ASSESSING THE FEEDBACK THINKING, HOMOLOGICAL REASONING, AND FEEDBACK RECOGNITION LEVELS OF SENIOR PRE-SERVICE MIDDLE SCHOOL SCIENCE TEACHERS USING DOMAIN-SPECIFIC AND DOMAIN-GENERAL SCENARIOS

by

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ABSTRACT

ASSESSING THE FEEDBACK THINKING, HOMOLOGICAL REASONING, AND FEEDBACK RECOGNITION LEVELS OF SENIOR PRE-SERVICE MIDDLE SCHOOL SCIENCE TEACHERS USING DOMAIN-SPECIFIC AND DOMAIN-GENERAL SCENARIOS

As the world becomes increasingly complex and many systems problems such as hunger and global warming are encountered in everyday life, individuals need to be equipped with systems thinking skills to deal with these complex systems. Teachers play an important role in educating students to become systems thinkers, so it is valuable to examine teachers' systems thinking skills. However, it is noted that systems thinking studies that include pre-service and in-service teachers as participants are very limited. The purpose of this study is to assess the feedback thinking, homological reasoning, and feedback recognition levels of senior pre-service middle school science teachers through domain-specific and domain-general scenarios. Ten senior pre-service middle school science teachers with strong science and mathematics backgrounds from a leading public university participated in this study. The Systems-Based Inquiry (S-BI) protocol developed by Sweeney and Sterman (2007) was selected for this study, and it was deemed appropriate to revise this protocol due to the earth-shattering effects of the 21st century. Data were analyzed using the revised S-BI protocol scoring rubric. The results showed that participants' feedback thinking, homological reasoning, and feedback recognition skills were limited. This study is considered to be a pioneering study for future studies by revealing the systems thinking skills of individuals in areas that are familiar and unfamiliar to them.

ÖZET

ORTAOKUL FEN BİLİMLERİ ÖĞRETMEN ADAYLARININ GERİ BİLDİRİM DÜŞÜNME, HOMOLOJİK MUHAKEME VE GERİ BİLDİRİMİ TANIMA DÜZEYLERİNİN ALANA ÖZGÜ VE ALANA ÖZGÜ OLMAYAN SENARYOLAR KULLANILARAK DEĞERLENDİRİLMESİ

Dünya giderek karmaşıklaşırken ve günlük hayatta açlık, küresel ısınma gibi birçok sistem sorunuyla karşılaşılırken, bireylerin bu karmaşık sistemlerle başa çıkabilmeleri için sistem düşüncesi becerileriyle donatılmaları gerekmektedir. Öğrencilerin sistem düşünürü olarak yetiştirilmelerinde öğretmenlerin rolü büyüktür ve bu nedenle öğretmenlerin sistem düşüncesi becerilerini incelemek değerlidir. Fakat hizmet öncesi ve hizmet içi öğretmenlerin katılımcı olarak yer aldığı sistem düşünesi çalışmalarının çok kısıtlı olduğu belirtilmektedir. Bu çalışmanın amacı, ortaokul fen bilgisi öğretmen adaylarının geribildirim düşünme, homolojik muhakeme ve geribildirimi tanıma düzeylerini alana özgü ve olmayan senaryolar aracılığıyla değerlendirmektir. Bu çalışmaya, önde gelen bir devlet üniversitesinde güçlü bir fen ve matematik geçmişine sahip 10 son sınıf ortaokul fen bilgisi öğretmeni katılmıştır. Bu çalışma için Sweeney ve Sterman (2007) tarafından geliştirilen Sistem Tabanlı Sorgulama (STS) protokolü seçilmiş ve 21. yüzyılın dünyayı sarsan etkileri nedeniyle bu protokolün revize edilmesi uygun görülmüştür. Veriler revize edilmiş STS protokol puanlama anahtarı kullanılarak analiz edilmiştir. Sonuçlar, katılımcıların geri bildirim düşünme, homolojik muhakeme ve geri bildirim tanıma becerilerinin sınırlı olduğunu göstermiştir. Bu çalışmanın, bireylerin aşina oldukları ve olmadıkları alanlarda sistem düşüncesi becerilerini ortaya koyarak gelecek çalışmalar için öncü bir çalışma olacağı düşünülmektedir.

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LIST OF SYMBOLS

%	Percentage

LIST OF ACRONYMS/ABBREVIATIONS

CK	Content Knowledge
MoNE	Ministry of National Education
NGSS	Next Generation Science Standards
PCK	Pedagogical Content Knowledge
S-BI	Systems - Based Inquiry
SDG	Sustainable Development Goal
STS	Sistem Tabanlı Sorgulama

1. INTRODUCTION

"Reality is made up of circles, but we see straight lines" (Senge, 2006, p. 73). Understanding and interpreting complex systems requires a systems thinking approach (Senge, 1990). Systems thinking is the ability of individuals to see the world as consisting of many complex systems and to see the interconnectedness of variables within these complex systems (Sterman, 2000). People with systems thinking skills are better able to understand the interdependencies and changes that occur in complex systems (Senge *et al.*, 1999).

Individuals should be able to understand dynamic systems to be trained as systems thinkers, and one of the most effective ways to achieve this is through education. Dynamic thinking is the ability to see and reason about patterns of behavior (Richmond, 1993). Dynamic thinking is also described as an individual's ability to recognize interrelationships and cyclical processes in a system and to think of phenomena as the result of cyclical processes (Dorani *et al.*, 2015; Richmond, 1993). A systems thinker needs to have the ability to understand dynamic behavior in dynamic systems (Richmond, 1997; Sweeney and Sterman, 2000).

Systems thinking is widely accepted as a prerequisite for successfully managing the complicated dynamic systems at the heart of major complex issues such as poverty, global climate change, and natural resource degradation (Sweeney and Sterman, 2007). Systems thinking has the potential to enable people to understand complex sustainability issues and the reality of sustainability in local, national, and global contexts and across different domains such as environmental, social, and economic (Bianchi *et al.*, 2022). Systems thinking is, therefore, an important tool for making sustainable decisions and taking action for a sustainable future (Molderez *et al.*, 2018). When combined with sustainability literacy, systems thinking can help shape a more sustainable future for current and future generations, and it can lead to unsustainable actions (Bianchi *et al.*, 2022).

Systems thinking is valuable in science education as it enables educators and students to take a holistic view of current socio-scientific issues and to connect learning to sustainability (Delaney *et al.*, 2021). Empirical evidence shows that incorporating activities into the science classroom that encourage students to explore systems can improve their higher-order thinking skills (Jacobson, 2001; Wilensky and Resnick, 1999). Students may need scaffolding to become good systems thinkers (Hmelo-Silver and Azevedo, 2006) because systems thinking skills are not acquired through experience alone (Sweeney and Sterman, 2000). In this sense, teachers can help students scaffold the complex systems they encounter, both today and in the future, by using complex systems as learning tools in their lessons. Teachers can help students answer what if questions that allow them to think holistically and question the parts of systems and the relationships between the parts (Maani and Maharaj, 2004).

As there is a growing body of research on the importance of teaching complex systems in science education, Yoon *et al.* (2018) conducted a review study to examine the teaching and learning of complex systems in K-12 science education. This study revealed that while a great deal of research has been done on students' understanding of complex systems, very little research has been done on teachers' understanding of complex systems (Yoon *et al.*, 2018). Recent literature reviews have also revealed that very few studies on systems thinking involve pre-and in-service teachers as participants (Bielik *et al.*, 2023; Budak and Ceyhan, 2024). However, more research is needed on how pre- and in-service teachers think and reason about complex systems in science contexts (Lee *et al.*, 2019).

To achieve the goal of integrating systems thinking into science education, more information is needed about teachers' understanding of complex systems (Lee *et al.*, 2019). Teachers' systems thinking skills need to be assessed to obtain this information. For this reason, a wide variety of guidelines and tools have been developed for assessing systems thinking skills (Dayarathna *et al.*, 2021). For example, Stave and Hopper (2007) matched the levels of Bloom's taxonomy with systems thinking skills as a result of their literature review. Stave and Hopper (2007) defined recognizing

interconnections, identifying feedback, and understanding dynamic behavior as basic systems thinking skills; differentiating types of variables and flows and using conceptual models as intermediate systems thinking skills; and creating simulation models and testing policies as advanced systems thinking skills.

Yoon *et al.* (2018) stated that for individuals to understand complex systems, they should be able to recognize static and dynamic equilibria in which aspects of a system change while maintaining stability. Similarly, Mor and Zion (2021) stated that for a systems thinker to understand dynamic equilibria in a system, it is necessary to understand the cycles that regulate and maintain the process of a system, called feedback loops. Balancing feedback loops seek to balance and stabilize things by moving them toward a desired condition, while reinforcing feedback loops combine change in one direction with more change in the same direction (Monat and Gannon, 2015). Identifying feedback loops is one of the most fundamental skills in dynamic thinking (Stave and Hopper, 2007; Sweeney and Sterman, 2000). In addition to identifying feedback loops, recognizing feedback is also an important skill. Feedback recognition is about distinguishing between balancing and reinforcing feedback loops, and this skill requires additional systems skills (Arnold and Wade, 2017). In all dynamics, including social and natural dynamics, it is important to distinguish between balancing and reinforcing feedback loops as they emerge from the interplay of feedback loops (Sterman, 2012). Pre-service science teachers who have not received training focused on systems thinking may struggle to move to higher levels without being successful at feedback thinking levels. Therefore, it is crucial to examine pre-service science teachers' feedback thinking skills and feedback recognition skills.

Since one of the structures of the system is feedback loops, it is important that similar structures in feedback loops can be recognized and transferred between domains by homological reasoning (Sweeney, 2004). Homological reasoning is a cognitive reasoning process about the similarity of structures or patterns of interrelationships in a complex system (Sweeney, 2005). Teachers can give students the opportunity to make homological reasoning by asking them for examples of similar dynamic structures in

different subjects of the dynamic structures in a subject they are teaching. In this way, students can learn from their own field of study while recognizing patterns in dynamic systems relationships in different fields, giving them the power to move between subjects (Forrester, 1996; Sweeney, 2005). Therefore, considering that it is important for teachers to have homological reasoning skills to educate future generations (Forrester, 1992), it is reasonable to investigate the homological reasoning skills of senior pre-service middle school science teachers in the feedback systems structures presented in this study.

Systems and systems models are important because they are one of the crosscutting concepts in the Next Generation Science Standards (NGSS). Using systems and systems models in science and engineering is significant because it simplifies complex systems through modeling (NGSS Lead States, 2013). In the present study, the focus was on science education to obtain in-depth information about the systems, and therefore, pre-service science teachers were selected to serve as the target population of the study. Pre-service science teachers have potential to comprehend students' development of systems thinking and conceptual modeling skills (Lavi and Dori, 2019) and to integrate systems thinking in science education through their internship (Lee *et al.*, 2019). Middle school science teachers have the potential to educate students at a very young age by using the systems thinking approach in their classrooms (Doganca-Kucuk and Saysel, 2018). Since it is assumed that middle school science teachers work in middle school science classrooms, where the first steps towards environmental and sustainability issues are taken (Doganca-Kucuk and Saysel, 2018), this study focused specifically on middle school science teachers. Therefore, this study has attempted to narrow the scope of the research by planning to work specifically with senior pre-service middle school science teachers because they have completed college science courses (e.g., physics, chemistry, biology) and teaching methods courses and are currently doing their internships.

One of the biggest problems in measuring systems thinking skills is deciding on the appropriate assessment tool. Self-report instruments have been widely used

to assess various constructs, including systems thinking skills (Davis *et al.*, 2023). However, these instruments have limited capacity to reflect individuals' skills (Norris *et al.*, 2018; Peng *et al.*, 1997). Because multiple-choice questions only indirectly assess people's skills, this assessment format is limited for measuring skills (Brookhart and Nitko, 2019). For this reason, alternative assessment tools have been investigated. Scenario-based assessments provide a deeper source of information and can provide a more comprehensive view of an individual's skills and understanding (O'Reilly *et al.*, 2018; O'Reilly and Sabatini, 2013; Sabatini *et al.*, 2013). Scenario-based assessments can also highlight the context-dependent nature of challenging situations (Dugan *et al.*, 2021). It is argued that scenario-based assessment tools can effectively assess participants' skills by presenting them with a realistic problem (Grohs *et al.*, 2018). Therefore, scenario-based assessments are reasonable to evaluate people's ideas about complex real-world problems (Dugan *et al.*, 2021).

Exploring the feedback thinking levels of pre-service teachers is crucial because they have the potential to train students to be systems thinkers and to shape future generations when they enter the profession. Numerous studies have shown that even highly educated adults perform poorly on tasks that measure systems thinking skills (e.g., Palmberg *et al.*, 2017; Plate and Monroe, 2014; Sweeney and Sterman, 2000). It is also noted that when people evaluate a problem or case in their area of expertise, they may immediately recognize familiar features (Simon, 1986). However, although there are studies in the educational literature on domain-specific (e.g., Karaarslan-Semiz and Teksoz, 2020; Lee *et al.*, 2015) and domain-general (e.g., Norris *et al.*, 2022) topics in systems, there is a need for more empirical studies that use scenarios to assess individuals' systems thinking skills and improve our understanding (Davis *et al.*, 2023).

As Dugan *et al.* (2021) noted, scenario-based assessments can highlight the significance of context in challenging problems. Therefore, in this study, scenarios were classified as domain-specific and domain-general to emphasize the importance of context. This study defined domain-specific topics as topics in which middle school science teachers are experts, i.e., topics with which individuals are familiar, as stated by

Sweeney and Sterman (2000). The domain-specific scenarios were selected from scenarios dealing with middle school (5-8 grades) science curriculum topics. Sweeney and Sterman (2000) also stated that systems thinkers need to have scientific reasoning skills and familiarity with the domain-specific knowledge of the system problems presented.

In this study, domain-general topics were defined as topics that middle school science teachers are not experts in, such as topics that individuals are not familiar with, as stated by Sweeney and Sterman (2000). The domain-general scenarios were selected from universal scenarios that do not directly address topics in the middle school science curriculum. Regarding evaluating systems thinking skills, Sweeney and Sterman (2000) argued that individuals may perform well on systems tasks presented in familiar contexts but perform poorly in unfamiliar contexts. In this context, feedback thinking, which is one of the systems thinking skills, has been studied in the literature on domain-specific (e.g., Sommer and Lücken, 2010; Wellmanns and Schmiemann, 2022) or domain-general topics (e.g., Jordan *et al.*, 2023). This study attempted to go beyond the studies in the literature by comparing the feedback thinking, homological reasoning and feedback recognition skills of pre-service science teachers in domain-specific and domain-general subjects to gain new insights into their familiarity. Therefore, this study utilized a scenario-based assessment tool to assess the level of feedback thinking, homological reasoning and feedback recognition of senior pre-service middle school science teachers in domain-specific and domain-general scenarios.

1.1. Purpose of the Study

The purpose of this study is to assess the feedback thinking, homological reasoning, and feedback recognition levels of senior pre-service middle school science teachers through domain-specific and domain-general scenarios.

1.2. Significance of the Study

Research studies and policy documents reveal that systems thinking is a higher-order thinking skill that is a prerequisite for understanding concepts and principles in science education (Bianchi *et al.*, 2022; Frank, 2000). However, more research is needed on pre- and in-service teachers' understanding of complex systems (Bielik *et al.*, 2023; Lee *et al.*, 2019). Furthermore, while there has been a slow growth in the study of systems thinking in the field of science education in recent years, it is noted that the literature needs more empirical support (Budak and Ceyhan, 2024).

This study aimed to determine the level of feedback thinking, homological reasoning and feedback recognition of senior pre-service middle school science teachers through domain-specific and domain-general scenarios. This study has made several significant contributions to the literature. First, a recent review study showed that while most of the research on systems thinking in science education has been conducted in the United States and Germany, very few studies have been conducted in other countries (Budak and Ceyhan, 2024). This study has broadened our understanding of systems thinking by providing empirical data from Turkey. In addition, by conducting this study in Turkey, it has made social contributions such as suggestions for educational policies in the national arena and innovative contributions to the scientific literature in the international arena.

Second, as few empirical studies focus on pre-service and in-service teachers, this study provided empirical results to the literature by focusing on pre-service teachers' systems thinking skills in science education. Third, it is very important to examine the feedback thinking, homological reasoning and feedback recognition levels of pre-service teachers who are at a certain level of education and reasoning and who have not been trained in the systems thinking approach. This is because the quality of pre-service teachers' explanations of feedback dynamics, their reasoning and homological examples of these feedback dynamics, and their ability to distinguish and explain balancing and reinforcing feedback loops can reveal the current state of teacher education.

Fourth, the results of this study can be used as an evidence-based indicator for curriculum development for teacher preparation programs by determining the level of senior pre-service middle school science teachers' feedback thinking, homological reasoning and feedback recognition skills and revealing their understanding of systems.

Fifth, experts have a high level of understanding of systems related to their areas of expertise (e.g., Hmelo-Silver *et al.*, 2007). However, more in-depth research is needed to provide more evidence on the performance of experts in scenarios in their areas of expertise (Lavi and Dori, 2019). In this study, presenting two domain-specific and two domain-general scenarios to senior preservice middle school science teachers and comparing their feedback thinking, homological reasoning, and feedback recognition levels in domain-specific and domain-general scenarios makes a significant contribution. Finally and most importantly, this study provided empirical evidence not previously presented in the literature on what factors contribute to the differences in senior pre-service middle school science teachers' feedback thinking, homological reasoning, and feedback recognition skills in domain-specific and domain-general scenarios. Thus, this study attempted to fill the gap in the literature by providing original evidence from multiple perspectives.

1.3. Research Questions

The main research question addressed in this study is as follows: What is the level of feedback thinking of senior pre-service middle school science teachers in domain-specific and domain-general scenarios? In further answering this research question, this thesis focuses on the following research questions:

(i) What is the feedback thinking level of senior pre-service middle school science teachers in domain-specific scenarios?

What is the feedback thinking level of senior pre-service middle school science teachers in balancing feedback loops in domain-specific scenarios?

What is the feedback thinking level of senior pre-service middle school science teachers in reinforcing feedback loops in domain-specific scenarios?

(ii) What is the feedback thinking level of senior pre-service middle school science teachers in domain-general scenarios?

What is the feedback thinking level of senior pre-service middle school science teachers in balancing feedback loops in domain-general scenarios?

What is the feedback thinking level of senior pre-service middle school science teachers in reinforcing feedback loops in domain-general scenarios?

(iii) What is the homological reasoning level of senior pre-service middle school science teachers in domain-specific scenarios?

What is the homological reasoning level of senior pre-service middle school science teachers in balancing feedback loops in domain-specific scenarios?

What is the homological reasoning level of senior pre-service middle school science teachers in reinforcing feedback loops in domain-specific scenarios?

(iv) What is the homological reasoning level of senior pre-service middle school science teachers in domain-general scenarios?

What is the homological reasoning level of senior pre-service middle school science teachers in balancing feedback loops in domain-general scenarios?

What is the homological reasoning level of senior pre-service middle school science teachers in reinforcing feedback loops in domain-general scenarios?

(v) What is the feedback recognition level of senior pre-service middle school science teachers in balancing and reinforcing feedback loops?

What is the feedback recognition level of senior pre-service middle school science teachers in balancing feedback loops?

What is the feedback recognition level of senior pre-service middle school science teachers in reinforcing feedback loops?

What is the feedback recognition level of pre-service middle school science teachers in the differences between balancing and reinforcing feedback loops?

2. LITERATURE REVIEW

In this section, firstly, systems thinking and the concepts associated with systems thinking are explained to provide a general perspective on systems thinking. Secondly, the importance of systems thinking in education and domain-general and domain-specific studies on systems thinking are presented. Finally, the data collection tools used to assess systems thinking skills are presented and critiqued.

2.1. Systems Thinking

As Meadows (1991) mentioned, if we are going to solve serious problems in the world we live in and if we are going to restructure existing systems, everyone, the whole society, needs to think differently. In this sense, Stave and Hopper (2007) stated that systems thinking is necessary for the whole society to think differently. However, a clear definition of systems thinking has not been defined since it was first mentioned by Richmond (1993), and it has been defined and redefined in many different ways (Arnold and Wade, 2015). While there is no consensus on the operational definition of systems thinking, there is consensus on its importance (Dugan *et al.*, 2021).

Systems thinking is a framework for identifying patterns in a system rather than focusing on entities, their interrelationships rather than static manifestations, and it is a principle that extends to a wide range of fields, from the physical and social sciences to engineering and management (Senge, 1990). Unlike Senge (1990), Forrester (1994) avoided giving a clear definition of systems thinking and offered an explanation of what systems thinking is not (Arnold and Wade, 2015). Forrester (1994) noted that some individuals use systems thinking as an alternative to systems dynamics, and that systems thinking is more than just recognizing that systems are important and thinking and talking about them. Although there are many definitions of systems thinking in the literature, it is generally emphasized that complex systems consist of interconnected and interdependent elements and that it is difficult to define and analyze a system holis-

tically. It is also emphasized that interconnectedness, synthesis, emergence, feedback loops, feedback recognition, causality, and time delays are commonly used to describe the characteristics of systems thinking (Liu, 2022).

Systems dynamics and dynamic thinking are terms associated with systems thinking. First, systems thinking is different from systems dynamics (Richmond, 1994). Systems thinking is defined as an approach that focuses on the relationship between the parts that make up the system, while systems dynamics is defined as the creation of computer models of complex problems involving causal relationships, dynamic complexity, and time delays, and the study of the behavior of these models over time (Caulfield and Maj, 2001). Second, dynamic thinking is one of the systems thinking skills (Dorani *et al.*, 2015) and contrasts with static thinking (Richmond, 2000). Dynamic thinking can be defined as putting the pattern of behavior of a complex problem over time into a time-scale context (Maani and Maharaj, 2004). In other words, dynamic thinking allows mental models of a complex problem to expand over time, from the cause of its occurrence in the past to the future indirect effects of that problem (Dorani *et al.*, 2015).

2.2. Systems Thinking in Education

As systems become more complex in our time (Wade and Heydari, 2014), interest in systems thinking is growing (Mahaffy *et al.*, 2018), and its need and importance in education are increasingly emphasized (Lee *et al.*, 2019). Yet, despite the fact that the world is becoming more complex, schools insist on breaking subjects into pieces and do not allow students to see the connections between subjects and patterns of behavior (Sweeney and Sterman, 2007). There is a consensus that systems thinking is an effective approach for students to develop an understanding of and solutions to complex systems (Maani and Maharaj, 2004; Sweeney and Sterman, 2007).

We encounter many examples of complex systems in everyday life, such as social and natural systems dynamics. Complex systems in our environment, such as eco-

logical systems, lunar phase formation, energy transmission (Evagorou *et al.*, 2009), are also included in science education curricula. Therefore, science education should promote systems thinking skills to help students understand the dynamics and functions of complex systems (Evagorou *et al.*, 2009). However, science curricula typically present fragmented conceptual structures and assume that students can construct a holistic mental schema from these structures (Mahaffy *et al.*, 2018). Therefore, one of the main expectations in science education is that students should be able to make connections between parts of systems and understand the interrelationships and effects of the systems (Evagorou *et al.*, 2009). To realize this expectation, the importance of systems thinking, a transdisciplinary perspective for solving complex problems, should be emphasized (Karaarslan-Semiz and Teksoz, 2020).

In Ben-Zvi Assaraf and Orion's (2005) study of secondary school students' systems thinking skills in the context of Earth System Education, pre-test results show that many students struggle with all aspects of systems thinking, even the most fundamental aspects. Unfortunately, it has been shown that students started 8th grade with incomplete or incorrect perceptions of the water cycle, which is an essential science topic (Ben-Zvi Assaraf and Orion, 2005). Grotzer and Solis (2015) also conducted a study with 2nd, 4th and 6th grade students and found that students reasoned superficially. In the current study by Mambrey *et al.* (2020) in the context of ecology, a further study with 5th and 6th graders showed that students had difficulty in identifying direct cause-effect relationships and their indirect effects. The results of this study are consistent with Sweeney and Sterman's (2007) findings that both middle school students and teachers fail to understand the indirect effects of complex systems. However, Mambrey *et al.* (2020) found that once students understood the indirect relationships in a moderately complex system, they had little difficulty understanding other systems of increasing complexity, thus improving their systems thinking skills. These findings support Evagorou *et al.*'s (2009) argument that young students can develop systems thinking skills. Therefore, it is possible to train the systems thinkers of the future by teaching systems thinking in formal educational settings (Elsawah *et al.*, 2022; Richmond, 1991).

From a pedagogical perspective, using systems thinking in science education should be encouraged because it provides students with a holistic view of systems and problems compared to traditional teaching methods. Consistent with the educational goals of the 21st century, highly competent pre-service teachers are needed to educate well-equipped students (Kriswandani *et al.*, 2022) because teachers at all academic levels can engage students in tasks that require higher-order systems thinking skills and enable them to master difficult-to-learn skills (Zohar and Dori, 2003). However, a review of the literature indicates that middle and high school students are the most common participants in systems thinking studies in science education, and teachers are the most limited participants (Budak and Ceyhan, 2024). Therefore, more information is needed about how teachers think and reason about complex systems in science contexts (Lee *et al.*, 2019).

A review of the science education literature indicates that very little is documented about systems thinking in the field of science education (Verhoeff *et al.*, 2008). In the area of science education, research has been conducted in the areas of systems thinking in biology (Boersma *et al.*, 2011; Gilissen *et al.*, 2020; Mahler *et al.*, 2017; Puig and Uskola, 2021; Riess and Mischo, 2010), environmental education (Ghalichi *et al.*, 2021; Strapasson *et al.*, 2022; Zidny and Eilks, 2022), physics (Gero and Zach, 2014), chemistry (Delaney *et al.*, 2021; Eaton *et al.*, 2019; Hayes *et al.*, 2020; Hrin *et al.*, 2016; Schultz *et al.*, 2021), earth science (Ben-Zvi Assaraf and Orion, 2005; Lee *et al.*, 2019; Sajjadi *et al.*, 2022), climate change education (Shepardson *et al.*, 2014; Soltis *et al.*, 2019), engineering education (Lavi and Dori, 2019). Budak and Ceyhan (2024) noted that domain-specific studies in science education are limited to subjects such as ecosystems and cell biology and recommended investigating systems thinking in different subjects in science education to improve our understanding and to be supported by empirical evidence in the literature. Therefore, conducting research in the area of systems thinking in science education can contribute to the educational literature and enhance our collective knowledge.

When the systems thinking studies were analyzed, the content of the studies focused on either domain-specific or domain-general. In one of the domain-specific studies, Karaarslan-Semiz and Teksoz (2020) investigated the systems thinking skills of pre-service science teachers through the outdoor education for sustainable development course and noted that most participants improved their systems thinking skills. Similarly, in another domain-specific study, which examined in-service and pre-service teachers' knowledge of the water cycle as a familiar complex systems and their knowledge of systems thinking, it was found that participants had difficulties in identifying components, processes and understanding relationships, and considering human impacts on the water cycle when applying systems thinking in their classrooms (Lee *et al.*, 2019). Similar to the domain-specific studies, in one of the domain-general studies, an assessment of MIT business students' understanding of systems concepts showed that although the participants had strong mathematical and scientific backgrounds, they were weak in understanding topics such as stocks and flows, time delays, and feedback recognition (Sweeney and Sterman, 2000). In another domain-specific study, research conducted to investigate the systems thinking competencies of undergraduate students on climate change in an interdisciplinary course found that while statistically significant changes were found in the climate change competencies of the participants, they had great difficulty in defining goal setting and implementation challenges within the scope of systems thinking competencies (Liu, 2022).

An analysis of the domain-specific and domain-general studies in the literature shows that there is a lack of empirical studies examining the systems thinking skills of pre-service science teachers (e.g., Karaarslan-Semiz and Teksoz, 2020). However, science teachers need to develop their systems thinking skills to educate students who are systems thinkers (Karaarslan-Semiz and Teksoz, 2020). The recent systematic literature review conducted by Budak and Ceyhan (2024) supports the statement of Bielik *et al.* (2023) that there are very few studies with pre-service and in-service teachers. Therefore, examining the systems thinking skills of pre-service teachers in this study can make a valuable contribution to the educational literature.

Understanding complex systems requires understanding the structures and their interrelationships, but an important question is how much this understanding differs between novices and experts (Hmelo-Silver and Pfeffer, 2004). Jacobson's (2001) study revealed that experts use multiple causations while novices tend to use simple causation, and that this is an expected result because experts have more domain-specific knowledge about the subject they are familiar with. Sweeney and Sterman (2000) also argued that individuals may perform well on systems problem tasks in contexts with which they are familiar, i.e., contexts in which they are experts, but perform poorly in contexts with which they are unfamiliar, i.e., contexts in which they are not experts. Hmelo-Silver and Pfeffer's (2004) study of water systems representations also showed that novices' representations include static components of the system, while experts' representations include functional components of the systems that are difficult to represent.

In line with Sweeney and Sterman's (2007) argument, Hmelo-Silver *et al.*'s (2007) study of expert and novice understanding of the human respiratory systems and the aquarium ecosystem, which found little difference between the expert and novice groups in terms of systems structure, is inconsistent with the results of Jacobson's (2001) and Hmelo-Silver and Pfeffer's (2004) studies. In a more recent study, Lavi and Dori (2019) assessed the systems thinking skills of science and engineering teachers and reported that the groups of participants were more familiar with the modeling task they chose from their science or engineering teaching area than with the modeling task about a general scientific phenomenon. Similarly, Luo *et al.* (2021) conducted a study to better understand the systems thinking of professional engineers and engineering students and found that the systems thinking of professional engineers and senior engineers was similar, but first year students differed significantly from their peers due to their limited knowledge and lack of experience. In light of these studies, it is believed that this study contributes more empirical evidence to the current literature by examining the level of feedback thinking, one of the systems thinking skills of senior pre-service middle school science teachers.

An individual's ability to recognize feedback loops requires additional systems skills (Arnold and Wade, 2017). The ability to recognize feedback loops is important not only to identify balancing and reinforcing feedback loops in systems, but also to recognize the dynamic structure in the system (Arnold and Wade, 2017), because all dynamic systems arise from the interaction of these loops (Sterman, 2000). Sweeney and Sterman (2007) found that middle school students and their teachers had difficulty distinguishing and explaining balancing and reinforcing feedback loops. In another study, Hogan (2000) reported that students' ability to identify feedback loops was limited in a study of 11-year-old students on food web disruptions and the effects of pollutants in ecosystems. The reason that individuals have difficulty recognizing feedback loops in systems may be that they are prone to simple causal explanations (Ben-Zvi Assaraf and Orion, 2005; Jacobson, 2001).

As Senge (1990) points out, if balancing and reinforcing feedback loops and delays are like nouns and verbs in a sentence, then repetitive patterns of behavior in systems are like simple stories. With more recognition of similar behavior patterns, it becomes easier to explain behavior patterns in different domains. When students can see parallel dynamic structures between disciplines, the transfer and retention of learned knowledge is enhanced, and a more coherent and logical framework is provided across the curriculum (Sweeney, 2005). Homological reasoning, also known as system archetypes, is the ability to see recurring patterns of behavior in many different domains, and these recurring patterns of behavior can be found in balancing and reinforcing feedback loops (Kim, 1992). This study uses the term homologous reasoning, as used by Sweeney (2005), and Sweeney and Sterman (2007), because it is thought to encompass causal patterns related to uncovering underlying structures and also cognitive science. To illustrate homological reasoning Forrester (1992) gave the example of a secondary school student growing bacteria in a culture dish and studying the limited growth pattern. The fact that this student associated this growth model with the world population problem and recognized the structural similarities in systems in different fields showed that the student applied the knowledge learned in different fields. For this reason, it is argued that students have the potential to transfer their insights to

different domains, as similar structural patterns in systems can be repeated in systems in different domains (Forrester, 1992).

Hallett and Hobbs (2020) stated that repeatedly observed patterns of behavior help to better identify the links between actions and outcomes in environmental problems in environmental systems, and to relate these problems to feedback processes. Furthermore, Moallemi *et al.* (2022) argue that in an effort to fully understand the Sustainable Development Goals (SDGs), it is important to understand the complex interactions between the different SDGs in order to see the causal factors and recurrent structures underlying these goals. However, the results of the study by Gilissen *et al.* (2020) emphasized that upper secondary biology students find it difficult to transfer the seven systems characteristics, including feedback, to different contexts, and therefore, students need to practice reasoning in a variety of biological contexts. Similarly, the results of Sweeney and Sterman's (2007) research with middle school students and their teachers showed that both groups of participants were weak in recognizing the underlying feedback structure in a system and applying it to other similar situations in different domains through homological reasoning. Therefore, this study also measured the level of homological reasoning of senior pre-service middle school science teachers, because homological reasoning is important for them to be able to see homologous structures in complex systems within and across domains and to show them to their students.

2.3. Assessing Systems Thinking Skills

As systems dynamics and systems thinking education have attracted attention in recent years, research in this area has been emphasized, and questions about evaluating the effectiveness of systems thinking education have been at the forefront of the agenda. There is a need for an instrument to measure the level of systems thinking skills in individuals (Dorani *et al.*, 2015). However, creating relevant tasks that represent real-life tasks is a challenge in decision studies (Davis *et al.*, 2020). The literature suggests that several methods can be used to assess systems thinking skills (Liu, 2022). Peng *et*

al. (1997) criticize that self-report instruments are widely used but fall short in their ability to predict participant understanding and behavior. Therefore, scenario-based assessment tools are reported to be effective and efficient methods for assessing various systems thinking skills (Grohs *et al.*, 2018; Mazzurco and Daniel, 2020).

Scenario-based assessment tools allow participants to use real-life scenarios, make connections between personal experiences and the scenario, and evaluate potential behaviors in hypothetical real-life situations (Erdogan and Tuncer, 2009; Mazzurco and Daniel, 2020). In this study, the researcher conducted a systematic literature review to identify research on systems thinking using scenarios and to select the data collection tool. Table 1 presents empirical studies that used scenarios in systems thinking research, along with their study focus and participant groups.

In this study, a literature review was conducted to identify empirical research on systems thinking using scenarios identified from thirteen studies. As can be seen in Table 1, studies using scenarios in systems thinking research have been conducted with different participants. When analyzing the studies in which the participants were selected within a course, Table 1 shows that the participants were selected from those taking the systems dynamics course (Pala and Vennix, 2005; Sterman and Sweeney, 2002; Sweeney and Sterman, 2000), those taking the compulsory statistics course (Kainz and Ossimitz, 2002), those taking the sustainability course (Remington-Doucette *et al.*, 2013) and those taking the climate change course (Liu, 2022). Furthermore, in empirical studies of systems thinking using scenarios, participants are selected from those who have been exposed to an intervention (Doganca-Kucuk and Saysel, 2018) and those who have not been exposed to an intervention or have not taken a course (Davis *et al.*, 2020; Green, 1997; Grohs *et al.*, 2018; Haque *et al.*, 2023; Norris *et al.*, 2022; Sweeney and Sterman, 2007). In general, it was found that most of the participants in the thirteen studies identified in this study were undergraduate and/or graduate students. However, it was identified that only one of the studies reviewed had secondary school students as participants (Doganca-Kucuk and Saysel, 2018), and only one study had both teachers and students as participants (Sweeney and Sterman, 2007).

Table 2.1. List of empirical studies using scenarios.

References	Study focus	Participants
Green, 1997	- predator-prey relationships - size of a fox population over time - impact of problem complexity	Undergraduate psychology students
Sweeney and Sterman, 2000	- to assess the level of understanding of the concepts of feedback, delays and stock and flow thinking of students taking the introduction to system dynamics course	Undergraduate management students
Kainz and Ossimitz, 2002	- to investigate the impact of a crash course (compulsory statistics course) introducing basic stock-flow concepts on students' stock-flow thinking skills	Undergraduate business students
Sterman and Sweeney, 2002	- to assess the intuitive understanding of the structure of the global climate and climate dynamics of those who have taken the introduction to system dynamics course	Undergraduate and graduate students representing diverse disciplines
Pala and Vennix, 2005	- to investigate the impact of an introduction to system dynamics course on students' understanding of stock-flows, time delays, and feedback structures	Undergraduate students
Sweeney and Sterman, 2007	- to investigate how students or teachers without training in system dynamics think about feedback, stocks and flows, and time delays in scenarios presented to them	Middle school students and teachers
Remington-Doucette *et al.*, 2013	- to investigate how the sustainability course develops core sustainability competencies in students	Undergraduate students representing diverse disciplines

Table 2.1 List of empirical studies using scenarios. (cont.)

References	Study focus	Participants
Doganca-Kucuk and Saysel, 2018	- to investigate the understanding of system structures and dynamic systems behavior in the context of environmental problems in systems-based environmental instruction	Seventh grade middle school students
Grohs *et al.*, 2018	- to present a framework for systems thinking competence - to introduce the community-level problem scenario (Village of Abeesee) and rubric developed based on this framework	Undergraduate and graduate students representing diverse disciplines
Davis *et al.*, 2020	- to introduce the Lake Urmia vignette, developed to assess how individuals understand complexity in socio-environmental systems	Engineering graduate students
Norris *et al.*, 2022	- to evaluate student performance and approaches in the Village of Abeesee and Lake Urmia vignette scenarios for integrating systems thinking teaching into the engineering curriculum	Undergraduate students in mechanical and civil engineering.
Liu, 2022	- to investigate the effects of a climate change course on students' systems thinking competence and content knowledge about climate change using the Chenyi County scenario	Undergraduate students representing diverse disciplines
Haque *et al.*, 2023	- to analyze the environmental problem and possible solutions using the Lake Urmia vignette, which depicts a real environmental disaster	Engineering graduate students

When the empirical studies on systems thinking using scenarios were evaluated according to their focus, it was found that most of the studies were aimed at assessing systems thinking skills (e.g., Pala and Vennix, 2005). However, as can be seen in Table 2.1, a very limited number of studies have been carried out to develop a scenario-based assessment tool for use in systems thinking studies. From the studies analyzed in Table 2.1, three studies have been carried out on scenario development as an assessment tool. While two of these studies (Davis *et al.*, 2020; Grohs *et al.*, 2018) introduced new scenarios to the literature, one (Liu, 2022) was created by adapting one of the existing scenarios. While Grohs *et al.* (2018) introduced a new community-level problem scenario and Davis *et al.* (2020) introduced a new vignette on complexity in socio-environmental systems, Liu (2022) adapted the existing scenario developed by Grohs *et al.* (2018) to a local context. As shown in Table 1, the number of instruments that use scenarios to assess teachers' systems thinking skills is very limited in the literature. For this reason, as a result of this literature review, Sweeney and Sterman's (2007) S-BI protocol was selected as the data collection tool as the participants of this study were teachers and the aim of this study was the feedback thinking of teachers who had not received any training in systems thinking.

3. METHODOLOGY

This section presents the research design, participants, data collection instrument, procedure, data analysis, and ethical considerations.

3.1. Research Design

This study used a mixed methods research design to determine the feedback thinking levels of senior pre-service middle school science teachers through domain-specific and domain-general scenarios. A mixed methods research design allows for a better understanding of the research question by using the rigor of quantitative and qualitative methods and combining their strengths in a single study, rather than using only one method in research (Gay *et al.*, 2012). The reason for choosing a mixed methods research design for this study is to analyze the findings from different perspectives, using the advantages of both qualitative and quantitative research methods (Creswell and Creswell, 2018). Malina *et al.* (2011) stated that mixed methods research design provides insights beyond exploring complex relationships in the social world and that its use provides the best chance of answering research questions in detail.

Specifically, this study used an embedded mixed method research design. Embedded research design embeds a secondary qualitative or quantitative research design within the primary qualitative or quantitative research design (Creswell and Creswell, 2018). This research design allows the research question to be discussed in more detail by supporting the primary quantitative or qualitative data with supporting secondary data collected simultaneously (Sahin and Ozturk, 2019). Therefore, it was considered appropriate to use an embedded mixed method research design to explore the participants' level of feedback thinking in addressing the research questions of this study in depth. In this study, the interview, one of the qualitative research tools, was used as the primary data collection source, and descriptive statistics, one of the quantitative research methods, was used to support the primary data. Interviews with senior pre-

service middle school science teachers who had not previously taken a course focusing on systems thinking in this study. By choosing the semi-structured interview as a qualitative research data collection tool, it was thought that the participants' feedback thinking levels could be revealed by evaluating their reasoning processes in the domain-specific and domain-general scenarios, and explanations could be provided as to what factors contribute to the differences in feedback thinking levels between domain-specific and domain-general scenarios. Descriptive statistics were used to enrich the qualitative data from the interviews and to scale and rank the data to make the findings more meaningful.

3.2. Participants

This section describes the context of why the university was selected for the study, and then this section continues with the participant selection criteria.

In this study, senior pre-service middle school science teachers were selected from one of the leading universities in Turkey. The selected university is a top university with an undergraduate science education program that accepts students with the highest scores in Turkey and offers English as the medium of instruction. The undergraduate science education program at the university to be selected does not include a course on systems thinking in its required courses, while it does include required courses in physics, earth science, general chemistry, cellular and molecular biology, and environmental dimensions. In addition to science courses, participants are required to take courses that require pedagogical content knowledge (PCK), such as Introduction to Education, Educational Psychology, and Teaching Methods. There are two reasons for selecting participants from this university. The first reason is that the researcher has had previous contact with the selected university. The second and most important reason for selecting participants from the university that admitted the highest scoring students to the undergraduate science education program in Turkey is that the students at this university have a very strong mathematics and science background compared to students at other universities in Turkey. Sweeney and Sterman (2000) noted that if

participants selected from a pool of highly educated subjects are found to have a poor understanding of the concept(s) of systems thinking, the general public is unlikely to perform any better. Therefore, by selecting the subject pool in this study from such a highly educated university, it is desired to have an idea of the level of feedback thinking of senior pre-service middle school science teachers studying in other universities in Turkey.

In this study, participants were specifically selected from senior pre-service middle school science teachers. The age range of the targeted population was between 22-24 years old. There are three reasons for selecting senior pre-service middle school science teachers for the study. First, because the participants were senior pre-service middle school science teachers, they had already taken courses in a variety of science disciplines and had a basic understanding of natural and social systems. The second is that the data obtained from senior pre-service middle school science teachers will have the potential to be used as an evidence-based indicator for the development of the next curriculum for teacher preparation programs by providing background information on the current curriculum (Strand, 2006). The third and most important reason is that senior pre-service middle school science teachers can make an important contribution to the development of the systems thinking skills needed to deal with the complex problems facing future generations (Karaarslan-Semiz, 2021).

Cronin *et al.* (2009) indicated that adults have critical misunderstandings of complex systems, so it is important to improve the quality of education (Karaarslan-Semiz, 2021). However, it is reported that there needs to be more research investigating the systems thinking skills of pre-service teachers and undergraduate students (Karaarslan-Semiz, 2021). In line with these findings, Fanta *et al.* (2020) recommend that research on systems thinking should be conducted at the university level and that systems thinking should be included in teacher training. Therefore, it is important to assess pre-service teachers' systems thinking skills and how they think about complex systems in the context of science education (Lee *et al.*, 2019).

For these reasons, the focus of this study was specifically on the senior pre-service middle school science teachers rather than the lower-year pre-service middle school science teachers.

Each year, 40 students are accepted into the undergraduate science education program at the selected university. However, when the researcher checked the current number of senior pre-service middle school science teachers, it was found that the potential number of participants had dropped from 40 to 30. Possible reasons for this could be that some students transfer to another department within the same university or change universities during their undergraduate years. Therefore, the target sample was 30 senior pre-service middle school science teachers. Participants were selected through convenience sampling from 30 senior pre-service middle school science teachers. Convenience sampling, commonly used in developmental science, is a sampling strategy in which participants are selected based on their accessibility to the research (Bornstein *et al.*, 2013) and is commonly used to select student volunteers to participate in the study (Jager *et al.*, 2017).

Sweeney and Sterman (2007) collected data from 11 middle school teachers in their study in which they developed the S-BI protocol used in this study, and Liu (2022) collected data from 10 participants in a study measuring undergraduate students' systems thinking skills. Given the studies in the literature, 10 participants were interviewed in this study.

3.3. Data Collection Instrument

This section first presents the rationale for instrument selection, the adaptation of the Systems-Based Inquiry (S-BI) protocol procedures, the content and rationale of the system scenarios, the validity procedures, and then presents the conceptual and operational definition of key terms.

3.3.1. Rationale for Instrument Selection

After reviewing the scenarios used in each study, the Systems-Based Inquiry (S-BI) protocol that was developed by Sweeney and Sterman (2007) was purposefully selected as the data collection tool for this study. The S-BI protocol is a semi-structured interview format consisting of a series of natural and social dilemma scenarios designed to elicit an understanding of systems concepts (Sweeney and Sterman, 2007). Sweeney and Sterman (2007) conducted various analyses such as classical item analysis, corrected item-total correlation, Cronbach's alpha, factor analysis, and Rasch analysis for validity studies and found that the S-BI protocol has good psychometric properties. The Cronbach's alpha of the S-BI protocol was 0.94, indicating a high degree of reliability (Sweeney and Sterman, 2007).

There were four reasons why the S-BI protocol was selected as the data collection tool. The first reason was that the questions in the S-BI protocol emphasize feedback dynamics and allow participants to evaluate the underlying dynamics of the scenarios through loop comparison (Sweeney and Sterman, 2007). The other reason was that the S-BI protocol was designed as a semi-structured interview and was thought to provide richer data by allowing the researcher to witness the participant's think-aloud process. Another reason was that the S-BI protocol developed by Sweeney and Sterman (2007) has been revised and used by other researchers in domain-specific areas. For example, Bendoly's (2014) management study, which examined the impact of group members' understanding of systems dynamics on their project performance in a project setting, used the S-BI protocol as a data collection tool by revising it to fit its context and purpose.

The final reason was that the S-BI protocol has already been successfully administered to teachers by Sweeney and Sterman (2007), and they explicitly recommend that it can be used in research in other nations to measure the systems thinking skills of adolescents and adults. For these reasons, as this study aims to determine the level of feedback thinking of senior pre-service middle school science teachers through

domain-specific and domain-general scenarios, it was considered that the use of the S-BI protocol as a data collection tool would serve the purpose of this study.

The fact that the S-BI protocol is used to reveal participants' feedback thinking levels, that it is in an interview format, and that different researchers have used it are very valid reasons for using it as a data collection tool in this study. However, the content of the scenarios in the S-BI protocol published in 2007 may not be appropriate for Generation Z, those born after 1995 (Jayatissa, 2023). The reason why these scenarios are considered inadequate is that in the 21st century, globalization and the information explosion, as well as the world-shaking impact of technology, have led to extraordinary changes in many different aspects of modern society (Mahanani, 2018; Malik, 2018). Thus, as societies change, civilizations will gradually evolve, and the next generations will face more complex problems (Mahanani, 2018). Therefore, in this study, the content of the scenarios in the S-BI protocol developed by Sweeney and Sterman (2007) was revised to be meaningful to Generation Z and to make real-world connections with the questions in the S-BI protocol. The next section details the adaptation process of the S-BI protocol.

3.3.2. Adaptation Process of the Systems-Based Inquiry (S-BI) Protocol

The original Systems-Based Inquiry (S-BI) protocol included scenarios to elicit participants' understanding of feedback dynamics, homological reasoning, loop comparisons, and policy thinking (Sweeney and Sterman, 2007). In the scenario designed to elicit participants' understanding of policy thinking, participants are presented with a one-paragraph social systems dilemma related to traffic congestion and are asked to make judgements and policy recommendations. The questions in the feedback dynamics, homological reasoning, and loop comparisons scenarios are designed to assess feedback thinking skills and homological reasoning skills, while the questions in the policy thinking scenario are designed to assess policy testing skills (Sweeney and Sterman, 2007). As this study aimed to assess the feedback thinking levels of senior pre-service middle school science teachers, it was determined that the scenario for assessing policy

testing skills did not serve the purpose of this study. Therefore, this part was removed from the revised S-BI protocol.

In this study, the revised S-BI protocol in semi-structured interview format was divided into two parts. In the interview questions, the four scenarios and questions presented in Part I were about feedback dynamics and homological reasoning, while the questions presented in Part II were about comparing loop dynamics. The following section provides a detailed description of the development process and the rationale for selecting the systems scenarios in the revised S-BI protocol used in this study.

3.3.3. Content and Rationale of Systems Scenarios in the Systems-Based Inquiry (S-BI) Protocol

The systems scenarios in the revised S-BI protocol are designed to understand how participants think about systems, and participants are asked to think aloud about the given scenarios. This study aims to determine the feedback thinking levels of senior pre-service middle school science teachers through domain-specific and domain-general scenarios. Therefore, for this study, the researcher and an expert in systems thinking wrote a total of four systems scenarios by revising the questions in Sweeney and Sterman's (2007) original S-BI protocol: two domain-specific scenarios with a balancing feedback loop and a reinforcing feedback loop, and two domain-general scenarios with a balancing feedback loop and a reinforcing feedback loop.

The domain-specific systems scenarios were selected from those related to the topics included in the middle school science curriculum of the Turkish Ministry of National Education (MoNE) (2018). The domain-general system scenarios were selected from universal topics not included in the middle school science curriculum of the MoNE (2018). The revised S-BI protocol was developed in Turkish, as Turkish is the native language of the participants, so that they could provide more detailed explanations and feel more comfortable. The full set of scenarios and semi-structured interview questions in the revised S-BI protocol are detailed in Appendix C in the English version and in

Appendix D in the Turkish version. Below is a general outline of the domain-specific and domain-general scenarios selected for this study, followed by their content (see Figure 3.1).

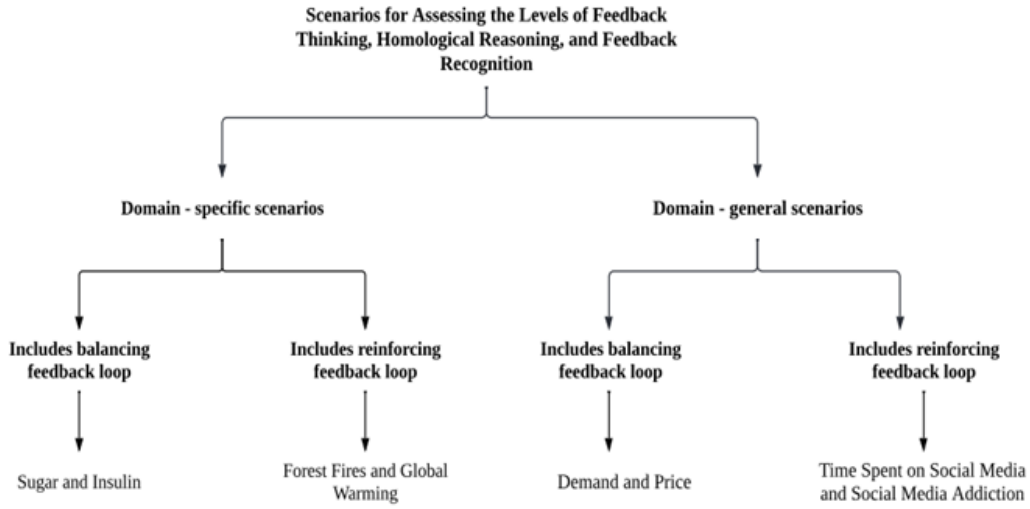


Figure 3.1. Outline of the scenarios used in this study.

3.3.3.1. Sugar and Insulin. This scenario was inspired by the Systems Thinking Association's work published in 2023. This scenario focuses on a balancing (negative) feedback loop between sugar and insulin in natural systems dynamics. The relationship between sugar and insulin is that an increase in sugar in the blood increases insulin in the blood, and insulin in the blood decreases sugar in the blood. This system scenario is classified as a domain-specific scenario, as it relates to the concept of the endocrine system in the topic of surveillance and regulatory systems of the Systems and Health in the Body topic of the 6th grade middle school science curriculum of the MoNE (2018).

3.3.3.2. Forest Fires and Global Warming. This scenario focuses on a reinforcing (positive) feedback loop between forest fires and global warming in natural systems dynamics. The relationship between forest fires and global warming is that an increase in forest fires increases global warming, and global warming increases forest fires. This

system scenario is classified as a domain-specific scenario, as it relates to the concept of environmental dynamics in material cycles and environmental issues of the Energy Conversions and Environmental Science topic of the 8th grade of the middle school science curriculum of the MoNE (2018).

3.3.3.3. Demand and Price. This scenario was inspired by Sterman's work published in 2000. This scenario focuses on a balancing (negative) feedback loop between demand and price in social systems dynamics. The relationship between the demand for a product and the price of that product is that an increase in the demand for a product increases the price of that product, and an increase in the price of that product decreases the demand for that product.

This system scenario is classified as a domain-general scenario because it is not directly related to any grade-level science topics in the middle school science curriculum of the MoNE (2018). This scenario is thought to reflect a universal theme in the context of economy, as we all live in a consumer society (Paterson, 2018), and we all need to have an individual basic level of financial literacy, which is one of the core competencies of the 21st century (Malik, 2018).

3.3.3.4. Time Spent on Social Media, Social Media Addiction. This scenario focuses on a reinforcing (positive) feedback loop between time spent on social media and social media addiction in social systems dynamics. The relationship between time spent on social media and social media addiction is that an increase in time spent on social media increases social media addiction, and social media addiction increases time spent on social media. This system scenario is classified as a domain-general scenario because it is not directly related to any grade-level science topics in the middle school science curriculum of the MoNE (2018).

This scenario is thought to reflect a universal theme in the context of social media, as today, especially young users spend excessive time on social media platforms,

creating an addictive feedback loop to the extent that social media addiction is said to be a global problem (Bhargava and Velasquez, 2021; Cheng *et al.*, 2021).

3.3.4. The Revised Systems-Based Inquiry (S-BI) Protocol

This section details the questions related to the systems scenarios in the revised S-BI interview protocol used in this study. In Part I, Feedback Dynamics of the revised S-BI protocol, participants were presented with natural and social systems scenarios involving systems dynamics to assess systems structure and behavior. In Part I, Feedback Dynamics of the revised S-BI protocol, four scenarios were presented to measure the participants' level of feedback thinking. Each scenario had six questions, and the order and focus of the questions in each scenario were identical. The first question in each scenario is designed to establish a relationship between the variables presented in the scenarios. The second, third, fourth, and fifth questions in each scenario are prompts. This allows participants to compare the level of feedback thinking before and after the prompting questions.

In their original S-BI protocol, Sweeney and Sterman (2007) asked both middle school students and their teachers to tell a story about the relationships in the scenario presented in the first question. However, in the revised S-BI protocol, since the participants were only adults, this question was changed to ask what they thought about the relationships in the scenario presented, in order to be appropriate for the maturity level of the participants. Other than this change, the structure of the remaining questions was not changed, only their content, as described in the previous section.

A preliminary question was added to only two domain-general scenarios. The following question was added to the Demand and Price scenario: "Have you ever taken an economics course? If you have taken an economics course, can you briefly describe its content?".

The addition of this question was intended to determine whether participants already knew more about the concepts of demand and price, i.e., whether they were more familiar with them. The following question was added to the Time Spent on Social Media and Social Media Addiction scenario: "Do you use social media? If you use social media, how often do you use it?" The addition of this question was intended to find out whether participants had previous experience with social media, i.e., whether they were more familiar with it.

Table 3.1 shows the specific focus of the questions in each scenario in Part I. Feedback Dynamics of the revised S-BI protocol. As can be seen in Table 2, the first five questions in each scenario aimed to elicit participants' concepts of static vs. dynamic change, causality, and feedback dynamics (reinforcing or balancing feedback loops). The sixth question in each scenario asked participants to imagine different interrelated scenarios from each scenario presented, focusing on their homological reasoning when imagining this homologous structure.

Table 3.1. Questions in part 1, feedback dynamics of the revised S-BI protocol and their focus.

Number of Questions	**Focus**
1	Describing static vs. dynamic change in a system
2 and 3	Understanding of the multiple interconnections and feedback in a system
4 and 5	Demonstrating cycles, causality, and feedback dynamics in a system
6	Demonstrating the dynamics of change, causality, multiple feedback loops, and recognizing homologous structures in a system

In Part II. Loop Comparisons of the revised S-BI protocol, participants were asked to compare the dynamics underlying the four scenarios presented. In this part, the visuals shown for each of the four scenarios and the questions posed encourage participants to think about the similarities and differences between the feedback loops. The aim was to measure their feedback recognition level. There are four questions

in Part II, Loop Comparisons. The first one was an open-ended question and the other four were prompted questions. The first question in Part II, Loop Comparisons, was an open-ended question: Which of the following visuals do you think are similar or different regarding the situations shown? Please explain (Sweeney and Sterman, 2007). The focus was, therefore, on how they explained the feedback loops. Participants were then given the opportunity to explain by asking four prompting questions and pointing to the pictures with balancing and reinforcing feedback loops relevant to each question.

So far, this subsection has presented the content of the domain-specific and domain-general systems scenarios in the revised S-BI protocol and the focus of each question in these scenarios. Consequently, using the revised S-BI protocol as a data collection tool in this research aims to answer each research question. Overall, Table 3.2 shows in detail which parts of the revised S-BI protocol, which scenarios, and which relevant questions within these scenarios were used as a data source to answer each research question.

Table 3.2. Research questions intended to be answered.

Research Questions	**Part**	**Scenario/s**	**Question number/s**
What is the feedback thinking level of senior pre-service middle school science teachers in balancing feedback loops in domain-specific scenarios?	Part I	Sugar and Insulin	1, 2, 3, 4, 5
What is the feedback thinking level of senior pre-service middle school science teachers in reinforcing feedback loops in domain-specific scenarios?	Part I	Forest Fires and Global Warming	1, 2, 3, 4, 5
What is the feedback thinking level of senior pre-service middle school science teachers in balancing feedback loops in domain-general scenarios?	Part I	Demand and Price	1, 2, 3, 4, 5

Table 3.2 Research questions intended to be answered. (cont.)

Research Questions	**Part**	**Scenario/s**	**Question number/s**
What is the feedback thinking level of senior pre-service middle school science teachers in reinforcing feedback loops in domain-general scenarios?	Part I	Time Spent on Social Media and Social Media Addiction	1, 2, 3, 4, 5
What is the homological reasoning level of senior pre-service middle school science teachers in balancing feedback loops in domain-specific scenarios?	Part I	Sugar and Insulin	6
What is the homological reasoning level of senior pre-service middle school science teachers in reinforcing feedback loops in domain-specific scenarios?	Part I	Forest Fires and Global Warming	6
What is the homological reasoning level of senior pre-service middle school science teachers in balancing feedback loops in domain-general scenarios?	Part I	Demand and Price	6
What is the homological reasoning level of senior pre-service middle school science teachers in reinforcing feedback loops in domain-general scenarios?	Part I	Time Spent on Social Media and Social Media Addiction	6
What is the feedback recognition level of senior pre-service middle school science teachers in balancing feedback loops?	Part II	All scenarios	All questions in Part II
What is the feedback recognition level of senior pre-service middle school science teachers in reinforcing feedback loops?	Part II	All scenarios	All questions in Part II
What is the feedback recognition level of pre-service middle school science teachers in the differences between balancing and reinforcing feedback loops?	Part II	All scenarios	All questions in Part II

3.3.5. Validity Procedures for the Systems-Based Inquiry (S-BI) Protocol

A face validity study was conducted by the researcher for the revised Systems-Based Inquiry (S-BI) protocol developed in collaboration between the researcher, an expert in systems thinking, and two experts in systems thinking in science education. Face validity is the degree to which the measurement tool appears to be able to measure the characteristic it claims to measure (Leedy and Ormrod, 2004). To ensure face validity, the opinions of experts in the field of the measurement tool are sought. In other words, it is the content validation of the measurement tool (Gay *et al.*, 2012). Therefore, to ensure the face validity of the revised S-BI protocol, it was sent to two university faculty members who are experts in systems thinking in science education.

One of the domain-general scenarios in the revised S-BI protocol was from the field of economics, and the other was from the field of technology. One of the experts in systems thinking in science education stated that participants would not need domain-specific knowledge to answer the questions in the two domain-general scenarios. The other experts in systems thinking in science education was unsure whether participants needed financial literacy to answer the Demand and Price scenario questions. For this reason, both experts in systems thinking in science education suggested that in order to understand in depth whether the Demand and Price scenario requires financial literacy or not, an economist's opinion should be taken for the scenario, and it should also be supported by the literature.

Since this study aimed to determine the feedback thinking levels of senior pre-service middle school science teachers through domain-specific and domain-general scenarios, it was intended that domain-specific scenarios would require domain-specific knowledge, while domain-general scenarios would not require any domain-specific knowledge in the revised S-BI protocol. For this reason, the researcher sent the Demand and Price scenario to an economist to ensure that the scenario did or did not contain domain-specific knowledge. The economist explained that the questions in the Demand

and Price scenario are the kind of questions that adults can answer at a basic level and that participants do not need to have any financial literacy to answer them. However, to make the questions in the Demand and Price scenario easier to understand, the economist suggested replacing the words demand and price in the first five questions with the words demand for a product and the price of that product (see Table 3.3).

Table 3.3. Suggestions from an economist on the demand and price scenario.

Revised S-BI Protocol Sentences	**Suggested Sentences**
What do you think about the relationship between the demand and price? Please explain.	What do you think about the relationship between the demand for a product and its price? Please explain.
How might demand and price be interrelated? Please explain.	How might the demand for a product and its price be interrelated? Please explain.
What do you think will happen to demand and price over time? Please explain.	What do you think will happen to the demand for a product and its price over time? Please explain.
If demand increases, what will happen to the price? Please explain.	If the demand for a product increases, what will happen to the price of that product? Please explain.
If the price increases, what will happen to the demand? Please explain.	If the price of a product increases, what will happen to the demand for that product? Please explain.

According to Taylor (1996), it is a fundamental concept that the price of a product can change according to temporary changes in demand. To illustrate this point, Taylor (1996) used the example of wheat and the wheat farmer. According to Taylor (1996), the wheat farmer does not need to read The Wealth of Nations to analyze whether the price of wheat can rise or fall due to weather or other temporary factors, because

wheat farmers already have the basic economic concepts to analyze changes in the price of wheat. In addition to the opinion of the economist, the literature supports the idea that the questions in the Demand and Price scenario do not require financial literacy. Then, the researcher presented the literature and the economist's opinion to two experts in systems thinking in science education. The experts concluded that revised S-BI protocol was appropriate in terms of both content and question structure and that it accurately measured the level of feedback thinking of the participants. In this way, the face validity of the revised S-BI protocol was assured.

3.4. Conceptual and Operational Definition of Key Terms

This section presents the conceptual and operational definitions of key terms.

3.4.1. Conceptual Definition of Key Terms

- System; The term 'system' refers to an assembly of elements or parts, organized and interconnected into a coherent pattern or structure which produces characteristic behavior, generally categorized as its function or intended purpose. Therefore, systems should consist of three elements: elements, interconnections, and function or purpose (Meadows, 2008).
- Systems Thinking; Systems thinking is an approach and a cognitive skill that looks holistically at the complexity of the systems from the big picture, including intended and unintended outcomes (Delaney *et al.*, 2021).
- Identifying and Understanding Feedback; Defining and understanding feedback loops involves recognizing interconnections, identifying cause-and-effect feedback loops as a result of combining interconnections, and identifying causal chains (Stave and Hopper, 2007). In addition, identifying and understanding feedback in a system requires the ability to explore and represent the positive and negative feedback thinking processes underlying models of systems behavior (Sweeney and Sterman, 2000).

- Homological Reasoning; Homological reasoning is a cognitive activity that involves identifying and practicing systems structures, such as feedback loops, by transferring them from one domain to another (Sweeney, 2004).
- Feedback Recognition; Feedback recognition is concerned with identifying and distinguishing between balancing and reinforcing feedback loops in dynamic systems and explaining the behavior of these feedback loops (Stroh, 2015).

3.4.2. Operational Definition of Key Terms

- Feedback Thinking Level; The level of feedback thinking is determined by assessing participants' responses to the first five questions in each system scenario in Part I. Feedback Dynamics of the revised S-BI protocol. According to the revised S-BI protocol scoring rubric, the level of feedback thinking ranges from Level 0: Incorrect or shows no relationship to Level 4: Fuller utilization of systems intelligence (Sweeney and Sterman, 2007).
- Homological Reasoning Level; Participants' levels of homological reasoning are determined by evaluating other situations in which they think the relationships presented in the last questions of each system scenario in Part I. Feedback Dynamics of the revised S-BI protocol could exist. According to the revised S-BI protocol scoring rubric, the level of homological reasoning ranges from Level 0: no examples to Level 4: with multiple homologies provided from the different domains as the domain in the scenarios presented (Sweeney and Sterman, 2007).
- Feedback Recognition Level; The feedback recognition level is about comparing feedback loop dynamics. It is determined by assessing participants' responses in Part II. Comparison of Loop Dynamics of the revised S-BI protocol to identify and explain the similarities and differences between the balancing feedback loops or reinforcing feedback loops underlying the systems scenarios. According to the revised S-BI protocol scoring rubric, the level of comparison of feedback loop dynamics ranges from Level 0: no explanations to Level 3: right matches with appropriate explanations.

3.5. Procedure

This section presents the procedures for the pilot study and the main study.

3.5.1. Pilot Study

It is important to conduct a pilot study to identify any uncertainties in the data collection instrument to be used in the main study so that necessary improvements can be made and to allow the researcher to practice the interview questions. In this study, the pilot study participants were students who had graduated from the science education program at the selected university, who were continuing their master's studies at the same university, and who had not taken a specific course in systems thinking. The reason for selecting students in the master's program was to avoid losing potential participants in the study sample and to have the same academic background as the study sample.

Before collecting data for the pilot study and the main study, ethical permission was obtained for data collection from the Human Research Ethics Committee of Bogazici University in the fields of Science and Engineering (E-84391427-050.01.04-156639) (see Appendix A). Therefore, the researcher informed the master's students about the study by email and also sent them an informed consent form (see Appendix B). Voluntary participants signed the consent form and declared their voluntary participation to the researcher by email.

In this study, a pilot study was conducted iteratively with three master's students. The revised Systems-Based Inquiry (S-BI) protocol in Appendix D was administered in Turkish, the students' native language. The English version of the revised S-BI protocol can also be found in Appendix C. Each participant was interviewed online via ZOOM on different days.

The participants were interviewed on different days because the researcher needed time to assess whether or not the participants' suggestions for the revised S-BI protocol were reasonable. Each interview lasted approximately 30 - 40 minutes and was videotaped for transcription. At the end of each interview, participants were asked about any unclear sentences in the interview and their suggestions for improving the implementation of the revised S-BI protocol. The researcher made changes in revised S-BI protocol by consulting with an expert in systems thinking and two experts in systems thinking in science education. The improved version of the revised S-BI protocol was then administered to the new participants, and further suggestions were received from them.

Table 3.4 shows the suggestions made by the participants regarding the questions in the revised S-BI protocol and accepted by the researcher. The first participant only suggested the Demand and Price scenario in Part I, Feedback Dynamics, in the revised S-BI protocol, which was accepted. The first participant stated that it was unclear whether the black market situation should be considered when assessing the relationship between the demand for a product and its price in the Demand and Price scenario. Therefore, the first participant stated that an addition to the question, as shown in Table 3.4, would make this scenario more understandable. In addition, when the second and third participants were asked the questions in the Price and Demand scenario, as suggested by the first participant, they stated that this scenario was very clear and understandable.

The second participant stated that for the three prompting questions in Part II, Comparison of Loop Dynamics, in the revised S-BI protocol, it is not clear how to decide whether the pictures shown are similar or different. For this reason, the second participant stated that a revision should be made for all three guiding questions, as shown in Table 3.4. These suggestions from the participant were considered reasonable and accepted by the researcher. In addition, the participant did not make any suggestions other than these three questions. A pilot study was then carried out with a third and final participant to assess whether further improvements were needed in the

revised S-BI protocol. The third participant stated that all questions in the revised S-BI protocol were clear and understandable and made no suggestions. In this way, the revised S-BI protocol was iteratively refined and improved based on participants' feedback.

Table 3.4. Participants' suggestions for revised S-BI protocol.

	Revised S-BI Protocol Sentences	**Suggested Sentences**
Suggestion from the first participant	Let's think about the relationship between the demand for a product and its price.	Let's think about the relationship between the demand for a product and its price. **However, when considering this relationship, let us assume there are enough products to satisfy demand.**
Suggestions from the second participant	Referring to the two pictures of the balancing feedback loop, participants are asked the following question: Do you think these are similar or different? Why?	Referring to the two pictures of the balancing feedback loop, participants are asked the following question: Do you think these are similar or different in terms of **the relationships** shown? Why?
	Referring to the two pictures of the reinforcing feedback loop, participants are asked the following question: Do you think these are similar or different? Why?	Referring to the two pictures of the reinforcing feedback loop, participants are asked the following question: Do you think these are similar or different in terms of **the relationships** shown? Why?

Table 3.4 Participants' suggestions for revised S-BI protocol. (cont.)

	Revised S-BI Protocol Sentences	**Suggested Sentences**
	Referring to the pictures of a reinforcing feedback loop and a balancing feedback loop, participants are asked the following question: How are these two similar or different? Why?	Referring to the pictures of a reinforcing feedback loop and a balancing feedback loop, participants are asked the following question: How are these two similar or different **in terms of the relationships shown?** Why?

3.5.2. Main Study

After the revisions to the pilot study, data collection for the main study began. As this study aims to determine the level of feedback thinking of senior pre-service middle school science teachers through domain-specific and domain-general scenarios, the researcher informed the senior pre-service middle school science teachers about the scope of the study in an email and sent the informed consent form as an attachment (see Appendix B). A small number of participants who wished to take part in the study voluntarily signed the consent form and returned it to the researcher by email. The researcher then used email as one of the follow-up strategies to increase the number of participants and sent another email to the participants. A common date and time for the interviews was agreed with the participants. The revised Systems-Based Inquiry (S-BI) protocol was administered to the participants online via ZOOM in Turkish. The interviews were also recorded for transcription. At the end of this process, a total of ten participants were interviewed in the main study.

3.6. Data Analysis

This section details the data analysis procedure, followed by the revised Systems-Based Inquiry (S-BI) protocol rubric used to score the data.

3.6.1. Data Analysis Procedure

To analyze the data, the researcher revised Sweeney and Sterman's (2007) original Systems-Based Inquiry (S-BI) protocol scoring rubric in collaboration with an expert in systems thinking. (see Appendix E). The next section provides a detailed description of the revised S-BI protocol scoring rubric.

The researcher first transcribed all interviews to analyze the data. The Excel program was used for data analysis. Participants were assigned a number, and their feedback thinking, homological reasoning, and feedback recognition levels were analyzed according to the revised S-BI protocol scoring rubric. The size of the dataset determines the percentage of data coded by the second coder, but in general, 20% of the total dataset is usually analyzed by the second coder (Syed and Nelson, 2015). However, to increase the reliability of this study, an expert in systems thinking was asked to analyze the entire data set after explaining the purpose of the study and the data analysis process.

Cohen's Kappa is a measure of the overall agreement between two raters who classify categorical variables into a particular set of categories (Kvålseth, 1989). Therefore, for the reliability of the study, the researcher compared the data analysis of an expert in systems thinking and Cohen's Kappa value was found to be 0.90. This kappa value indicates that the strength of agreement between the two raters is almost perfect (Landis and Koch, 1977).

Then, for the data that the researcher and expert in systems thinking had categorized differently, a meeting was arranged in which they explained the reasons for their

different categorizations and achieved 100% agreement through persuasion. Therefore, this agreement between the researcher and expert in systems thinking can be said to be an empirical indicator of the reliability of the study.

After the researcher and an expert in systems thinking reached full agreement, each participant's feedback thinking, homological reasoning, and feedback recognition levels were scaled and ranked to show their frequency, which is one of the descriptive statistics. Various tables and figures were then created to visualize the data. In addition, qualitative data was also used to provide a deeper understanding of these quantitative data. The participants' quotations were tabulated so that the quantitative data were supported by the qualitative data.

3.6.2. Revised Systems-Based Inquiry (S-BI) Protocol Scoring Rubric

In this study, Sweeney and Sterman's (2007) scoring rubric for the S-BI protocol was revised (see Appendix E) and used to score participants' responses to questions about measuring levels of feedback thinking, homological reasoning, and feedback recognition, in collaboration with the researcher and an expert in systems thinking. The purpose of developing the S-BI protocol scoring rubric is not to assess the accuracy of the terms used by participants to describe systems, but to assess the extent to which they appreciate the systems nature of phenomena in scenarios involving systems dynamics (Sweeney and Sterman, 2007).

The revised S-BI protocol scoring rubric consists of three scoring rubrics. The first five questions about the feedback dynamics in each scenario in Part I, Feedback Dynamics, of the revised S-BI protocol were scored as five levels of feedback thinking. The first five questions about feedback dynamics in each scenario in Part I were analyzed as a package to determine the level of feedback thinking of the respondents for each scenario. The sixth question about the homological reasoning in each scenario in Part I, Feedback Dynamics, of the revised S-BI protocol was scored as five levels of homological reasoning.

Four questions were scored as a package, one open-ended and four prompted questions to assess the underlying dynamics of the cycles in Part II. Loop comparisons of the S-BI protocol. In this part, the feedback recognition level of the participant was determined by scoring on four levels.

Table 3.5 shows the revised S-BI protocol scoring levels for feedback thinking, homological reasoning, and feedback recognition levels (Sweeney and Sterman, 2007).

Table 3.5. Overall scoring levels of the revised S-BI protocol scoring rubric.

	S-BI Protocol Scoring Levels
Feedback Thinking Levels	**Level 0**: Incorrect or shows no relationship
	Level 1: Explains simple connections and relationships
	Level 2: Describes aspects of interconnections
	Level 3: Demonstrates understanding of principles guiding system behaviors
	Level 4: Fuller utilization of systems intelligence
Homological Reasoning Levels	**Level 0**: Gives no example
	Level 1: Gives wrong homology
	Level 2: Gives a correct homology provided from the same domain as the domain in the scenarios presented
	Level 3: Gives a correct homology provided from the different domain as the domain in the scenarios presented
	Level 4: Gives multiple homologies provided from the different domain as the domain in the scenarios presented
Feedback Recognition Levels	**Level 0**: Gives no explanation
	Level 1: Gives both wrong matches and wrong explanations
	Level 2: Gives right matches but wrong or incomplete explanations
	Level 3: Gives right matches with appropriate explanations

It should be noted that minor changes were made to the original rubric. In the original rubric for scoring levels of feedback thinking, the description of Level 1 and Level 2 included the phrase describing interconnections (Sweeney and Sterman, 2007). In this study, it was considered appropriate to change only Level 1 from "describing interconnections" to "describing connections", as this change allowed Level 1 and Level 2 to be easily separated. Otherwise, no changes were made to the feedback thinking rubric. Moreover, in the original rubric, feedback recognition levels were scored on three levels (Sweeney and Sterman, 2007). However, in this study, scoring feedback recognition levels at four levels was deemed appropriate. Only Level 0 was added to this rubric, and it was considered appropriate to score participants who provided no explanation at Level 0. Moreover, since Level 0 was also included in the feedback thinking and homological reasoning levels rubrics, it was thought that the three rubrics should be compatible. Appendix E provides examples of participant responses for each score.

3.7. Ethical Considerations

At each stage of this study, great attention was paid to all ethical issues. Firstly, ethical permission for data collection was obtained from the Boğaziçi University Institutional Review Board with a document dated 6 December 2023, presented in Appendix A (E-84391427-050.01.04-156639). No risks were foreseen for the senior pre-service middle school science teachers who comprise this study's participant group. Therefore, it is assumed that any risks that may occur are minimal. To minimize any potential risks, participants were informed of the study by email and given an informed consent form. Participants were informed of the purpose of this scientific study, their rights in the study, and had the opportunity to ask the researcher any questions they had. Furthermore, participants were informed that they had the right to withdraw from the study at any time. The participants then signed the informed consent form, stating that they were volunteering to take part in this study.

In this scientific research, the name of the university and the names of the participants were not disclosed to third parties, and each participant was assigned a number and coded for data analysis. In addition, participants were informed that the recordings of the interview conducted via ZOOM would be requested for data analysis that the study data would be stored on the researcher's computer and would not be shared with anyone other than the researcher and the thesis advisor. In this way, the principle of confidentiality of participant information was maintained.

4. RESULTS

This section presents the findings in three main sections - Feedback Thinking, Homological Reasoning, and Feedback Recognition - to provide an in-depth insight into the research questions.

4.1. Feedback Thinking

In the first five questions of each system scenario in Part I, Feedback Dynamics of the S-BI protocol, participants are asked to evaluate the feedback dynamics in the scenario presented. In the first question of each system scenario, participants were asked what they thought about the relationship between the two variables presented in the scenario without any prompts. Participants were then asked second, third, fourth, and fifth prompt questions to elaborate on their answers.

One of the aims of this thesis was to analyze how participants identified and explained the feedback loops underlying each system scenario. Although one of the aims of this study was not to compare participants' levels before and after the reminder questions, these results were also presented in the Results section. One reason for this is that in a similar study conducted by Sweeney and Sterman (2007), although one of the research questions was not to compare the levels before prompt question and after prompt questions, these findings were included.

In addition, the second and most important reason is that the prompting questions guide the participants to think more deeply. For this reason, it is considered important to present these findings in order to convey the results to the reader in an accurate and reliable manner.

As a result, the participants' level of feedback thinking was assessed in the context of the first five questions in each of the systems scenarios in the Part I, Feedback Dy-

namics of the S-BI protocol. This section first presents possible mental models for the participants and quotes from the participants' explanations to illustrate each participant's understanding and reveal their mental models. It then compares participants' levels of thinking about feedback before (Question 1) and after (at the end of Question 5) the prompts. The following sections addressed each research question separately with sub-research questions.

4.1.1. RQ 1: What is The Feedback Thinking Level of Senior Pre-Service Middle School Science Teachers in Domain-Specific Scenarios?

What is the feedback thinking level of senior pre-service middle school science teachers in balancing feedback loops in domain-specific scenarios?

The Sugar and Insulin scenario is a domain-specific scenario, as it is related to the concept of the endocrine system in the middle school science curriculum of the MoNE (2018). This domain-specific scenario was designed to elicit participants' understanding of the balancing feedback loop.

Participants' feedback thinking levels for the Sugar and Insulin scenario were modeled using STELLA modeling software. Below are possible models and participant descriptions to illustrate each level of feedback thinking for the Sugar and Insulin scenario.

Participants were scored at Level 0 if they gave an incorrect answer or showed no relationship between the amount of sugar in the blood and the amount of insulin in the blood (see Figure 4.1).

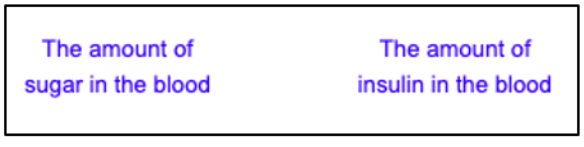


Figure 4.1. Possible model for feedback thinking Level 0 in the sugar and insulin scenario.

Participants were scored at Level 1 if they gave answers that showed an understanding of causality, connections, relationships, and linear chains of causality in a system. For example, participants were scored at Level 1 if they explained a relationship, such as an increase in the amount of sugar in the blood would increase the amount of insulin in the blood, or an increase in the amount of insulin in the blood would decrease the amount of sugar in the blood (see Figure 4.2).

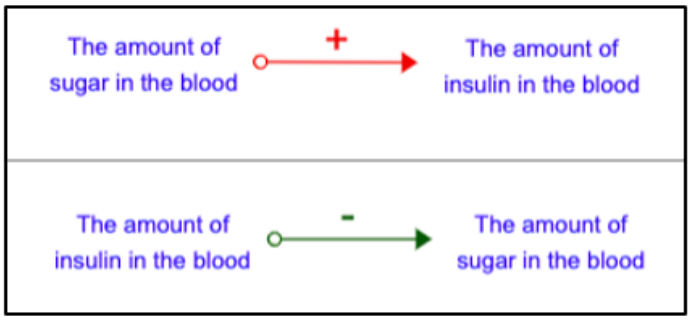


Figure 4.2. Possible models for feedback thinking Level 1 in the sugar and insulin scenario.

Participants were scored at Level 2 if they provided responses that described aspects of the relationships in a system. For example, participants were scored at Level 2 if they explained the relationship as a decrease in the amount of insulin in the blood and an increase in other factors that cause changes in blood sugar levels. Participants were also scored at Level 2 if they explained the relationship as an increase in the amount of insulin in the blood and other effects of changes in blood sugar levels (see Figure 4.3).

Participants were scored at Level 3 if they provided answers demonstrating an understanding of system feedback. For example, participants were scored at Level 3 if they provided an explanation that demonstrated an understanding of a balancing feedback loop in a system such that when the amount of sugar in the blood increases, the amount of insulin in the blood increases, and when the amount of insulin in the blood increases, the amount of sugar in the blood decreases (see Figure 4.4).

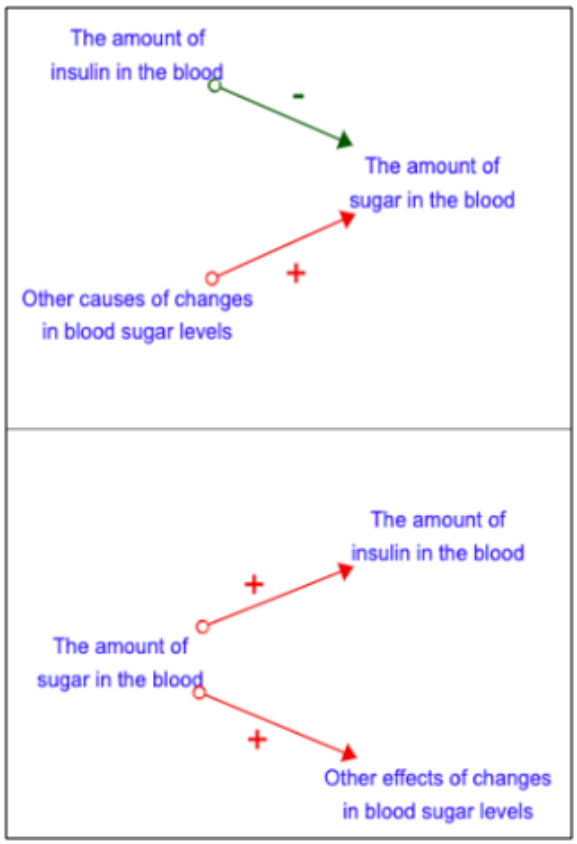


Figure 4.3. Possible models for feedback thinking Level 2 in the sugar and insulin scenario.

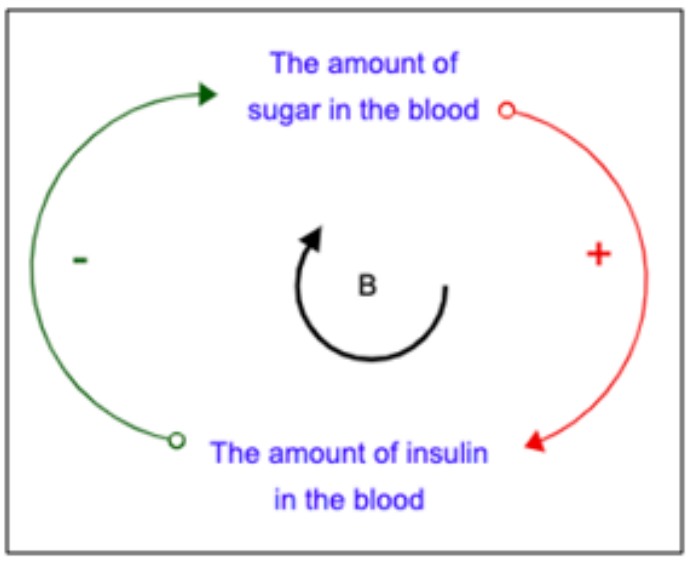


Figure 4.4. Possible model for feedback thinking Level 3 in the sugar and insulin scenario.

Participants were scored at Level 4 if they provided answers demonstrating multiple feedback loops in a system. Participants achieved a Level 4 score when they presented the balancing feedback loop such that when the amount of sugar in the blood increases, the amount of insulin in the blood increases, and when the amount of insulin in the blood increases, the amount of sugar in the blood decreases, and then presented an additional example of a balancing feedback loop. As can be seen in Figure 4.5, participants achieved a Level 4 score when they provided additional balancing feedback such that when the amount of insulin in the blood increases, the amount of glucagon in the blood decreases, and when the amount of glucagon in the blood decreases, the amount of insulin in the blood increases.

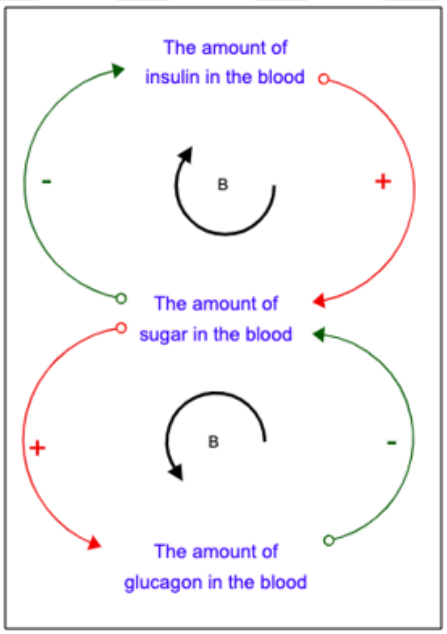


Figure 4.5. Possible model for feedback thinking Level 3 in the sugar and insulin scenario.

Figure 4.6 shows the participants' explanations for the Sugar and Insulin scenario before any prompts were given and their feedback thinking levels according to the revised S-BI protocol scoring rubric (see Appendix E). Participants' responses were scored on the following question: "What do you think about the relationship between the amount of sugar in the blood and the amount of insulin in the blood?".

The results showed that regarding feedback thinking levels, P2, P6, P7, P9, and P10 were at Level 3, P3, P4, P5, and P8 were at Level 1, and only P1 was at Level 0. No participants were identified at Level 2 and Level 4.

Table 4.1. Participants' explanations before prompts in scenario 1.

Feedback Thinking Levels	**Explanations**	**Participants**
Level 3	When the amount of sugar in the blood increases, the hormone insulin is activated and at some point the amount of sugar in the blood needs to be reduced.	P2
Level 3	As the amount of sugar in the blood increases, the amount of insulin in the blood will increase to lower it. So it will actually feed off each other cyclically.	P6
Level 3	When the amount of sugar in the blood increases, the body secretes insulin. Insulin then lowers the amount of sugar in the blood. I am a diabetic and I know a lot about this topic. I have three insulin injections a day.	P7
Level 3	When the amount of sugar in the blood increases, the hormone insulin increases to lower it. Then the amount of sugar in the blood falls and the amount of insulin in the blood falls. Up and down and up and down together.	P9
Level 3	As the amount of sugar in the blood increases, the amount of insulin in the blood should also increase, as insulin is a hormone secreted to reduce the amount of sugar in the blood. So we should see that both increase upwards. Similarly, as the hormone insulin is released, the amount of sugar in the blood decreases.	P10
Level 1	I think that when the amount of sugar in the blood increases, the amount of insulin in the blood also increases. In other words, the body increases the	P3

Table 4.1 Participants' explanations before prompts in scenario 1. (cont.)

Feedback Thinking Levels	**Explanations**	**Participants**
Level 1	amount of insulin in the blood so that it can lower the amount of sugar in the blood. I think there is a linear relationship. As the amount of sugar in the blood increases, the amount of insulin in the blood increases accordingly. There is a linear relationship.	P4
Level 1	I know that the hormone insulin reduces the amount of sugar in the blood. I also have a diabetic friend who gets insulin injections when his blood sugar rises.	P5
Level 1	I remember that the more sugar in the blood, the more insulin was secreted, so I can say that there is a relationship.	P8
Level 0	I have no idea about the relationship between the amount of sugar in the blood and the amount of insulin in the blood.	P1
Words and phrases that indicate a positive relationship are colored red, while those that indicate a negative relationship are colored blue.		

Table 4.2 shows the participants' explanations of the Sugar and Insulin scenario after the prompts were given and their feedback thinking levels according to the revised S-BI protocol scoring rubric (see Appendix E). Prompting questions were: "How might the amount of sugar in the blood and the amount of insulin in the blood be interrelated?", "What do you think will happen to the amount of sugar in the blood and the amount of insulin in the blood over time?", "If the amount of sugar in the blood increases, what will happen to the amount of insulin in the blood?" and " If the amount of insulin in the blood increases, what will happen to the amount of sugar in the blood?"

The results showed that regarding feedback thinking levels, P2, P4, P5, P6, P7, P9, and P10 were at Level 3, P3 was at Level 2, only P8 was at Level 1, and only P1 was at Level 0. No participant reached Level 4.

Table 4.2. Participants' explanations after prompts in scenario 1.

Feedback Thinking Levels	**Explanations**	**Participants**
Level 3	The insulin hormone should be activated and increase the amount of insulin in the blood so that the amount of sugar in the blood decreases. In other words, it should be balanced so that there is no health problem.	P2
Level 3	When we take sugar into our bodies, the hormone insulin starts to increase so that the amount of sugar in the blood can be kept at an optimum level. As the amount of insulin in the blood increases, the amount of sugar in the blood starts to decrease.	P4
Level 3	When someone eats something with too much sugar, the sugar in the blood rises and the body produces insulin to balance it out. In other words, as the amount of sugar in the blood increases, the amount of insulin in the blood increases, and as the amount of insulin in the blood increases, the amount of sugar in the blood decreases.	P5
Level 3	If the amount of sugar in the blood increases, the amount of insulin in the blood will also increase, but later the amount of sugar in the blood will decrease because the insulin in the blood reduces the amount of sugar in the blood. Therefore, the amount of insulin needed in the blood will also decrease.	P6
Level 3	After eating, the amount of sugar in the blood increases depending on the amount of glucose we take in. When the body then receives glucose, the hormone insulin is	P7

Table 4.2 Participants' explanations after prompts in scenario 1. (cont.)

Feedback Thinking Levels	**Explanations**	**Participants**
	released, and when the amount of sugar in the blood reaches its normal balance, insulin continues to be released a little more. So it takes a bit longer to stop.	
Level 3	On average, I expect the amount of sugar in the blood of a healthy person to remain the same over time. In other words, if the amount of sugar in the blood increases from time to time, insulin will be released into the blood to balance it out. Then the amount of sugar in the blood starts to rise again because the amount of insulin in the blood falls.	P9
Level 3	If we look at a process, the amount of sugar in the blood needs to increase first, so that the amount of insulin in the blood increases. Then, as the amount of insulin in the blood increases, the amount of sugar in the blood needs to decrease. Then the amount of insulin in the blood must fall again and a balance needs to be reached.	P10
Level 2	When the amount of sugar in the blood reaches a certain level, I think the amount of insulin in the blood will increase over time because its presence will continue to do other things. For example, it will cause glucose to be removed from the blood. The body will probably have to stop the insulin from rising to keep the sugar level from falling further. The amount of sugar in the blood changes as insulin is sent out and taken back in over time.	P3
Level 1	When the amount of sugar in the blood increases, the amount of insulin in the blood also increases.	P8
Level 0	I don't know much about this and may not be able to explain it. When the amount of sugar in the blood increases, the amount of insulin in the blood decreases. That's all I know.	P1

Figure 4.6 shows the overall level of participants' feedback thinking before and after the prompt questions in the Sugar and Insulin scenario to provide a holistic view. Prior to the prompt, most participants were at Level 3, followed by Level 1, and no participants were at Level 2 and Level 4. The results showed that while most participants were able to demonstrate an understanding of feedback in a system (Level 3) and explain simple connections and relationships (Level 1), one participant did not report any relationships (Level 0) before the prompts.

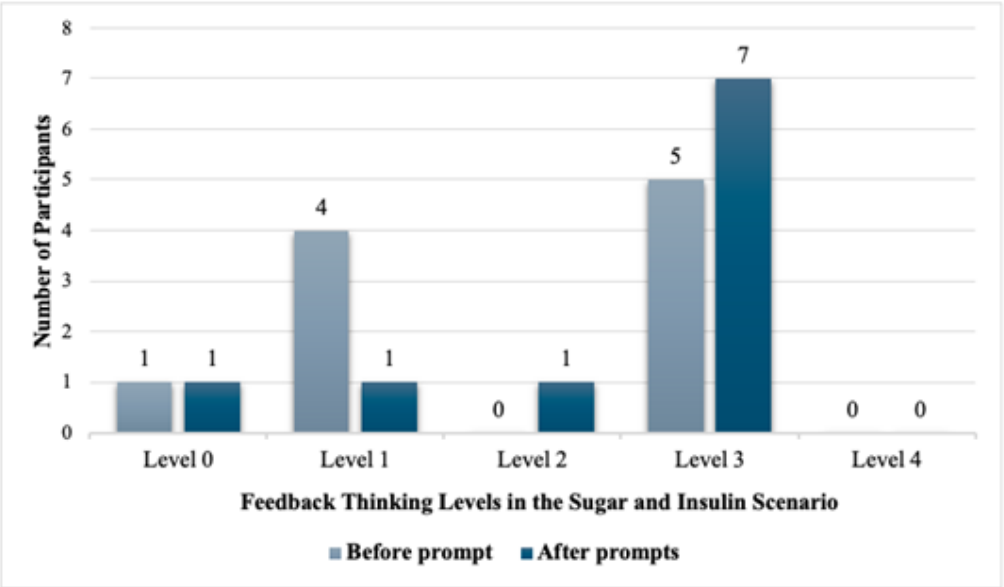


Figure 4.6. Participants' overall levels of feedback thinking before and after the prompts in the sugar and insulin scenario.

At the end of the prompt questions, while the number of Level 3 and Level 2 participants increased, the number of Level 1 participants decreased. There were also no participants who increased their level to Level 4. Interestingly, despite the prompts, the number of participants at Level 0 remained the same (see Figure 4.6). These results showed that while most participants were able to demonstrate an understanding of feedback in a system (Level 3), few participants were able to describe aspects of interconnections (Level 2), explain simple connections and relationships (Level 1), and show no relationship (Level 0) at the end of the prompts.

Table 4.3 shows each participant's level of feedback thinking before and after the prompting questions in the Sugar and Insulin scenario to provide a holistic perspective. Table 4.3 shows that participants P3, P4, and P5 increased their feedback thinking levels after the prompts, while the rest had the same feedback thinking levels before and after the prompts.

Table 4.3. Each participant's level of feedback thinking before and after prompt questions in the Sugar and Insulin scenario.

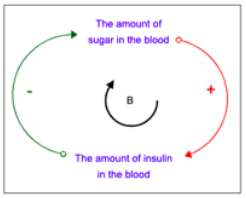
	Sugar and Insulin Scenario (Domain-specific scenario including balancing feedback loops)	
Participants	**Feedback Thinking Levels Before Prompt**	**Feedback Thinking Levels After Prompts**
P1	Level 0	Level 0
P2	Level 3	Level 3
P3	Level 1	Level 2
P4	Level 1	Level 3
P5	Level 1	Level 3
P6	Level 3	Level 3
P7	Level 3	Level 3
P8	Level 1	Level 1
P9	Level 3	Level 3
P10	Level 3	Level 3

Figure 4.7 shows the statements of the participants who showed a major change, increasing their level of feedback thinking by two levels from before to after the prompts. Two participants increased their level from Level 1 to Level 3 after the prompts, but the Figure 4.7 shows the change for only one of them.

Before the prompt questions, P4 made one-way connections between the amount of sugar in the blood and the amount of insulin in the blood, and P5 made one-way connections between the hormone insulin and the amount of sugar in the blood. In other words, they showed the static change in the system. After the prompt questions, both participants recognized the balancing feedback loop. The change in participants' level of feedback thinking for each question is shown in Appendix F.

Sugar and Insulin Scenario

(Domain-specific scenario including balancing feedback loops)

Participants	Explanations Before Prompt	Before Prompt Model	Explanations After Prompts	After Prompt Model
P5	***Level 1:*** I know that the hormone insulin reduces the amount of sugar in the blood. I also have a diabetic friend who gets insulin injections when his blood sugar rises.		***Level 3:*** When someone eats something with too much sugar, the sugar in the blood rises and the body produces insulin to balance it out. In other words, as the amount of sugar in the blood increases, the amount of insulin in the blood increases, and as the amount of insulin in the blood increases, the amount of sugar in the blood decreases.	

Words and phrases that indicate a positive relationship are colored red, while those that indicate a negative relationship are colored blue.

Figure 4.7. Participants' explanations of levels of feedback thinking before and after prompts in the sugar and insulin scenario.

What is the feedback thinking level of senior pre-service middle school science teachers in reinforcing feedback loops in domain-specific scenarios?

The Forest Fires and Global Warming scenario is a domain-specific scenario, as it is related to the concept of environmental dynamics and environmental issues in the middle school science curriculum of the MoNE (2018). This domain-specific scenario was designed to elicit participants' understanding of the reinforcing feedback loop.

Participants' possible feedback thinking levels for the Forest Fires and Global Warming scenario were modeled using STELLA modeling software. Below are possible models and participant descriptions to illustrate each level of feedback thinking for the Forest Fires and Global Warming scenario. Participants were scored at Level 0 if they gave an incorrect answer or showed no relationship between forest fires and global warming (see Figure 4.8).



Figure 4.8. Possible model for feedback thinking Level 0 in the forest fires and global warming scenario.

Responses that showed an understanding of causality, connections, relationships, and linear causal chains in a system were scored at Level 1. For example, participants were scored at Level 1 if they explained a relationship, such as how an increase in forest fires would increase global warming or an increase in global warming would increase forest fires (see Figure 4.9).

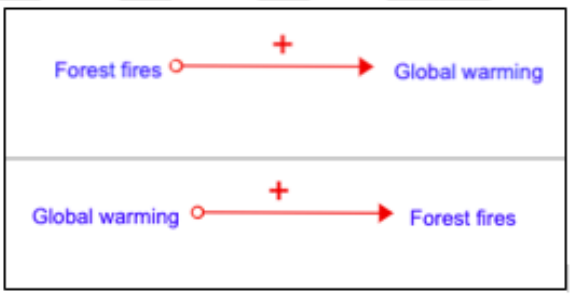


Figure 4.9. Possible models for feedback thinking Level 1 in the forest fires and global warming scenario.

Responses that described the aspects of the interconnections in a system were scored at Level 2. For example, participants were scored at Level 2 if they explained the relationship as an increase in forest fires and other factors causing global warming, such as the human factor, leading to an increase in global warming. Participants also were scored at Level 2 if they explained the relationship as an increase in forest fires and other effects of global warming, such as drought causing an increase in global warming (see Figure 4.10).

Responses that demonstrated an understanding of feedback in a system were scored at Level 3. For example, participants were scored at Level 3 if they provided an explanation that demonstrated an understanding of a reinforcing feedback loop in a

system such that when forest fires increase, global warming increases, and when global warming increases, forest fires increase (see Figure 4.11).

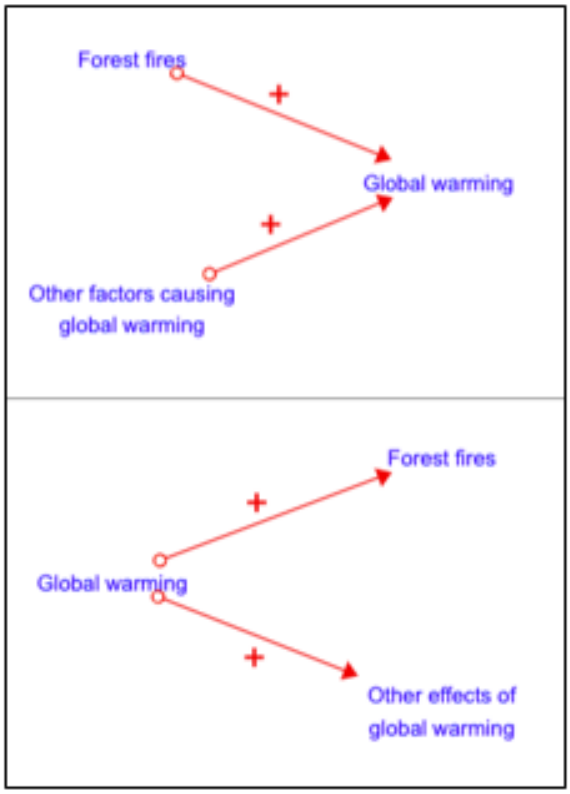


Figure 4.10. Possible models for feedback thinking Level 2 in the forest fires and global warming scenario.

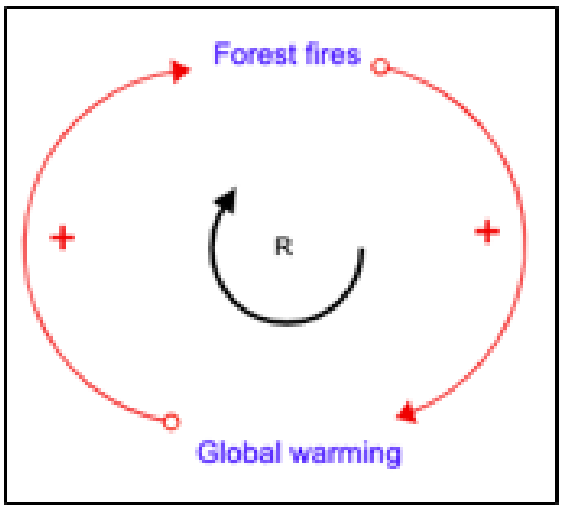


Figure 4.11. Possible model for feedback thinking Level 3 in the forest fires and global warming scenario.

Responses that demonstrated multiple feedback loops in a system were scored at Level 4. Participants achieved a Level 4 score when they presented the reinforcing feedback loop such that when forest fires increase, global warming increases, and when global warming increases, forest fires increase and then presented an additional example of a reinforcing feedback loop. Figure 4.12 shows that participants achieved a Level 4 score by providing additional reinforcing feedback. For instance, when global warming decreases, the albedo effect also decreases, which in turn leads to a decrease in global warming.

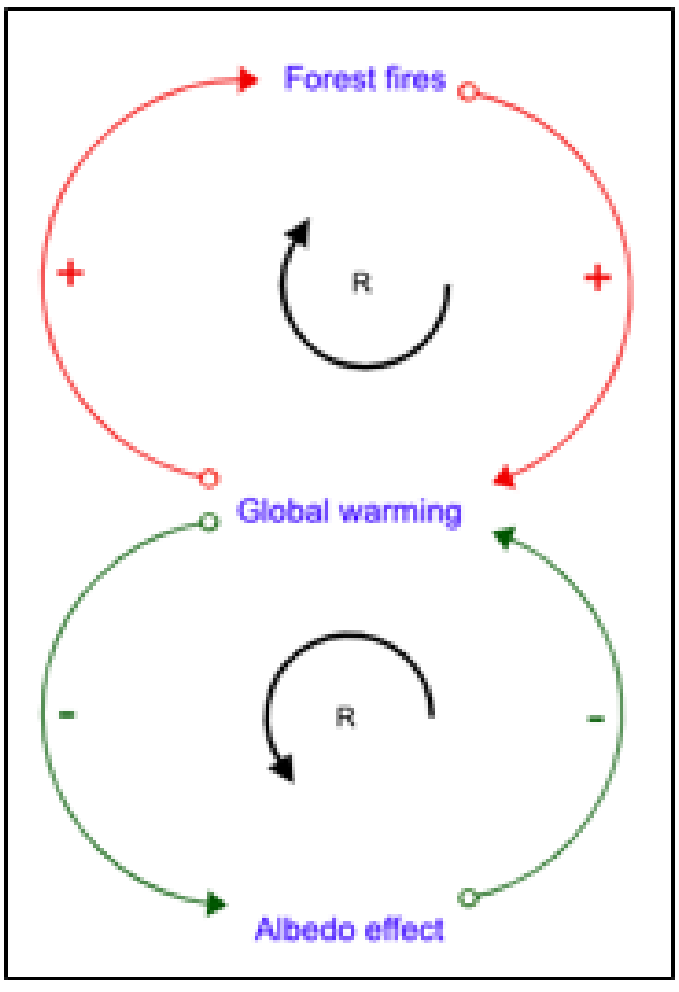


Figure 4.12. Possible model for feedback thinking Level 4 in the forest fires and global warming scenario.

Table 4.3 shows the participants' explanations for the Forest Fires and Global Warming scenario before any prompts were given and their feedback thinking levels according to the revised S-BI protocol scoring rubric (see Appendix E). Participants' responses were scored on the following question: "What do you think about the relationship between forest fires and global warming?"

The results showed that in terms of feedback thinking levels, P4 and P10 were at Level 3, P1 and P5 were at Level 1, and P7, P8, and P9 were at Level 0. No participants were identified at Level 4.

Table 4.4. Participants' explanations before prompts in scenario 2.

Feedback Thinking Levels	**Explanations**	**Participants**
Level 3	Global warming is actually the earth's inability to cool down, and global warming increases the frequency and severity of forest fires. As forest fires increase, it actually becomes a cycle that feeds on each other because forest fires release a lot of gases and the world gets warmer again. This supports global warming, and they enter into such a cycle.	P4
Level 3	As global warming increases, forest fires will increase because global warming triggers forest fires as air temperature increases. At the same time, forest loss will increase as forest fires increase. Therefore, an increase in forest fires will mean an increase in global warming. The two will feed each other.	P6

Table 4.4 Participants' explanations before prompts in scenario 2. (cont.)

Feedback Thinking Levels	**Explanations**	**Participants**
Level 3	As forest fires increase, so does the amount of carbon dioxide released. As the amount of carbon dioxide emitted increases, so does global warming, which causes the environment to heat up more. As the environment gets warmer, the likelihood of forest fires increases. It actually goes into a cycle like that. Again forest fires increase, again global warming increases.	P10
Level 2	Since forests are a source of oxygen, burning them not only reduces our oxygen supply, but also releases other harmful gases into the air. For this reason, of course, it has an increasing effect on global warming. In other words, the harmful situations that can occur with the release of more carbon dioxide and other harmful gases into the atmosphere will increase global warming. So it has a negative effect.	P2
Level 2	As forest fires increase, the amount of oxygen decreases. On the other hand, global warming is also caused by excessive accumulation of carbon dioxide. There are other reasons that cause forest fires. I think it's in a cycle, like they affect each other.	P3
Level 1	As the amount of carbon dioxide from forest fires increases, global warming increases even more. This is what I know.	P1

Table 4.4 Participants' explanations before prompts in scenario 2. (cont.)

Feedback Thinking Levels	**Explanations**	**Participants**
Level 1	Increased forest fires will also increase global warming. I likened it to the relationship between the amount of sugar in the blood and the amount of insulin in the blood.	P5
Level 0	Deforestation means that trees are unable to photosynthesize, which increases the amount of carbon dioxide. In other words, the loss of forests keeps more of that carbon dioxide in the atmosphere.	P7
Level 0	Forest fires release various gases that can damage the ozone layer or otherwise cause things like acid rain.	P8
Level 0	The world is getting warmer and warmer. It's happening all the time, and we're accelerating it. As the interior of the earth heats up, the burning of dry grasses also increases, but it is not something that happens in forests. In Africa, for example, dry grasses or small bushes will burn and that area will start to burn. But would a forest in Turkey, for example, burn because of global warming? No, no.	P9

Table 4.5 explanations for the Forest Fires and Global Warming scenario after the prompts were given and their feedback thinking levels according to the revised S-BI protocol scoring rubric (see Appendix E). Prompting questions were: "How might forest fires and global warming be interrelated?", "What do you think will happen to forest fires and global warming over time?", "If the number of forest fires increases,

what will happen to global warming?", "If global warming increases, what will happen to the number of forest fires?".

The results showed that in terms of feedback thinking levels, P2, P3, P4, P5, P6, P7, and P10 were at Level 3, P2 and P9 were at Level 2, and only P1 was at Level 1. No participants were identified at Level 0 and Level 4.

Table 4.5. Participants' explanations after prompts in scenario 2.

Feedback Thinking Levels	**Explanations**	**Participants**
Level 3	As global warming increases, forest fires increase, I think it triggers them. So as global warming increases, forest fires increase. Looking at the rise in global warming, there's a connection.	P2
Level 3	I think forest fires will increase because there is already global warming. Global warming will probably increase more forest fires, and increasing more forest fires will increase more global warming. So, I think they will feed each other to increase over time.	P3
Level 3	I think that as global warming increases, forest fires will increase. I think that if forest fires increase, they will again contribute to global warming and increase global warming.	P4
Level 3	I think global warming triggers forest fires. So I think forest fires will increase again. So there could be a cycle.	P5
Level 3	Over time, as forest fires increase, global warming will also increase to some extent. As forest fires release harmful gases, their combustion	P6

Table 4.5 Participants' explanations after prompts in scenario 2. (cont.)

Feedback Thinking Levels	**Explanations**	**Participants**
	will accelerate, further increasing global warming.	
Level 3	As global warming increases, I think forest fires will increase again because the temperature is increasing. We see more forest fires in the summer. When it is hotter, it somehow causes the forests to burn.	P7
Level 3	In fact, we observe this situation every summer. Every summer it gets hotter and hotter because of global warming. The hotter it gets, the more likely it is to start forest fires, so more forest fires start, and the hotter it gets, the more global warming increases. This cycle will actually accelerate as it ends. I think in the future it will happen more rapidly in shorter periods of time.	P10
Level 2	As global warming increases, there will be more desertification and depletion of water resources. There is already deforestation. More soil will dry up and trees will stop growing because there will be drought. In other words, forest fires may cause more of the remaining forests to burn because there will be more heat and it will affect them in some way. This heat will make the plants and forests less productive.	P8

Table 4.5 Participants' explanations after prompts in scenario 2. (cont.)

Feedback Thinking Levels	**Explanations**	**Participants**
Level 2	We throw shards of glass and it heats up, sparks and a fire starts. You know, the more trees there are, the more shade there is and the less chance of forest fires. If there are trees, there is no desertification and global warming is slower. If there are more forest fires, global warming will be faster, but if the forest is not burning, global warming will be slower.	P9
Level 1	If forest fires increase, global warming increases. If global warming increases, there will be no change in forest fires. Forest fires may increase because of something left in the forest, because of the heat, because of the sun, but I don't think there will be forest fires because of global warming.	P1

Figure 4.13 shows the overall level of participants' feedback thinking before and after the prompt questions in the Forest Fires and Global Warming scenario to provide a holistic view. Before the prompt, most participants were at Level 0 and Level 3, with the same number of participants at both levels. The levels with the second most participants were Level 1 and Level 2, and the number of these participants was the same at both levels. There were also no participants at Level 4. These results indicated that participants had different levels of understanding of a system, ranging from showing an incorrect or no relationship (Level 0) to showing an understanding of the principles that guide the system's behavior (Level 3) before the prompts.

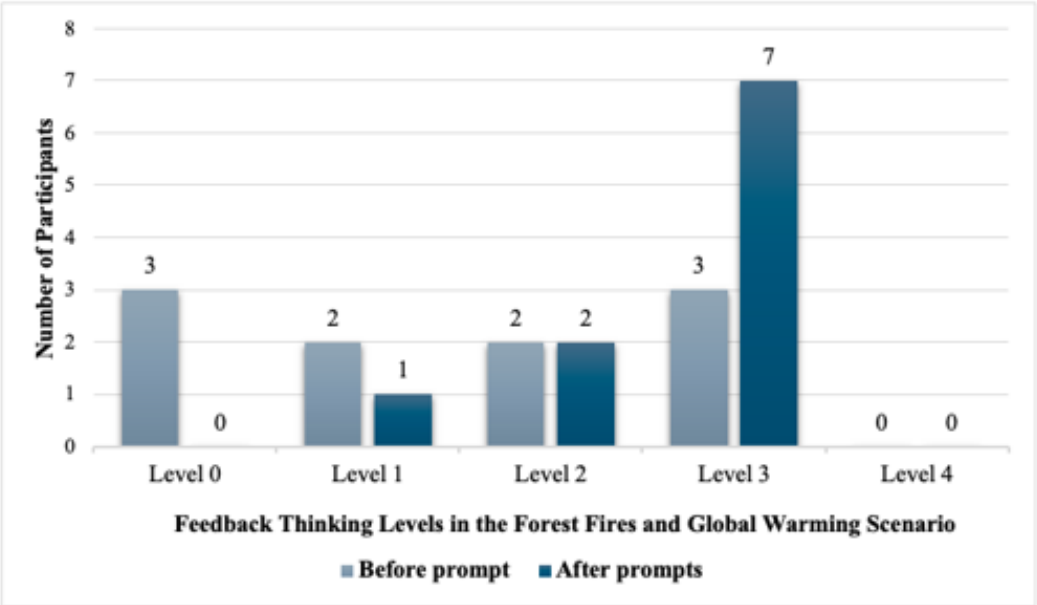


Figure 4.13. Participants' levels of feedback thinking before and after the prompts in the forest fires and global warming scenario.

At the end of the prompt questions, the number of participants in Level 3 increased significantly, while the number of participants in Level 1 decreased. The number of participants in Level 2 remained the same and there were no participants in Level 0 and Level 4 (see Figure 4.13).

These results showed that while the majority of the participants were able to demonstrate an understanding of the feedback in a system (Level 3), a few participants described aspects of interconnections (Level 2), and one participant was able to explain simple connections and relationships (Level 1) at the end of the prompts.

Table 4.6 shows each participant's feedback thinking level before and after the prompts in the Forest Fires and Global Warming scenario to provide a holistic perspective. Table 11 shows that participants P2, P3, P5, P7, P8, and P9 increased their feedback thinking levels after the prompts, while the rest had the same feedback thinking levels before and after the prompts.

Table 4.6. Each participant's level of feedback thinking before and after prompt questions in the forest fires and global warming scenario.

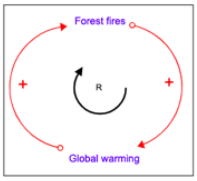
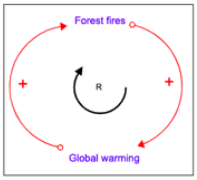
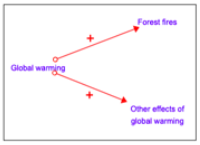
	Forest Fires and Global Warming Scenario (Domain-specific scenario including reinforcing feedback loops)	
Participants	**Feedback Thinking Levels Before Prompt**	**Feedback Thinking Levels After Prompts**
P1	Level 1	Level 1
P2	Level 2	Level 3
P3	Level 2	Level 3
P4	Level 3	Level 3
P5	Level 1	Level 3
P6	Level 3	Level 3
P7	Level 0	Level 3
P8	Level 0	Level 2
P9	Level 0	Level 2
P10	Level 3	Level 3

Figure 4.14 shows quotes from participants who showed a major change, increasing their level of feedback thinking by two levels or more after the prompts compared to before the prompts. P5, P8, and P9 moved up two levels after the prompts, while P7 moved up three levels, but Figure 4.14 shows an example of a move from the same level.

Before the prompts, P7, P8, and P9 could not make connections between forest fires and global warming, while P5 made one-way connections between forest fires and global warming. After the prompts, P8 and P9's answers showed the interconnections in the system, while P5 and P7 recognized the reinforcing feedback loop in the system scenario and were able to explain the feedback in the system. The change in participants' level of feedback thinking for each question is shown in Appendix F.

Forest Fires and Global Warming Scenario

(Domain-specific scenario including reinforcing feedback loops)

Participants	Explanations Before Prompt	Before Prompt Model	Explanations After Prompts	After Prompt Model
P5	***Level 1:*** Increased forest fires will also increase global warming. I likened it to the relationship between the amount of sugar in the blood and the amount of insulin in the blood.		***Level 3:*** I think global warming triggers forest fires. So, I think forest fires will increase again. So, there could be a cycle.	
P7	***Level 0:*** Deforestation means that trees are unable to photosynthesize, which increases the amount of carbon dioxide. In other words, the loss of forests keeps more of that carbon dioxide in the atmosphere.		***Level 3:*** As global warming increases, I think forest fires will increase again because the temperature is increasing. We see more forest fires in the summer. When it is hotter, it somehow causes the forests to burn.	
P8	***Level 0:*** Forest fires release various gases that can damage the ozone layer or otherwise cause things like acid rain.		***Level 2:*** As global warming increases, there will be more desertification and depletion of water resources. There is already deforestation. More soil will dry up and trees will stop growing because there will be drought. In other words, forest fires may cause more of the remaining forests to burn because there will be more heat and it will affect them in some way. This heat will make the plants and forests less productive.	

Words and phrases that indicate a positive relationship are color coded red, while those that indicate a cause and effect relationship are color coded orange.

Figure 4.14. Participants' explanations of levels of feedback thinking before and after prompts in the forest fires and global warming scenario.

4.1.2. RQ 2: What is the Feedback Thinking Level of Senior Pre-Service Middle School Science Teachers in Domain-General Scenarios?

What is the feedback thinking level of senior pre-service middle school science teachers in balancing feedback loops in domain-general scenarios? The Demand and Price scenario is a domain-general scenario that presents universal themes from the economic context as social systems dynamics, which are not included in the MoNE (2018) middle school science curriculum. This domain-general scenario was designed to elicit participants' understanding of the balancing feedback loop.

The possible feedback thinking levels of the participants for the Demand and Price scenario were modeled using the STELLA modeling software. Below are possible models and participant descriptions to illustrate each level of feedback thinking for the Demand and Price scenario.

Participants were scored at Level 0 if they gave an incorrect answer or showed no relationship between demand and price (see Figure 4.15).



Figure 4.15. Possible model for feedback thinking Level 0 in the demand and price scenario.

Participants were scored at Level 1 if they provided answers that showed an understanding of causality, connections, relationships, and chains of causality in a system. For instance, participants were assigned a Level 1 score if they provided an explanation of a relationship, such as how an increase in demand would lead to an increase in price, or how a decrease in price would result in a decrease in demand (see Figure 4.16).

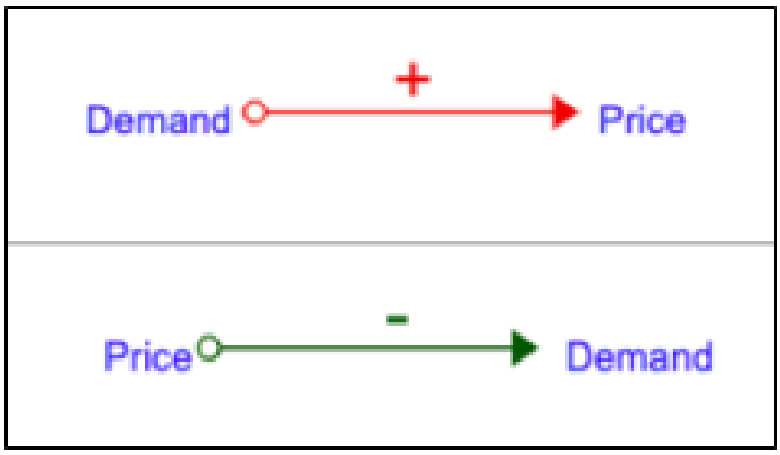


Figure 4.16. Possible models for feedback thinking Level 1 in the demand and price scenario.

Participants were scored at Level 2 if they provided answers describing aspects of a system's interconnections. For example, participants were scored Level 2 if they explained the relationship as a decrease in demand and an increase in supply, resulting in an increase in price. Participants also were scored Level 2 if they explained the relationship as an increase in price causing an increase in demand and a decrease in supply (see Figure 4.17).

In this example, participants are not expected to say the word supply directly. The word supply is used in Figure 4.17 to name the participants' explanations about the products that are put on the market with the intention of being sold in general.

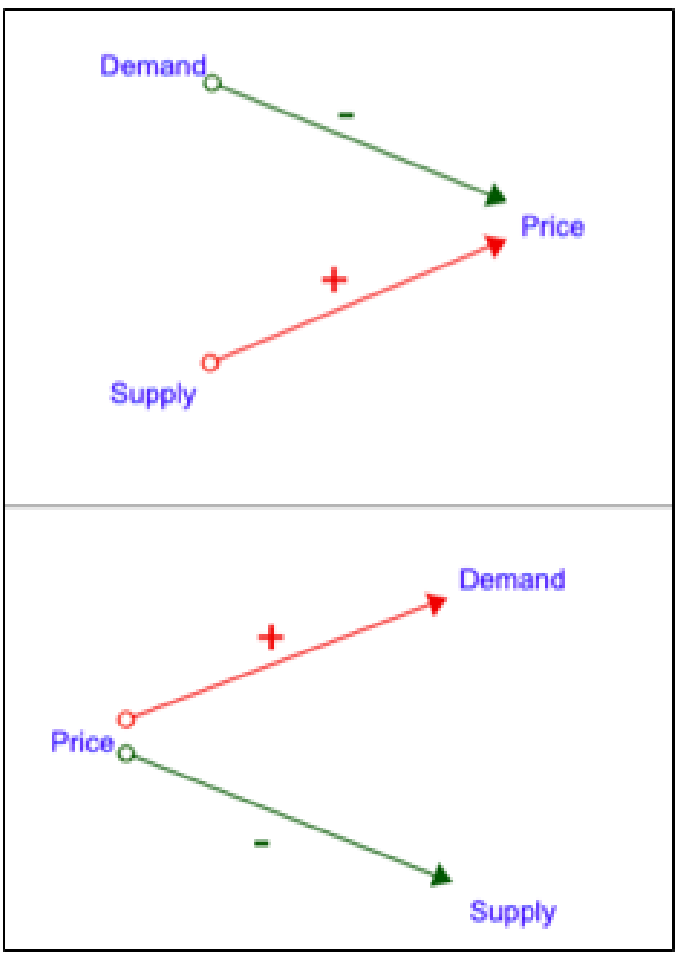


Figure 4.17. Possible models for feedback thinking Level 2 in the demand and price scenario.

Participants were scored at Level 3 if they provided answers demonstrating an understanding of system feedback. For instance, if they explained a balancing feedback loop in a system, where an increase in demand leads to an increase in price, which in turn leads to a decrease in demand (see Figure 4.18).

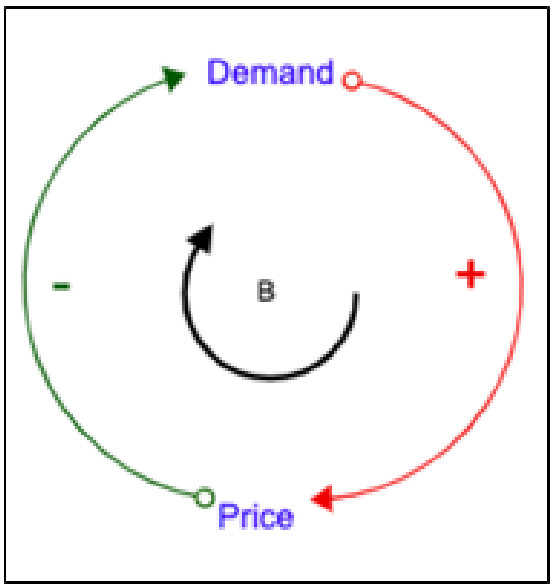


Figure 4.18. Possible model for feedback thinking Level 3 in the demand and price scenario.

Participants were scored at Level 4 if they demonstrated multiple feedback loops in a system. Participants achieved a Level 4 score when they presented the balancing feedback loop such that when demand increases, price increases, and price increases, demand decreases, and then presented an additional example of a balancing feedback loop.

As shown in Figure 4.19, participants achieved a Level 4 score when they provided additional balancing feedback such that when price increases, supply decreases, and when supply decreases, price increases.

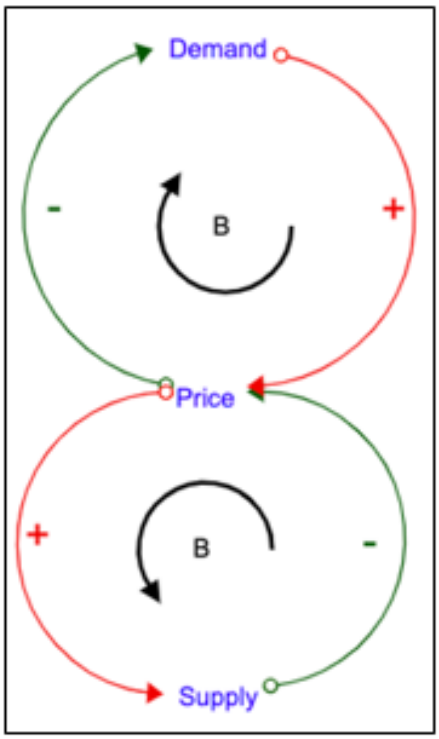


Figure 4.19. Possible model for feedback thinking Level 4 in the demand and price scenario.

Table 4.7 shows the participants' explanations for the Demand and Price scenario before any prompts were given and their feedback thinking levels according to the revised S-BI protocol scoring rubric (see Appendix E). Participants' responses were scored on the following question: "What do you think about the relationship between the demand for a product and its price?". The results showed that P1, P3, P9, and P10 were at Level 0, and all other participants were at Level 1 regarding feedback thinking. No participants were scored at Level 2, Level 3, and Level 4.

As a preliminary question, participants were asked if they had taken any economics courses, and only P10 reported that he had taken an introductory economics course. In addition, P10 stated that he had not taken an economics course but was familiar with economics because one of his parents had a Ph.D. in economics. Surprisingly, the initial level of feedback thinking for both of these participants was Level 0.

Table 4.7. Participants' explanations before prompts in scenario 3.

Feedback Thinking Levels	**Explanations**	**Participants**
Level 1	As the demand for a product increases, that is, as more people want to buy it, of course, I think the price will go up. This is something that I actually encounter in a current way. For example, if we buy from a shopping site where there are many people who wear size 39, if we choose the shoe with size 39, if the price of the shoe is 3 thousand Turkish Liras, it becomes 5 thousand Turkish Liras because they increase the price because the demand for it increases. So I actually think that as the demand increases in a linear way, the price also increases.	P2
Level 1	As the demand increases, the price increases at the same rate because more people want to buy the product, which opens the doors for companies to earn more income. So as the demand increases, the price increases.	P4
Level 1	In general, I see that the higher the demand for a product, the higher the price of a product. Companies actually have an ambition to make more money. So there is a demand for my product, so why should I sell it at a low price? I think they raise the price to make more money.	P5
Level 1	If the demand increases, the price of the product will also increase because everyone wants to buy it. So if one goes up, the other will go up.	P6

Table 4.7 Participants' explanations before prompts in scenario 3. (cont.)

Feedback Thinking Levels	**Explanations**	**Participants**
Level 1	For example, if I want to sell a phone and there is not enough demand for it, I will lower the price of the phone so that I can sell it. But if there is demand, I can raise the price.	P7
Level 1	As the demand for a product increases, the price of that product can be increased to make more money because there is demand. When there is demand, the product is bought. So as demand increases, the price increases.	P8
Level 0	Artificial intelligence is at the forefront. The code language needed for artificial intelligence is Python. Since Python is at the forefront, Python courses can be opened. For example, Python training in 6 months, you can give courses by starting things like Python courses from scratch. Python courses may increase right now due to demand.	P1
Level 0	I think that if the demand increases, maybe the price can be lowered because if people see that it is even cheaper, they can buy more. I am not a person who understands a lot of economics in everyday life.	P3
Level 0	Let's say we sell apples. We have enough apples and everyone buys them. As the apples become less and less, my money increases, but too much money is not good for me. I have to spend the money because if I don't spend it, if I keep the money, people won't buy apples. So I have to keep the	P9

Table 4.7 Participants' explanations before prompts in scenario 3. (cont.)

Feedback Thinking Levels	**Explanations**	**Participants**
	money flowing, so I can buy bananas, for example. There is such a cycle.	
Level 0	Under normal circumstances, there should be no relationship between demand and price.	P10

Table 4.8 shows the participants' explanations for the Demand and Price scenario after the prompts were given and their feedback thinking levels according to the revised S-BI protocol scoring rubric (see Appendix E). Prompting questions were: "How might the demand for a product and its price be interrelated?", "What do you think will happen to the demand for a product and its price over time?", "If the demand for a product increases, what will happen to the price of that product?", "If the price of a product increases, what will happen to the demand for that product?". The results showed that regarding feedback thinking levels, P6, P8 and P10 were at Level 3, P2, P4, and P5 were at Level 1, and P1, P3, and P9 were at Level 0. No participants were found at Level 4.

Table 4.8. Participants' explanations after prompts in scenario 3.

Feedback Thinking Levels	**Explanations**	**Participants**
Level 3	As the price increases, people's interest in that product will decrease, i.e. they will avoid paying that price. If a product that was originally 100 Turkish Liras is increased to 200 Turkish Liras, people will be less interested in that product. Therefore, since there	P6

Table 4.8 Participants' explanations after prompts in scenario 3. (cont.)

Feedback Thinking Levels	**Explanations**	**Participants**
	is less demand for this product, the price of the product will be reduced in order to increase sales.	
Level 3	Over time, demand for a product will increase, and its price will rise. After a while, this demand may decrease due to the increase in price. When demand falls, the price will fall.	P8
Level 3	I suppose that the price will gradually increase because there is demand, but at some point, if price is increased too much, the demand will no longer meet the customer's expectations in terms of price performance. So, the demand for that product will decrease.	P10
Level 2	I think demand depends on how much the price goes up. If the price of a basic product goes up, there will be demand for it. For example, if the demand for diapers goes up, they'll raise the price. But if the price of a luxury product that is not a basic need goes up a lot, I think the demand will go down. It depends on people's needs.	P7
Level 2	If the price of a product goes up, the demand for that product can go down. I mean, I think it is also a little bit related to purchasing power, so in which market, in which country it is sold. I think demand can go down as the price goes up.	P5

Table 4.8 Participants' explanations after prompts in scenario 3. (cont.)

Feedback Thinking Levels	**Explanations**	**Participants**
Level 1	If the price of a product goes up, the demand may go down because at some point the price of the product may become unreasonable. So, there will actually be an inverse relationship effect, as one increases, the other will begin to decrease.	P2
Level 1	If the price of a product increases, it will not be accessible to different groups. If the price increases, the demand for that product will decrease.	P4
Level 0	The price of a product depends on the brand of the product. For example, if a brand like X produces a product that everyone can buy, the price will not increase, the demand will not increase, but if an expensive brand like Y produces a product, the demand may increase. I think it depends on the brand.	P1
Level 0	If a seller wants to have more demand for the product, the seller lowers the price of the product. I think people will prefer it more because the price of the product will be cheaper.	P3
Level 0	If there is no purchasing power, people cannot buy this product, but people with high purchasing power can buy this product, but they are limited. Since there are multiple	P9

Table 4.8 Participants' explanations after prompts in scenario 3. (cont.)

Feedback Thinking Levels	**Explanations**	**Participants**
	factors, we cannot look at it from one side, because I am trying to see the buyer, the seller, and the middlemen. I cannot say it will be this way or that way.	
Words and phrases that indicate a positive relationship are color coded red, those that indicate a negative relationship are color coded blue, and those that indicate a cause and effect relationship are color coded orange.		

Figure 4.20 shows the overall levels of participants' feedback thinking before and after the prompt questions in the Demand and Price scenario to provide a holistic view. Interestingly, prior to the prompt, all participants were almost evenly split between Level 0 and Level 1, with no participants at Level 2, Level 3, and Level 4. These results showed that most of the participants were able to explain simple connections and relationships (Level 1) and showed incorrect or no relationships (Level 0) before the prompts.

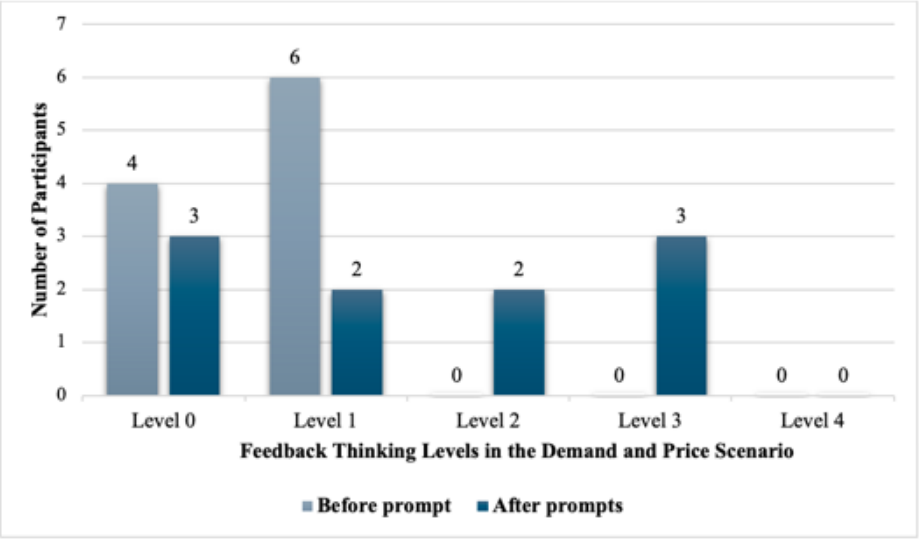


Figure 4.20. Participants' levels of feedback thinking before and after the prompts in the demand and price scenario.

At the end of the prompt questions, the number of participants in Level 2 and Level 3 increased. The number of participants at Level 0 decreased slightly, while the number of participants at Level 1 decreased. No participants were identified at Level 4 (See Figure 4.20). These results showed that participants had different levels of understanding of a system, ranging from showing an understanding of the principles that guide how the system behaves (Level 3) at the end of the prompts an incorrect or no relationship (Level 0).

To provide an overall perspective, Table 15 shows the feedback thinking levels of each participant before and after the prompts in the Demand and Price scenario. Table 15 shows that participants P6, P7, P8, and P10 increased their feedback thinking levels after the prompts, while the rest of the participants had the same feedback thinking levels before and after the prompts.

Table 4.9. Each participant's level of feedback thinking before and after prompt questions in the demand and price scenario.

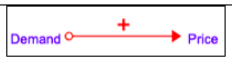
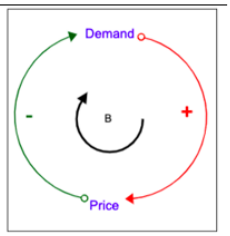
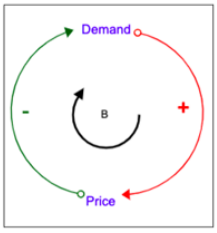
	Demand and Price Scenario (Domain-general scenario including balancing feedback loops)	
Participants	**Feedback Thinking Levels Before Prompt**	**Feedback Thinking Level After Prompts**
P1	Level 0	Level 0
P2	Level 1	Level 1
P3	Level 0	Level 0
P4	Level 1	Level 1
P5	Level 1	Level 1
P6	Level 1	Level 3
P7	Level 1	Level 2
P8	Level 1	Level 3
P9	Level 0	Level 0
P10	Level 0	Level 3

Figure 4.21 shows quotes from participants who showed a major change, increasing their level of feedback thinking by two levels or more after the prompts compared to before the prompts. P6, and P8 moved up two levels after the prompts, while P10 moved up three levels, but Figure 4.21 shows an example of a move from the same level.

Before the prompts, P6 and P8 made one-way connections between demand and price, while P10 could not make a simple connection between demand and price. After the prompts, these participants' responses recognized the balancing feedback loop in the system and were able to explain the feedback in the system. The change in participants' level of feedback thinking for each question is shown in Appendix F.

Demand and Price Scenario

(Domain-general scenario including balancing feedback loops)

Participants	Explanations Before Prompt	Before Prompt Model	Explanations After Prompts	After Prompt Model
P6	***Level 1:*** If the demand increases, the price of the product will also increase because everyone wants to buy it. So if one goes up, the other will go up.		***Level 3:*** As the price increases, people's interest in that product will decrease, i.e. they will avoid paying that price. If a product that was originally 100 Turkish Liras is increased to 200 Turkish Liras, people will be less interested in that product. Therefore, since there is less demand for this product, the price of the product will be reduced in order to increase sales	
P10	***Level 0:*** Under normal circumstances, there should be no relationship between demand and price.		***Level 3:*** I suppose that the price will gradually increase because there is demand, but at some point, if the price is increased too much, the demand will no longer meet the customer's expectations in terms of price performance. So the demand for that product will decrease.	

Words and phrases that indicate a positive relationship are colored red, while those that indicate a negative relationship are colored blue.

Figure 4.21. Participants' explanations of levels of feedback thinking before and after prompts in the demand and price scenario.

What is the feedback thinking level of senior pre-service middle school science teachers in reinforcing feedback loops in domain-general scenarios?

The Time Spent on Social Media and Social Media Addiction scenario is a domain-general scenario that presents universal themes from the technological context as social systems dynamics, which are not included in the MoNE (2018) middle school science curriculum. In this domain-general scenario was designed to elicit participants' understanding of the reinforcing feedback loop. Participants' possible feedback thinking levels for the Time Spent on Social Media and Social Media Addiction scenario were modeled using STELLA modeling software. Below are possible models and participant descriptions to illustrate each level of feedback thinking for the Time Spent on Social Media and Social Media Addiction scenario.

Participants were scored at Level 0 if they gave an incorrect answer or showed no relationship between the time spent on social media and social media addiction (see Figure 4.22).



Figure 4.22. Possible model for feedback thinking Level 0 in the time spent on social media and Social Media Addiction scenario.

Responses that showed an understanding of causality, connections, relationship, and linear causal chains in a system were scored at Level 1. For example, participants were scored at Level 1 if they explained a relationship, such as how an increase in time spent on social media would increase social media addiction or an increase in social media addiction would increase the time spent on social media (see Figure 4.23).

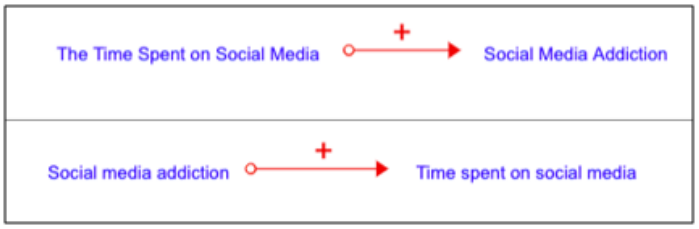


Figure 4.23. Possible models for feedback thinking Level 1 in the time spent on social media and social media addiction scenario.

Responses that described the aspects of the interconnections in a system were scored at Level 2. For example, participants were scored at Level 2 if they explained the relationship as an increase in time spent on social media and other factors that cause social media addiction, such as asociality, leading to an increase in social media addiction. Participants also were scored at Level 2 if they explained the relationship as an increase in time spent on social media and other effects of social media addiction, such as asociality or introversion, leading to an increase in social media addiction (see Figure 4.24).

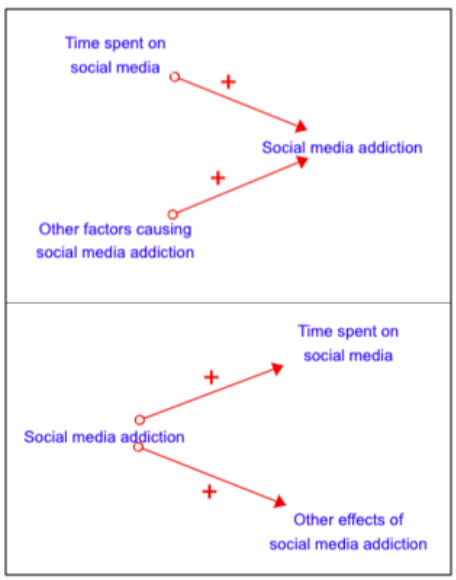


Figure 4.24. Possible models for feedback thinking Level 2 in the time spent on social media and social media addiction scenario.

Responses that demonstrated an understanding of feedback in a system were scored at Level 3. For example, participants were scored at Level 3 if they provided an explanation that demonstrated an understanding of a reinforcing feedback loop in a system, such as when time spent on social media increases, social media addiction increases, and when social media addiction increases, time spent on social media increases (see Figure 4.25).

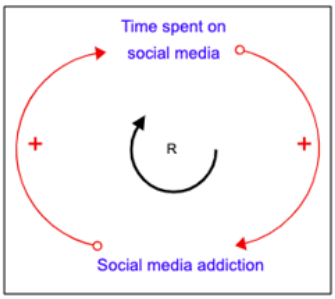


Figure 4.25. Possible model for feedback thinking Level 3 in the time spent on social media and social media addiction scenario.

Responses demonstrating multiple feedback loops in a system were scored at Level 4. A Level 4 score was achieved when the reinforcing feedback loop was presented, showing that when social media addiction increases, time spent on social media also increases. An additional example of a reinforcing feedback loop was then provided. Figure 24 illustrates that participants achieved a Level 4 score by providing additional reinforcing feedback. For example, as social media addiction increases, the time spent on social media decreases, leading to an increase in social media addiction (see Figure 4.26).

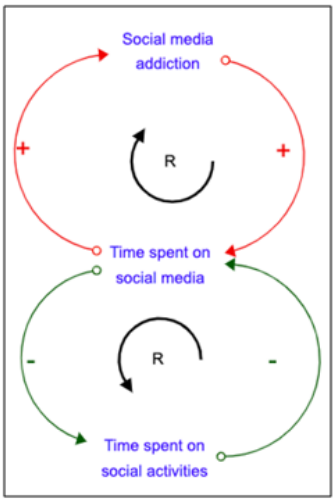


Figure 4.26. Possible model for feedback thinking Level 4 in the time spent on social media and social media addiction scenario.

Table 4.10 shows the participants' explanations for the Time Spent on Social Media and Social Media Addiction scenario before any prompts were given and their feedback thinking levels according to the revised S-BI protocol scoring rubric (see Appendix E). Participants' responses were scored on the following question: "What do you think about the relationship between time spent on social media and social media addiction?".

The results showed that regarding feedback thinking levels, P6 and P10 were at Level 3, P1, P2, P3, P4, P5, and P8 were at Level 1, and P7 and P9 were at Level 0. No participants were scored at Level 2 and Level 4. As a preliminary question, participants were asked if they used social media, and all reported using social media.

Table 4.10. Participants' explanations before prompts in scenario 4.

Feedback Thinking Levels	**Explanations**	**Participants**
Level 3	As time spent on social media increases, so does the level of addiction. As the level of addiction increases, the time spent on social media will increase. In other words, people will want to spend more time.	P6
Level 3	First, the time spent on social media increases. As the time spent increases, it becomes an addiction, and once an addiction is formed, it continues to increase in itself. In other words, it continues in an ever-increasing way.	P10
Level 1	The more time you spend on social media, the more addicted you become. I think this is an undeniable fact because, for example, when I am at home, I use social media a lot out of boredom. The more time you spend on social media, the more addicted you become.	P1
Level 1	As addiction to social media increases, so does the time spent on it. Especially during the pandemic,	P2

Table 4.10 Participants' explanations before prompts in scenario 4. (cont.)

Feedback Thinking Levels	**Explanations**	**Participants**
	I noticed that I spent more time when I was not communicating on social media before. So, there is a linear relationship.	
Level 1	I think if people spends too much time on social media, their addiction increases.	P3
Level 1	The more time spent on social media, the greater the addiction.	P4
Level 1	I think that the more time spent on social media, the more addiction to it will occur and increase.	P5
Level 1	When the time spent on social media goes beyond a certain period of time, when it gets to the point where I can no longer stop using it, it becomes an addiction.	P8
Level 0	I applied the social media addiction test to college students in Statistics 101, and there was actually no relationship between addiction and time spent. I mean, I couldn't find a significant relationship. I agree. I look at social media for a week, but it happens when I don't use it at all, I don't know.	P7
Level 0	I cannot think in general, because the duration of social media use by certain age groups and its relationship to addiction is very different. There is a huge difference between the use of social media by an adult and an employee or a student. So all these things have to be considered one by one and then an average should be taken.	P9

Table 4.11 shows the participants' explanations for the Time Spent on Social Media and Social Media Addiction scenario after the prompts were given and their feedback thinking levels according to the revised S-BI protocol scoring rubric (see Appendix E). Prompting questions were: "How might time spent on social media and

social media addiction be interrelated?", "What do you think will happen to time spent on social media and social media addiction over time?", "If time spent on social media increases, what will happen to social media addiction?", "If social media addiction increases, what will happen to the time spent on social media?"

The results showed that regarding feedback thinking levels, P1 and P7 were at Level 1, P9 was at Level 2, and the rest of the participants were at Level 3. No participants were found at Level 0 and Level 4.

Table 4.11. Participants' explanations after prompts in scenario 4.

Feedback Thinking Levels	**Explanations**	**Participants**
Level 3	As social media addiction increases, I think the time spent on social media will also increase. The time spent on social media will gradually trigger social media addiction. If you're already addicted, if you don't do it somehow, you're going to go through withdrawal. So it's like the definition of addiction. I think social media addiction will also gradually encourage and increase the time spent on it.	P2
Level 3	Social media addiction will increase more because this will increase the time people spend on social media. I think the increase in time spent on social media will also increase people's addiction.	P3
Level 3	As social media addiction increases, the time spent on social media will increase. When people become addicted	P4

Table 4.11 Participants' explanations after prompts in scenario 4. (cont.)

Feedback Thinking Levels	**Explanations**	**Participants**
	to something, they start to not enjoy it as much as they used to, and it doesn't meet that expectation. So they start to increase their screen time to meet their old expectations or their old pleasure. Therefore, as screen time, i.e. time spent on social media, increases, so does the addiction to it.	
Level 3	As the addiction to social media increases, the time spent on social media increases. I think that relationship is always going to increase over time because addiction is something like that. I mean, I think this is something that is more of a feature of this addiction. I think that the more time you spend on social media, the more you want to spend.	P5
Level 3	For example, you spend 2 hours a day on social media. Then let's say he reaches this level of addiction. As the time spent on social media increases, 2 hours will not be enough, it will increase to 3 hours. Eventually, 3 hours will not be enough, and it will continue to increase. As the time spent increases, the level of addiction will increase. When addicted, the person will need to spend more time.	P6

Table 4.11 Participants' explanations after prompts in scenario 4. (cont.)

Feedback Thinking Levels	**Explanations**	**Participants**
Level 3	As the time spent on social media increases, the addiction to social media increases, and there is no decrease. As the time spent increases, the addiction gradually reaches a serious level. As social media addiction increases, time spent on social media increases.	P8
Level 3	I see it spiraling in front of my eyes, a spiral, but upward. First, the time spent on social media increases, and that leads to social media addiction. Social media addiction makes you spend more time on social media, and I think of it as a cycle because it increases and increases.	P10
Level 2	When we scroll too much on social media, you don't want to get out, you want to use it more and more. When you look outside, when it's slower and quieter, you don't feel like going out. Then you look at social media more, you say I'm bored outside, I shouldn't go out. Then you use social media more because it's boring outside. Then when you go out again, you get even more bored and you want to use that social media.	P9
Level 1	The more time you spend on social media, the more addicted you become. That's how it works for me.	P1

Table 4.11 Participants' explanations after prompts in scenario 4. (cont.)

Feedback Thinking Levels	**Explanations**	**Participants**
Level 1	I think the level of addiction can affect the amount of time you spend on social media. If you are addicted, you might spend more time, but spending a lot of time might not make you addicted.	P7

Figure 4.27 shows the overall levels of participants' feedback thinking before and after the prompt questions in the Time Spent on Social Media and Social Media Addiction scenario to provide a holistic view. Before the prompt question, most participants were Level 1, with an equal number of Level 0 and Level 3 participants. There were no Level 2 and Level 4 participants. These results showed that while few participants described aspects of interconnections (Level 2), and were able to show no relationship (Level 0), most of the participants explained simple connections and relationships (Level 1) before the prompts.

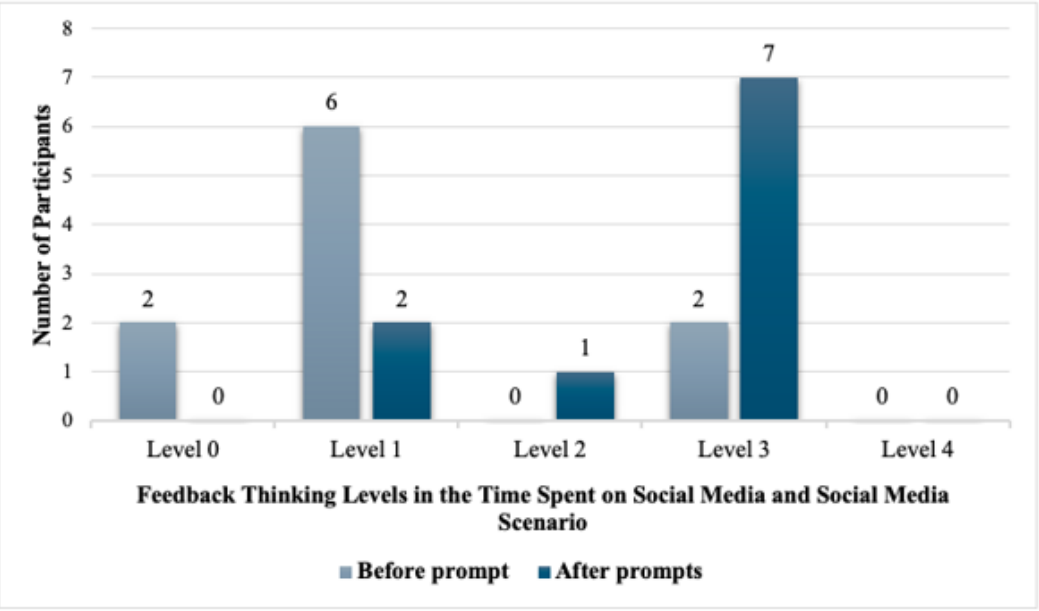


Figure 4.27. Participants' levels of feedback thinking before and after the prompts in the time spent on social media and social media addiction scenario.

At the end of the prompt questions, the number of Level 3 participants increased significantly, while the number of Level 1 participants decreased dramatically. The number of Level 2 participants increased slightly, while there were no Level 0 and Level 4 participants (See Figure 4.27). The results showed that while most participants could demonstrate an understanding of feedback in a system (Level 3), one participant described aspects of interconnections (Level 2), and few participants explained simple connections and relationships (Level 1) at the end of the prompts.

For a more complete picture, Table 19 shows the feedback thinking levels of each participant before and after the prompts in the Time Spent on Social Media and Social Media Addiction scenario. Table 19 shows that participants P2, P3, P4, P5, P7, P8, and P9 increased their feedback thinking levels after the prompts, while the rest had the same feedback thinking levels before and after the prompts.

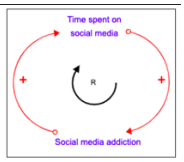
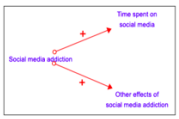
Table 4.12. Each participant's level of feedback thinking before and after prompt questions in the time spent on social media and social media Addiction scenario.

	Time Spent on Social Media and Social Media Addiction(Domain-general scenario including reinforcing feedback loops)	
Participants	**Feedback Thinking Levels Before Prompt**	**Feedback Thinking Levels After Prompts**
P1	Level 1	Level 1
P2	Level 1	Level 3
P3	Level 1	Level 3
P4	Level 1	Level 3
P5	Level 1	Level 3
P6	Level 3	Level 3
P7	Level 0	Level 1
P8	Level 1	Level 3
P9	Level 0	Level 2
P10	Level 3	Level 3

Figure 4.28 shows quotes from participants who showed a significant change, increasing their level of feedback thinking by two levels or more after the prompts compared to before the prompts. P2, P3, P4, P5, P8, and P9 moved up two levels after the prompts, but Figure 4.28 shows an example of a move from the same level.

Time Spent on Social Media and Social Media Addiction

(Domain-general scenario including reinforcing feedback loops)

Participants	Explanations Before Prompt	Before Prompt Model	Explanations After Prompts	After Prompt Model
P2	***Level 1:*** As addiction to social media increases, so does the time spent on it. Especially during the pandemic, I noticed that I spent more time when I was not communicating on social media before. So, there is a linear relationship.		***Level 3:*** As social media addiction increases, I think the time spent on social media will also increase. The time spent on social media will gradually trigger social media addiction. If you're already addicted, if you don't do it somehow, you're going to go through withdrawal. So, it's like the definition of addiction. I think social media addiction will also gradually encourage and increase the time spent on it.	
P9	***Level 0:*** I cannot think in general, because the duration of social media use by certain age groups and its relationship to addiction is very different. There is a huge difference between the use of social media by an adult and an employee or a student. So all these things have to be considered one by one and then an average should be taken.		***Level 2:*** When we scroll too much on social media, you don't want to get out, you want to use it more and more. When you look outside, when it's slower and quieter, you don't feel like going out. Then you look at social media more, you say I'm bored outside, I shouldn't go out. Then you use social media more because it's boring outside. Then when you go out again, you get even more bored, and you want to use that social media.	

Words and phrases that indicate a positive relationship are color coded red, while those that indicate a cause and effect relationship are color coded orange.

Figure 4.28. Participants' explanations of levels of feedback thinking before and after prompts in the time spent on social media and Social media addiction scenario.

Before the prompts, P9 could not make a simple connection between the time spent on social media and social media addiction, while P2, P3, P4, P5, and P8 made one-way connections between the time spent on social media and social media addiction. After the prompts, while P9 described aspects of interconnectedness in the system, other participants' responses recognized the reinforcing feedback loop in the system and were able to explain the feedback in the system. The change in participants' level of feedback thinking for each question is shown in Appendix F.

4.2. Homological Reasoning

After the participants had evaluated the relationships presented in each system scenario, they were asked "Can you think of other situations where such a relationship might exist? Please explain". For example, after explaining the relationship between the amount of sugar in the blood and the amount of insulin in the blood in the first systems scenario, participants were asked to describe another similar situation. The aim was to see how the participants recognized homologous structures in each system scenario and to give examples.

As a result, the participants' homological reasoning level was assessed in the context of the sixth question, which is the last question in each system scenario in Part I. Feedback Dynamics of the S-BI protocol. In this section, the participants' level of homological reasoning in each system scenario was revealed, and then quotes from the participants' explanations were presented to show each participant's understanding and reveal their mental models. Each research question was addressed separately with sub-research questions in the following sections.

4.2.1. RQ 3: What is the Homological Reasoning Level of Senior Pre-Service Middle School Science Teachers in Domain-Specific Scenarios?

What is the homological reasoning level of senior pre-service middle school science teachers in balancing feedback loops in domain-specific scenarios?

The relationship between sugar and insulin is to increase the amount of insulin in the blood to balance the increased amount of sugar in the blood, and to decrease the amount of insulin in the blood once the sugar in the blood is balanced.

Therefore, there is a balancing (negative) feedback loop in the mechanism underlying sugar and insulin. One of the aims of this scenario is to assess how participants

recognize the balancing feedback loop underlying this system's scenario and how they transfer the balancing feedback loop from one domain to another.

Figure 4.29 shows the participants' levels of homological reasoning in the Sugar and Insulin scenario. Answers with multiple homologies provided from a different domain than the domain in the presented scenarios are coded as Level 4. Answers with a correct homology provided from a different domain than the domain in the presented scenarios are coded as Level 3. Answers with correct homology provided from the same domain as the domain in the presented scenarios are coded as Level 2. Answers that provide incorrect homology are coded as Level 1, while answers that do not provide examples are coded as Level 0.

Figure 4.29 shows that there were very few participants at Level 2 and Level 3, while most participants were at Level 1. No participants were at Level 0 and Level 4. Few participants were able to correctly transfer the balancing feedback loop in the scenario to the same domain as the presented scenario (Level 2) or from a domain outside the domain of the presented scenario (Level 3). These results showed that many participants gave examples of wrong homology (Level 1).

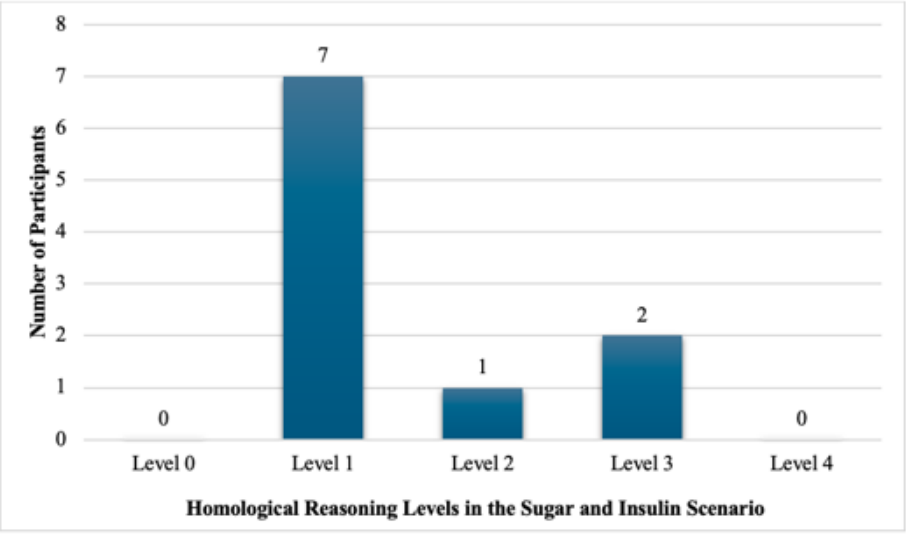


Figure 4.29. Participants' level of homological reasoning in the sugar and insulin scenario.

Table 4.13 shows the participants' homological examples for the Sugar and Insulin scenario and their homological reasoning levels according to the revised S-BI protocol scoring rubric (see Appendix E). It should be noted that in order for participants to provide an accurate example of homology, they need to close the loop, i.e., indicate a two-way relationship rather than just a one-way relationship. The results showed that P3, P7, and P10 were at Level 3, P10 was at Level 2, and all other participants were at Level 1 regarding homological reasoning levels. No participants were found at Level 0 and Level 4.

Table 4.13. Participants' homology examples for scenario 1.

Homological Reasoning	**Participants' Homology Examples**	**Participants**
Level Level 3	As the algae grows, a rise in the surface is observed. Because the algae is green, it constantly reflects the incoming sunlight outward. This has a negative effect on the fish species below. An example is trying to reduce algae in rivers or lakes by using chemicals when the algae numbers are increasing. As the use of chemicals increases, the number of algae in the lakes decreases. This disrupts the food chain. Therefore, since the number of algae is decreasing, the use of chemicals is reduced and an attempt is made to increase the number of algae.	P3
Level 3	In fact, in the case of the weather, for example, the wind blowing is a similar example. The wind blows from hot to cold, and as the hot air blows against the cold air, the temperature drops and comes to an equilibrium, and then as it gets colder, the cold air gets warmer again thanks to the hot air blowing from the other direction. There is such a cycle.	P7
Level 2	This is how enzymes work. When enzymes work as a team, when the	P10

Table 4.13 Participants' homology examples for scenario 1. (cont.)

Homological Reasoning	**Participants' Homology Examples**	**Participants**
	substrate ratio increases, the enzyme ratio increases, but when the products produced are transformed, the enzyme ratio decreases again. So their work was to decrease the substrate ratio.	
Level 1	I can give an example of pressure. As the surface area of an object decreased, the pressure increased. Sugar and insulin had an inverse relationship. Maybe that's why I thought of such an opposite relationship.	P1
Level 1	As carbon dioxide emissions increase, global warming increases. It's a linear effect; as one increases, so does the other.	P2
Level 1	In areas with heavy traffic, roads are widened to ensure that traffic flows smoothly. Therefore, as the road width increases, traffic decreases.	P4
Level 1	I think that when things go bad in our lives, there are also things that go good, and life somehow balances out and reaches a point where we can survive. So, I think that even though the things that are troublesome for us increase, at some point the things that can be good for us and help us overcome them also increase.	P5
Level 1	As the amount of greenhouse gases in the air increases, the temperature will rise. As the temperature increases, the dissolution of greenhouse gases in the air will also increase. These will become situations that constantly feed each other.	P6
Level 1	When you lose energy, you feel hungrier. To suppress the feeling of hunger, there is a desire to eat more.	P8
Level 1	When my mother gets angry, my stress level goes up.	P9

Table 4.14 shows each participant's level of feedback thinking after the prompts and homological reasoning in the Sugar and Insulin scenario. The results show that most of the participants scored at Level 3 for feedback thinking, while they scored at Level 1 for homological reasoning. In other words, while most of the participants were able to explain the balancing feedback loop in the scenario, they were not able to give an example of homology similar to this loop.

Table 4.14. Each participant's overall feedback thinking level and homological reasoning level in the sugar and insulin scenario.

	Sugar and Insulin (Domain-specific scenario including balancing feedback loops)	
Participants	**Feedback Thinking Level**	**Homological Reasoning Level**
P1	Level 0	Level 1
P2	Level 3	Level 1
P3	Level 2	Level 3
P4	Level 3	Level 1
P5	Level 3	Level 1
P6	Level 3	Level 1
P7	Level 3	Level 3
P8	Level 1	Level 1
P9	Level 3	Level 1
P10	Level 3	Level 2

Interestingly, P3 was scored at Level 2 for feedback thinking, but at Level 3 for homological reasoning. In other words, P3 was unable to recognize the balancing feedback loop, but interestingly, P3 was able to provide a correct homology example from the same domain. P1, on the other hand, was scored at Level 0 in feedback thinking, which means that P1 could not see any relationship in the system and, therefore, gave an incorrect homology example and was scored at Level 1. As a result, although participants generally scored at Level 3 on the feedback thinking, only three participants were able to provide correct homology examples, P10 from the same domain and P3 and P7 from a different domain.

What is the homological reasoning level of senior pre-service middle school science teachers in reinforcing feedback loops in domain-specific scenarios?

The relationship between forest fires and global warming is such that an increase in forest fires triggers and increases global warming, which in turn increases forest fires. Thus, there is a reinforcing (positive) feedback loop in the mechanism underlying wildfires and global warming. One of the aims of this scenario is to assess how participants recognize the reinforcing feedback loop underlying this system's scenario and how they transfer this balancing feedback loop from one domain to another.

Figure 4.30 shows the participants' levels of homological reasoning in the Forest Fires and Global Warming scenario. Responses with more than one homology provided from a different domain than the domain in the presented scenarios are coded as Level 4. Responses with one correct homology provided from a different domain than the domain in the presented scenarios are coded as Level 3. Correct homology responses from the same domain as the domain in the presented scenarios are coded Level 2. Responses that provide incorrect homology are coded as Level 1, and responses that do not provide examples are coded as Level 0.

Figure 4.30 shows that most participants were at Level 1, while there were very few at Level 0 and Level 2. There were no participants at Level 3 and Level 4. These results revealed that the vast majority of participants gave wrong homology examples (Level 1). Only one of the participants gave no homology examples (Level 0), while only one gave a correct homology example from the same domain as the scenario presented (Level 2).

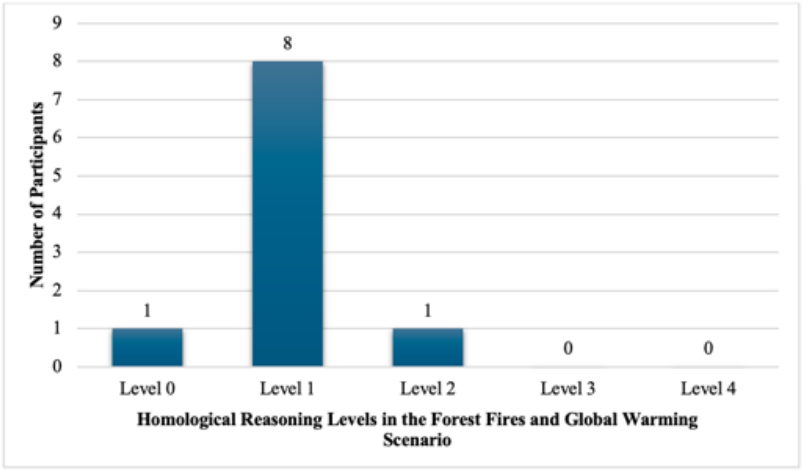


Figure 4.30. Participants' level of homological reasoning in the forest fires and global warming scenario.

Table 4.15 shows the participants' homological examples for the Forest Fires and Global Warming scenario and their homological reasoning levels according to the revised S-BI protocol scoring rubric (see Appendix E). It should be noted that in order for participants to provide an accurate example of homology, they are required to close the loop, i.e., indicate a two-way relationship rather than just a one-way relationship. The results showed that P6 was at Level 2, P9 was at Level 0, and all other participants were at Level 1 regarding homological reasoning levels. No participants were found at Level 3 and Level 4.

Table 4.15. Participants' homology examples for scenario 2.

Homological Reasoning Level	**Participants' Homology Examples**	**Participants**
Level 2	Melting glaciers could be an example. As the temperature rises, the glaciers will melt. As the glaciers melt, the world will warm more quickly.	P6
Level 1	I can say that the more time you spend on a lesson in a day, the more your understanding of that lesson will increase. For example, if you study for 2 hours a day instead of 1 hour, you will have more knowledge in that lesson.	P1

Table 4.15 Participants' explanation. (cont.)

Homological Reasoning Level	**Participants' Homology Examples**	**Participants**
	The more time you spend on a lesson, the more understanding you will gain.	
Level 1	When we think about the separation of plastic, paper, various recycling materials, I think that if such activities are implemented, the use of resources and various problems that may occur later will actually decrease. In other words, as recycling activities increase, I think the problems that may arise in terms of the use of resources will decrease.	P2
Level 1	In electric circuits, as you increase the electric current, the brightness of the light bulb increases. For some reason, I suddenly focused on physics and electricity came to mind. If you decrease the electric current, the brightness of the light bulb decreases. They affect each other.	P3
Level 1	Global warming is increasing today. Evaporation increases and the amount of water in the atmosphere decreases.This contribute to global warming.	P4
Level 1	When you are promoted in a job, the responsibility you are given increases according to your status.	P5
Level 1	Sometimes I'm nervous, something else is on my mind and I can't speak properly, and I get more and more nervous and I can't express myself. Sometimes I really want to express myself. I have a good grasp of the subject but somehow I cannot put the sentence together and then my tension increases.	P7
Level 1	There will be droughts due to global warming because the earth will get very hot, and evaporation will increase greatly. As a result, the glaciers will melt. So as global warming increases, drought will increase.	P8
Level 1	As the greenhouse effect increases, these gases are released into the atmosphere, making	P10

Table 4.15 Participants' explanation. (cont.)

Homological Reasoning Level	**Participants' Homology Examples**	**Participants**
	the water more polluted. That's just off the top of my head.	
Level 0	Drama education may have an effect on children's attention span because there are many factors, one of which may increase, decrease or be unrelated to the other. These effects may vary according to other factors such as gender, age and subject.	P9

Table 4.16 shows each participant's level of feedback thinking after the prompts and homological reasoning in the Forest Fires and Global Warming scenario. The results show that participants predominantly scored at Level 3 in feedback thinking, but predominantly at Level 1 in homological reasoning. In other words, most participants were able to demonstrate an understanding of reinforcing feedback loop in the scenario, but were unable to provide a correct homology example.

Table 4.16. Each participant's overall feedback thinking level and homological reasoning level in the forest fires and global warming scenario.

	Forest Fires and Global Warming (Domain-specific scenario including reinforcing feedback loops)	
Participants	**Feedback Thinking Level**	**Homological Reasoning Level**
P1	Level 1	Level 1
P2	Level 3	Level 1
P3	Level 3	Level 1
P4	Level 3	Level 1
P5	Level 3	Level 1
P6	Level 3	Level 2
P7	Level 3	Level 1
P8	Level 2	Level 1
P9	Level 2	Level 0
P10	Level 3	Level 1

Significantly, only P6 was able to explain the reinforcing feedback loop in the system and transfer the loop to the same context. As a result, although participants

generally scored at Level 3 on the feedback thinking, only P6 was able to provide correct homology examples from the same domain.

4.2.2. RQ 4: What is the Homological Reasoning Level of Senior Pre-Service Middle School Science Teachers in Domain-General Scenarios?

What is the homological reasoning level of senior pre-service middle school science teachers in balancing feedback loops in domain-general scenarios?

The relationship between demand and price is such that an increase in demand for a product increases the price of that product, and a decrease in demand for that product due to an increase in the price of that product. There is, therefore, a balancing (negative) feedback loop between demand and price. One of the aims of this scenario is to assess how participants recognize the balancing feedback loop underlying this system's scenario and how they transfer the balancing feedback loop from one domain to another.

Figure 4.31 shows the participants' levels of homological reasoning in the Demand and Price scenario. Level 4 answers are those with multiple homologies provided from a domain other than the domain in the presented scenarios. Level 3 answers are those with one correct homology provided from a domain that is different from the domain in the presented scenarios. Level 2 answers are those that provide correct homology from the same domain as the domain in the presented scenarios. Level 1 answers are those that provide incorrect homology, while Level 0 answers are those that do not provide examples.

Figure 4.31 shows that most of the participants were at Level 1. Significantly, one participant was at Level 2, and three were at Level 3. There were no participants at Level 0 and Level 4. These results showed that many participants gave incorrect examples of homology (Level 1). three of the participants were able to correctly transfer

it to a domain outside the domain of the presented scenario (Level 3), while only one of them was able to correctly transfer the balancing feedback loop to the same domain as the presented scenario (Level 2).

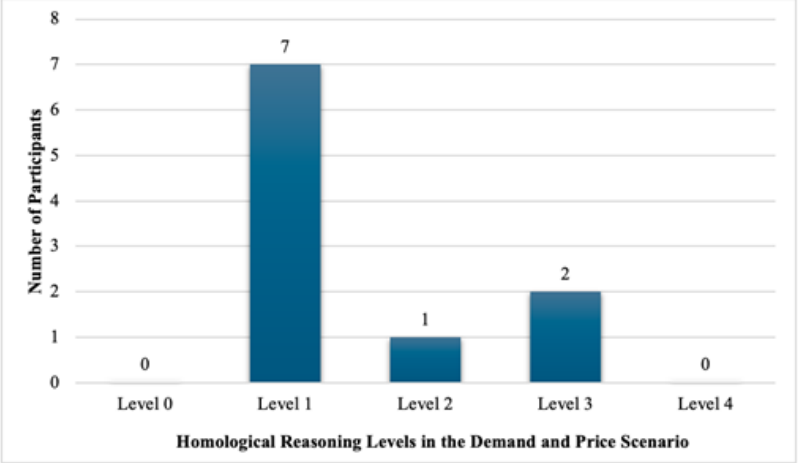


Figure 4.31. Participants' level of homological reasoning in the demand and price scenario.

Table 4.17 shows the participants' homological examples for the Demand and Price scenario and their homological reasoning levels according to the revised S-BI protocol scoring rubric (see Appendix E). It should be emphasized that in order for participants to provide an accurate example of homology, they would have to close the loop, i.e., indicate a two-way relationship rather than just a one-way relationship. The results showed that P4, and P9 were at Level 3, P7 was at Level 2, and all other participants were at Level 1 regarding homological reasoning levels.

No participants were found at Level 0 and Level 4. Interestingly, although the scenario presented contained a balancing feedback loop, P6 gave an example of homology with a reinforcing loop from a different context. Therefore, the participant was coded as Level 1 because the response did not provide an example of the type of feedback loop contained in the scenario presented.

Table 4.17. Participants' homology examples for scenario 3.

Homological Reasoning Level	**Participants' Homology Examples**	**Participants**
Level 3	For example, a student receives tutoring. As the student's success increases, the need for tutoring decreases. As a result, his/her attention may wander. Later, the student's success may drop again and he/she may need tutoring again.	P4
Level 3	My father encourages me to study, and my enthusiasm for studying increases. But, as my enthusiasm increases, the encouragement decreases, and then my enthusiasm decreases again.	P9
Level 2	The more foreign currency is bought, the higher the price of foreign currency. As the price of foreign exchange increases, the demand for foreign exchange decreases.	P7
Level 1	The more budget is spent on computer games, in other words, the more it is advertised, the more it can be played. For example, a new game came out, it was advertised a lot, and people were curious about it. So, there is a lot of demand because of the advertising.	P1
Level 1	I was thinking of the example of master's or Ph.D. students who want to go to successful schools applying to more successful schools. In other words, I can say something like, as the success of the school increases, as its prestige increases, maybe more people will apply and more people will interview and take exams and want to go to that school.	P2
Level 1	When we exercise, body fat decreases, but when we don't exercise, body fat increases.	P3

Table 4.17 Participants' homology examples for scenario 3. (cont.)

Homological Reasoning Level	**Participants' Homology Examples**	**Participants**
Level 1	If we show too much interest in people, if we show too much love, on the contrary, they may avoid us. So, it is an inverse relationship. I think there can be a psychological push in that way.	P5
Level 1	One example is traffic density and the construction of new roads. As traffic density increases, new roads are built. If new roads are built, the number of vehicles will increase and traffic density will increase again. Then new roads are built and the process continues.	P6
Level 1	The price of new cars is high and everyone buys them, but after a while the car gets old. So, the demand for them decreases. As the demand decreases and the car gets old, people start not buying it.	P8
Level 1	For a very long time, tea and coffee were very cheap, but now coffee prices have risen so much that people prefer other things instead, and coffee sells less and less. Because the price of coffee has risen so much, the demand for coffee is falling.	P10

Table 4.18 shows each participant's level of feedback thinking after the prompts and homological reasoning in the Demand and Price scenario. The results show that participants scored at different levels on feedback thinking, but mostly scored at Level 1 on homological reasoning. In other words, most participants were unable to provide an example of homology for the balancing feedback loop in the scenario.

Table 4.18. Each participant's overall feedback thinking level and homological reasoning level in the demand and price scenario.

	Demand and Price (Domain-general scenario including balancing feedback loops)	
Participants	**Feedback Thinking Level**	**Homological Reasoning Level**
P1	Level 0	Level 1
P2	Level 1	Level 1
P3	Level 0	Level 1
P4	Level 1	Level 3
P5	Level 1	Level 1
P6	Level 3	Level 3
P7	Level 2	Level 2
P8	Level 3	Level 1
P9	Level 0	Level 3
P10	Level 3	Level 1

Interestingly, P4 was scored at Level 1 for feedback thinking but at Level 3 for homological reasoning. In other words, P3 was able to explain a simple relationship, but interestingly, the participant was able to provide a correct homology example from the different domains. It is noteworthy that P9 was unable to make a connection between demand and price but was able to give an example of a correct homology from a different domain. P1 and P3, on the other hand, were scored at Level 0 in feedback thinking, which means that they could not see any relationship in the system and, therefore, gave an incorrect homology example and were scored at Level 1. As a result, although participants performed at different levels of feedback thinking, only P7 provided correct homology examples from the same domain, whereas P4, P6, and P9 provided correct homology examples from different domains.

What is the homological reasoning level of senior pre-service middle school science teachers in reinforcing feedback loops in domain-general scenarios

The relationship between time spent on social media and social media addiction is that as individuals spend more time on social media, their addiction to social media increases, and this addiction causes them to spend more time on social media. Therefore, there is a reinforcing (positive) feedback loop between time spent on social media and social media addiction. One of the aims of this scenario is to assess how participants recognize the reinforcing feedback loop underlying this system scenario and how they transfer the reinforcing feedback loop from one domain to another.

Figure 4.32 shows the participants' levels of homological reasoning in the Time Spent on Social Media and Social Media Addiction scenario. Level 4 is coded to responses with multiple homologies provided from a domain other than the domain in the presented scenarios. Level 3 is coded for answers with a correct homology that was provided from a domain that is different from the domain in the presented scenarios. Level 2 is coded for correct homology provided from the same domain as the domain in the presented scenarios. Level 1 is coded for responses that provide incorrect homology, while level 0 is coded for responses that do not provide examples.

Figure 4.32 shows that most participants were at Level 1 and Level 2, and the number of participants at both levels was equal. Significantly, one of the participants was at Level 3 and another at Level 4. There were no participants at Level 0. These results showed that while many participants provided incorrect homology examples (Level 1), many others provided correct homology examples from the same domain as the scenario presented (Level 2). Only one of the participants was able to correctly transfer the reinforcing feedback loop by giving a homology example to a domain other than the domain of the presented scenario (Level 2), while one of them was able to correctly transfer it to multiple homologies from different domains in the presented scenarios (Level 3).

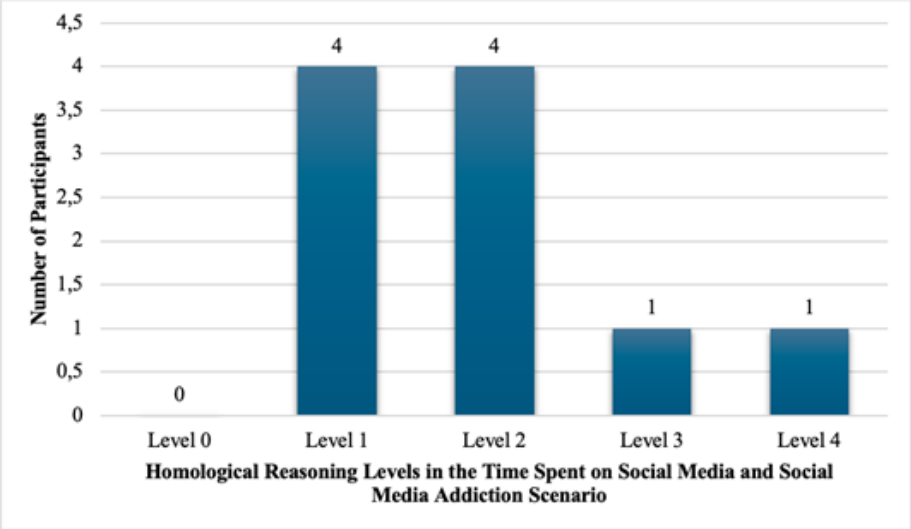


Figure 4.32. Participants' level of homological reasoning in the time spent on social media and social media addiction scenario.

Table 4.19 shows the participants' homological examples for the Time Spent on Social Media and Social Media Addiction scenario and their homological reasoning levels according to the revised S-BI protocol scoring rubric (see Appendix E). It should be noted that in order for participants to provide an accurate example of homology, they need to close the loop, i.e., indicate a two-way relationship rather than just a one-way relationship.The results showed that P4 was at Level 4, P10 was at Level 3, P3, P4, P5 and P8 were at Level 2 and P1, P2, P7 and P9 were at Level 1.

Table 4.19. Participants' homology examples for scenario 4.

Homological Reasoning Levels	**Participants' Homology Examples**	**Participants**
Level 4	We can give examples of inflation from everyday life. When inflation rises, the price of products also rises. When the price of products rises, inflation continues to rise because workers' wages increase. So, we are in a vicious circle. Everything goes up.	P6

Table 4.19 Participants' homology examples for scenario 4. (cont.)

Homological Reasoning Levels	**Participants' Homology Examples**	**Participants**
	Workers' wages go up, but the price of products also goes up. Also, because the price of products is going up, the cost of services is going up, and because the cost of services is going up, the price of products is going up. Then the workers' wages go up, and then they go up again, but it's a vicious circle.	
Level 3	An individual wants to consume and already creates a demand and when there is a discount, that consumption increases. Then, as the discounts increase, it leads to more consumption, and as consumption increases, people wait for the next discount period and consume more. As they consume more, they will always find an opportunity to buy something, so perhaps a similar relationship can be established between the desire to take advantage of discounts and consumption.	P10
Level 2	I was thinking about sweet cravings. When we start eating sweets, our addiction to sweets increases over time. Of course, as our addiction to sweets increases, we begin to eat even more sweets.	P3
Level 2	If we eat too much chocolate, it becomes an addiction. After a while, the amount of sugar you normally consume is not enough and you need to increase it. At first you can satisfy yourself with one or two chocolates, but over time you try to satisfy yourself by increasing to four because your body wants more and you become more addicted.	P4
Level 2	I think that in a process where a person who uses drugs becomes addicted over time, as the drug addiction increases, that person's	P5

Table 4.19 Participants' homology examples for scenario 4. (cont.)

Homological Reasoning Levels	**Participants' Homology Examples**	**Participants**
	desire to take more of that drug and to get more of it will increase. It is a similar relationship.	
Level 2	It could be smoking. A person becomes addicted to the substances in cigarettes. That is, the more you smoke, the more you want to smoke, and you cannot stop. This creates an addiction. There are even people who smoke two or three packs of cigarettes a day. In other words, the more you smoke, the more you want to smoke, the more you can't stop, and you become addicted. When you are addicted, you smoke more cigarettes.	P8
Level 1	I think game addicts are like that, I mean, it's the same logic again. When a game comes out, there is a desire to play that game. This is the same logic, so I can say that game addiction is an example.	P1
Level 1	I think the more books you read from a young age, the better your reading comprehension and reading speed will be. I think it has to do with that. I think it will be effective both in speaking and in reading and understanding a text.	P2
Level 1	Perhaps spending time in loving relationships does not always increase addiction, but two people who are dependent on each other tend to spend more time together. Spending a lot of time does not increase addiction, but if you are very dependent on someone, you will spend more time with them.	P7
Level 1	The 14th of February is coming. On the 14th of February you think you should spoil your lover, and you spoil your lover more and more. It could be something like that, something that goes on and on and on.	P9
Words and phrases that indicate a positive relationship are colored red.		

Table 4.20 shows each participant's level of feedback thinking after the prompts and homological reasoning in the Time Spent on Social Media and Social Media Addiction scenario. The results show that participants mostly scored at Level 3 in feedback thinking but mostly scored at Level 1 and Level 2 in homological reasoning. In other words, most participants were able to either demonstrate an understanding of reinforcing feedback (Level 3) or explain simple connections (Level 1) in this scenario, and most were also able to provide a correct homology example.

Table 4.20. Each participant's overall feedback thinking level and homological reasoning level in the time spent on social media and social media addiction scenario.

	Time Spent on Social Media and Social Media Addiction (Domain-general scenario including reinforcing feedback loops)	
Participants	**Feedback Thinking Level**	**Homological Reasoning Level**
P1	Level 1	Level 1
P2	Level 3	Level 1
P3	Level 3	Level 2
P4	Level 3	Level 2
P5	Level 3	Level 2
P6	Level 3	Level 4
P7	Level 1	Level 1
P8	Level 3	Level 2
P9	Level 2	Level 1
P10	Level 3	Level 3

Interestingly, P6 was scored at Level 3 for feedback thinking but at Level 4 for homological reasoning. In other words, P6 recognized the reinforcing feedback loop in the system and gave multiple provided from the different domains as the domain in the scenarios presented. As a result, participants generally scored at Level 3 in feedback thinking, and six participants gave correct homology examples. P3, P4, P5, and P8 gave correct homology examples from the same domain, while P10 gave correct

homology examples from a different domain. Surprisingly, P6 gave a correct homology example with multiple feedback loops from a different domain.

4.3. Feedback Recognition

In Part I, Feedback Dynamics of the S-BI protocol, participants were asked to explain the relationships presented in each system scenario and also to imagine situations similar to the situation in the presented scenario. In Part II, Comparison of Loop Dynamics of the S-BI protocol, the participants were visually presented with the four systems scenarios. The following question was then asked "Which of the following visuals do you think are similar or different in terms of the situations shown? Please explain". The aim was to assess how the participants distinguished between balancing and reinforcing feedback loops and to evaluate their explanations.

As a result, the participants' level of feedback recognition was evaluated in the context of Part II. Comparison of the Loop Dynamics S-BI protocol by using revised S-BI protocol scoring rubric (see Appendix E).

In this section, participants' levels of feedback recognition were presented, followed by statements from participants' explanations to illustrate each participant's understanding. The research question was addressed separately with sub-research questions.

4.3.1. RQ 5: What is the Feedback Recognition Level of Senior Pre-Service Middle School Science Teachers in Balancing and Reinforcing Feedback Loops?

What is the feedback recognition level of senior pre-service middle school science teachers in balancing feedback loops?

The Sugar and Insulin scenario and the Demand and Price scenario are similar scenarios in that they both involve balancing feedback loops. However, the former is a domain-specific scenario, while the latter is a domain-general scenario. Participants were shown pictures of both scenarios and asked to explain whether the two pictures were similar or different. Responses were coded in the category identifying and explaining similar balancing feedback loops. Level 3 scores are given for a correct match with an adequate explanation. Level 2 scores are given for correct matches but incorrect or incomplete explanations. Level 1 scores are given for both incorrect matches and incorrect explanations. Level 0 scores are given for no explanation.

Table 4.21 shows the participants' explanations for identifying and explaining balancing feedback loops and their feedback recognition levels according to the revised S-BI protocol scoring rubric (see Appendix E). The results showed that regarding feedback recognition levels, P2, P4, P6, P7, and P10 were at Level 3, P1, P3 and P8 were at Level 2, and P5 and P9 were at Level 1.

Table 4.21. Feedback recognition level for balancing feedback loops.

Feedback Recognition Levels	**Explanations**	**Participants**
Level 3	As the amount of sugar in the blood increases, the amount of insulin in the blood will increase to reduce and stabilize the amount of sugar in the blood. In the same way, as the demand for a product increases, the price of that product will increase, but as the price increases, the demand will decrease. I think there is a similar relationship between them.	P2
Level 3	These are similar. As the amount of sugar in the blood increases, the amount of insulin in the blood also increases. As the amount of insulin in the blood increases, the amount of sugar in the blood begins	P4

Table 4.21 Feedback recognition level for balancing feedback loops. (cont.)

Feedback Recognition Levels	**Explanations**	**Participants**
	to decrease. When the demand for a product increases, the price of that product increases, and when the price increases, the demand for that product starts to decrease.	
Level 3	The two are similar because as the amount of sugar in the blood increases, insulin increases, but as insulin increases, the amount of sugar in the blood decreases. As the amount of sugar in the blood decreases, so does the amount of insulin in the blood. So they balance each other out. We have the same thing here. When the demand for a product increases, the price of the product increases. If the price of the product goes up, the demand for it goes down. As the demand for the product decreases, the price of the product decreases. When the price of the product goes down, the demand for it goes up. So I think they balance each other out again.	P6
Level 3	**Sugar and Insulin and Demand** and Price Scenarios are similar. As the amount of sugar in the blood increases, the amount of insulin in the blood increases. Then the amount of sugar in the blood decreases and finally the amount of insulin in the blood decreases. Similarly, if the demand for a product increases, the price increases, and if the price increases, the demand decreases. In other words,	P7

Table 4.21 Feedback recognition level for balancing feedback loops. (cont.)

Feedback Recognition Levels	**Explanations**	**Participants**
	in both scenarios, one thing is increasing and one thing is decreasing.	
Level 3	As the amount of sugar in the blood increases, the amount of insulin in the blood increases, and as the amount of insulin in the blood increases after a while, it should reduce the amount of sugar in the blood. So something that causes it to go up will cause it to go down. We see a cycle. Similarly, there is a similar situation in the economic scenario. If the demand for a product increases, the price of the product increases, but the price of the product increases so much that after a while the demand for the product decreases.	P10
Level 2	As the amount of sugar in the blood increases, so does the amount of insulin in the blood. When the demand for a product increases, the price increases. So, I think the two are similar.	P1
Level 2	I thought that as the amount of sugar in the blood increased, the amount of insulin in the blood would increase, and also that as the demand for a product increased, the price of that product would decrease. I think that blood sugar and the price of a product are related **in this way.**	P3
Level 2	The two are similar in terms of damage. If the sugar in the blood increases, the amount of insulin in the blood increases and this creates an imbalance in the body. This can cause health	P8

Table 4.21 Feedback recognition level for balancing feedback loops. (cont.)

Feedback Recognition Levels	**Explanations**	**Participants**
	problems in the future and disrupt the system. As the demand for a product increases, the price will increase, but this will also harm the person's budget.	
Level 1	If demand for a product increases, the price may rise. If the amount of sugar in the blood increases, the amount of insulin in the blood may also increase. Because the body has a systematic order, the amount of sugar in the blood and the amount of insulin in the blood can go the same way. However, this is different with the Demand and Price scenario, because I think the demand for a product and the price of that product will not always be the same. Therefore, these two **are not similar.**	P5
Level 1	The amount of sugar in the blood increases, the amount of insulin in the blood increases. The Price and Demand scenario depends on the marketing tactic. Therefore, they are not similar.	P9

Figure 4.33 shows the participants' overall level of feedback recognition in the balancing feedback loops. Most of the participants were at Level 3, followed by Level 2. Only two participant was at Level 1 and no participant was at Level 0.

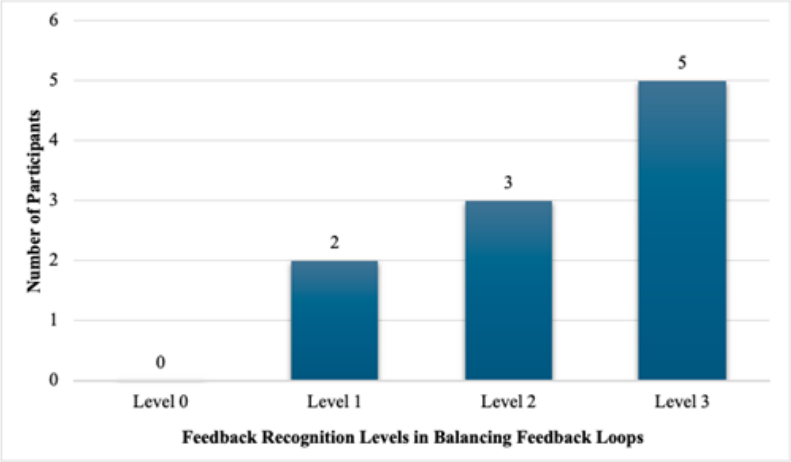


Figure 4.33. Participants' overall level of feedback recognition in the balancing feedback loops.

These results showed that, remarkably, the majority of participants both correctly matched the reinforcing feedback loops and provided appropriate explanations (Level 3). However, the second highest number of participants correctly matched the reinforcing feedback loops but provided incorrect or incomplete explanations (Level 2). The second highest number of participants both mismatched the reinforcing feedback loops and provided incorrect explanations (Level 1).

What is the feedback recognition level of senior pre-service middle school science teachers in reinforcing feedback loops? The Forest Fires Global Warming scenario and the Time Spent on Social Media and Social Media Addiction scenario are scenarios that involve reinforcing feedback loops. However, the former is a domain-specific scenario, while the latter is a domain-general scenario. People were presented with pictures of both scenarios and asked to explain whether the two pictures were similar or dissimilar. Responses were coded in the category identifying and explaining similar reinforcing feedback loops. Answers for a correct match with an adequate explanation are scored as Level 3. Answers for correct matches but incorrect or incomplete explanations are scored as Level 2.

Answers for both incorrect matches and incorrect explanations are scored as Level 1. Answers for no explanation are scored as Level 0. Table 4.22 shows the participants' explanations for the identification and explanation of reinforcing feedback loops and their feedback recognition levels according to the revised S-BI protocol scoring rubric (see Appendix E). The results revealed that regarding feedback recognition levels, P2, P4, P6, and P10 were at Level 3, P1, P3 and P8 were at Level 2, and P5, P7, and P9 were at Level 1.

Table 4.22. Feedback recognition level for reinforcing feedback loops.

Feedback Recognition Levels	**Explanations**	**Participants**
Level 3	As forest fires increase, so does global warming. As global warming increases, so do forest fires. This creates a cycle. As time spent on social media increases, addiction increases. As addiction increases, time spent naturally increases. The time spent also triggers the addiction. I think they are similar.	P2
Level 3	These two are similar. If we start with global warming, global warming increases forest fires. Forest fires also increase global warming. Here, as time spent on social media increases, addiction to it increases, and as addiction increases, time spent increases.	P4
Level 3	These two are similar. Why are they similar? Because as one increases, the other increases, supports each other and the process continues. A cycle is formed. As the time spent on social media increases, the level of addiction will increase, and as the level of addiction increases, the time spent will increase	P6

Table 4.22 Feedback recognition level for reinforcing feedback loops. (cont.)

Feedback Recognition Levels	**Explanations**	**Participants**
	even more. As global warming increases, forest fires will increase because global warming will cause them. As global warming increases, so will forest fires.	
Level 3	As forest fires increase, global warming increases because carbon dioxide emissions increase, but as global warming increases, it causes forest fires to increase. They are always in a relationship that increases as they increase. Similarly, as time spent on social media increases, it causes social media addiction. Once that addiction occurs, it comes back and increases the time spent on social media. Therefore, these two are **similar.**	P10
Level 2	As global warming increases, will forest fires increase? I think so. If time spent on social media increases, will social media addiction increase? I think so. So, the two are similar.	P1
Level 2	I think these are similar. I thought that forest fires and global warming and time spent on social media and social media addiction are in a cycle that is increasingly affecting each other.	P3
Level 2	I can say that Forest Fires and Social Media scenarios are similar. I can say this because of the damage people do to themselves. Forest fires and global warming damage the environment. In the scenario of time spent on social media and social media addiction, people damage their own system, that is, they disrupt their	P8

Table 4.22 Feedback recognition level for reinforcing feedback loops. (cont.)

Feedback Recognition Levels	**Explanations**	**Participants**
	own cycle, whether it is their ability to think or their ability to speak, they lose it over time.	
Level 1	The two are different. I think that forest fires and global warming trigger each other and increase each other gradually. I think it increases in direct proportion. Social media addiction and time spent on social media will increase in direct proportion at some point, and as one increases, the other will increase. However, there might be a change. After a while, it may become an inverse proportion with the effect of external factors.	P5
Level 1	The two are not the same. Forest fires increase as global warming increases. As social media addiction increases, time spent increases, but as time spent on social media increases, the addict may or may not increase.	P7
Level 1	The two are not the same. Forest fires and global warming have a very indirect relationship. Social media and addiction, on the other hand, are on an upward trajectory. The more time you spend on social media, the more you want to spend time on it. As the time you spend increases, the addiction will increase.	P9

Figure 4.34 shows the participants' overall level of feedback recognition in the reinforcing feedback loops. Most participants were at Level 3, followed equally by Level 1 and Level 3. No participant was at Level 0.

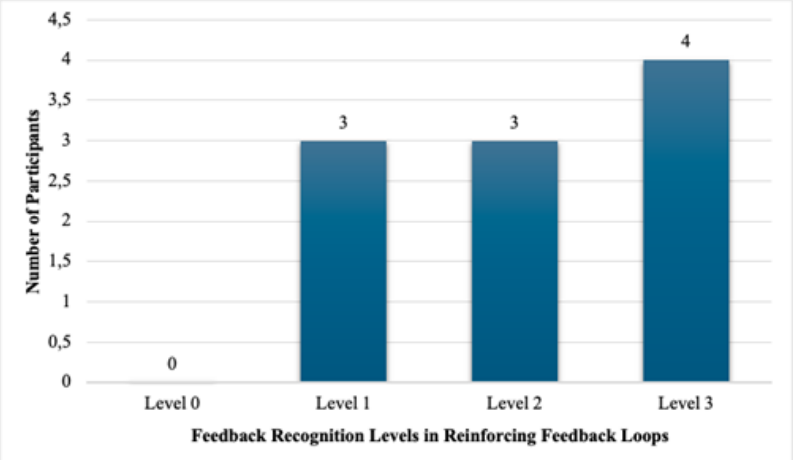


Figure 4.34. Participants' overall level of feedback recognition in the reinforcing feedback loops.

These results showed that most participants both correctly matched the reinforcing feedback loops and provided appropriate explanations (Level 3). These results indicated that the remaining participants either correctly matched reinforcing feedback loops but gave incorrect or incomplete explanations (Level 2) or mismatched both the reinforcing feedback loops and gave incorrect explanations (Level 1).

What is the feedback recognition level of pre-service middle school science teachers in the differences between balancing and reinforcing feedback loops? While the Sugar and Insulin scenario and the Demand and Price scenario involve balancing feedback loops, the Forest Fires and Global Warming scenario and the Time Spent on Social Media and Social Media Addiction scenario involve reinforcing feedback loops. Participants were presented with pictures of the scenarios and asked to explain whether the two pictures were similar or dissimilar. Responses were coded in the category identifying and explaining the difference between balancing feedback loops and reinforcing feedback loops. Level 3 scores are assigned for a correct match with an adequate explanation. Level 2 scores are assigned for correct matches but incorrect or incomplete explanations. Level 1 scores are assigned for both incorrect matches and incorrect explanations. Level 0 scores are assigned for no explanation. Table 4.23 shows the participants' explanations for identifying and explaining balancing and reinforcing feedback

loops and their feedback recognition levels corresponding to the revised S-BI protocol scoring rubric (see Appendix E). The words and phrases indicating positive relationships were colored red, and those indicating negative relationships were colored blue. The results revealed that regarding feedback recognition levels, P2, P4, P6, and P10 were at Level 3, P3, P5, P7, and P9 were at Level 2, and P1, and P8 were at Level 1.

Table 4.23. Participants' feedback recognition in feedback loops.

Feedback Recognition Levels	**Explanations**	**Participants**
Level 3	As the amount of sugar in the blood increases, the amount of insulin in the blood increases, so the amount of sugar in the blood decreases. I think there is such a loop. As social media addiction increases, the time spent on social media increases, but as the time spent increases, the addiction increases, but there is no decreasing effect here. In other words, I cannot say that as addiction increases, time decreases. **So I think these are different.**	P2
Level 3	The two are different because they do not feed each other. Firstly, as the amount of sugar in the blood increases, the amount of insulin in the blood increases, and as the amount of insulin in the blood increases, the amount of sugar in the blood begins to decrease. In other words, they work in opposite directions and balance each other out. But here, time spent on social media and social media addiction support each other, like feedback, when one increases, the other increases.	P4

Table 4.23 Participants' feedback recognition in feedback loops. (cont.)

Feedback Recognition Levels	**Explanations**	**Participants**
Level 3	I think they are different. As time spent on social media increases, social media addiction will increase. As the addiction increases, the time spent will increase. The amount of insulin in the blood will increase because the amount of sugar in the blood will increase, but as the amount of insulin in the blood increases, the amount of sugar in the blood will decrease. However, as the time spent on social media increases, the addiction will increase. In other words, there will not be a decrease similar to the amount of sugar in the blood due to the amount of insulin in the blood.	P6
Level 3	The two are different because as the amount of sugar in the blood increases, the amount of insulin in the blood increases, but as the amount of insulin in the blood increases, the amount of sugar in the blood decreases. As time spent on social media increases, social media addiction increases, and this addiction in turn increases time spent on social media. While there is an increasing relationship in the social media scenario, this is not the case in the sugar and insulin scenario.	P10
Level 2	These two images are different because they do not always have an effect that causes a continuous increase in each other, or vice versa, when looking at a decrease they do not always cause a decrease in both.	P3

Table 4.23 Participants' feedback recognition in feedback loops. (cont.)

Level 2	The two are different. If the amount of sugar in the blood increases, the amount of insulin in the blood increases. If the time spent on social media increases, the addiction to it increases. These two scenarios will increase in direct proportion up to a point. However, both can change. In other words, after a while they may become inversely proportional, which is related to the introduction of external factors.	P5
Level 2	The two are different because as the amount of sugar in the blood increases, insulin is released and the amount of insulin in the blood increases. Then, as the insulin in the blood increases, the sugar in the blood decreases. However, if the time spent on social media increases, we cannot say that social media addiction may increase or decrease.	P7
Level 2	The amount of sugar in the blood increases and the amount of insulin in the blood increases, then the amount of sugar in the blood decreases and the amount of insulin in the blood decreases. It stabilizes itself. Social media addiction depends on what the person is using it for. Using it for entertainment is different from using it for business. This is also a situation that varies according to age. So, these two **are different.**	P9
Level 1	I said that as the amount of sugar in the blood increases, the amount of insulin in the blood increases. As the	P1

Table 4.23 Participants' feedback recognition in feedback loops. (cont.)

Feedback Recognition Levels	**Explanations**	**Participants**
	time spent on social media increases, social media addiction increases. I think these two pictures are similar.	
Level 1	I think the scenario about the amount of sugar in the blood and the amount of insulin in the blood and the time spent on social media and the scenarios of social media addiction are similar because they both damage the human system. I likened them to systemic damage to oneself, like disrupting the cycle in nature. In the first case it is biological damage to the human being and in the second case it is damage to the human ability to think.	P8

Figure 4.35 shows the participants' overall level of feedback recognition in distinguishing between balancing and reinforcing feedback loops. Most of the participants were at Level 3 and Level 2. The remaining participants at Level 1, and no participants were found at Level 0.

These results showed that most participants could distinguish between balancing and reinforcing feedback loops and provided appropriate explanations (Level 3) or could distinguish between balancing and reinforcing feedback loops but unfortunately provided incorrect or incomplete explanations (Level 2). The remaining participants could not distinguish between balancing and reinforcing feedback loops and provided incorrect explanations (Level 1).

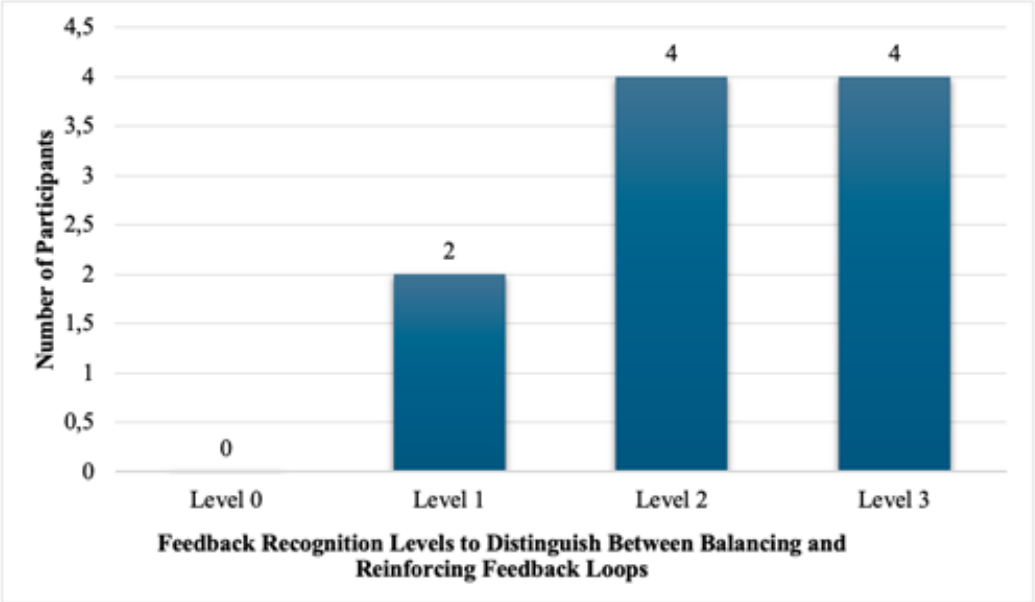


Figure 4.35. Participants' overall level of feedback recognition in distinguishing between balancing and reinforcing feedback loops.

4.4. Summary of Results

Table 4.24 shows participants' overall levels of feedback thinking before prompts in domain-specific and domain-general scenarios. When the table is interpreted in general, it can be summarized as the following results.

- Before any prompts were given, participants' feedback thinking level was higher in domain-specific scenarios than in domain-general scenarios.
- In the domain-specific scenarios, participants scored higher in the Sugar and Insulin scenario.
- In the domain-general scenarios, participants scored higher in the Time Spent on Social Media and Social Media Addiction scenario.

Table 4.24. Participants' overall levels of feedback thinking before prompts in domain-specific and domain-general scenarios.

	Domain-specific scenarios		**Domain-general scenarios**	
Participants	**Feedback Thinking Levels on Sugar and Insulin**	**Feedback Thinking Levels on Forest Fires and Global Warming**	**Feedback Thinking Levels on Demand and Price**	**Feedback Thinking Levels on Time Spent on Social Media and Social Media Addiction**
P1	Level 0	Level 1	Level 0	Level 1
P2	Level 3	Level 2	Level 1	Level 1
P3	Level 1	Level 2	Level 0	Level 1
P4	Level 1	Level 3	Level 1	Level 1
P5	Level 1	Level 1	Level 1	Level 1
P6	Level 3	Level 3	Level 1	Level 3
P7	Level 3	Level 0	Level 1	Level 0
P8	Level 1	Level 0	Level 1	Level 1
P9	Level 3	Level 0	Level 0	Level 0
P10	Level 3	Level 3	Level 0	Level 3

Table 4.25 shows participants' overall levels of feedback thinking after prompts in domain-specific and domain-general scenarios. When the table is interpreted in general, it can be summarized as the following results.

- After prompts were given, participants' feedback thinking level increased in both domain-specific scenarios and domain-general scenarios.
- In the domain-specific scenarios, participants raised their levels even higher in the Sugar and Insulin scenario and in the Forest Fires and Global Warming scenario.
- In the domain-general scenarios, participants were more able to increase their levels in the Time Spent on Social Media and Social Media Addiction scenario, but less able to increase their levels in the Demand and Price scenario.

Table 4.25. Participants' overall levels of feedback thinking after prompts in domain-specific and domain-general scenarios.

	Domain-specific scenarios		**Domain-general scenarios**	
Participants	**Feedback Thinking Levels on Sugar and Insulin**	**Feedback Thinking Levels on Forest Fires and Global Warming**	**Feedback Thinking Levels on Demand and Price**	**Feedback Thinking Levels on Time Spent on Social Media and Social Media Addiction**
P1	Level 0	Level 1	Level 0	Level 1
P2	Level 3	Level 3	Level 1	Level 3
P3	Level 2	Level 3	Level 0	Level 3
P4	Level 3	Level 3	Level 1	Level 3
P5	Level 3	Level 3	Level 1	Level 3
P6	Level 3	Level 3	Level 3	Level 3
P7	Level 3	Level 3	Level 2	Level 1
P8	Level 1	Level 2	Level 3	Level 3
P9	Level 3	Level 2	Level 0	Level 2
P10	Level 3	Level 3	Level 3	Level 3

4.4.1. Summary Results for Homological Reasoning

Table 4.26 shows participants' overall levels of homological reasoning in domain-specific and domain-general scenarios. When the table is interpreted in general, it can be summarized as the following results.

- Participants' homological reasoning level was higher in domain-general scenarios than in domain-specific scenarios.
- In the domain-specific scenarios, participants performed almost similarly in the Sugar and Insulin scenario, the Forest Fires and Global Warming scenario, and were scored at Level 1.

- In the domain-general scenarios, participants received higher scores in the Time Spent on Social Media and Social Media Addiction scenario.

Table 4.26. Participants' overall levels of homological reasoning in domain-specific and domain-general scenarios.

	Domain-specific scenarios		**Domain-general scenarios**	
Participants	**Homological Reasoning Levels on Sugar and Insulin**	**Homological Reasoning Levels on Forest Fires and Global Warming**	**Homological Reasoning Levels on Demand and Price**	**Homological Reasoning Levels on Time Spent on Social Media and Social Media Addiction**
P1	Level 1	Level 1	Level 1	Level 1
P2	Level 1	Level 1	Level 1	Level 1
P3	Level 3	Level 1	Level 1	Level 2
P4	Level 1	Level 1	Level 3	Level 2
P5	Level 1	Level 1	Level 1	Level 2
P6	Level 1	Level 2	Level 3	Level 4
P7	Level 3	Level 1	Level 2	Level 1
P8	Level 1	Level 1	Level 1	Level 2
P9	Level 1	Level 0	Level 3	Level 1
P10	Level 2	Level 1	Level 1	Level 3

4.4.2. Summary Results for Feedback Recognition

Table 4.27 shows participants' overall levels of feedback recognition in domain-specific and domain-general scenarios. When the table is interpreted in general, it can be summarized as the following result.

- Participants generally scored the same on all three feedback recognition questions. In other words, most participants scored the same on feedback recognition for

balancing feedback loops, feedback recognition for reinforcing feedback loops, and feedback recognition for distinguishing between balancing and reinforcing feedback loops.

- Participants generally scored Level 2 and Level 3 on all three feedback recognition questions. Table 35. Participants' overall levels of feedback recognition in domain-specific and domain-general scenarios

Table 4.27. . Participants' overall levels of feedback recognition in domain-specific and domain-general scenarios.

Participants	**Feedback recognition in balancing feedback loops**	**Feedback recognition in reinforcing feedback loops**	**Feedback recognition in distinguishing between balancing and reinforcing feedback loops**
P1	Level 2	Level 2	Level 1
P2	Level 3	Level 3	Level 3
P3	Level 2	Level 2	Level 2
P4	Level 3	Level 3	Level 3
P5	Level 1	Level 1	Level 2
P6	Level 3	Level 3	Level 3
P7	Level 3	Level 1	Level 2
P8	Level 2	Level 2	Level 1
P9	Level 1	Level 1	Level 2
P10	Level 3	Level 3	Level 3

5. DISCUSSION

This section presents the discussion under three main sections - Feedback Thinking, Homological Reasoning, and Feedback Recognition-to answer the research questions in detail.

5.1. Feedback Thinking

In science education, the goal is for students to be able to identify the parts of a system, to understand the relationships, interrelationships, interconnections, and feedback between the parts, and to develop systems thinking skills that demonstrate this understanding (Evagorou *et al.*, 2009). Stave and Hopper (2007) define the recognition of interrelationships, the identification of feedback, and the understanding of dynamic feedback as foundational systems thinking skills. It is critical for teachers to have these fundamental systems thinking skills in order for students to acquire these skills. However, in this study, before any guiding questions were given, it was evident that participants' feedback thinking skills, one of the core systems skills, were limited. Participants often focused on simple causal and unidirectional relationships in the system scenarios presented, demonstrating a static understanding of change and ignoring the dynamics of balancing and reinforcing feedback loops (e.g., Sweeney and Sterman, 2007).

The results of this study are similar to the results of Sweeney and Sterman's (2007) research with middle school students and teachers, where both groups of participants were shown to have limited ability to recognize the feedback structure in a system. These findings also support the argument in several studies that individuals have difficulty developing systems thinking skills (Ben-Zvi Assaraf and Orion, 2005; Jacobson, 2001; Mambrey *et al.*, 2020; Sweeney and Sterman, 2007). The results of the present study also showed that although the participants had strong science and mathematics backgrounds, they had limited systems thinking skills. These findings

are similar to those reported in many studies that show that even well-trained adults perform poorly on tasks that measure systems thinking skills (e.g., Palmberg *et al.*, 2017; Plate and Monroe, 2014; Sweeney and Sterman, 2000).

The current study showed that when participants were asked additional guiding questions, their level of feedback thinking increased in both domain-specific and domain-general scenarios. These findings are valuable because they show that even adults who have not taken a systems thinking course, but who have reasoning skills due to their higher education, can recognize the balancing and reinforcing feedback loops in scenarios presented in a guided way. Therefore, the use of guiding questions can be an effective way to equip people with systems thinking skills (Sterman, 2000).

A comparison of participants' performance on feedback loops in domain-specific and domain-general scenarios revealed that participants had higher levels of feedback thinking in domain-specific scenarios. This finding supported the idea that people may perform better when analyzing complex systems in contexts they are familiar with, i.e., their domain of expertise, than in unfamiliar contexts, i.e., contexts in which they are not experts (Simon, 1986; Sweeney and Sterman, 2000). Similarly, Hmelo-Silver and Pfeffer's (2004) study of representations of water systems found that experts' understanding of functions and behaviors in systems was higher than that of middle school students and preservice teachers, and middle school students and preservice teachers had similar understanding. Lavi and Dori (2019) stated that in tasks given to groups of teachers to assess systems thinking, science and engineering teachers tend to choose topics in their areas of expertise because of their familiarity. The results of this study differed from the results of Hmelo-Silver *et al.*'s (2007) study, in which they found little difference in terms of systems structure between expert and novice groups on the human respiratory system and the aquarium ecosystem.

Participants should be able to further increase their level of feedback thinking, especially in the Sugar and Insulin and Forest Fires and Global Warming scenarios from their own discipline because they teach biological dynamics and environmental

dynamics to students. It is also very important for them to see the feedback loops underlying complex dynamic systems such as the environment, especially as they contribute to the sustainability of the world by teaching environmental issues to students. For individuals to be trained as systems thinkers, it is not enough to increase their domain knowledge alone; it would be useful to provide them with systems thinking training that shows them how to apply their knowledge (Monroe *et al.*, 2015). For instance, Sweeney and Sterman (2000) showed that participants did not understand system dynamics in the bathtub and bank account system tasks, in which they had both experience and knowledge.

We recommend empowering individuals with systems thinking skills, both in knowledge and practice. For example, Ceyhan and Budak (Under Review) concluded in a study that pre-service middle school science and mathematics students were able to practice the new knowledge they learned using systems dynamics tools and improve their dynamic and feedback thinking skills in a systems thinking course that focused on Sustainable Development Goals (SDGs). Thus, faculties of education can play an important role in building a more sustainable society by providing students with both content knowledge and practice in environmental issues, which is one of the complex issues.

In the domain-general scenarios, participants scored higher on the Time Spent on Social Media and Social Media Addiction scenarios than on the Demand and Price scenarios. When participants were asked about their familiarity with these contexts, they generally stated that they were familiar with the first scenario because they use social media in their daily lives, while they were not familiar with the second scenario because they did not take economics courses but had shopping experiences from their daily lives. Since the participants in this study clearly stated that they were familiar with the economic context from their daily lives, the fact that they received the lowest scores in the demand and price scenarios can be interpreted as their lack of basic financial literacy. Similarly, Luo *et al.* (2021) conducted a study to examine the systems thinking skills of expert engineers and novice engineering students and found that

expert engineers performed better than novice engineers due to their limited knowledge. Therefore, we recommend that curricular efforts should be made to ensure that individuals become financially literate at a basic level.

5.2. Homological Reasoning

Understanding similar structures in feedback loops and transferring them across domains is one of the most important systems skills (Sweeney, 2004). Kim (1992) referred to this homological reasoning skill, or systems archetypes, as capturing common patterns that recur in different domains of systems dynamics. Capturing and reflecting on common patterns across disciplines is critical to making fundamental changes in complex systems problems. In the General Systems Theory, the biologist von Bertalanffy (1968) argued that analogies are not useful to individuals because they do not provide similarities in terms of causal factors, but that homologies, i.e., understanding causal factors in different complex systems, are very useful.

This study found that participants' homological reasoning skills were generally limited in both domain-specific and domain-general scenarios. These findings are recalled by Sweeney's (2005) example of wolves and rabbits in support of von Bertalanffy's (1968) views. Individuals may use analogy to say that wolves and rabbits and lynx and hares are similar in the sense that they are mammals, but without homological reasoning, individuals tend to overlook that these animal pairs are an important part of the predator-prey relationship in a complex ecosystem. These findings support Monroe *et al.*'s (2015) view that people fail to understand homologous structures in complex systems, both in social and natural systems that we face in everyday life. The results of this study are similar to those of a study of middle school students and teachers, which showed that both middle school teachers and their students were weak at exemplifying similar feedback loops in presented scenarios through homological reasoning across domains (Sweeney and Sterman, 2007). In a more recent study similar to these findings, Gilissen *et al.* (2020) concluded in a study with high school biology students that participants had difficulty transferring feedback loops to different contexts.

In this study, participants were assumed to be familiar with the biological system dynamics emphasized in the Sugar and Insulin scenario and the environmental dynamics emphasized in the Forest Fires and Global Warming scenario. However, when comparing domain-specific and domain-general scenarios, participants' homological reasoning skills were slightly higher in the domain-general scenarios than in the domain-specific scenarios. Therefore, the results of this study differed from Sweeney and Sterman's (2000) idea that people perform better on system tasks with which they are familiar than on system tasks with which they are unfamiliar.

The inability of participants to provide homology examples of balancing and reinforcing feedback loops for domain-specific scenarios they are familiar with can be related to two reasons from the literature. First, as stated in other studies, the reason why individuals cannot transfer the knowledge in the domains in which they are experts to different domains may be due to the participants' lack of domain-specific knowledge (e.g., Douvdevany *et al.*, 1997). Second, in Dunnet and Lundmark's (2024) study of earth science teachers, students' inability to apply their knowledge of buoyancy in physics to isostasy in earth science may be due to their lack of prior knowledge in disciplines in which they are not experts.

Boersma *et al.* (2011) noted that due to the complex nature of biological systems, understanding requires higher-order thinking, which can be enhanced through scaffolding. For this reason, Glissen *et al.* (2020) emphasized the importance of students practicing reasoning, especially in system dynamics presented from biological contexts. Given that one of the domain-specific scenarios, the Sugar and Insulin scenario, involves biological systems, the literature suggests that individuals' higher-order thinking in biological contexts should be further explored and they should be given more room, activities, and scaffolding in educational environments where they can reason.

When the domain-specific and domain-general scenarios were evaluated, participants scored highest on homological reasoning in the domain-general scenario of Time

Spent on Social Media and Social Media Addiction. All participants also indicated that they were very active users of social media in their daily lives. Participants usually provided correct homology examples from the context of the scenario presented, i.e., the domain of addiction, such as chocolate addiction, drug addiction, and smoking addiction. Thus, participants were able to transfer the reinforcing feedback loop in the presented scenario from a domain they were familiar with and practiced in to contexts we frequently encounter in everyday life. These results showed that people have the potential to transfer similar homologous structures across systems, as suggested by Forrester (1992).

In terms of homological reasoning, the participants scored lowest on the scenario of Forest Fires and Global Warming, which is related to environmental dynamics. Except for one person, no one was able to give a correct homology example from this scenario, which involves reinforcing feedback loops. These findings are particularly alarming for the participants in this study, who are pre-service middle school science teachers, because students are learning about the environment and ecology for the first time in science class. The ability to see repeatedly observed behaviors in dynamic systems is valuable in helping individuals recognize the dynamics between actions and outcomes and take precautions, especially in complex problems such as environmental problems (Hallett and Hobbs, 2020). Moallemi *et al.* (2022) argued that to fully understand the Sustainable Development Goals (SDGs), it is important to look at recurrent structures to understand the underlying causal factors, policy implications, and complex interactions among the SDGs. Therefore, individuals' understanding and reasoning about underlying causality and systems feedbacks are seen as effective interventions for their actions to solve ecosystem problems (Hallett and Hobbs, 2020).

5.3. Feedback Recognition

Recognizing feedback loops is one of the most important systems thinking skills (Sweeney, 2004). Systems thinkers should be able to distinguish between balancing and reinforcing feedback loops and explain the underlying dynamics of systems (Arnold

and Wade, 2017). In this study, both domain-specific and domain-general scenarios included balancing and reinforcing feedback loops. Participants were mostly able to recognize the balancing and reinforcing feedback loops in the systems, but were unable to provide an appropriate explanation. Therefore, it was found that the participants in this study had limited levels of feedback recognition. Similarly, Sweeney and Sterman (2007) showed in their study of middle school students and their teachers that they had limited ability to recognize the balancing and reinforcing feedback processes in the scenarios presented. Similarly, Wellmanns and Schmiemann (2022) found that high school students focused on incomplete and indirect cause-and-effect relationships when investigating the regulation of blood glucose, one of the biological systems. Several studies have reported that elementary school students (e.g., Hokayem, 2012) and even undergraduates (e.g., Hokayem *et al.*, 2015; Jacobson and Wilensky, 2006) had and continue to have difficulty recognizing feedback loops (Wellmanns and Schmiemann, 2022).

Many researchers have found that people overwhelmingly understand that changes in systems have a single cause (e.g., Plous, 1993) and focus on applying simple causality (e.g., Jacobson, 2001). As Jacobson (2001) noted, participants in this study often focused on unidirectional relationships when explaining the similarities and differences of feedback loops and were unable to close the feedback loops. Thus, the present study showed that participants' responses had difficulty recognizing the dynamics in systems and focused on static changes. Similarly, Hogan (2000), studying food web disruption and the effects of pollutants in ecosystems, reported that young students were able to identify one-way linear relationships in ecosystem dynamics but were unable to close feedback loops. However, the results of this study contradict Jacobson's (2001) argument that experts tend to use multiple causation in familiar contexts while novices tend to use simple causation, because the participants in this study did not achieve higher feedback recognition scores in scenarios presented from domain-specific than from domain-general scenarios.

The reasons for individuals' inability to recognize feedback loops may be due to their inability to analyze the connections and processes in complex systems (Jacobson, 2001) or their tendency to show a deep-rooted resistance to understanding the variables and processes in complex systems (Resnick, 1994). Another reason may be the lack or inadequacy of individual content knowledge. In this study, pre-service science teachers were able to distinguish between balancing and reinforcing feedback loops in domain-specific scenarios involving biological system dynamics and environmental system dynamics. However, they mentioned unidirectional linear relationships as described in the literature (e.g., Sweeney and Sterman, 2007; Wellmanns and Schmiemann, 2022). Similarly, Douvdevany *et al.* (1997) reported in their study of the living cell, which was familiar to secondary school science teachers, that they were unable to make connections between some basic concepts and had little understanding of feedback loops.

Plous (1993) explained that individuals often think that they have shown sufficient understanding once they have found a reason and therefore have a tendency to stop reasoning. It is noted that more scaffolding is needed for individuals to acquire feedback recognition skills (Jordan *et al.*, 2023). For this reason, we recommend educational interventions at an early age to develop people's systems thinking skills and suggest that educational policies should be designed to equip students with systems thinking skills at all levels of education, from primary school to university.

5.4. Implications

This study provides several important empirical evidence and contributions to the field of systems thinking in science education. First and foremost, unfortunately, the participants' systems thinking skills were low, and these findings suggest that teacher education programs in particular should include various opportunities and activities for pre-service teachers to engage in systems thinking practices to improve their systems thinking skills. Second, participants were able to increase their level of feedback thinking in both domain-specific and domain-general scenarios after being given guiding questions, whereas they scored higher in domain-specific scenarios before being

given guiding questions. These results are a strong indication of how appropriate and effective prompting questions can have a major impact on the teaching of systems thinking. Therefore, these findings once again emphasize the need for guiding questions in systems thinking practice. Third, the scenario in which participants scored the lowest was the Demand and Price scenario, indicating that these individuals have poor financial literacy, which is considered a basic requirement. These results suggest that efforts should be made to improve the basic economic literacy of teachers who will be educating future citizens.

5.5. Limitations

This thesis has several limitations. The first limitation is that this study was conducted with 10 out of 30 senior pre-service middle school science teachers at a state university. Therefore, the results are limited to this sample group and cannot be generalized. The second limitation is that the participants were selected from senior pre-service middle school science teachers at one of the leading universities in Turkey, and therefore the characteristics of the participants were similar. As in Sweeney and Sterman's (2000) study, the participants in this study had a very strong background in mathematics and science compared to other universities. Therefore, the results of the study should not mislead the readers because the participants in the study are students with much higher than average knowledge. Accordingly, another limitation is that this study does not provide findings on pre-service teachers with low and medium backgrounds in mathematics and science. The third limitation is that the selection of participants was done through convenience sampling, which is a random sampling method. Therefore, although this study aimed to provide data from highly educated pre-service teachers, it was limited to one university from one region in the research country. Therefore, the results of the study are not representative of this group. The last limitation is that although the revised S-BI protocol in this study was prepared by taking the opinions of one expert in systems thinking and two experts in systems thinking in science education, a pilot study was conducted with a limited number of people.

5.6. Recommendations for Future Research

The purpose of this study was to determine the level of feedback thinking, homological reasoning, and feedback recognition of pre-service middle school science teachers through domain-specific and domain-general scenarios. First, the participant group in this study consisted of pre-service middle school science teachers. In future studies, the S-BI protocol can be administered to first, second, and third year pre-service middle school teachers to compare the differences in their systems thinking skills. In addition, the participants in this study could not be limited to pre-service teachers, but could be expanded to include in-service teachers. Thus, a comparison can be made between the two groups. In addition, the participants in this study can be expanded beyond middle school science teachers to include pre-service and in-service teachers of physics, chemistry, and biology. Thus, it can provide rich data for curriculum studies by revealing the level of feedback thinking, homological reasoning, and feedback recognition of pre-service and in-service teachers in different branches of science. In addition, the familiarity of individuals from different branches of science education with domain-specific and domain-general scenarios can be revealed. Thus, their systems thinking skills in domain-specific scenarios can provide insight into their content knowledge (CK), as experts are expected to use multiple causality in the topics with which they are familiar.

It is recommended that the S-BI protocol, the data collection tool used in this study, be used in a larger population for further validation studies. In addition, when evaluating the content of the S-BI protocol, the domain-specific scenarios are Sugar and Insulin and Forest Fires and Global Warming. The former is from the biology context and the latter is from the environmental context. Considering that science teachers teach physics, chemistry, biology, and environmental contexts to their students and are familiar with these contexts, it is meaningful to add scenarios from physics and chemistry contexts to the revised S-BI protocol. Thus, more empirical data on middle school science teachers' familiarity with feedback dynamics can be obtained by comparing systems thinking skills in these four contexts. The domain-general scenarios

in the S-BI protocol are Demand and Price and Time Spent on Social Media and Social Media Addiction. The former is from an economic context, while the latter is from a social media context. These two scenarios are used in this study because they are considered to reflect universal themes. However, universal themes are not limited to these two contexts, and therefore it is recommended that universal themes from different contexts be added to the S-BI protocol to more comprehensively assess participants' familiarity with universal themes and systems thinking skills. Finally, we recommend using various techniques to elicit deeper responses from participants, such as think-aloud protocols.

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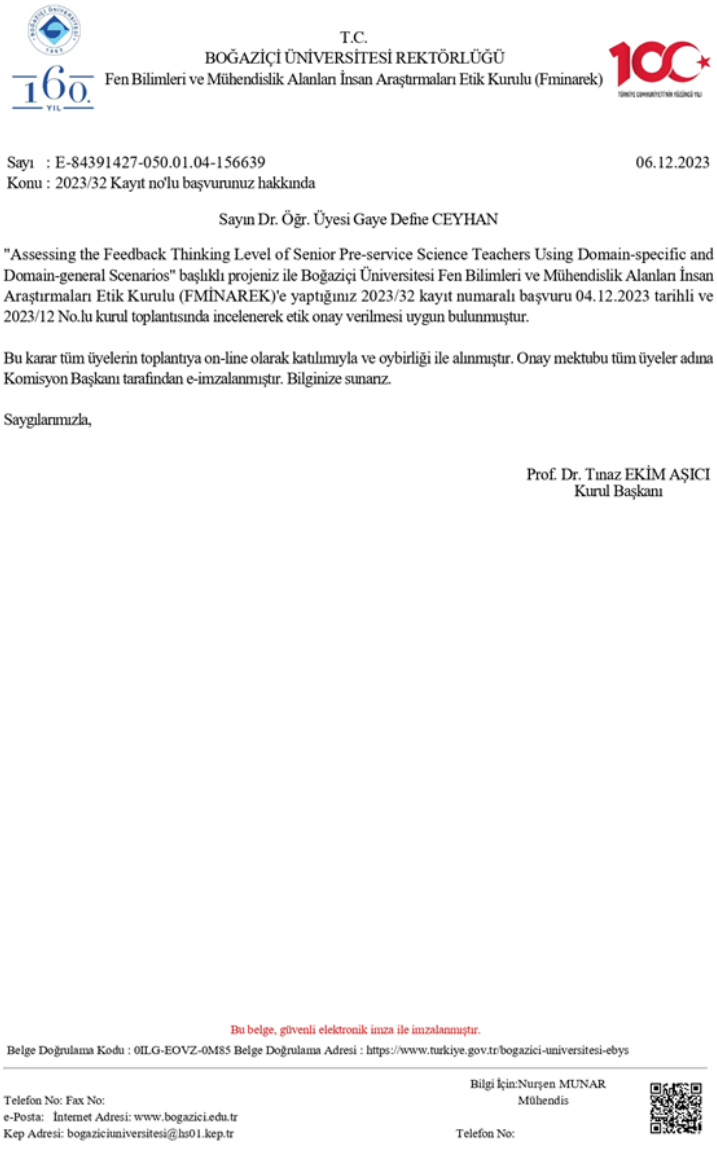
APPENDIX A: INSTITUTIONAL ETHICAL APPROVAL FROM BOGAZİCİ UNIVERSITY

Ethical approval was obtained from Boğaziçi University.



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

Sayı : E-84391427-050.01.04-156639 06.12.2023
Konu : 2023/32 Kayıt no'lu başvurunuz hakkında

Sayın Dr. Öğr. Üyesi Gaye Defne CEYHAN

"Assessing the Feedback Thinking Level of Senior Pre-service Science Teachers Using Domain-specific and Domain-general Scenarios" başlıklı projeniz ile Boğaziçi Üniversitesi Fen Bilimleri ve Mühendislik Alanları İnsan Araştırmaları Etik Kurulu (FMİNAREK)'e yaptığınız 2023/32 kayıt numaralı başvuru 04.12.2023 tarihli ve 2023/12 No.lu kurul toplantısında incelenerek etik onay verilmesi uygun bulunmuştur.

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

Saygılarımızla,

Prof. Dr. Tınaz EKİM AŞICI
Kurul Başkanı

Bu belge, güvenli elektronik imza ile imzalanmıştır.
Belge Doğrulama Kodu : 0ILG-EOVZ-0M85 Belge Doğrulama Adresi : https://www.turkiye.gov.tr/bogazici-universitesi-ebys

Bilgi İçin:Nurşen MUNAR
Mühendis

Telefon No: Fax No:
e-Posta: İnternet Adresi: www.bogazici.edu.tr
Kep Adresi: bogaziciuniversitesi@hs01.kep.tr

Telefon No:

Figure A.1. Ethics committee.

APPENDIX B: INFORMED CONSENT FORM

An example of a consent form is shown below.

T.C. BOĞAZİÇİ ÜNİVERSİTESİ
FEN BİLİMLERİ VE MÜHENDİSLİK ALANLARI
İNSAN ARAŞTIRMALARI ETİK KURULU
KATILIMCI BİLGİ ve ONAM FORMU
Araştırmayı destekleyen kurum: Boğaziçi Üniversitesi
Araştırmanın adı: Fen Bilgisi Öğretmen Adaylarının Geri Bildirim Duşunme Duzeylerinin Alana Özgu ve Alana Özgu Olmayan Senaryolar Kullanılarak Değerlendirilmesi
Proje Yurutucusu/Araştırmacının adı: Yuksek lisans tez öğrencisi Ülku Seher Budak, Dr. Öğretim uyesi Gaye Defne Ceyhan
Adresi: Boğaziçi Üniversitesi Kuzey Kampus ETA B 414, 34342 Bebek, İstanbul
E-mail adresi: ulku.budak@boun.edu.tr,gaye.ceyhan@boun.edu.tr
Sayın Fen Bilimleri Öğretmeni Adayları,

Boğaziçi Üniversitesi Matematik ve Fen Bilimleri Eğitimi yuksek lisans öğrencisi Ülku Seher Budak tarafından Boğaziçi Üniversitesi Matematik ve Fen Bilimleri Eğitimi Bölumu Dr. Öğretim Üyesi Gaye Defne Ceyhan danışmanlığında "Fen Bilgisi Öğretmen Adaylarının Geri Bildirim Duşunme Duzeylerinin Alana Özgu ve Alana Özgu Olmayan Senaryolar Kullanılarak Değerlendirilmesi" adlı bilimsel bir araştırma yurutulmektedir. Bu araştırmada fen bilimleri öğretmen adaylarının geri-bildirim duşunme duzeylerini alana özgu ve alana özgu olmayan senaryolar aracılığıyla belirlemeyi amaçlamaktayız. Bu bilimsel araştırmada bize yardımcı olmanız için fen bilimleri öğretmenleri adaylarını araştırmamıza davet ediyoruz. Kararınızdan önce araştırma hakkında sizi bilgilendirmek istiyoruz. Bu bilgileri okuduktan sonra araştırmaya katılmak istiyorsanız, lutfen onay formundaki "EVET" ifadesini yuvarlak içerisine alınız.

Bu araştırmaya katılmaya katılmayı kabul ettiğiniz takdirde uygunluk durumunuza göre görüşmenin gerçekleşeceği gun ve saat belirlenecektir. Belirlenen gun ve saatte sizlerle ZOOM uygulaması uzerinden çevrimiçi bireysel görüşmeler gerçekleştireceğiz. Bu görüşmelerde size alana özgu ve alana özgu olmayan senaryolar sunacağız ve bu senaryolar hakkında size sunulan senaryolardaki sistemleri duşunmenizi sorular soracağız. Bu görüşmelerde vereceğiniz cevaplar araştırma verisi olarak kullanılacaktır. Çevrimiçi bireysel görüşmelerin yaklaşık 40 dakika ile 1 saat arasında surmesi beklenmektedir.

Çevrimiçi bireysel görüşmelerde vereceğiniz cevapların araştırma verisi olarak kullanılacağını hatırlatmak isteriz. Bu görüşmelerde araştırmacıların verileri analiz edebilmesi amacıyla görüşmenin video kaydı alınacaktır. Bu çalışmada katılımcı bilgilerinin gizliliği esas alınacaktır ve verileriniz bilimsel bir araştırmada kullanılacaktır. Araştırma tamamlandıktan sonra görüşmelerin video kayıtları araştırmacının kilitli hard diskinde muhafaza edilecek ve araştırmacılar dışında verileriniz kesinlikle uçuncu kişilerle paylaşılmayacaktır. Bu araştırmaya katılım tamamen gönulluluk esasına dayanmaktadır. Bu çalışmaya katıldığınız takdirde herhangi bir ucret veya bir ödul almayacağınızı belirtmek isteriz. Araştırmanın sizin için bir risk oluşturması beklenmemektedir. Çalışmaya katıldığınız takdirde çalışmanın herhangi bir aşamasında herhangi bir sebep göstermeden onayınızı çekme hakkına sahipsiniz. Çalışmadan çekilmek istediğinizde verileriniz tamamen silinecektir ve hiçbir yerde paylaşılmayacaktır.

Araştırma hakkında ek bilgi almak isterseniz lutfen Boğaziçi Üniversitesi Matematik ve Fen Bilimleri Eğitimi Bölumu Öğretim Üyesi Dr. Gaye Defne Ceyhan (e-mail: gaye.ceyhan@boun.edu.tr, Adres: Boğaziçi Üniversitesi, Kuzey Kampus ETA B 414, Bebek, İstanbul) veya yuksek lisans öğrencisi Ülku Seher Budak (e-mail: ulku.budak@boun.edu.tr) ile iletişime geçiniz. Ayrıca, bu araştırmadaki haklarınız hakkında daha fazla bilgi almak için Boğaziçi Üniversitesi Fen Bilimleri ve Muhendislik Alanları İnsan Araştırmaları Etik Kurulu'na (fminarek@boun.edu.tr) da danışabilirsiniz. Eğer bu araştırmaya katılmayı kabul ediyorsanız, lutfen bu formu imzalayıp araştırmacıya e-mail (ulku.budak@boun.edu.tr) yoluyla gönderiniz.

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

Bu koşullarda söz konusu araştırmaya kendi isteğimle, hiçbir baskı ve zorlama olmaksızın gönüllü olarak katılmayı ve yapılacak görüşmenin video kaydının alınmasını kabul ediyorum.

EVET / HAYIR

Formun bir örneğini aldım / almak istemiyorum (bu durumda araştırmacı bu kopyayı saklar).

Katılımcının

Adı-.....

Soyadı:.....

İmzası:.....

Adresi (varsa Telefon No, Faks No): .....

.....

Tarih (gün/ay/yıl):...../...../.....

Araştırmacının Adı-Soyadı: Ülkü Seher Budak

İmzası:.....

.....

Tarih (gün/ay/yıl):...../...../.....

APPENDIX C: SYSTEMS - BASED INQUIRY (S-BI) PROTOCOL (ENGLISH VERSION)

Below is the English version of the S-BI protocol.

Systems - Based Inquiry (S-BI) Protocol

(This protocol was adapted from the Sweeney and Sterman (2007) study to fit the purpose and context of this study).

PART I. Feedback Dynamics

A. Sugar and Insulin

Say: Let's think about the relationship between the amount of sugar in the blood and the amount of insulin in the blood.

(i) What do you think about the relationship between the amount of sugar in the blood and the amount of insulin in the blood? Please explain.

(ii) How might the amount of sugar in the blood and the amount of insulin in the blood be interrelated? Please explain.

(iii) What do you think will happen to the amount of sugar in the blood and the amount of insulin in the blood over time? Please explain.

(iv) If the amount of sugar in the blood increases, what will happen to the amount of insulin in the blood? Please explain.

(v) If the amount of insulin in the blood increases, what will happen to the amount of sugar in the blood? Please explain.

(vi) Can you think of other situations where such a relationship might exist? Please explain.

B. Forest Fires and Global Warming Say: Let's think about the relationship between forest fires and global warming.

(i) What do you think about the relationship between forest fires and global warming? Please explain.

(ii) How might forest fires and global warming be interrelated? Please explain.

(iii) What do you think will happen to forest fires and global warming over time? Please explain.

(iv) If the number of forest fires increases, what will happen to global warming? Please explain.

(v) If global warming increases, what will happen to the number of forest fires? Please explain.

(vi) Can you think of other situations where such a relationship might exist? Please explain.

C. Demand and Price Preliminary Question: Have you ever taken an economics course? If you have taken an economics course, can you briefly describe its content? Say: Let's think about the relationship between the demand for a product and its price. However, when considering this relationship, let us assume there are enough products to satisfy demand.

(i) What do you think about the relationship between the demand for a product and its price? Please explain.

(ii) How might the demand for a product and its price be interrelated? Please explain.

(iii) What do you think will happen to the demand for a product and its price over time? Please explain.

(iv) If the demand for a product increases, what will happen to the price of that product? Please explain.

(v) If the price of a product increases, what will happen to the demand for that product? Please explain.

(vi) Can you think of other situations where such a relationship might exist? Please explain.

D. Time Spent on Social Media and Social Media Addiction Preliminary Question: Do you use social media? If you use social media, how often do you use it?

Say: Let's think about the relationship between time spent on social media and social media addiction.

(i) What do you think about the relationship between time spent on social media and social media addiction? Please explain.

(ii) How might time spent on social media and social media addiction be interrelated? Please explain.

(iii) What do you think will happen to time spent on social media and social media addiction over time? Please explain.

(iv) If time spent on social media increases, what will happen to social media addiction? Please explain.

(v) If social media addiction increases, what will happen to the time spent on social media? Please explain.

(vi) Can you think of other situations where such a relationship might exist? Please explain.

PART II. Comparison of Loop Dynamics

(i) Participants are shown four pictures (see below) and asked the following question without reference to any of the pictures: Which of the following visuals do you think are similar or different in terms of the situations shown? Please explain.

Prompting Questions:

(i) Referring to the two pictures of the balancing feedback loop, participants are asked the following question: Do you think these are similar or different in terms of the relationships shown?

(ii) Referring to the two pictures of the reinforcing feedback loop, participants are asked the following question: Do you think these are similar or different in terms of the relationships shown? Why?

(iii) Referring to the pictures of a reinforcing feedback loop and a balancing feedback loop, participants are asked the following question: How are these two similar or different in terms of the relationships shown? Why?

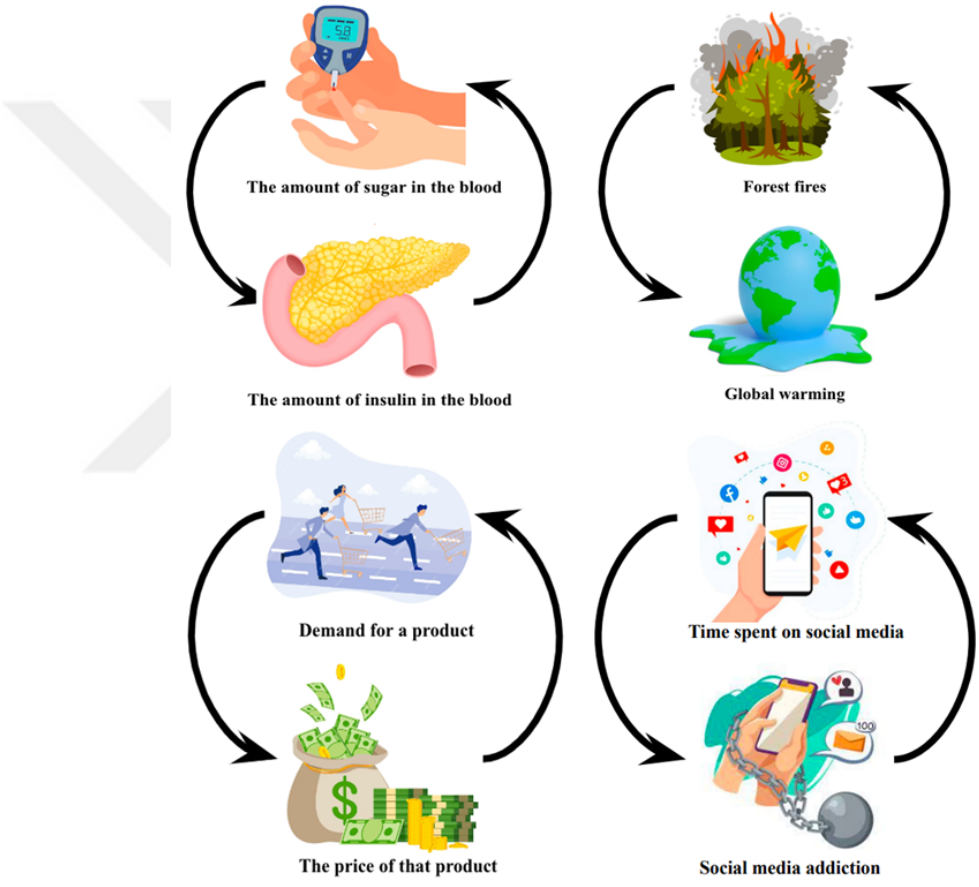


Figure C.1. Visuals in the revised English S-BI protocol.

APPENDIX D: SYSTEMS - BASED INQUIRY (S-BI) PROTOCOL (TURKISH VERSION)

S-TS protokolünün Türkçe versiyonu aşağıda yer almaktadır.

Sistem Tabanlı Sorgulama (STS) Protokolü

(Bu protokol, Sweeney ve Sterman'ın (2007) çalışmasından bu çalışmanın amacına ve bağlamına uyacak şekilde uyarlanmıştır).

BÖLÜM I. Geri Bildirim Dinamikleri A. Şeker ve İnsülin Söyle: Kandaki şeker miktarı ile kandaki insülin miktarı arasındaki ilişkiyi düşünelim.

(i) Kandaki şeker miktarı ile kandaki insülin miktarı arasındaki ilişki hakkında ne düşünüyorsunuz? Lütfen açıklayınız.

(ii) Kandaki şeker miktarı ile kandaki insülin miktarı birbiriyle nasıl ilişkili olabilir? Lütfen açıklayınız.

(iii) Zaman içerisinde kandaki şeker miktarına ve kandaki insülin miktarına ne olacağını düşünüyorsunuz? Lütfen açıklayınız.

(iv) Kandaki şeker miktarı artarsa, kandaki insülin miktarı ne olur? Lütfen açıklayınız.

(v) Kandaki insülin miktarı artarsa, kandaki şeker miktarı ne olur? Lütfen açıklayınız.

(vi) Böyle bir ilişkinin var olabileceği başka durumlar düşünebiliyor musunuz? Lütfen açıklayınız.

B. Orman Yangınları ve Küresel Isınma Söyle: Orman yangınları ve küresel ısınma arasındaki ilişkiyi düşünelim.

(i) Orman yangınları ve küresel ısınma arasındaki ilişki hakkında ne düşünüyorsunuz? Lütfen açıklayınız.

(ii) Orman yangınları ve küresel ısınma birbiriyle nasıl ilişkili olabilir? Lütfen açıklayınız.

(iii) Zaman içerisinde orman yangınları ve küresel ısınmaya ne olacağını düşünüyorsunuz? Lütfen açıklayınız.

(iv) Orman yangınları artarsa, küresel ısınmaya ne olur? Lütfen açıklayınız.

(v) Küresel ısınma artarsa, orman yangınlarına ne olur? Lütfen açıklayınız.

(vi) Böyle bir ilişkinin var olabileceği başka durumlar düşünebiliyor musunuz? Lütfen açıklayınız.

C. Talep ve Fiyat Ön Soru: Hiç ekonomi dersi aldınız mı? Ekonomi dersi aldıysanız, içeriğini kısaca anlatabilir misiniz? Söyle: Bir ürüne olan talep ve o ürünün fiyatı arasındaki ilişkiyi düşünelim. Bu ilişkiyi göz önünde bulundururken, talebi karşılayabilecek yeteri kadar ürün olduğunu varsayalım.

(i) Bir ürüne olan talep ve o ürünün fiyatı arasındaki ilişki hakkında ne düşünüyorsunuz? Lütfen açıklayınız.

(ii) Bir ürüne olan talep ve o ürünün fiyatı birbiriyle nasıl ilişkili olabilir? Lütfen açıklayınız.

(iii) Zaman içerisinde bir ürüne olan talep ve o ürünün fiyatına ne olacağını düşünüyorsunuz? Lütfen açıklayınız.

(iv) Bir ürüne olan talep artarsa, o ürünün fiyatına ne olur? Lütfen açıklayınız.

(v) Bir ürünün fiyatı artarsa, o ürüne olan talebe ne olur? Lütfen açıklayınız.

(vi) Böyle bir ilişkinin var olabileceği başka durumlar düşünebiliyor musunuz? Lütfen açıklayınız.

Sosyal Medyada Geçirilen Zaman ve Sosyal Medya Bağımlılığı

Ön Soru: Sosyal medya kullanıyor musunuz? Eğer sosyal medya kullanıcısıysanız ne sıklıkla kullanıyorsunuz?

Söyle: Sosyal medyada geçirilen zaman ile sosyal medya bağımlılığı arasındaki ilişkiyi düşünelim.

(i) Sosyal medyada geçirilen zaman ile sosyal medya bağımlılığı arasındaki ilişki hakkında ne düşünüyorsunuz? Lütfen açıklayınız.

(ii) Sosyal medyada geçirilen zaman ile sosyal medya bağımlılığı birbiriyle nasıl ilişkili olabilir? Lütfen açıklayınız.

(iii) Zaman içerisinde sosyal medya bağımlılığına ve sosyal medyada geçirilen zamana ne olacağını düşünüyorsunuz? Lütfen açıklayınız.

(iv) Sosyal medyada geçirilen zaman artarsa, sosyal medya bağımlılığına ne olur? Lütfen açıklayınız.

(v) Sosyal medya bağımlılığı artarsa, sosyal medyada geçirilen zamana ne olur? Lütfen açıklayınız.

(vi) Böyle bir ilişkinin var olabileceği başka durumlar düşünebiliyor musunuz? Lütfen açıklayınız.

BÖLÜM II. Döngü Dinamiklerinin Karşılaştırılması

(i) Katılımcılara dört resim gösterilir ve resimlerden herhangi birine atıfta bulunmadan şu soru sorulur: Şu görsellerden hangilerinin gösterilen ilişkiler açısından benzer veya farklı olduğunu düşünüyorsunuz? Lütfen açıklayınız.

(i) Dengeleyici geri bildirim döngüsünün iki resmine atıfta bulunarak, katılımcılara şu soru sorulur: Sizce bunlar gösterilen ilişkiler açısından benzer mi yoksa farklı mı? Neden?

(ii) Pekiştirici geri bildirim döngüsünün iki resmine atıfta bulunarak katılımcılara şu soru sorulur: Sizce bunlar gösterilen ilişkiler açısından benzer mi yoksa farklı mı? Neden?

(iii) Bir pekiştirici ve bir dengeleyici geri bildirim döngüsü resimlerine atıfta bulunarak katılımcılara şu soru sorulur: Bu ikisi gösterilen ilişkiler açısından nasıl benzer ya da farklıdır? Neden?

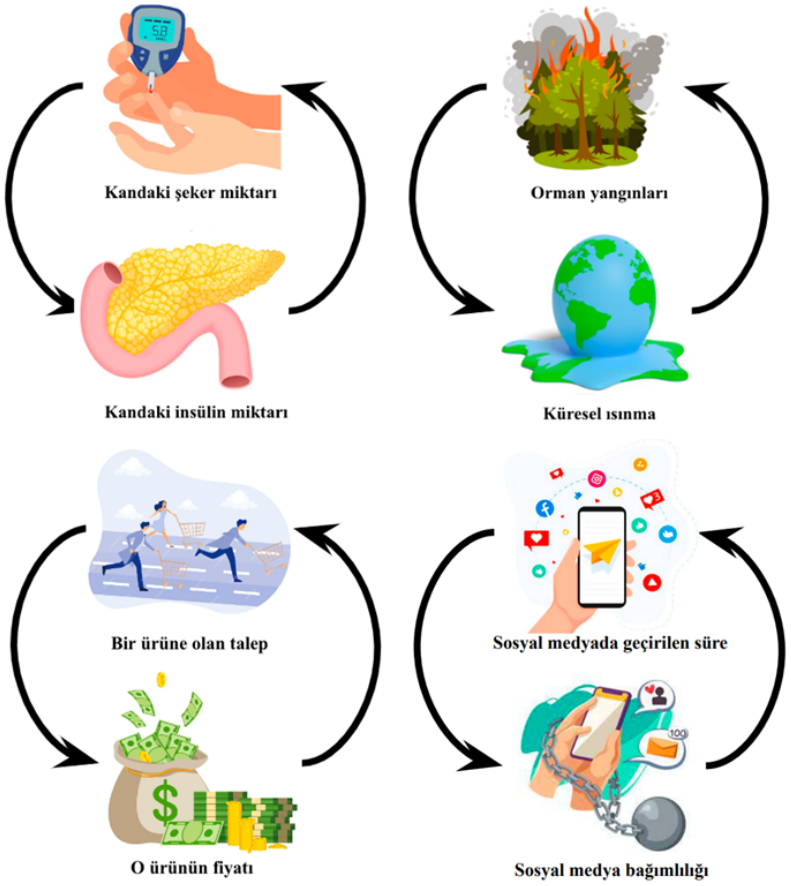


Figure D.1. Based inquiry (S-BI) protocol 1.

APPENDIX E: S-BI PROTOCOL SCORING RUBRIC

Revised S-BI Protocol Scoring Rubric

This rubric for scoring the revised S-BI protocol was adapted from Sweeney and Sterman's (2007) study to fit the purpose and context of this study.

E.1. Scoring Rubric for Part I. Feedback Dynamics

The first five questions in each scenario in Part I. Feedback dynamics of the S-BI Protocol are analyzed as a package to determine the level of feedback thinking of the participants.

Below are the levels of feedback thinking and examples of participants' responses to the Sugar and Insulin scenario to help understand each level clearly. The words and phrases indicating positive relationships were colored red, those indicating negative relationships were colored blue, and those indicating cause and effect were colored orange.

E.1.1. Feedback Thinking Levels

Feedback thinking levels are scored as follows: Level 0: Incorrect or shows no relationship

Sample response	Explanation of the score	Model
``*I don't know much about this and may not be able to explain it. When the amount of sugar in the blood increases, the amount of insulin in the blood decreases. That's all I know*`` *(P1).*	The statement shows an incorrect explanation.	

Figure E.1. Level 0 score are assigned to non-responses, responses that are not correct, applicable or indicate no relationship.

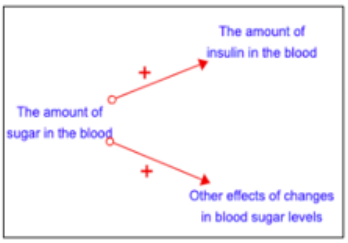
Level 1: Explains simple connections and relationships

Sample response	Explanation of the score	Model
"When the amount of sugar in the blood increases, the amount of insulin in the blood also increases" (P8).	The statement shows a one-way relationship between the amount of sugar in the blood and the amount of insulin in the blood.	

Words and phrases that indicate a positive relationship are color coded red.

Figure E.2. Level 1 scores are assigned to responses that show understanding causality, connections, relationships and linear chains of causality in a system.

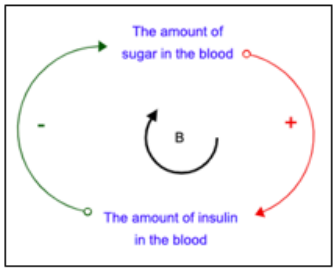
Level 2: Describes aspects of interconnections

Sample response	Explanation of the score	Model
"When the amount of sugar in the blood reaches a certain level, I think the amount of insulin in the blood will increase over time because its presence will continue to do other things. For example, it will cause glucose to be removed from the blood. The body will probably have to stop the insulin from rising to keep the sugar level from falling further. The amount of sugar in the blood changes as insulin is sent out and taken back in over time" (P3).	The statement shows a one-way relationship between the amount of sugar in the blood and the amount of insulin in the blood, and also the aspect of interconnections.	

Words and phrases that indicate a positive relationship are color coded red, while those that indicate a cause and effect relationship are color coded orange.

Figure E.3. Level 2 scores are assigned to responses that show interconnections in a system.

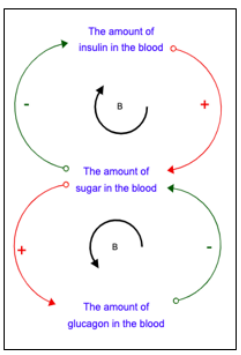
Level 3: Demonstrates understanding of principles guiding system behaviors

Sample response	Explanation of the score	Model
"If the amount of sugar in the blood increases, the amount of insulin in the blood will also increase, but later the amount of sugar in the blood will decrease because the insulin in the blood reduces the amount of sugar in the blood. Therefore, the amount of insulin needed in the blood will also decrease" (P6).	The statement shows an understanding of the balancing feedback loop underlying the amount of sugar in the blood and the amount of insulin in the blood mechanism.	

Words and phrases that indicate a positive relationship are colored red, while those that indicate a negative relationship are colored blue.

Figure E.4. Level 3 scores are assigned to responses that demonstrate an understanding of feedback in a system and show a feedback loop in a system.

Level 4: Fuller utilization of systems intelligence.

Potential response	Explanation of the score	Model
*One of the hormones produced by the pancreas is insulin. When the amount of sugar in the blood increases, the amount of insulin in the blood increases. When the amount of insulin in the blood increases, the amount of sugar in the blood decreases. Another hormone produced by the pancreas is glucagon. When the amount of sugar in the blood decreases, the amount of glucagon in the blood increases. When the amount of glucagon in the blood increases, the amount of sugar in the blood increases. As a result, insulin works to lower blood sugar while glucagon works to raise it, and so these two hormones regulate blood sugar.**	The statement shows multiple feedback loops. The first feedback loop is shown for the relationship between the amount of sugar in the blood and the amount of insulin in the blood, while the second feedback loop is shown for the relationship between the amount of sugar in the blood and the amount of glucagon in the blood.	

Words and phrases that indicate a positive relationship are colored red, while those that indicate a negative relationship are colored blue.

* No Level 4 response was received from any scenario. To better understand Level 4, this potential response was written by the researcher for the Sugar and Insulin scenario.

Figure E.5. Level 4 scores are assigned to responses that demonstrate multiple feedback loops in a system.

No Level 4 response was received from any scenario. To better understand Level 4, this potential response was written by the researcher for the Sugar and Insulin scenario.

E.2. Scoring Rubric for S-BI Protocol for Homological Reasoning

The sixth question in each scenario in Part I. Feedback dynamics of the S-BI protocol are scored as analyzed to determine the level of homological reasoning of the participants.

Below are the levels of homological reasoning and examples of participants' responses to the Time Spent on Social Media and Social Media Addiction scenario to help understand each level clearly.

E.2.1. Homological Reasoning Levels

The homological reasoning levels are scored as follows

Table E.1. Level 0 scores are given to responses that do not provide an example.

Sample response	**Explanation of the score**
"Drama education may have an effect on children's attention span because there are many factors, one of which may increase, decrease or be unrelated to the tother. These effects may vary according to other factors such as gender, age, and subject" (P9). *	This sentence does not reflect an example, but only indicates the factors that may increase, decrease, or be unrelated to the effect of drama education on children's attention span.

(*Since there are no Level 0 participants in the Time Spent on Social Media and Social Media Addiction scenario, the example above is taken from the Forest Fires and Global Warming scenario. In addition, “I don’t know“ and “I can’t imagine right now“ are possible responses for this level).

Table E.2. Descriptives statistics of participants.

Sample response	**Explanation of the score**
“I think game addicts are like that, I mean, it’s the same logic again. When a game comes out, there is a desire to play that game. This is the same logic, so I can say that game addiction is an example” (P1).	This sentence doesn’t reflect homology. It shows a one-way cause and effect relationship between gaming addiction and the desire to play games, as opposed to a dynamic relationship between time spent on social media and social media addiction, as in the scenario presented.
Words and phrases that indicate a positive relationship are colored red.	

Table E.3. Level 3 scores are given to responses that provide a correct homology from a different domain than the domain in the scenarios presented.

Sample response	**Explanation of the score**
“It could be smoking. A person becomes addicted to the substances in cigarettes. That is, the more you smoke, the more you want to smoke, and you cannot stop. This creates an addiction. There are even people who smoke two or three packs of cigarettes a day. In other words, the more you smoke, the more you want to smoke, the more you can’t stop, and you become addicted. When you are addicted, you smoke more cigarettes” (P8).	This sentence reflects a correct **example of homology involving a reinforcing feedback** loop, which is also included in the scenario presented, but this example is from the domain of addiction, which reflects the **same domain as the scenario presented.**
Words and phrases that indicate a positive relationship are colored red.	

Table E.4. Level 4 scores are given to responses that provide multiple homologies provided from the different domain as the domain in the scenarios presented.

Sample response	**Explanation of the score**
"We can give examples of inflation from everyday life. When inflation rises, the price of products also rises. When the price of products rises, inflation continues to rise because workers' wages increase. So we are in a vicious circle. Everything goes up. Workers' wages go up, but the price of products also goes up. Also, because the price of products is going up, the cost of services is going up, and because the cost of services is going up, the price of products is going up. Then the workers' wages go up, and then they go up again, but it's a vicious circle" (P6).	This sentence reflects multiple correct homologies involving two reinforcing feedback loops, which is also included in the scenario presented, and this example is also from the domain of economics, which reflects the different domain than the scenario presented. This sentence shows both a feedback loop between inflation and product prices and another feedback loop between product prices and workers' wages.
Words and phrases that indicate a positive relationship are colored red.	

E.3. Scoring Rubric for Part II. Comparison of Feedback Loop Dynamics

In Part II, participants are asked to identify and explain the similarities and differences between four feedback loops underlying the systems scenarios they addressed in scenarios. Below are the levels of feedback recognition and examples of participants' responses to identify and explain the similarities and differences between the balancing feedback loops in the Sugar and Insulin and Time Spent on Social Media and Social Media Addiction scenarios to help understand each level. The words and phrases indicating positive relationships were colored red, and those indicating negative relationships were colored blue.

E.3.1. Responses are Coded in Three Categories

Loop-b: Identify and explain similar balancing feedback loops

Loop-r: Identify and explain similar reinforcing feedback loops

Loop-difference: Identify and explain the difference between balancing feedback loops and reinforcing feedback loops

Explanation of responses are scored as follows:

Table E.5. Level 0 scores are assigned for no given explanation.

Potential response	**Explanation of the score**
"I don't know" and "I can't imagine right now". *	The statement does not show any explanation.
*Since there are no Level 0 participants the example above is written from the researcher.	

Table E.6. Level 1 scores are assigned for both wrong matches and wrong explanations.

Sample response	**Explanation of the score**
"The amount of sugar in the blood increases, the amount of insulin in the blood increases. The Price and Demand scenario depends on the marketing tactic. Therefore, they are not similar" (P9).	This explanation shows a lack of **understanding of the balancing** feedback loops in both scenarios.
Words and phrases that indicate a positive relationship are colored red	

Table E.7. Level 2 scores are assigned for right matches but wrong or incomplete explanations.

Sample response	**Explanation of the score**
"The two are similar in terms of damage. If the sugar in the blood increases, the amount of insulin in the blood increases and this creates an imbalance in the body. This can cause health problems in the future and disrupt the system. As the demand for a product increases, the price will increase, but this will also harm the person's budget" (P8).	This explanation shows that balancing **feedback loops are identified in** both scenarios, but the explanation **does not reflect a full understanding** of balancing feedback loops because it does not close the loops.
Words and phrases that indicate a positive relationship are colored red.	

Table E.8. Level 3 scores are assigned for right matches with appropriate explanations.

Sample response	**Explanation of the score**
"Sugar and Insulin and Demand and Price Scenarios are similar. As the amount of sugar in the blood increases, the amount of insulin in the blood increases. Then the amount of sugar in the blood decreases and finally the amount of insulin in the blood decreases. Similarly, if the demand for a product increases, the price increases, and if the price increases, the demand decreases. In other words, in both scenarios, one thing is increasing and one thing is decreasing" (P7).	This explanation shows that balancing feedback loops are identified in both scenarios and reflects a full **understanding of balancing** feedback loops because it closes the loops.
Words and phrases that indicate a positive relationship are colored red, while those that indicate a negative relationship are colored blue.	

APPENDIX F: PARTICIPANTS' LEVEL OF FEEDBACK THINKING FOR EACH QUESTION

The figure F.1 illustrates the level of participants' feedback thinking for each question.

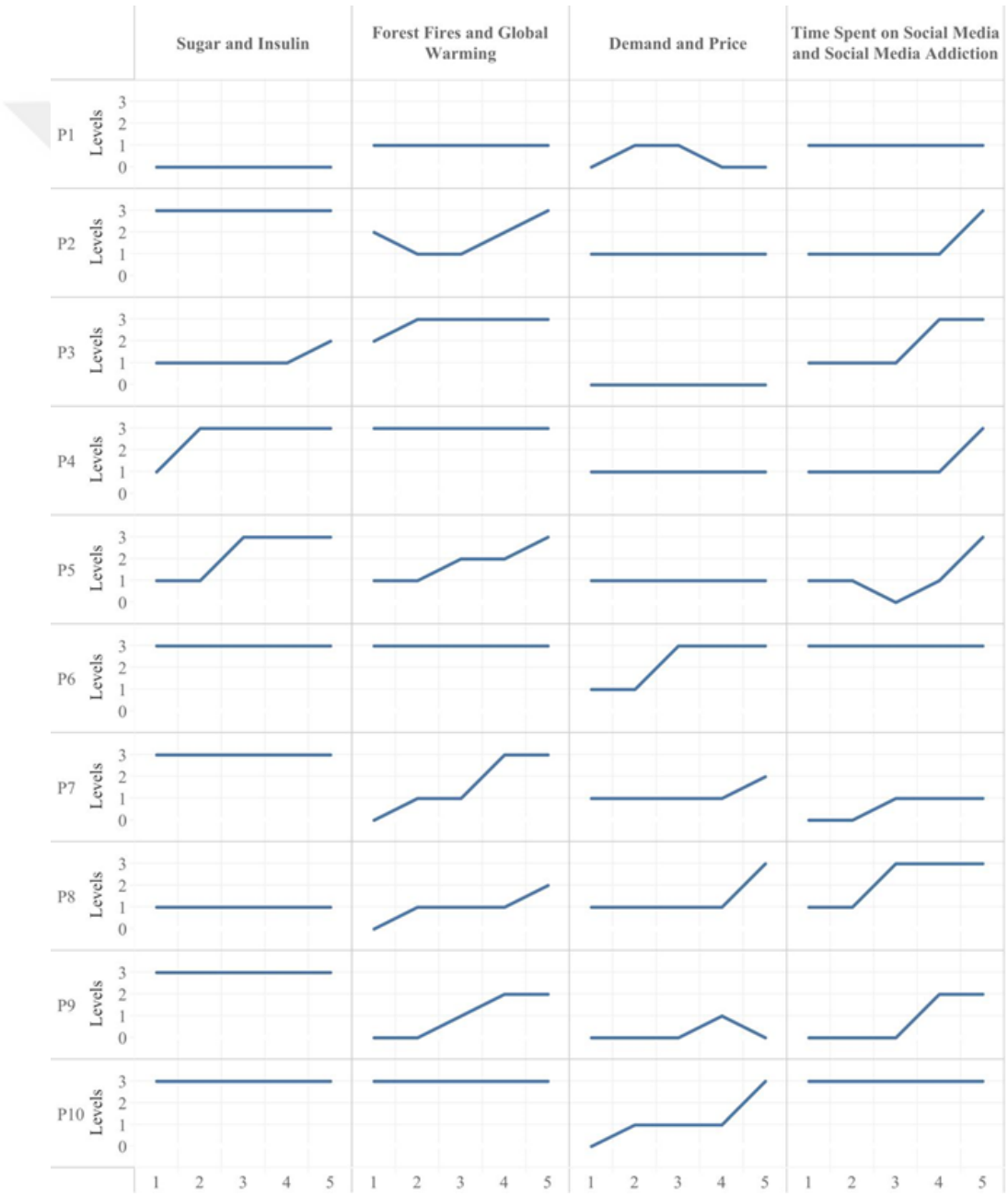


Figure F.1. Participants' level of feedback thinking for each question.