feedback loop. Therefore, the objective is not applicable for identifying and understanding component and received zero points from the matrix created for the understanding of the system structure component. Recognizing the interconnections, as well as the goal of illustrating the feedback loops, are essential to understanding the system structure. In this case, interconnections with cause-effect relationships are not explicitly stated, and the objective does not include any feedback mechanism. For this reason, it received one point for understanding the system structure component.

Eighteen objectives received two points from the understanding system structure component (Figure 4.7). The criteria for receiving two points for the understanding system structure component were scored based on the matrix created for recognizing interconnections, and identifying and understanding feedback components criteria (Table 3.3). An example of an objective that receives two points from this component is “Discover the variables affecting solid pressure by experimenting” (MoNE, 2018, p. 49). This objective received three points from the recognizing interconnections component. Since the expression of effect is used and variables affecting each other are mentioned, the objective aims to identify interconnections of solid pressure. On the other hand, it is not applicable to showing a feedback mechanism since it does not have feedback loops. Thus, the objective scored zero points for identifying and understanding the feedback component. Therefore, the objective is scored two points for understanding the system structure component. No objective received three points from this component, indicating that no objectives in the eighth-grade curriculum aim to recognize and understand interconnections and feedback loops of the system fully (Figure 4.7).

4.4.1.4. Differentiating Types of Stocks, Flows, and Variables. Thirty-four objectives received a score of zero, indicating the objective is not applicable for the differentiating types of stocks, flows, and variables (Figure 4.7). An example of an objective that meets this criterion is "Explain the adaptation of living things to their environment by observation" (MoNE, 2018, p. 49). Since the objective cannot be represented by stocks and flows, it is not applicable to differentiating stocks, flows, and variables component.

Twenty-seven objectives received a score of one from this component, indicating the objective is applicable for the differentiating types of stocks, flows, and variables but is not included (Figure 4.7). An example of an objective that meets this criterion is "Discover by experimenting that the heat required to change state is related to the type and mass of matter" (MoNE, 2018, p. 51). In the objective, the relationship between the change of state and the type and mass of the substance can be shown with stocks and flows, but it is not aimed at showing stocks and flows. No objective received two or three points indicating that the objectives in the eighth-grade science curriculum are not aimed at showing stocks, flows, and variables (Figure 4.7).

4.4.1.5. Identifying, Understanding Nonlinear Relationshis. Fifty- two objectives received a score of zero from the identifying and understanding nonlinear relationships component, indicating the objective is not applicable for identifying and understanding nonlinear relationships (Figure 4.7). An example of an objective that meets this criterion is "Solve problems related to single character crosses and comments on the results" (MoNE, 2018, p. 48). Since there is no nonlinear relationship in the single character crosses which is related to the heredity, the objective received zero points for this component. Nine objectives received a score of one from this component, indicating the objective is applicable for identifying and understanding nonlinear relationships but is not included (Figure 4.7). An example of an objective that meets this criterion is "Give examples of producers, consumers and decomposers in the food chain" (MoNE, 2018, p. 52). The food chain contains nonlinear relationships with feedback loops, but the objective is not aimed to show the nonlinear relationships.

No objective received two or three points, indicating that the objectives in the eighth-grade science curriculum are not aimed at identifying and understanding nonlinear relationships in the systems (Figure 4.7).

4.4.1.6. Understanding Dynamic Behavior. The understanding dynamic behavior component was scored depending on the scoring of the differentiating stocks, flows, and variables, and identifying and understanding nonlinear relationships components (Table 3.4). Thirty-four objectives received a score of zero on understanding dynamic behavior component indicating that the objective is not applicable for differentiating types of stocks, flows, and variables, and identifying and understanding nonlinear relationships (Figure 4.7). An example of an objective that meets this criterion is "Explain modification using examples" (MoNE, 2018, p. 48). Since the objective aims to show the description of the modification, it cannot be represented by stocks and flows or has a nonlinear relationship. Therefore, the objective is also not applicable to the understanding of dynamic behavior component.

Twenty-seven objectives received one point from the understanding dynamic behavior component (Figure 4.7). The criteria for receiving one point from the understanding dynamic behavior component were scored according to the matrix created for the differentiating stocks, flows, and variables, and identifying and understanding nonlinear relationships components criteria (Table 3.4). An example of an objective that receives one point from this component is "Explain the adaptation of living things to the environment they live in by observation" (MoNE, 2018, p. 49). The adaptation of living things can be shown with stock flows, but such a purpose is not included in the objective. For this reason, it received one point from both differentiating stocks, flows, and variables. Similarly, the objective received one point for identifying and understanding nonlinear relationships as it also has nonlinear relationships but there is no purpose for this in the objective. Therefore, the objective is scored as one point for the understanding dynamic behavior component.

No objective was found that received two points from the understanding dynamic behavior component (Figure 4.7). These results indicate that there was no objective received two points from both differentiating types of stocks, flows, and variables, and identifying and understanding nonlinear relationship components. An objective that receives two points from both components is an objective that partially includes these two components in its content. In another case, receiving two points from the understanding dynamic behavior means that the objective received two points from the differentiating types of stocks, flows, and variables component while receiving one point from the identifying and understanding component. This indicates that the objective partially includes stock, flow, and variables, while it may include nonlinear relationships but does not. In another case, receiving two points from the understanding dynamic behavior also means that the objective received two points from the differentiating types of stocks, flows, and variables component while receiving zero points from the identifying and understanding component. This indicates that the objective partially includes stock, flow, and variables, but it is not applicable to show nonlinear relationships. A nonlinear relationship is not necessary for every representation that can be described by stocks and flows. One way to understand the dynamic behavior of the system is to use stocks and flows to illustrate an issue that does not involve a nonlinear relationship. Consequently, the understanding of the system structure component may receive two points, while the goal of identifying and understanding nonlinear relationships receives zero points.

No objective received three points on this component, indicating the objective is applicable for understanding dynamic behavior and is fully included. These results indicate that objectives in the eighth-grade science curriculum do not fully include stocks and flows, and nonlinear relationships.

4.4.1.7. Reducing Complexity by Modeling Systems. Thirty-four objectives received a score of zero for reducing complexity by modeling systems conceptually, indicating the objective is not applicable for reducing complexity by modeling systems conceptually (Figure 4.7). An example of an objective that meets this criterion is “Relate genetic

engineering and biotechnology" (MoNE, 2018, p. 49), since the objective does not aim to modeling.

Twenty-three objectives received a score of one point for this component indicating that the objective is applicable for reducing complexity by modeling systems conceptually but is not included (Figure 4.7). An example of an objective that meets this criterion is "Classify elements as metals, semimetals and nonmetals on the periodic table" (MoNE, 2018, p. 50). In the objective, it is not clear whether the expression classifying the elements in the periodic table refers to modeling. While objective could have implied modeling in conjunction with the periodic table, it does not aim at modeling.

No objective received two points indicating that the objectives in the eighth-grade science curriculum do not partially include modeling (Figure 4.7). Four objectives received three points from this component, indicating the objective is applicable for reducing complexity by modeling systems conceptually and is fully included (Figure 4.7). An example of an objective that meets this criterion is "Design a model based on the conversion of electrical energy into heat, light or motion energy" (MoNE, 2018, p. 54). Since the objective is explicitly aims to create a model for electrical energy, it received three points.

4.4.1.8. Understanding Systems at Different Scales. Twenty-eight objectives received zero points, indicating that the objective is not applicable for understanding systems at different scales (Figure 4.7). An example of an objective that meets this criterion is "Explain the advantages of simple machines through examples" (MoNE, 2018, p. 51). The objective aims to exemplify the advantages of simple machines and is not applicable to understanding and interpreting systems from different perspectives. Thirty-three objectives received one point, indicating that the objective is applicable for understanding systems at different scales but is not included (Figure 4.7). An example of an objective that meets this criterion is "Relate the state changes that occur in daily life to heat exchange" (MoNE, 2018, p. 51). State changes that occur due to

the effect of heat have feedback mechanisms that affect each other. Thus, the objective is applicable to the component of understanding systems at different scales, but the objective does not aim to interpret the systems from different scales and perspectives.

No objective was found to receive two or three points on this component, indicating no objective in the eighth-grade science curriculum aims to interpret at different scales and show the hierarchy, if any, between systems (Figure 4.7).

4.4.1.9. Devising Modifications to Produce Desired Effect. Thirty-five objectives received zero points on devising modifications to produce the desired effect component, indicating the objective is not applicable for devising modifications to produce the desired effect (Figure 4.7). An example of an objective that meets this criterion is "Give examples of acids and bases from daily life" (MoNE, 2018, p. 50). The objective aims to provide examples of acids and bases and is not applicable to producing a solution to a problem. Nineteen objectives received one point on this component, indicating that the objective is applicable for devising modifications to produce the desired effect but is not included (Figure 4.7). An example of an objective that meets this criterion is "Research the development of the chemical industry in Turkey from past to present" (MoNE, 2018, p. 51). While the objective may include an aim to solve a problem in the chemical industry in Turkey, it focuses only on the research part of the subject.

Two objectives received two points from this component, indicating the objective is applicable for devising modifications to produce the desired effect but is partially included (Figure 4.7). An example of an objective that meets this criterion is "Research professions in the chemical industry and offers suggestions about new professions in the future" (MoNE, 2018, p. 51). The objective involves providing recommendations based on professions in the chemical industry, but it may also involve solving a problem that may occur in that field.

Five objectives received three points from this component, indicating the objective is applicable for devising modifications to produce the desired effect and is fully

included (Figure 4.7). An example of an objective that meets this criterion is "Offer solutions to prevent acid rain" (MoNE, 2018, p. 50). Since the objective involves finding a solution to a problem such as acid rain, it received three points on this component.

4.4.2. Inclusion of ST in the Eighth-Grade Science Textbook

This subsection covers ST inclusion in the eighth-grade science textbook. There are a total of seven units and twenty-two chapters in the eighth-grade science textbook. Figure 8 shows the scores obtained regarding the extent to which the eighth-grade science textbook includes ST according to the rubric.

4.4.2.1. Recognizing Interconnections. All chapters in the eighth-grade science textbook received two points on the recognizing interconnections component, indicating ST tools can be used in the chapter but not used; instead, other tools are used for recognizing interconnections (Figure 4.8). The results indicate that all chapters in the eighth-grade science textbook focus on recognizing and understanding interconnections. On the other hand, there is no content in the chapters explained with ST tools.

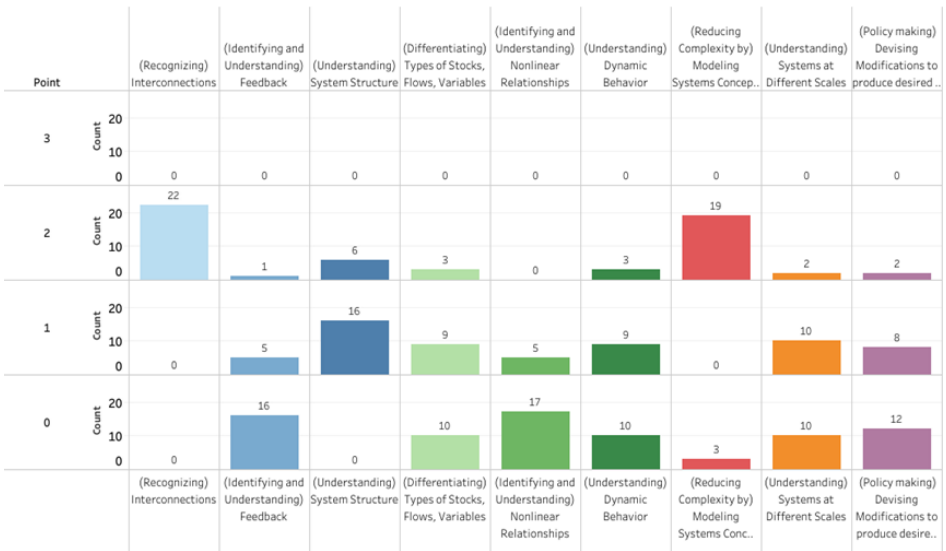

Figure 4.8. Inclusion of ST in the eighth-grade science textbook.

4.4.2.2. Identifying and Understanding Feedback. Sixteen chapters received zero points for identifying and understanding feedback, indicating the chapter is not applicable for identifying and understanding feedback (Figure 4.8). An example of a chapter that meets this criterion is Pressure. The chapter aims to introduce the factors affecting solid pressure. Therefore, the chapter has no feedback loops and is not applicable to show feedback loops.

Five chapters received one point on this component, indicating that CLD can be used in the chapter but not used, nor is any tool used instead for identifying and understanding feedback (Figure 4.8). An example of a chapter that meets this criterion is Interaction of Matter with Heat. In this chapter, the change of state of matter under the influence of heat has contains feedback mechanisms. On the other hand, these causal loops are not mentioned in the textbook content.

One chapter received two points on this component, indicating CLD can be used in the chapter but not used; instead, other tools are used for identifying and understanding feedback (Figure 4.8). An example of a chapter that meets this criterion is Matter Cycles and Environmental Problems. In the chapter, matter cycles and environmental problems are explained with graphics, tables, visual and written explanations, although not with CLD. The chapter also includes the interaction of environmental problems and human, although there is no content explicitly pointing to feedback loops. Therefore, it received two points from the identifying and understanding feedback component.

No chapter received three points on the identifying and understanding feedback component indicating that CLD is not included in the eighth-grade science textbook content (Figure 4.8).

4.4.2.3. Understanding System Structure. Depending on the points received from recognizing interconnections and, identifying and understanding feedback components, the understanding system structure component was scored (Table 3.6). No chapter received zero points for understanding the system structure component, which indi-

cates the chapter is not applicable for recognizing interconnections and identifying and understanding feedback (Figure 8). These results show that all of the chapters in the eighth-grade science textbook are applicable to the understanding system structure.

Sixteen chapters received one point on this component (Figure 4.8). The criteria for receiving one point from the understanding system structure component were scored according to the matrix created for the recognizing interconnections, and identifying and understanding feedback components criteria (Table 3.6). An example of a chapter that receives one point from this component is Electrically Charged Objects. This chapter received two points for the recognizing interconnections component and zero points for the identifying and understanding feedback component. This indicates that interconnections are present in the chapter about the electrically charged objects and electrification, although not with ST tools, while the chapter is not applicable for showing feedback loops. It is essential to recognize the feedback loops that the system's interconnections create to understand the system structure. However, electrical charge and electrification lack a feedback mechanism. Despite this, both written and visual explanations, and tables for interconnections are included in the chapter.

As a result, the chapter scored one point for the understanding of the system structure component. The chapter only received one point instead of two because it is not applicable to causal loops.

Six chapters received two points from the understanding system structure component (Figure 4.8). The criteria for receiving two points from the understanding system structure component were scored according to the matrix created for the recognizing interconnections, and identifying and understanding feedback components criteria. An example of a chapter that receives two points from this component is Food Chain and Energy Flow. This chapter received two points for the recognizing interconnections component and one point for the identifying and understanding feedback component. The chapter identifies and shows interconnections related to the food chain and energy flow in the textbook, although not with ST tools. The chapter also contains feedback

loops that are not explicitly shown. The distinction from the chapter that receives one point for the understanding system structure component is that food chain and energy flow have causal loops. Interconnections are showed by visual and written explanations in the textbook. Feedback mechanisms are not included, although can be shown, resulting in the chapter receiving two points instead of one in the understanding system structure component.

No chapter received three points on understanding system structure component, which indicates that no chapter in the eighth-grade science textbook is explained with ST tools for understanding system structure (Figure 4.8).

4.4.2.4. Differentiating Types of Stocks, Flows, and Variables. For the differentiating stocks, flows, and variables component, ten chapters received a score of zero, indicating the chapter is not applicable for the differentiating types of stocks, flows, and variables (Figure 4.8). An example of a chapter that meets this criterion is Mutation and Modification. Mutation and Modification do not include a feedback loop, and this chapter applicable to showing stocks and flows.

Nine chapters received a score of one, indicating SFD can be used in the chapter but not used, nor is any tool used instead for differentiating types of stocks, flows, and variables (Figure 4.8). An example of a chapter that meets this criterion is Sustainable Development. While the economic and social impacts of sustainable development and recycling can be demonstrated through stocks and flows, they are not included in the textbook content. Three chapters received two points indicating SFD can be used in the chapter but not used; instead, other tools are used for differentiating types of stocks, flows, and variables (Figure 8). An example of a chapter that meets this criterion is Climate and Weather. In the chapter, factors such as pressure, humidity, and temperature that affect the climate are explained with visuals, although they can be shown with SFD. No chapter was found that received three points indicating that SFD was not used in the eighth-grade science textbook (Figure 4.8).

4.4.2.5. Identifying, Understanding Nonlinear Relationship. Seventeen chapters received a score of zero from the identifying and understanding nonlinear relationships component indicating the chapter is not applicable for identifying and understanding nonlinear relationships (Figure 4.8). An example of a chapter that meets this criterion is Simple Machines since it does not have nonlinear relationships.

Five chapters received a score of one from this component indicating BOTG can be used in the chapter but not used, nor is any tool used instead for identifying and understanding nonlinear relationships (Figure 4.8). An example of a chapter that meets this criterion is Food Chain and Energy Flow. Although the chapter has nonlinear relationships with feedback mechanisms, nonlinear relationships are not mentioned in the textbook. No chapter was found to receive two or three points indicating that nonlinear relationships are not explained with BOTG in the chapters in the eighth-grade science textbooks (Figure 4.8).

4.4.2.6. Understanding Dynamic Behavior. Depending on the scores obtained on differentiating stocks, flows, and variables, and identifying and understanding nonlinear relationships components, understanding dynamic behavior was scored (Table 3.7). Ten chapters received zero points, indicating the chapter is not applicable for differentiating stocks, flows, and variables, and identifying and understanding nonlinear relationships components (Figure 4.8). An example of a chapter that meets this criterion is Physical and Chemical Changes. The chapter explains the physical and chemical changes that cannot be represented with stocks and flows and have no nonlinear relationships. Therefore, it is also not applicable to understanding dynamic behavior.

Nine chapters received one point on this component (Figure 4.8). The criteria for receiving one point from the understanding dynamic behavior component were scored according to the matrix created for the differentiating stocks, flows, and variables, and identifying and understanding nonlinear relationships components criteria (Table 3.7). An example of a chapter that receives one point from this component is DNA and Genetic Code. In this chapter, While the concepts of nucleotide, gene, DNA, and

chromosome can be illustrated with SFD, they are not. The textbook does not mention stocks and flows, resulting chapter receiving only one point for the differentiating types of stocks, flows, and variables component. On the other hand, the chapter has no nonlinear relationships. Thus, it is not applicable to the identifying and understanding nonlinear relationship component. Therefore, the chapter received zero points for identifying and understanding nonlinear relationships. Displaying concepts and ideas using stocks and flows is crucial for understanding the dynamic nature of a system. This chapter gets one point for understanding dynamic behavior even though it does not include SFD in its content. The chapter might have received two points instead of one if the textbook had covered stocks and flows even though it did not use ST tools.

Three chapters received two points on the understanding dynamic behavior component (Figure 4.8). The criteria for receiving two points from the understanding dynamic behavior component were scored according to the matrix created for the differentiating stocks, flows, and variables, and identifying and understanding nonlinear relationships components criteria. An example of a chapter that receives one point from this component is Climate and Weather. In this chapter, the factors such as temperature, pressure, and humidity that affect the climate and weather is represented with visuals, although not with SFD itself. Therefore, it received two points in the differentiating types of stocks, flows, and variables component. On the other hand, the chapter has no nonlinear relationships. Therefore, it received zero points for the identifying and understanding nonlinear relationship component. While chapter stocks and flows were depicted, they were not shown using ST tools. Stocks and flows need not have nonlinear relationships. As a result, the chapter received two points on the understanding dynamic behavior component.

No chapter was found to receive three points on this component, which indicates that no chapter in the eighth-grade science textbook is explained with ST tools such as SFD and BOTG for understanding dynamic behavior (Figure 4.8).

4.4.2.7. Reducing Complexity by Modeling Systems. Three chapters received three points for this component indicating the chapter is not applicable for reducing complexity by modeling systems conceptually (Figure 4.8). An example of a chapter that meets this criterion is Adaptation. Since this chapter aims to show how the adaptation process occurs and cannot be represented by modeling, it received zero points on this component.

No chapter received one point indicating ST tools can be used in the chapter but not used, nor is any tool are used instead for reducing complexity by modeling systems conceptually (Figure 4.8). The results show that although ST tools are not included in the models in the eighth-grade science textbook.

Nineteen chapters received two points indicating ST tools can be used in the chapter but not used; instead, other tools are used for reducing complexity by modeling systems conceptually (Figure 4.8). An example of a chapter that meets this criterion is Biotechnology. Although it contains models related to biotechnology and genetic engineering, none of them are integrated with ST tools. No chapter received three points for this component indicating that none of the models presented in the eighth-grade science textbook were created or displayed using ST tools (Figure 4.8).

4.4.2.8. Understanding Systems at Different Scales. Ten chapters received zero points for the understanding systems at different scale component indicating the chapter is not applicable for understanding systems at different scales (Figure 4.8). An example of a chapter that meets this criterion is Acids and Bases. This chapter does not include different systems that can be interpreted in a hierarchical manner, so it is not applicable for understanding systems at different scales component.

Ten chapters received one point on this component indicating ST tools can be used in the chapter but not used, nor is any tool used instead for understanding systems at different scales (Figure 4.8). An example of a chapter that meets this criterion is Sustainable Development. Sustainability has many different dimensions, such as

economic and social, and each dimension appears as a system in itself. For this reason, sustainable development can be interpreted from different scales in this chapter. Therefore, in this chapter, ST tools can be used to highlight the understanding systems at different scales component, but they are not used.

Two chapters received two points indicating ST tools can be used in the chapter but not used; instead, other tools are used for understanding systems at different scales (Figure 4.8). An example of a chapter that meets this criterion is DNA and Genetic Code. Nucleotide, gene, DNA and chromosome are a system within themselves, and when they come together, they become parts of a larger system. In the textbook, it is explained with visuals, although not with ST tools. No chapter was found to receive three points indicating that none of the chapters in the eighth-grade science textbook employ any tools to understand systems at varying scales (Figure 4.8).

4.4.2.9. Devising Modifications to Produce Desired Effect. Twelve chapters received zero points for the revising modifications to produce desired effect component indicating the chapter is not applicable for devising modifications to produce the desired effect (Figure 4.8). An example of a chapter that meets this criterion is Electrically Charged Objects. Chapter aims to explain electric charges and electrically charged objects, and it is not applicable to the purpose of creating a solution to a problem.

Eight chapters received one point indicating ST tools can be used in the chapter but not used, nor is any tool are used instead for devising modifications to produce the desired effect (Figure 4.8). An example of a chapter that meets this criterion is Pressure. This chapter is applicable to finding solutions to problems that may arise related to situations that create overpressure and underpressure in daily life, but there is no content regarding seeking a solution in the textbook.

Two chapters received two points from this component indicating ST tools can be used in the chapter but not used; instead, other tools are used for devising modifications to produce the desired effect (Figure 4.8). An example of a chapter that meets this

criterion is Conversion of Electrical Energy. Although it is not integrated with ST tools, the chapter includes activities related to finding solutions to problems regarding the use of electrical energy. No chapter was found that received three points, indicating that the chapters in the eighth-grade science textbook do not include an integrated explanation with ST tools to seek a solution or to solve a problem by making changes to create the desired effect (Figure 4.8).

4.4.3. Inclusion of ST in the Eighth-grade Science Curriculum and Textbook by Units

In this subsection, a unit-based content analysis of ST inclusion in eighth-grade science curriculum and textbook are presented.

The first unit, Seasons and Climate, covers chapters on the Formation of Seasons, Climate and Weather. It explores the causes and consequences of seasonal changes, compares climate and weather, and examines their interconnections. The unit fulfills both the curriculum objectives and the textbook content for recognizing interconnections component. The unit also has a causal loop that contains linear relationships in the pressure and wind relationship within the chapter on climate and weather. In this regard, it is important to understand the feedback loop and know the ideal gas formula -PV = nRT-, how the pressure difference factors in the formation of wind and can change depending on the variables in the formula. However, since the eighth-grade curriculum content does not include aims to know this formula, a feedback mechanism explanation for air currents through the ideal gas equation is not applicable in this age group. Instead, an SFD containing stock flows for air flows can be adapted to suit the age level.

The textbook includes a visual representation of air flows for low and high pressures (ATA Publishing, 2023, p. 30), but there is no SFD representation. There is no objective aims to show stock and flow as well. Although the curriculum objectives do not aim for modeling, the textbook contents include models related to seasons, cli-

mate, and weather for reducing complexity by modeling conceptually component. For the understanding of systems at different scales component, the formation of seasons, climate, and weather can be viewed as an event that occurs within the world system, which can be seen as a smaller system within the universe system. However, the curriculum objectives and textbook contents lack a systemic perspective on the interaction between the universe and the world. For devising modifications to produce the desired effect component, no objective explicitly includes a purpose for this component. Additionally, there is no activity or evaluation involving ST in the activity, assessment, and SEEA sections provided for the devising modifications to produce desired effect component.

The second unit, DNA and Genetic Code, covers several chapters including DNA, Genetic Code, Heredity, Mutation, Modification, Adaptation, and Biotechnology. The unit explains the relationship between nucleotides, genes, DNA, and chromosomes in the context of DNA and genetic code. Additionally, it discusses the relationship between biotechnological applications and genetic engineering, which are present in both curriculum objectives and textbook contents. The textbook content also includes relationships and connections related to inheritance, mutation, modification, and adaptation, even though there is no objective to define these relationships in the curriculum objectives in accordance with the recognizing interconnections component.

The unit does not include any causal loops with nonlinear relationships, except for the topic of adaptation. Although adaptation involves a causal loop with nonlinear relationships due to the interaction between humans and the environment, neither the curriculum objectives nor the textbook content provides any information about this causal loop. The SFD representation can be adapted to concepts such as nucleoid, gene, DNA, chromosome within DNA, and genetic code, as well as the relationship between humans and the environment regarding adaptation.

However, the curriculum objectives and textbook content do not include any information on stocks and flows. The unit covers modeling in which ST tools are not

used about DNA and genetic code, heredity, and biotechnology and the curriculum objectives align with the component of reducing complexity by modeling systems conceptually.

The unit is relevant to understanding systems at different scales component, such as the effects of mutation on the individual and society, or DNA is a complex system, and genes are systems within DNA, and the textbook includes a hierarchical visualization of DNA structure (ATA Publishing, 2023, p.45). Additionally, the chapters on heredity, mutation, modification, and adaptation can be related to DNA within the framework of ST, allowing for a holistic perspective and systematic approach to these concepts, however, it lacks insightful content. There is also no objective containing a purpose for this component.

While the textbook could include an activity for the component on devising modifications to produce desired effects for consanguineous marriage or biotechnological applications, neither the curriculum nor the textbook includes such an objective or content. Additionally, the activity and assessment, and SEEA sections do not have an activity or assessment into which ST tools can be integrated.

The third unit, Pressure, covers chapters on Solid, Liquid, and Gas Pressure. The chapters include the types of pressure and their relationships, in accordance with the recognizing interconnections component in both the curriculum and textbook content, even though it does not cover ST tools. The unit does not apply to causal loops with nonlinear relationships in the curriculum and textbook content. However, when combined with the variables that affect pressure, it is suitable for SFD representation through stocks and flows. On the other hand, the curriculum objectives and textbook content do not cover stocks and flows. The unit is not applicable to the understanding systems at different scales component regarding the curriculum objectives. However, the textbook provides models in which ST tools are not used for reducing complexity by modeling conceptually component, although there are no objective aims at modeling. The devising modifications to produce the desired effect component is applicable based

on the areas of use of solid, liquid, and gas pressures in daily life, but the curriculum objectives and textbook do not provide any activity to create a solution to a problem related to the subject. The activity, assessment, and SEEA sections do not include any evaluations or activities that involve ST tools. The fourth unit, Matter and Industry, covers chapters such as the Periodic System, Physical and Chemical Changes, Chemical Reactions, Acids and Bases, the Interaction of Matter with Heat, and the Chemical Industry in Turkey. Although the curriculum objectives of all chapters in this unit are not aimed at recognizing relationships, they are explained in the textbook content in a compatible way with the recognizing interconnections component, without including ST tools. The chapter on the interaction of matter with heat can be applied to a causal loop representation with nonlinear relationships. The chapter involves state change and heat exchange, similar to the subject of state change in the fifth-grade. The state change occurs with the effect of heat, and the state of the substance does not remain the same due to the effect of heat. When a substance is heated or cooled, state change does not continue forever; this makes the phase change a balancing loop containing nonlinear relationships. However, the curriculum objectives and textbook content do not cover nonlinear relationships and causal loops about the interaction of matter with heat.

The chapter on chemical reactions and the interaction of matter with heat are applicable to SFD representation with stocks and flows (i.e., the amounts of substances forming chemical reactions and the change of state can be shown with stock flows). However, SFD representation has not been included in the curriculum objectives or textbook contents. Modeling is applicable and included in all chapters except for the chemical industry in Turkey, in accordance with the component of reducing complexity by modeling conceptually, even ST tools are not used in the models. On the other hand, there is no objective explicitly aims at modeling.

In addition, the curriculum objective and the chapter contain an activity on the application of the devising modifications to produce desired effect component for preventing acid rain. On the other hand, the activity may also discuss individual,

country, and worldwide precautions that can be taken against acid rain, as well as the effects of import and export on the chemical industry in Turkey. Although it is not in the SEEA section and does not contain ST tools, the question of what can be done about acid rain was posed to students in an activity in the textbook. Additionally, no content related to ST tools was found in the activity and assessment sections.

The fifth unit, Simple Machines, includes the relationships of simple machine types and the conveniences they provide in our lives are included in the curriculum objectives and textbook content, in accordance with the recognizing interconnections component, although not with ST tools. Except for recognizing interconnections, the unit is only applicable to the components of reducing complexity by modeling systems conceptually and devising modifications to produce the desired effect regarding the objectives. There is an objective aimed at modeling and textbook content include models that represent simple machines in which ST tools are not used in the chapter. No activity or evaluation involving ST tools was found in the activity and assessment sections. Although it is not included as a heading in the SEEA section, there is an activity that does not include ST tools but is aimed at creating solutions. The guideline for the activity is shown below.

> Design a mechanism that will make work easier by using simple machines (ATA Publishing, 2023, p. 181).

The sixth unit, Energy Conversions and Environmental Problems, includes chapters such as Food Chain and Energy Flow, Energy Conversions, Matter Cycles and Environmental Problems, and Sustainable Development. These chapters aim to reveal relationships in accordance with the recognizing interconnections component in the curriculum objectives and the textbook content. All chapters are also applicable to causal loops involving nonlinear relationships, which can also be represented by stocks and flows. Examples of such relationships include changes in the food chain, variables affecting material cycles such as relative humidity, and sustainability in the context of the relationship between humans and the environment. However, the curriculum objectives and textbook content do not cover nonlinear relationships, CLD, or

SFD representations in the chapter. While the textbook includes various diagrams for food chains and material cycles, it lacks content featuring ST tools. All chapters are modellable, but the models do not utilize ST tool. There is one objective related to reducing complexity by modeling conceptually component "Explain matter cycles by showing them on a diagram" (MoNE, 2018, p. 52).

The unit is also relevant to understanding systems at different scales. For example, living things at different levels of the food chain are systems within themselves. Loops such as photosynthesis and respiration, as well as matter cycles, are systems that affect each other. The economic use of resources and sustainability interactions between countries and the world are also systems. Climate change, one of the environmental problems, is a complex systemic issue involving multiple systems. The unit solely focuses on the effects of global warming on living things, and the textbook includes research questions on this issue as well as matter cycles.

Although there are objectives that aim to provide a solution regarding the chapter content, such as "Design projects for economical use of resources" (MoNE, 2018, p. 53) and "Offers solution suggestions using research data on the contribution of recycling to the country's economy" (MoNE, 2018, p. 53), there are no activities or projects aimed at finding solutions to these problems. Additionally, the activity and assessment sections do not involve the use of ST tools. Although not included in the SEEA section and lacking ST tools, there is an activity aimed at solving a problem related to the subject.

> Research projects for the economical use of resources from the general network and other sources. Design a project for the economical use of a resource that has been determined (ATA Publishing, 2023, p. 214).

The seventh unit, Electric Charges and Electric Energy, includes chapters such as Electric Charges and Electricity, Electrically Charged Objects, and Conversion of Electrical Energy. Although there is one objective aims to identify the cause-effect relationship "Classify electric charges and explains the effects of same and different

types of electric charges on each other" (MoNE, 2018, p. 53), all chapters in the textbook include relationships in line with the recognizing interconnections component about electrical energy and factors affecting electrification. This unit does not apply to causal loops with nonlinear relationships, both in the curriculum objectives and textbook content. On the other hand, electrification and electrically charged objects can be represented by stocks and flows. Accordingly, there is no representation of SFD in the curriculum objectives and textbook contents. Reducing complexity by modeling systems conceptually component is applicable to the chapter, regarding the curriculum objectives. Although the textbook contents do not contain ST tools, models are included in the textbook. Unit is also applicable to understanding systems at different scales in the context of the use and effects of electrical energy. However, no objective aims to interpret the systems in different contexts. Unit is also applicable for devising modifications to produce the desired effect components regarding the effects of electrical energy usage. But there is no objective that aims to produce a solution to a problem. The activity, assessment and SEEA sections do not include any integration of ST tools, but the textbook includes a project activity for converting electrical energy.

> Design a model that converts electrical energy into heat, light, or motion energy based on a need encountered in daily life. If possible, use a 3D model of the design (ATA Publishing, 2023, p. 243).

4.5. Summary of the Results

An analysis of the fifth-grade science curriculum and textbook reveals a blended integration of systems thinking (ST) principles. While there are objectives included in the textbook content about recognizing interconnections, there is a lack of integration on the use of ST tools, which negatively impacts the depth of understanding in key components such as feedback mechanisms, nonlinear relationships, and system structures. Despite some chapters demonstrating causal relationships, the absence of ST tools hinders the comprehensive implementation of ST in the curriculum.

In the analysis of the sixth-grade science curriculum and textbook, recognizing interconnections is consistently addressed. However, the comprehensive utilization of ST tools across the curriculum exhibits notable deficiencies. While certain components, such as understanding feedback mechanisms and system structures, are partially included, there are clear gaps in the integration of specific ST tools like causal loops and Stock-Flow Diagrams (SFDs). Although there are instances where ST principles are discussed, particularly in chapters on matter and heat and human body systems, there is a clear need for a more systematic incorporation of ST tools to enhance students' comprehension of system dynamics and relationships within scientific contexts.

The evaluation of the seventh-grade science curriculum and textbook reveals a deficiency in the integration of ST tools. While there are objectives and contents for recognizing interconnections, there are notable deficiencies in the comprehensive utilization of ST tools in feedback mechanisms, nonlinear relationships, and hierarchical systems understanding. While some chapters touch upon relational dynamics within scientific contexts, such as in the exploration of celestial bodies or cellular processes, the absence of explicit integration of ST tools limits the depth of understanding in system dynamics.

Although some chapters employ conceptual modeling to mitigate complexity, traditional evaluation methods prevail, with limited application of ST principles in problem-solving activities. Overall, there is a clear need for a more systematic incorporation of ST tools to enhance students' comprehension of complex systems and their dynamics within the seventh-grade science curriculum and textbook.

An analysis of the eighth-grade science curriculum and textbook reveals a comprehensive emphasis on recognizing interconnections between scientific concepts. However, there are notable deficiencies in the integration of ST tools. While efforts to model conceptual systems are evident, there remains a need for greater integration of hierarchical systems understanding and the application of ST tools to reduce complexity.

Additionally, understanding systems at different scales and devising modifications for desired effects require further attention and integration into both the curriculum and textbook content. It is necessary to enhance students' critical thinking abilities and to facilitate a more profound comprehension of intricate scientific phenomena through a more comprehensive integration of ST principles and tools.

5. DISCUSSION

This chapter involves a discussion of the findings, implications, limitations and further studies. First, a summary of the theoretical background, the significance of the study, and the methodology are presented. The study's results are then interpreted and compared with previous studies. Then, the implications for teaching, learning, curriculum development, and different stakeholders are provided. The limitations of the study are presented in the final part to help guide future research.

5.1. Discussion of the Results

Systems thinking (ST) reveals a holistic description of the concepts and system dynamics that have always been involved in our lives (Ramage and Shipp, 2009). The ST approach emerges as a holistic view of interacting parts and loops that are constantly changing. It emerges as an approach that enhances our ability to create solutions in today's world, where the problems we face are becoming more intractable and the solutions more complicated (Richmond, 1990). The ST approach is essential for developing the ability to predict complex behaviors and consider consequences from a broad perspective.

The increasing importance of ST in addressing various societal challenges has been highlighted (Arnold and Wade, 2015). In the context of science education, ST develops students' creativity, critical thinking, and problem-solving skills, including analytical and critical thinking toward sustainable solutions (Blatti *et al.*, 2019). On the other hand, many students lack the necessary understanding of complex systems and the ability to seek solutions to complex problems at the end of K-12 education (Assaraf and Orion, 2005a; Eilam, 2012; Fortus *et al.*, 2019; Gilissen *et al.*, 2020; Ke *et al.*, 2020; Roychoudhury *et al.*, 2017; Sterman and Sweeney, 2002; Sweeney and Sterman, 2007). Similarly, middle and high school science teachers often find it difficult to integrate ST into their teaching due to insufficient knowledge and understanding (Ateskan and

Lane, 2018; Karaarslan Semiz and Teksöz, 2020; Kim and Lee, 2019; Lavi and Dori, 2019).

Curricula and textbooks play a crucial role in the effective integration of ST. Curriculum content should be aligned with ST principles to facilitate holistic understanding (Assaraf and Orion, 2005b; Fisher and Systems Thinking Association, 2023). Similarly, textbooks serve as primary resources for learning and should adequately reflect ST concepts (Oates, 2014). Therefore, assessing the inclusion of ST in middle school science curricula and textbooks is important for policymakers and stakeholders. Unlike domain-specific studies, this study adopted a domain-general approach to comprehensively evaluate the integration of ST across middle school science curricula and textbooks.

A rubric was developed to analyze ST inclusion in Turkish middle school science curricula and textbooks based on the nine ST components of the systemigram developed by Arnold and Wade in 2015, which was used as a theoretical framework. It is important to note that the inclusion of ST in Turkish middle school science curricula and textbooks is limited to analyzing the presence of ST rather than the adequacy of the objectives. Any objectives or chapters that score low on the developed rubric may still be compatible with a different approach other than ST, this study aims to reveal the extent to which the curriculum and textbooks integrate ST.

Analyzing science curricula and corresponding textbooks for fifth through eighth-grades reveals strengths and areas for improvement in integrating ST characteristics. There is a consistent emphasis on recognizing interconnections within scientific concepts across all grades, reflecting an understanding of the importance of holistic thinking in science education (Meadows, 2008). However, while interconnections can be viewed and interpreted from a broad perspective with ST tools, there is no integration with ST tools for the recognizing interconnections component. On the other hand, integrating other ST components, such as feedback mechanisms, system structures, and nonlinear relationships, varies considerably, indicating a need for further refinement in

curriculum design and instructional materials. A common finding across all grade levels is the limited use of ST tools, such as CLDs and SFDs, to explain complex system dynamics. Although some chapters mention interconnections and system structures of relevant topics, the lack of CLDs and SFDs hinders students' ability to visualize and analyze complex relationships within systems (Sweeney, 2017). Integrating analytical tools into the curriculum and textbooks can enhance students' problem-solving abilities and provide them with valuable analytical skills (Lesh and Doerr, 2003). Regarding these results, the analysis indicates a need for more consistency in addressing feedback mechanisms and nonlinear relationships across chapters and grade levels.

Turkey's middle school science curriculum follows a spiral design, with grade-specific knowledge content and uniform units and subjects (MoNE, 2018). The chapters are structured to facilitate interactive learning of scientific concepts during transitions between grade levels. For instance, the Living Things chapter in the fifth-grade curriculum provides information on classifying living things and their interconnections. However, it fails to emphasize the hierarchical structure among living things and the feedback resulting from this mechanism. It does not mention feedback loops, which could be suitable for ST integration.

Similarly, the Solar System and Eclipses chapter in the sixth-grade, and the Solar System chapter in seventh-grade curriculum may demonstrate the causal relationships between celestial bodies and their stocks and flows. These chapters are compatible with ST tools like SFD. The Human Body Systems, and the Health of Human Body Systems chapters in the sixth-grade curriculum are also suitable for demonstrating the stocks and flows of the systems in the human body and their non-causal feedback mechanisms with SFD and CLD. The chapter on Matter and Heat in the fifth-grade curriculum and the Matter and Change chapters in the sixth-grade curriculum may present similar integration. These chapters are applicable for using SFD and CLD to analyze matter and heat interactions. However, instead of using ST tools, it was used alternative teaching tools such as tables, experiments, and visuals.

The lack of integration in identifying and understanding feedback, nonlinear relationships, and different types of stocks, flows, and variables has hindered the applicability of understanding systems structure and dynamic behavior components (Sweeney, 2017). Showing feedback mechanisms and nonlinear relationships is crucial for comprehending the dynamic behavior of systems and predicting their responses to changes (Sterman, 2000). Neglecting these aspects may result in the curriculum and textbooks being inadequate in preparing students to tackle real-world challenges that frequently involve nonlinear dynamics and feedback loops. Sweeney (2017) stated that linear thinking can occur when cause-effect relationships are not analyzed in the context of causal loops.

Additionally, learning about Earth's systems separately and independently causes students to have difficulty understanding the connection and interaction between systems (Batzri *et al.*, 2015). Students also do not understand components in systems that are not easily visible (Hmelo-Silver *et al.*, 2007). For this reason, it is important to understand feedback mechanisms and nonlinear relationships to reveal and analyze what is not easily seen. Feedback loops are essential for understanding systems and interpreting system behavior (Haraldson, 2004). Therefore, identifying interconnections and interpreting interconnections within feedback loops can help understand the mechanisms of complex systems. In this context, the science curriculum should include systems in a way that shows their interactions, utilizing the ST perspective (Logan, 2018).

Another important point is the limited integration of hierarchical systems understanding across grade levels, related to the understanding systems at different scales component. Although some chapters discuss relationships within systems, there is a missed opportunity to explore how systems operate within larger systems, which is essential for understanding complex phenomena across different scales (Lesh and Doerr, 2003). Incorporating hierarchical thinking into the curriculum can aid students in developing a more nuanced understanding of the interconnectedness of natural phenomena and human activities.

In the context of reducing complexity by modeling conceptually components, the results indicate that while some chapters demonstrate efforts toward conceptual modeling, there is a need for improvement in its consistent application across grade levels. For example, chapters in sixth and eighth-grade textbooks such as Solar and Lunar Eclipses and Biotechnology illustrate conceptual modeling to reduce complexity. However, to enhance students' ability to analyze and address real-world problems, there is a need for greater emphasis on incorporating conceptual modeling techniques throughout the curriculum. Conceptual modeling serves as a foundational aspect of ST, enabling students to visualize and understand complex systems (Ackoff, 1971; Jonassen, 1997; Jonassen, Strobel, and Lee, 2006). Therefore, when students seek solutions to complex problems, understanding numerical or non-numerical modeling or existing models may enhance their creativity and problem-solving skills.

Moreover, devising modifications to produce desired effects within systems is essential for promoting students' critical thinking and problem-solving skills (Meadows, 2008). However, the results revealed that this aspect is not consistently addressed across all grade levels. Although some chapters offer opportunities to devise modifications to produce the desired effect, there are shortcomings in terms of integrating ST tools. As ST is an approach for solving complex problems, utilizing ST tools to develop solutions can aid in the search for detailed and long-term solutions that lead to policy-making, rather than seeking short-term fixes (Sterling *et al.*, 2005). The study results indicate that ST is not explicitly incorporated into the middle school curricula and textbooks in Turkey. The Ministry of National Education (MoNE, 2018) has developed middle school science curriculum documents that do not include any objectives for learning and teaching ST. Similarly, the purpose of including ST in teaching objectives is not clearly stated in the middle school science curricula of various countries, as evidenced by the Finnish National Board of Education (2016), MoNE (2018), the Ministry of Education (2015), the Ministry of Education in Singapore (2015a), OECD (2018), and The New Zealand Curriculum (2007). In this context, it is predictable not to see ST characteristics clearly in Turkish middle school science curricula and textbooks.

The results of the study also showed that ST can be effectively integrated into middle school science curricula and textbooks. The curriculum and textbooks already contain objectives and content that can be developed and integrated with ST, despite some deficiencies in the current integration. Although many chapters, such as Biodiversity, Human and Environment, Matter and Heat, Human Body Systems, Climate and Weather, Adaptation, Energy Transformations, Sustainable Development, Food Chain and Energy Flow, and Electric Charges and Electric Energy could include a teaching technique where ST tools can be integrated, on the other hand, the results show that curricula and textbooks do not meet this requirement.

Additionally, the component that received the highest scores from the rubric was recognizing interconnections. While the highest scoring and most common ST characteristic from the rubric was recognizing interconnections, when looking at the content of the textbook, it was seen that ST tools were not included to show interconnections. Additionally, the fact that the objectives that scored high on the recognizing interconnections component did not score high on the other components may be a sign that ST integration is insufficient in building a broad perspective that can be developed toward solving dynamic problems and integrating ST into middle school science subjects. This may result in deficiencies in students' adoption of concepts such as stock-flow, feedback, and system boundaries when generating solutions to complex problems. Additionally, reducing complexity by modeling conceptually and devising modifications to produce desired effects were also among the components that received high scores. However, the high-scoring components are also not presented in an integrated manner with ST tools.

The findings of the study are comparable to the study of the examination of the K-8 Turkish science curriculum and textbook by Karaarslan Semiz and Teksöz in 2023. Karaarslan Semiz and Teksöz (2023) assessed the presence of ST skills in the K-8 science curriculum by examining units related to sustainability. They found that the curriculum includes concepts related to sustainability, particularly in components such as recognizing interconnections and understanding system structure, although

these concepts are at a basic level. The study found that the curriculum and textbook did not adequately cover ST-related concepts (Karaarslan Semiz and Teksöz, 2023). The study also indicated a need for improvement in integrating ST into curricula and textbooks (Karaarslan Semiz and Teksöz, 2023). It is also stated that it is essential for the science curriculum to include a purpose to improve students' ST skills and content that includes ST components (Karaarslan Semiz and Teksöz, 2023).

Additionally, in his study on spatial thinking skills and ST integration in the Turkish primary school science curriculum, Şahingöz (2021) notes that the curriculum partially includes ST. The study suggests that subjects such as Space, Earth, and Sun are suitable for ST integration and that teaching resources could be improved to incorporate ST better (Şahingöz, 2021). From an international perspective, Chiu *et al.* (2019) evaluated the science curricula of the United States, Australia, Israel, and Taiwan and emphasized the importance of recognizing interconnections, understanding system structure and behavior, and evaluating and modeling cause-effect relationships. Although the study did not explicitly indicate the existence of ST, it stated that methods such as evaluating and modeling cause-effect relationships were integrated into the curriculum content (Chiu *et al.*, 2019). The study suggests that integrating ST into the curriculum can enhance students' comprehension of intricate global issues and enable them to generate solutions for complex problems (Chiu *et al.*, 2019).

The findings of the study are also consistent with the literature emphasizing the importance of integrating ST into the curriculum and textbooks, which serve as the source of the curriculum. Science education researchers have recently emphasized the importance of ST in science education curricula (Lee *et al.*, 2019). ST is also included in science curriculum standards, such as the Australian Science Curriculum (ACARA, 2017) and Next Generation Science Standards (NGSS, 2013).

Williams *et al.* (2017) emphasize the importance of ST in solving complex problems and increasing the applicability of sustainability. It is underlined that the characteristics of ST should be applied to sustainability teaching and curriculum (Williams

et al., 2017). Integrating concepts such as feedback loops and dynamic systems into the curriculum is crucial for students to develop an understanding of sustainability challenges (Williams *et al.*, 2017). Stroh (2015) suggests that including feedback loops, mental models, and leverage points, which are essential characteristics of ST, in the curriculum will help students understand interconnected dynamic systems.

A study conducted at the University of California examined students' learning of green chemistry by integrating the green chemistry curriculum, which is based on industrial principles, the relationship of chemistry with other branches of science, and sustainability with ST (Armstrong *et al.*, 2019). The study found that students better understood the principles and concepts of green chemistry (Armstrong *et al.*, 2019). In addition, the study highlighted that linking the green chemistry curriculum with the ST approach improves students' understanding of interconnected concepts (Armstrong *et al.*, 2019). Similarly, in a study that describes a model for evaluating science curricula and practices, the authors created various learning outcomes for chemistry using five different lenses, including the ST approach (Raycroft and Flynn, 2020). The study emphasizes the importance of teaching chemistry with the ST approach to understand the relationships between the components of systems on Earth.

In this context, studies that evaluated the impact of including ST in science teaching on learning found that students were able to assimilate scientific concepts and complex systems more meaningfully, and their interpretation and analysis skills improved (Assaraf and Orion, 2005b; Assaraf and Orion, 2010; Doganca Kucuk and Saysel, 2018; Roychoudhury *et al.*, 2017; Yoon, 2008). For instance, in a study, a course was designed to evaluate the knowledge level of ninth-grade students about reproduction, which is one of the complex genetic engineering subjects, and to encourage system thinking. Activities such as computer laboratory work, small group discussions, and whole-group online discussions were included in the teaching. The results of this study indicated that students improved in making sense of systematic concepts and gaining knowledge by reasoning (Yoon, 2008).

A mixed-method study examined students' ability to develop system thinking skills. The study utilized various measurement tools, including student drawings, word associations, repertory grids, interviews, observations, cyclic thinking questionnaires, and an ecology system inventory (Assaraf and Onion, 2010). The results revealed that teaching designed with ST significantly improved the abilities of 4th-grade students with very low ST skills in analyzing the components of systems (Assaraf and Onion, 2010). The connections between inquiry-based learning and system components were noticed by students, who made progress in concretizing abstract concepts (Assaraf and Onion, 2010).

A study has emphasized the importance of using ST in teaching climate change, which is one of the socioscientific issues presenting various challenges today and, in the future, (Roychoudhury *et al.*, 2017). The study revealed that students gained essential knowledge about climate change with the ST approach. However, they only established a superficial relationship between some variables (Roychoudhury *et al.*, 2017). Based on the results, it is suggested that further examination of students' knowledge and skills in ST regarding interconnected systems is necessary, with a greater emphasis on their development (Roychoudhury *et al.*, 2017). Additionally, a study was conducted to examine the effects of the ST on teaching complex environmental problems that created a systems-based classroom environment for seventh graders (Doganca Kucuk and Saysel, 2018). One group learned with the determined environment topic, while the other learned with integrated system tools. The results showed that learning with ST positively contributed to success in problem-solving (Doganca Kucuk and Saysel, 2018). Therefore, it can be inferred that integrating applied curriculum into ST is crucial for enhancing students' problem-solving skills and scientific application participation (Doganca Kuçuk and Saysel, 2018). Assaraf and Orion (2005b) evaluated the development of ST skills in eighth-grade students learning about Earth systems. The study applied a curriculum focused on cycles in Earth systems. The study found that students who demonstrated superficial ST skills at the beginning of the learning phase significantly improved their ST skills throughout their learning (Assaraf and Orion, 2005b). The study highlights the potential of ST-integrated teaching to enhance sci-

ence learning by emphasizing the importance of incorporating the teaching and practice of ST skills into science education (Assaraf and Orion, 2005b).

Kali *et al.* (2003) conducted a study to evaluate students' understanding of earth science education in the context of ST skills. They designed an activity that integrated ST to assess students' comprehension of rock cycles in earth science systems. The results showed a significant improvement in students' understanding of rock cycles and ST skills (Kali *et al.*, 2003). The students gained a greater understanding of the dynamic nature of the rock cycle and the feedback mechanisms involved (Kali *et al.*, 2003). According to Kali *et al.* (2003), ST can contribute and enhance environmental literacy, and therefore, curricula should include system-based content.

Fisher and the Systems Thinking Association (2023) evaluated the integration of ST activities into K-12 education over the past 20 years. The study aimed to provide activities that help students learn systemic behaviors toward complex problems they may encounter in the real world and to gain holistic thinking skills by adopting systemic thinking toward these behaviors (Fisher and Systems Thinking Association, 2023). According to Fisher and the Systems Thinking Association (2023), BOTG can be used in story books in primary school, while middle school students can benefit from the integration of SFD and modeling into their subjects, in addition to BOTG. For high school students, a more advanced framework can be used for numerical modeling, and BOTG and SFD can be employed at a more advanced level (Fisher and Systems Thinking Association, 2023). The study found that students were more willing to solve complex problems when engaging in ST-integrated activities and were able to comprehend the internal structure of systems (Fisher and Systems Thinking Association, 2023). The study highlights the significance of integrating ST into the K-12 curriculum at various grade levels. Fisher and the Systems Thinking Association (2023) suggest incorporating ST into the curriculum would make learning more student-centered. Fisher and the Systems Thinking Association (2023) also suggest that providing professional training and development on how to teach ST can enhance teachers' competence in ST and enable them to collaborate more effectively with other stakeholders, such as

school management, to integrate ST into education. In this regard, materials for using BOTG and SFD, creating simulations in conjunction with modeling, and additional materials on teaching ST are presented for teachers (Fisher and Systems Thinking Association, 2023). Additionally, they propose introducing ST tools into education, starting as early as kindergarten, can strengthen students' ability to analyze problems with dynamic scenarios (Fisher and Systems Thinking Association, 2023). It is also stated that developing ST skills at an early age could be useful in interpreting dynamic models and predicting dynamic behaviors in the following years (Fisher and Systems Thinking Association, 2023).

Delaney (2021) explores the perceptions of the benefits and challenges of an ST in teaching chemistry. The study involved several workshops with high school teachers, tertiary teachers, and researchers. After the workshops, it was concluded that teachers should be clear and deliberate when integrating ST into their teaching (Delaney, 2021). Furthermore, the curriculum should be modified to include systems thinking in the classroom. Delaney *et al.* (2021) suggest that providing adequate resources and time is crucial, especially in supporting vocational education. In another study, 39 science teachers from various regions of Turkey attended a workshop to investigate their evaluations of the ST integrated into the professional development program (Ateskan and Lane, 2018). The ST scale scores of teachers before and after the workshop showed statistically significant differences. However, it was noted that the teachers required support in analyzing concept maps related to various topics involving systems and associations (Ateskan and Lane, 2018). Therefore, it can be concluded that integrating ST with the curriculum and textbook content, which provides teachers support in their teachings, is crucial for effectively teaching complex scientific systems. In order for teachers to teach ST competently, it is very essential to provide them with the necessary support in their own learning of ST (Ateskan and Lane, 2018).

In a parallel study of 42 pre-service and in-service science and engineering teachers, participants were given conceptual modeling tasks on various topics (Lavi and Dori, 2019). The evaluations indicated that the assignments were challenging and re-

quired a comprehensive understanding. Furthermore, it has been revealed that these assignments promote the use of higher-order thinking skills. According to Lavi and Dori (2019), the ST approach is beneficial for both students in learning and teachers in teaching.

The strategic plan developed by the Catalina Foothills School District and reviewed by the Waters Foundation is an example of integrating ST into education. The plan emphasizes the incorporation of ST into learning and teaching, as well as the development of problem-solving, creativity, collaboration, and critical thinking skills, which are defined as learning competencies (Catalina Foothills School District, 2018). The strategic plan aims to encourage active student participation in analyzing complex systems and to ensure the implementation of ST outside the classroom by collaborating with experts and stakeholders (Catalina Foothills School District, 2018). It also aims to encourage teachers to receive training and support to incorporate ST into their teaching Catalina Foothills School District, 2018). Furthermore, a rubric was developed to assess K-12 students' ST skills based on the strategic plan and the determined learning competencies (Catalina Foothills School District, 2018). The rubric aims to support students' deep learning process by integrating concepts such as behavior over time, the system as the cause, big picture, and interdependencies (Catalina Foothills School District, 2018). It also serves as a guide to the level at which K-12 students demonstrate these skills while acquiring ST skills.

Most science textbooks do not emphasize the development of skills in adopting a systemic perspective on complex issues while focusing on scientific concepts (Liu and Hymelo-Silver, 2009). Therefore, the absence of explicit inclusion of ST in the curriculum and teaching objectives may be one of the most significant reasons why students and science teachers need to improve in developing solutions to dynamic and interactive problems. Studies on ST skills and characteristics have shown that students and science teachers need more understanding and integration of ST in various areas. These include recognizing feedback mechanisms (Eilam, 2012; Roychoudhury *et al.*, 2017), understanding the structure and dynamic behavior of a system (Ateskan and

Lane, 2018; Eilam, 2018; Gilissen *et al.*, 2020; Roychoudhury *et al.*, 2017), and making generalizations (Ormancı *et al.*, 2018). The lack of integration of ST into the curriculum creates difficulties for students in understanding and demonstrating ST characteristics and skills (Budak and Ceyhan, 2023; Semiz and Teksöz, 2019). For this reason, it can be inferred that integrating ST into the curriculum and textbook content can enhance students' problem-solving abilities by developing ST skills and providing a holistic perspective on complexity.

In conclusion, the results of the study indicate that Turkish middle school science curricula and textbooks need more specific objectives and content for ST. Therefore, future revisions of the curriculum may include explicit objectives for ST. While the curriculum objectives emphasize problem-solving and critical thinking (MoNE, 2018), there is no explicit emphasis on ST. Components such as identifying and understanding feedback, reducing complexity by modeling conceptually, and devising modifications to produce the desired effect are implicitly referred to. This may indicate a need for more middle school science curriculum and textbooks aimed at developing the ability to interpret the system from different aspects.

Understanding ST is crucial to comprehending how different components interact to create a whole and how they impact each other (Ndaruhutse *et al.*, 2019). ST differs from traditional learning methods in that it encourages the development of diverse perspectives by considering nonlinear behaviors and finding sustainable solutions to problems by taking a holistic approach to the world (Ndaruhutse *et al.*, 2019). Integrating ST into the curriculum and textbooks helps reveal the dynamism and complexity of our lives by promoting awareness and preparedness for this complexity (Meadows, 2008). Additionally, ST inclusion analysis of middle school science curricula and textbooks can provide guidance to curriculum makers, stakeholders, and textbook writers in including specific objectives and outcomes for ST characteristics.

The findings of the current study also provide significant data with implications and suggestions for teaching, learning, and various stakeholders. These implications

can guide teachers, curriculum developers, policymakers, and publishers in improving middle school science curricula and textbooks and in integrating them into science lessons to teach ST.

5.2. Limitations and Future Research

Although this study contributes to the existing body of literature by examining the inclusion of ST in Turkish middle school science curricula and textbooks, it is important to acknowledge the limitations of the current study that can guide future studies in this field.

The current study only examined ST inclusion in the fifth, sixth, and seventh science textbooks published by the Ministry of National Education of Turkey (MoNE) Publishing. On the other hand, it was intended to choose a textbook published by MoNE for the eighth-grade textbook for consistency since no textbook was published by MoNE, a book published by a private publisher whose copyrights by MoNE were chosen. Additionally, the school administration considered it mandatory to use textbooks published by the Ministry of Education in some schools in Turkey. However, there are other textbooks published by different publishers and copyrighted by MoNE, and some other schools in Turkey use textbooks from other publications. Therefore, future studies may investigate the inclusion of ST in other textbooks that were prepared by private publishers and are copyrighted by MoNE. In addition, future studies may also conduct studies with curriculum developers and textbook authors to reveal their knowledge of ST regarding the process of developing curriculum and textbooks.

Additionally, the analysis includes all middle school grade levels to provide a comprehensive perspective. Therefore, future studies may analyze the curriculum and textbooks at other grade levels to provide a broader understanding of ST inclusion in Turkish science curricula and textbooks. Lastly, the rubric developed to investigate the inclusion of ST in Turkish middle school science curricula and textbooks can be used in future studies to examine the inclusion of ST in the curriculum and textbooks

at different grade levels and courses such as Mathematics, Turkish, Social Sciences, Biology, Physics, and Chemistry.

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