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Research Article

The effects of project-supported education about food production on teacher candidates' systems thinking skills

Gıda üretimi konusunda proje destekli eğitimin öğretmen adaylarının sistem düşünme becerilerine etkisinin etkisi

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Abstract

Systems thinking is the interactive working of interconnected parts for a specific purpose. Global food production processes include sustainability, economics, engineering, nature and social dimensions. In this respect, it is important to develop the systems thinking skills of teacher candidates. This study aimed to examine the effect of project-supported education on the system thinking skills of teacher candidates on food production. A mixed research design and single-group pre-test-post-test experimental design were used in the research. The data were obtained from the systems thinking skill test, open-ended questions and concept maps. The quantitative study group of the research consisted of 100, and the qualitative study group consisted of 30 science teacher candidates. It was found that there was a significant difference between the system skill test pre-test and post-test. The concept maps developed by the teacher candidates were evaluated in terms of their level of understanding of the system's structure, function and behaviour and whether they could establish a link between the sectors related to food production. In the research, it was found that systems thinking skill tests and concept maps were effective in detecting systems thinking skills. The most important finding in this study was understanding the interdependence of systems, which is the most basic feature of ST.

Keywords: Systems Thinking, Production Management, Concept Map, Project-Supported Education

Jel Codes: C83, M11, I20, O22

Öz

Sistem düşüncesi, belirli bir amaç için birbirine bağlı parçaların etkileşimli çalışmasıdır. Küresel gıda üretim süreçleri, sürdürülebilirlik, ekonomi, mühendislik, doğa ve sosyal boyutları içerir. Bu açıdan öğretmen adaylarının sistem düşünme becerilerinin geliştirilmesi önemlidir. Bu çalışmanın amacı, proje destekli eğitimin öğretmen adaylarının gıda üretimine yönelik sistem düşünme becerilerine etkisini incelemektir. Araştırmada karma araştırma deseni ve tek grup ön test-son test deneysel desen kullanılmıştır. Veriler, sistem düşüncesi beceri testi, açık uçlu sorular ve kavram haritalarından elde edilmiştir. Araştırmanın nicel çalışma grubu 100, nitel çalışma grubu ise 30 fen bilgisi öğretmen adayından oluşmuştur. Sistem beceri testi ön test ve son test arasında anlamlı bir fark olduğu bulunmuştur. Öğretmen adaylarının geliştirdikleri kavram haritaları, sistemin yapısını, işlevini ve davranışını anlama düzeyleri ve gıda üretimi ile ilgili sektörler arasında bağlantı kurup kuramamaları açısından değerlendirilmiştir. Araştırmada sistem düşüncesi beceri testi ve kavram haritalarının sistem düşüncesi becerilerini tespit etmede etkili olduğu bulunmuştur. Bu çalışmanın en önemli bulgusu sistem düşüncesinin en temel özelliği olan sistemlerin birbirine bağımlılığının anlaşılması olmuştur.

Anahtar Kelimeler: Sistem Düşüncesi, Üretim Yönetimi, Kavram Haritası, Proje Destekli Eğitim

JEL Kodları: C83, M11, I20, O22

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Introduction

Food production has been one of the most important issues since the beginning of human history. Despite the importance of food, global warming, excessive population growth, and unplanned and rapid urbanization threaten production processes (Odegard and van der Voet, 2014). Food production's social and economic importance will increase in the coming period. Food production management includes complex and interacting processes which can apply systems thinking methodology.

Raising awareness of food production has become one of society and institutions' most important agenda items. Governments and educational institutions have the most important role in increasing this awareness and spreading it to every part of society.

In a world where problems and systems become more complex, systems thinking (ST) has become an important skill in every part of life. ST is an approach to examine complex situations and systems holistically. It is used in almost every branch of science with this feature. ST is the interactive working of interconnected elements for a goal (Verhoeff, Boersma and Waarlo, 2013). The components of a system must be understood first to understand the interaction among system elements holistically. Analyzing a system involves a high level of thinking capability. Systems-minded people are strong communicators curious, and innovative individuals. ST in engineering and science provides a holistic view of the system's structure, behaviour, and function (SBF) (Tripto, Ben-Zvi Assaraf, Snapir and Amit, 2017; Assaraf, Dodick and Tripto, 2013).

A system is a goal-oriented holistic entity to reach a certain result, which is formed according to a general plan, consisting of units of different parts that regularly affect each other and are connected. ST is understanding a system as a whole with the interaction of its elements and the stability of a system about its cause-effect cycle (Assaraf and Orion, 2005). According to NGSS (2013), ST is seen as a systems model that helps students understand basic disciplinary knowledge and improve a harmonious, scientific perspective. ST is the ability to comprehend the multi-level structure and dynamic and nonlinear relationships among the elements of the system. This mental process requires a wide range of cognitive abilities (Richmond, 2001; Hmelo-Silver and Azevedo, 2006).

ST is the ability to systematically evaluate the situation from a systems perspective (Crawley, Cameron and Selva, 2016; Assaraf and Orion, 2005; Checkland, 2000). The design phase requires many cognitive, social, and technical difficulties (Checkland, 1983). Design and ST are used together in science and engineering (Long, 2012). Industrial and systems engineering researchers have broadly defined the skills and behaviours required for the design phase (Frank, 2006), but cognitive approaches were somewhat limited (Greene, Gonzalez, Papalambros and McGowan, 2017). The ST tries to see the whole from different perspectives, and at the same time, it recognizes the interactions among the components.

Structural and procedural are two types of dynamic systems (Sommer and Lücken, 2010). Structural ST is the ability to define the relevant components of a system and the relationships among them and to determine the framework of the system together. Procedural ST is the ability to cover the systems' dynamic and time-related processes (Sterman, 2000). This two-dimensional ST overlaps with the ST model proposed by Assaraf and Orion (2005). Structural ST, the first dimension of ST, includes understanding the basic framework of relationships. The second dimension, procedural ST, includes understanding retrospective and predictive thinking about the cyclical and dynamic relationship development within the system.

Dolansky, Moore, Palmieri and Singh (2020) defined ST as "the ability to recognize, understand, and synthesize interactions and interdependencies in a set of components designed for a specific purpose". It is the capability to capture the elements in interactions and to understand how activities strengthen or neutralize all. It is essential to undertake certain methodologies to establish a set of components that comprise a whole (Dolansky et al., 2020).

Literature review

Project-based learning (PBL)

In the 21st century, there has been a paradigm shift in various areas of life. The current types of jobs seem to require different skills from the previous era. According to (NEA) (2002), jobs that require routine skills are experiencing a temporary decline, whereas jobs requiring non-routine, analytical and interactive communication skills continue to increase. To catch up with this trend, the education system should be redesigned to increase students' skills in the 21st century. Rotherham and Willingham (2009) stated that a student's success in the 21st century depends on skills learning and innovation skills (4Cs), namely critical thinking, communication, collaboration, and creativity. Educators design open-ended

PBL projects that focus on global issues, providing students with the opportunity to engage in realistic projects, allowing students to encounter and solve dilemmas, providing opportunities for collaboration, and solving future problems (Kingston, 2018; Han, Yalvac, Capraro and Capraro, 2015; Bell, 2010).

By promoting systems thinking and interdisciplinary connections, PBL offers an expanded perspective on issues and problems (Ekselsaa, Purwianingsihb, Anggraenib, Ghofar and Wicaksonoc, 2023; Kingston, 2018; Nagarajan and Overton, 2019; Blumenfeld, Soloway, Marx, Krajcik, Guzdial and Palincsar, 1991). Therefore, PBL is a context-based approach that relates learning to the real world (Åström, 2008; Czerniak and Johnson, 2014). PBL has its roots in constructivism learning theories. Learning is context-specific; students build their knowledge by engaging in meaningful real-life problems. They achieve their goals through social interactions by working collaboratively on their knowledge and projects. PBL results in artefacts or products developed to solve an identified problem. Numerous studies have been done with PBL recently. For example, they are strengthening students' identity formation (Jagers, Rivas-Drake and Williams, 2019), encouraging students to learn by developing collaborative products (Easley, 2020), making collaborative experimental science activities (Baser, Yasar and Karaarslan, 2017), integrating science learning with other disciplines (Arias, Davis, Carlos, Kademian and Palincsar, 2016; Fitzgerald, 2020), and providing equitable learning opportunities (Haas, Januszyk, Grapin, Goggins, Llosa and Lee, 2021; Haatainen and Aksela, 2021).

Structure, function, and behaviour model in system thinking

Systems generally fall into three types: function, structure, and behaviour. The structure and behaviour activate the system's role and purpose (Dori, Sillitto, Griego, McKinney, Arnold, Godfrey, Martin, Jackson and Krob, 2019; Crawley et al., 2016). ST is crucial to cover the problems encountered and develop solutions in the societies (Sweeney and Sterman, 2000). Understanding systems requires understanding and recognising the fundamental events and their interrelationships in them (Hmelo-Silver and Pfeffer, 2004). Studies have suggested that ST is considered a high-level ability essential for understanding functions in science and engineering (Verhoeff, Waarlo and Boersma, 2008). Complex systems learning and knowledge transfer are critical to improving scientific knowledge. Generally, system elements' behaviour, processes, and interactions affect the system's overall performance. These interrelationships are generally dynamic and invisible, which is hard to comprehend (Feltovich, Coulson and Spiro, 2001; Jacobson and Wilensky, 2006; Hmelo-Silver, Marathe and Liu, 2007).

SBF is a conceptual expression that promotes transfer between different systems (Goel, Gomez de Silva Garza, Grué, Murdock, Recker and Govinderaj, 1996). Structures in ST refer to the elements, while behaviours are the mechanisms in which the structures and functions happen. Functions are elements' roles in a system (Hmelo-Silver et al., 2007). Several structures can act interactively to fulfil the function. Computer simulations can also demonstrate the system environment's invisible structures and functions (Liu and Hmelo-Silver, 2009). What are the structures in the system, how are the behaviours, and why can the functions be revealed? An example of SFB in an aquarium system and how the food breakdown system works is given in Figure 1.

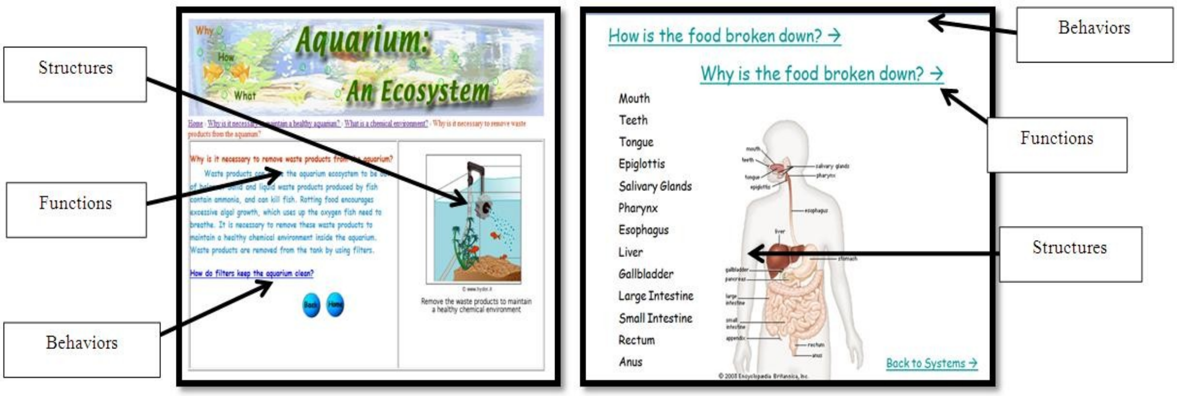

Figure 1: Structure, Function and Behaviour in ST

Source: (Sinha, Gray, Hmelo-Silver, Jordan, Eberbach, Goel & Rugaber, 2013)

Developing ST skill

It has been stated that ST skills are crucial for solving complex problems (Evagorou, Korfiatis, Nicolaou and Constantinou, 2009). Although the integration of ST into education has been noted as important, implementation has been limited (Plate, 2010; Jacobson and Wilensky, 2006). Several studies have been conducted to develop ST skills in education (Tamir, Ben-Zvi Assaraf and Maman, 2023; Shaked and

Schechter, 2019; Koral, Frank and Nissel, 2018). Assaraf and Orion (2010), Penner (2000), Sweeney and Sterman (2000) stated that "ST skills can be developed in primary and secondary education". Both Sweeney and Sterman (2000) and Frank (2006) pointed out the importance of ST in engineering university students. They also explained that ST requires the skills to examine, evaluate, and invent more than just remembering information. Transfer in learning is the process of learning information and abilities in new contexts. For this reason, learning environment designers are trying to create tools that will facilitate transfer. Such a tool should support students' holistic thinking of conceptual elements (Liu and Hmelo-Silver, 2009). It is hard to evolve a conception of systems for students, but it is worth achieving (Sabelli, 2006).

Concept maps (CMs) in the evaluation of ST

The use of CM is generally related to a "constructivist approach" in education. Hmelo-Silver and Azevedo (2006) argue that "scaffolding" support is needed to develop students' ST. Hence, they may be useful for instructors to reveal the students' knowledge level. Since CM focus on structure and connections, students' drawings are a good way of showing their perceptions of the concepts' relationships (White and Gunston, 1992; Zele, 2004). Concepts can actively promote students' knowledge integration and be an assessment tool. CMs are useful frameworks to organize students' knowledge, supporting learning by guiding them to capture common structures (Davis, Shrobe and Szolovits, 1993; Novick and Hmelo, 1994). This will increase understanding of system interrelationships (Liu and Hmelo-Silver, 2009). Evaluating ST abilities is crucial, as well as developing them. There is very limited research on the assessment of ST skills. Tripto et al. (2017) stated, "CMs are an important tool that can be used in evaluating ST due to their structural features". Akiri, Tal, Peretz, Dori and Dori (2020) also evaluated ST with CMs and rubrics. CMs are graphical tools for representing information recommended by NGSS (2013) to encourage students' thinking skills. CMs were developed by Novak in 1972 to track changes in students' knowledge (Novak and Musonda, 1991).

Studies have indicated that assessment tools are needed to assess appropriate ST regardless of education level. Otherwise, investigating ST skill improvement may be difficult (Boersma, Waarlo and Klaassen, 2011). The structure of the CM consists of a hierarchical or non-hierarchical schema as a representation of a mental model (Yin, Vanides, Ruiz-Primo, Ayala and Shavelson, 2005). These features of CMs are similar to those of ST: Structure, dynamism, and hierarchy. Therefore, the number of concepts and connections in CMs are valid parameters to evaluate ST level (Songer and Mintzes, 1994; Rye and Rubba, 1998; Martin, 2004). Therefore, CMs have been accepted as a good tool for evaluating mental models in conceptual understanding (Ruiz-Primo and Shavelson, 1996; Mintzes, Wandersee and Novak., 1998; Assaraf and Orion, 2010; Evagorou et al., 2009). Food production and safety have been at the top of the global agenda with globalisation and climate change. Hence, supporting a better understanding of food production at every level becomes the purpose of this study.

Method

This research was designed as a single-group pre-test/post-test experimental design, one of the quantitative research approaches. Experimental design is research to test the cause-effect relationship between variables (Cohen and Manion, 1997; Gay and Airasian, 2000). In experimental studies, researchers observe the effects of at least one independent variable on one or more dependent variables (Cohen and Manion, 1997; Gay and Airasian, 2000). There are many different experimental patterns. In the single-group pre-test/post-test experimental design, an independent variable is applied to a group, and measurement is made before and after the experiment (Cohen and Manion, 1997; Gay and Airasian, 2000). The difference between the pre-test and post-test shows the effect of the independent variable on the dependent variable. The single-group pre-test/post-test experimental design is one of the weakest among the experimental designs. However, as Creswell (2012) stated, it is the nature of the research to prefer the single-group experimental design in studies where a new training module is developed and applied. The concept maps prepared by the teacher candidates were evaluated qualitatively and supported by quantitative data.

Participants

The study group consisted of 100 students from a state university in Istanbul. Students were selected voluntarily. Data collection tools and study groups are;

- ST skill test is applied to 100 teacher candidates quantitatively (3rd and 4th grade students)
- The system knowledge test is applied to 30 teacher candidates quantitatively (3rd-grade students)
- Concept maps are applied to 30 teacher candidates qualitatively (3rd-grade students)

Since the system thinking skill test was translated into Turkish and a validity and reliability study was carried out, it was applied to both 3rd and 4th grades (100 students) as it should be applied to a large group. The System Knowledge Test, which consists of open-ended questions, was applied to 30 third-year students. Thirty third-year students were asked to draw CMs before and after the application.

Application

The research is planned for six weeks in October- November 2022. One week is reserved for pre-test and post-test applications, and four weeks for project-based practice. During the project implementations, the researcher lecturer guided the teacher candidates as a guide.

The Steps of Application

1. The system thinking test was applied to 100 teacher candidates as a pre-test.

2. The system knowledge test was applied to 30 teacher candidates as a pre-test. The same group of students was asked to draw a CM to reveal their pre-knowledge about food safety.

3. Thirty teacher candidates participating in the application were divided into six groups of five. The groups chose the production of food (such as coffee, chocolate, chicken, or cheese) they wanted. They prepared a CM with their preliminary information about the production system of this food.

4. In the design of the projects, the project design steps determined by Barak (2020) were applied. These include recognising the problem, identifying the known and unknown about the problem, forming hypotheses and deciding on a hypothesis, testing the hypothesis, collecting and interpreting data, writing and presenting the project report, and revising the project as a result of feedback.

5. After the project implementation, the system thinking skill and knowledge tests were applied as post-tests. At the end of the study, teacher candidates developed a new CM in line with the new information they learned.

Data collection tools

ST skill test

The study used a Likert-type scale Dolansky et al. (2020) developed. The development stages of the test developed by Dolansky et al. (2020) were as below:

- The test was initially prepared as 26 items. However, since the factor loads of 6 items were low, these items were removed, and the test was reduced to 20.

- They applied this 20-item test version to 36 healthcare professionals and found Cronbach's alpha value to be 0.74.

- Then, the test was applied to 342 healthcare professionals, and the Cronbach alpha was found to be 0.89. This level is a sufficient value for test development.

- It was then applied to 342 healthcare professionals, and the reliability value was noted as 0.89. Three academicians and a Turkish teacher examined and agreed on Turkish controls of the translated test. The test was applied as a pilot to 10 teacher candidates to examine the validity of the test. As a result of the application, the reliability value was found to be 0.86. This value is close to the result of Dolansky et al. (2020).

Items on the Likert-type scale were pointed as never (0), rarely (1), sometimes (2), often (3), and most of the time (4). A score ranging from 0 to 80 is obtained in the test. There is no reverse-coded item.

System knowledge test

It consists of 6 open-ended questions improved by the researchers to determine the conceptual knowledge of candidate teachers on systems thinking. Open-ended questions are shown below:

1. Define the system.

2. Give three system examples.

3. What makes them a system?

4. Is food production a system? So how? If not, explain why.

5. What are all the components and processes of food production?

6. How do these components and processes work together?

The open-ended questions were prepared by taking the opinion of 3 experts from the science education and engineering faculty. The open-ended questions were scored as 0 (lower), 1 (basic), 2 (intermediate), and 3 (upper).

Concept maps (CMs)

Various science education studies have used CMs to evaluate students' conceptual understanding. The CM includes the features of structure, dynamism, and hierarchy, which are the elements of ST. Research shows that concept and interaction numbers in CMs are good parameters for evaluating ST levels. Therefore, in this study, it was thought to be an appropriate tool to determine the system thinking levels of candidate teachers. CMs were tested with a rubric prepared by the researchers. It was determined that the raters had a high (92%) consistency level. It is scored as 0 (lower), 1 (basic), 2 (intermediate), 3 (upper).

Table 1: System Thinking Evaluation Criteria of CMs

ST Key Elements		Definition of ST Elements
STRUCTURE	Ability to define sub-elements in the system	Main process, Subprocesses, Number of concepts, Links among objects, and processes
FUNCTION	Main function, expected result/intended purpose, ability to describe simple interactions (Node Counts)	The expected result or intended purpose of the system Main process, agent operators and enablers
BEHAVIOUR	Ability to define dynamic relationships, Procedural connections	Links among objects and processes, Levels of detail
	Ability to organize system elements within the framework, Levels of complexity	Linear, divergent, convergent, and cyclical relationships

Findings

The study examined the effect of project-based education on teacher candidates' ST capabilities. The data obtained were presented in tables and graphs below.

Findings of the ST skill test

A reliability analysis was conducted, and the reliability value was .860. Skewness and Kurtosis values were examined to determine whether the pre-test and post-test data were normal distributions. Skewness shows the level of non-symmetry of a distribution. On the other hand, Kurtosis shows how many samples are in the middle of the distribution. It is a normal distribution if these values are between -1.5 and +1.5 (Tabachnick and Fidell, 2013). Consequently, it was found that the values were in the range of -1.5 to +1.5, so it showed normal distribution characteristics.

An independent t-test was conducted to see whether a significant difference existed between the means of the pre-test and post-test data. The resulting values are given in Table 2.

Table 2: T-test Findings of Pre-test and Post-test of the ST Scale

Variable	Groups	N	X	ss	t-test		
					t	sd	p
ST	Pre-test	30	70.73	4.076	-7.932	60	0.001
	Post-test	30	81.63	6.327			

When Table 2 is examined, it is found a significant difference between teacher candidates' pre-tests and post-tests on ST abilities ($t [60] = -7.932$; $p<0.05$). A one-way ANOVA test was conducted to determine whether there was a significant difference between teacher candidates' pre-test and post-test variances. The test of Homogeneity result was found as .375, and data was accepted as homogeneous as it was greater than 0.05.

Table 3: ANOVA Findings of Pre-test and Post-test of the ST Scale

Variable	Groups	N	X	ss	Source of Variance	Sum of Squares	sd	Mean Square	F	p
ST	Pre-test	30	70.73	4.076	Between Groups	1782.15	1	1782.15	62.91	0.001
	Post-test	30	81.63	6.327	Within Groups	1642.83	58	28.32		
	Total	60	76.18	7.619	Total	3424.98	59			

When Table 3 is examined, a significant difference was found between teacher candidates' pre-test and post-test ST abilities (F= 62.91; p<.05).

Findings of system knowledge test

Skewness and Kurtosis values to open-ended questions about ST were examined to see whether the pre-test and post-test data have normal distribution characteristics. It was found that the values were in the range of -1.5 to +1.5, so they showed normal distribution characteristics (Tabachnick and Fidell, 2013). An independent t-test was performed to see whether a significant difference existed between the means of the pre-test and post-test data. The results are given in Table 4.

Table 4: T-test Findings of Pre-test and Post-test of the Systems Knowledge

Variable	Groups	N	X	ss	t-test		
					t	sd	p
Systems Knowledge	Pre-test	30	6.70	2.200	-14.562	60	0.000
	Post-test	30	14.53	1.961			

When Table 4 is examined, teacher candidates' system knowledge levels show a significant difference between the pre-test and post-tests (t [60] =-14.562; p<0.05). A one-way ANOVA test was conducted to test whether there was a significant difference between teacher candidates' pre-test and post-test variances. The test of Homogeneity result was found as .496, and data was accepted homogeneous as it was greater than 0.05.

Table 5: ANOVA Findings of Pre-test and Post-test of the Systems Knowledge

Variable	Groups	N	X	ss	Source of Variance	Sum of Squares	sd	Mean Square	F	p
Systems Knowledge	Pre-test	30	6.70	2.200	Between Groups	920.417	1	920.417	212.038	0.000
	Post-test	30	14.53	1.961	Within Groups	251.767	58	4.341		
	Total	60	10.62	4.457	Total	1172.183	59			

When Table 5 is examined, a significant difference was found between teacher candidates' pre-test and post-test systems knowledge (F= 212.038; p<.05).

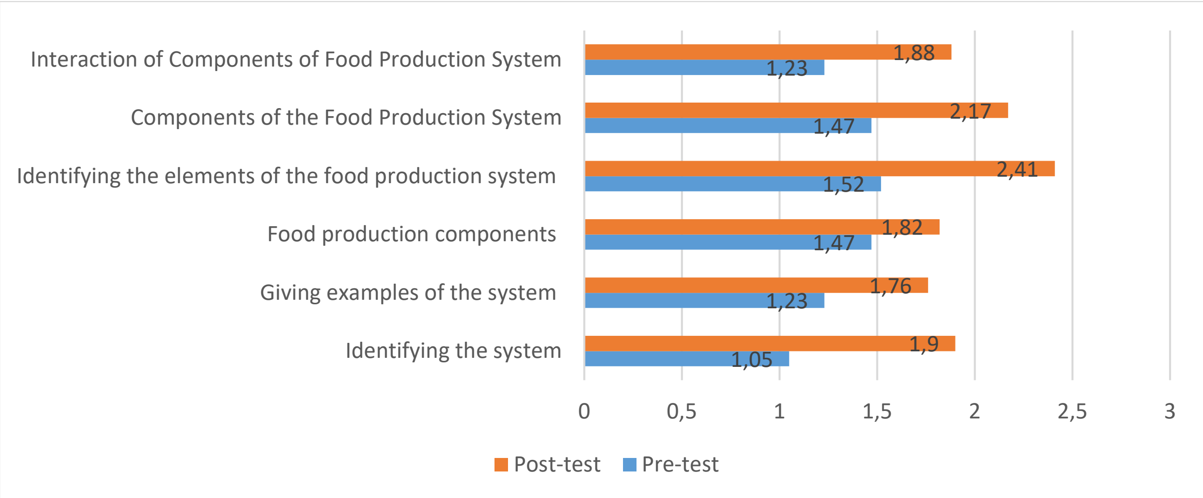

Figure 2: Teacher Candidates' System Knowledge Levels

Candidate teachers must describe and explain the system for evaluating ST skills. Therefore, a system knowledge test consisting of six open-ended questions was conducted for the teacher candidates. The findings obtained from this test are shown in Figure 2. When this test was analyzed, it was found that the teacher candidates' understanding of the system improved due to the project implementation. Looking at the mean score of the pre-test, it was determined that the lowest scores were defining the system (1.05), giving examples of the system (1.23), and food production system components (1.23). The most successful questions were identifying the elements of the food production system (1.52) and food production components (1.47). In the post-test, the area in which the teacher candidates made the least progress was giving an example to the system. Most of the teacher candidates gave the systems in our body and the ecosystem as an example of a system. They could not give system examples from other areas. This shows that they are unable to put their system information into practice. The results show that teacher candidates successfully recognised the food production system, which is the main subject of the project, in the post-test.

Findings of teacher candidates' CMs

CMs were used to gain insight into improving system thinking skills during and after project implementation. CMs prepared by teacher candidates about the food production system according to;

1. structure, function, and behaviour, which were the basic elements of ST skills,
2. the areas and processes related to food production were evaluated in terms of how much they included.

Evaluation of CMs in terms of ST elements

Teacher candidates' pre- and post-CMs of food production were evaluated with rubrics. Accordingly, the scores of the structure, function, and behaviour components are given in Table 6.

Table 6: Evaluation of CMs in terms of ST components

Systems Components		Pre-CM.	Post- CM
Structure	Identifying System Components	1.46	2.30
Function	Recognizing Simple Relationships	1.16	1.83
Behaviour	Defining Dynamic Relationships Organizing Interactions	0.83	1.46

Scale: 3 points= high level; 2 points= middle level; 1 point= basic level

When Table 6 is examined, it is found that all three components of ST have developed after the project implementation. The most progress was observed in the structure component (Pre-CM; 1.46, Post-CM; 2.30), then in the function component (Pre-CM; 1.16, Post-CM; 1.83), at least in the behaviour component (Pre-CM; 0.83, Post-CM; 1.46) was observed. When the final CMs were evaluated, it was determined that the structure (2.3) of the three components of ST approached the upper level, while the function (1.83) developed at the medium level and the behaviour (1.46) at the basic level. In Annex 1, two sample CMs created by the candidate teachers after the application are given.

Teacher candidates' levels of establishing relationships in the fields of food production

Teacher candidates' CMs were analyzed to recognise the elements of the food production system and notice the relationships among them. As seen in Figure 3, almost all of the candidate teachers included the food production stages, economy, and health in the food production system. In the food production system, teacher candidates' levels of inclusion in their preliminary CMs were found, when ordered from the most to the least, economy, food production stages, supply chain, health, marketing, society, hygiene, transformation into different products, nature sustainability, education, and engineering. In the final test, this ranking was as food production stages, economy, health, marketing, supply chain, societies, hygiene, conversion to different products, nature, education, sustainability, and engineering. As seen in the preliminary and final CMs, the teacher candidates established a relationship between close components such as production, marketing, and economy related to food production. They have made limited progress in relating more distant components of food production, such as sustainability, education, engineering and nature. It was determined that they were very good in the structure component of ST, moderate in the function component, and low in the behaviour component. Finally, it was seen that teacher candidates gave more place to the components of engineering, education, nature, and sustainability in their final CMs compared to the preliminary CMs.

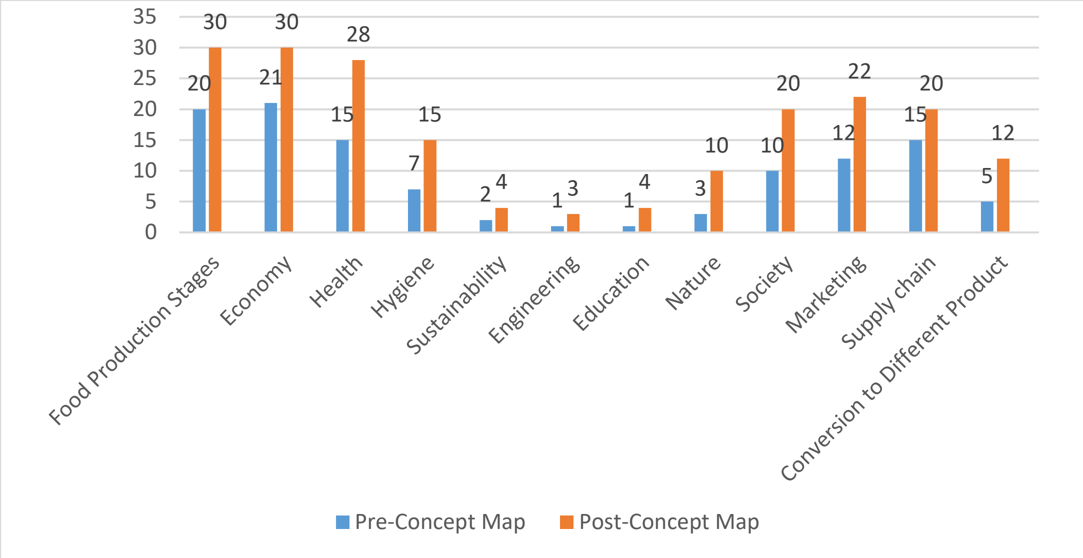

Figure 3: Teacher Candidates' Levels of Establishing Relationships Among the Fields of Food Production

Discussion

Researchers in education propose ST as a tool for today's complex problems. Therefore, this thinking skill has been studied from different perspectives. The ST test developed by Dolansky et al. (2020) was used in this study. They found the Cronbach alpha value of the test developed by the researchers to be 0.89. This study adapted this test to Turkish, and Cronbach's alpha value was found to be 0.86. This value supports the studies of Dolansky et al. (2020). Therefore, it is thought to be a tool that can be used to evaluate ST.

ST was previously thought to be a tool only for systems engineers. But today, it is accepted that system thinking is useful for individuals, organizations, and nations. Individuals, organizations, and countries often face complex problems with different dimensions. ST is necessary when solving these problems. ST begins with formulating well-thought-out goals and benchmarks. It has been stated that there is a need for tools related to the criteria of ST and how to measure it (Bedir, Desai, Kulkarni, Wallet, Wells and Smith, 2020). Assaraf and Orion (2005) developed the System Hierarchical Thinking Model to evaluate ST skills. Various studies that can be used to evaluate ST in different studies are also required. Among these, rubrics, Likert-type questionnaire, drawing analysis, word association, CM, interviews, simulations, and class discussions were used (Shepardson, Roychoudhury and Hirsch, 2017; Semiz and Teksöz, 2019; Batzri, Assaraf, Cohen and Orion, 2015; Shepardson, Roychoudhury, Hirsch, Niyogi and Top, 2014; Eilam, 2012; Hmelo- Silver and Pfeffer, 2004; Boersma et al., 2011; Evagorou et al., 2009; Assaraf and Orion, 2005). Similarly, Tripto et al. (2017) used one-on-one interviews as a measurement tool for evaluating ST skills and found that they were effective tools in assessing students' ST skills. Studies on developing ST scales continue to evaluate ST skills more objectively (Moore, Komton, Adegbite-Adeniyi, Dolansky, Hardin and Borawski, 2018; Dolansky et al., 2020).

In the research, the system knowledge test, which is used to understand the knowledge levels about the system, was used before determining their system thinking. Considering the total mean values of this test, a significant difference was found between the pre-test (X: 6.70) and the post-test (X: 14.63). This shows that the application improves the system information. When the questions in this test are analyzed one by one, the order of points from the lowest to the highest defines the system in the pre-test (1.05), giving examples of the system (1.23), food production system components (1.23), food production components (1.47), and recognizing the elements of the food production system (1.52). In the post-test, this score ranking is defined as defining the system (1.49), giving an example of the system (1.76), recognizing the elements that make up the system (1.82), recognizing the elements of the food production system (1.88), recognizing the components of the food production system (2.17), and understanding the food production system (2.41).

The test's general average and the analysis results contributed to the teacher candidates' understanding of the system. The most important finding in this study was understanding the interdependence of systems, which is the most basic feature of ST. This result is similar to previous studies on ST. For example, Batalden and Mohr (1997) defined ST as "the discipline of seeing all elements in a given environment about each other. It considers the effects of one part of the system's actions on other parts".

Change in the system is seen as a continuous procedure rather than a static action. It is crucial to be a systems thinker, comprehending the system as a whole rather than parts. With the study, teacher candidates knew that complex and dynamic systems consist of physical or intangible processes such as objects, information flows, relationships, and interactive components. Studies agree that ST is the sum of the capabilities to comprehend the system and its interrelationships to predict its effects for future improvements (Jacobson, 2001; Ossimitz, 2000; Anderson and Johnson, 1997).

Teacher candidates developed CMs twice, before and after the food production project. The CMs developed by the candidate teachers were evaluated primarily in terms of their comprehension of the system's structure, function, and behaviour, and secondly, whether they could establish a link between the sectors related to food production. CMs are a visual assessment tool that shows knowledge structuring in the mind. In this respect, dual-use can lead to easier understanding/education and implementing system thinking in different fields. When the scores obtained by the candidate teachers from the CMs were tested, it found that in the structure component (Pre-CM; 1.46, Post-CM; 2.30), in the function component (Pre-CM; 1.16, Post-CM; 1.83), in the behaviour component (Pre-CM; 0.83), Post-CM; 1.46). In all three components, it was seen that there was an increase in the post-test compared to the pre-test. When the final CMs were evaluated, it was determined that the structure (2.3) of the three components of ST approached the upper level, while the function (1.83) developed at the medium level and the behaviour (1.46) at the basic level.

Although there are different methods to evaluate ST, CMs are often preferred (Fisher, 2011; Plate, 2010; Sweeney and Sterman, 2000). CMs are a convenient tool for evaluating students' ST (Odom & Kelly, 2000; Songer and Mintzes, 1994). Some studies using CMs in developing ST skills are as follows: In their study, Chang and Chiu (2004) evaluated how students understand blood sugar balancing using CMs. In the CMs examined it was determined that the students understood and correlated the macro-level concepts better than the micro-level concepts. In the other study, CMs were used to understand 10th-grade students' ST skills and similar values were obtained (Assaraf et al., 2013). Related examples include Songer and Mintzes (1994), which studies marine life; Assaraf and Orion (2010) (Davis et al., 1993), which examines global atmospheric change. In these studies, it has been shown that CMs reflect students' ST and facilitate learning about complex systems. Odom and Kelly (2000) found that CMs effectively learned diffusion and osmosis. Likewise, Markow and Lonning (1998) demonstrated the effect of concept mapping on teaching in university chemistry laboratories. Students' CMs show the structural components of the systems and the processes within the system (Hmelo-Silver and Azevedo, 2006). Various studies shared the characteristics of CMs, ST, structure, dynamism, and hierarchy (Rye and Rubba, 1998; Songer and Mintzes, 1994). Studies show that the increase in the number of concepts, propositions, and cross-relationships in CMs is a good indicator to measure ST, and they have used CMs as a tool to evaluate ST skills in biology (Assaraf et al., 2013; Chang and Chiu, 2004). Similar studies have examined marine life (Whitner, 1985), the water cycle (Songer and Mintzes, 1994), used CMs to understand polar Earth systems (Assaraf and Orion, 2010), and global atmospheric change (Davis et al., 1993). Odom and Kelly (2000) showed that, besides showing students' ST, CMs facilitate learning complex systems. Elmas, Arslan, Pamuk, Pesman and Sözbilir (2021) analyzed methods related to the development of ST skills.

Teacher candidates' food production system CMs were examined regarding sectoral components in the system. As a result of this analysis shows, the sectors the candidate teachers included in their food production CMs and their close and distant relationships with each other, as shown in Figure 4. Food production processes are at the centre, and the closest relationship has been established with health, economy, and hygiene. The supply chain, society, nature, recycling, and environmental pollution occurred in the second level. At the third level, marketing is considered sustainability and conversion to new products. The most distant relationship has been education and engineering. Accordingly, candidate teachers could not establish a relationship between education and engineering with food production. The reason why candidate teachers have difficulty in establishing relationships between different sectors may be that they have experienced such an example for the first time. It is thought that as the number of these applications increases, ST skills will increase.

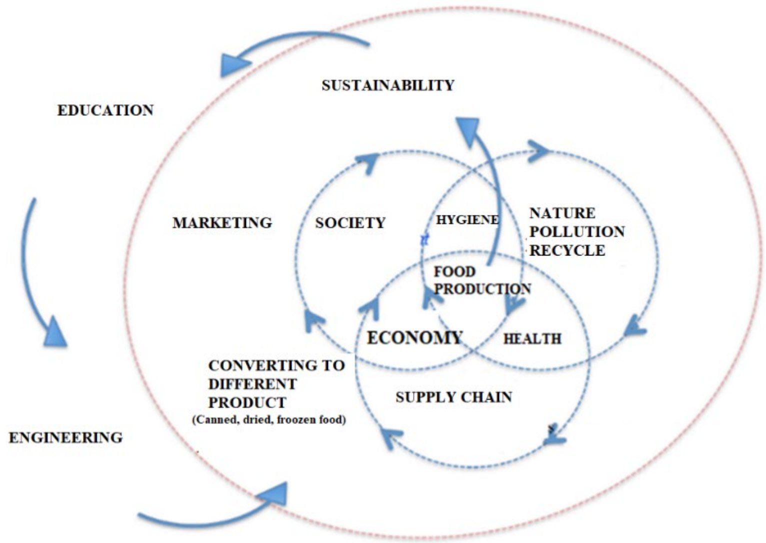

Figure 4: Analysis of CMs in Terms of Food Production Sectoral Relations

Sommer and Lücken (2010) stated that ST improves the establishment of meaningful relationships among system elements. Again, this process organizes instruction through conceptual representation, facilitating learning and helping to understand complex systems in depth. ST is a promising approach that reflects the multiple interactive components of the system and their interaction with each other. System thinking provides a holistic view of the structure and function of the complex concepts in science and the system in engineering (Hadgraft, Carew, Therese and Blundell, 2008).

Conclusion

The study used the ST skill test to evaluate the teacher candidates' system thinking skills. It has been determined that this test is a tool that can be used in ST. In addition, it has been seen that CMs are effective in ST. Another finding is the development of teacher candidates' understanding of structure, function, and behaviour, which are the system's basic components. Again, the success levels of candidate teachers have increased in understanding the relationship between the sectors in the food production system. This study also has limitations. The ST test is descriptive and may not measure actually observed proficiency. Future studies may be useful in different fields with different study groups because CMs are a useful tool that visualizes systems thinking and can be applied effectively and easily in every field. In conclusion, new interdisciplinary studies would be beneficial for developing strategies in food production and ST in different fields.

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References

Akiri, E., Tal, M., Peretz, R., Dori, D., & Dori, Y. J. (2020). STEM Graduate Students' Systems Thinking, Modeling and Scientific Understanding—The Case of Food Production. *Applied Sciences*, 10(21), 7417. MDPI AG. https://doi.org/10.3390/app10217417.

Anderson, V., & Johnson, L. (1997). *Systems thinking basics: From concepts to causal loops*. Waltham, MA: Pegasus Communications.

Arias, A., Davis, E., Carlos Marino, J., Kademian, S., & Palincsar, A. (2016). Teachers' use of educative curriculum materials to engage students in science practices. *International Journal of Science Education*, 38(9), 1504–1526. https://doi.org/10.1080/09500693.2016.1198059.

Assaraf, O. B., & Orion, N. (2005). Development of system thinking skills in the context of earth system education. *The Journal of Research in Science Teaching*, 42, 518–560. https://doi.org/10.1002/tea.20061.

Assaraf, O. B., & Orion, N. (2010). System thinking skills at the elementary school level. *Journal of Research in Science Teaching*, 47(5), 540-563. https://doi.org/10.1002/tea.20351.

Assaraf, O. B., Dodick, J., & Tripto, J. (2013). High School Students' Understanding of the Human Body System. *Research Science Education*, 43, 33-56. https://doi.org/10.1007/s11165-011-9245-2.

Åström, M. (2008). *Defining integrated science education and putting it to test*, Doctoral dissertation, Linköping University. Linköping University Electronic Press.

Barak, M. (2020). Problem-Project and Design-Based Learning: Their Relationship to Teaching Science, Technology and Engineering in School. *Journal of Problem-Based Learning*, 7, 94-97. https://doi.org/10.24313/jpbl.2020.00227.

Baser, D., Yasar O. M., & Karaarslan, H. (2017). Collaborative project-based learning: An integrative science and technological education project. *Research in Science and Technological Education*, 35(2), 131–148. https://doi.org/10.1080/02635143.2016.1274723.

Batalden, P. B., & Mohr, J. J. (1997). Building knowledge of health care as a system. *Quality management in health care*, 5(3), 1–12.

Batzri, O., Assaraf, O., Cohen, C., & Orion, N. (2015). Understanding the Earth Systems: Expressions of Dynamic and Cyclic Thinking Among University Students. *Journal of Science Education and Technology*, 24, 761–775. https://doi.org/10.1007/s10956-015-9562-8.

Bedir, A., Desai, R., Kulkarni, N., Wallet, K., Wells, R., & Smith, M. (2020). *Assessing Student Learning of Systems Thinking Concepts in an Online Education Module*, Systems and Information Engineering Design Symposium (SIEDS), Charlottesville, VA, USA, 1-6, https://doi.org/10.1109/SIEDS49339.2020.9106680.

Bell, S. (2010). Project-based learning for the 21st century: Skills for the future. *The Clearing House: A Journal of Educational Strategies, Issues and Ideas*, 83(2), 39–43. https://doi.org/10.1080/00098650903505415.

Blumenfeld, P. C., Soloway, E., Marx, R. W., Krajcik, J. S., Guzdial, M., & Palincsar, A. (1991). Motivating project-based learning: Sustaining the doing, supporting the learning. *Educational Psychologist*, 26(3-4), 369–398. https://doi.org/10.1080/00461520.1991.9653139.

Boersma, K., Waarlo, A. J., & Klaassen, K. (2011). The feasibility of systems thinking in biology education. *Journal of Biological Education*, 45(4), 190–197. https://doi.org/10.1080/00219266.2011.627139.

Chang, S.N., & Chiu, M.H. (2004). *Probing Students' Conceptions Concerning Homeostasis of Blood Sugar via Concept Mapping*. Proceedings of the Annual Meeting of the National Association for Research in Science Teaching, Vancouver/Canada.

Checkland, P. (1983). O. R. and the systems movement: Mappings and conflicts. *Journal of the Operational Research Society*, 8(4), 661–675. https://doi.org/10.1057/jors.1983.160.

Checkland, P. (2000). Soft systems methodology: A thirty year retrospective. *Systems Research and Behavioural Science*, 17(S1), S11–S58. https://doi.org/10.1002/1099-1743(200011)17:1+<::AID-SRES374>3.0.CO;2-O.

Cohen, L., & Manion, L. (1997). *Research methods in education (4th ed.)*. Routledge: London and New York.

Crawley, E. F., Cameron, B., & Selva, D. (2016). *System architecture: Strategy and product development for complex systems*. Hoboken, NJ, USA: Pearson Higher Education, Inc.

Creswell, J. W. (2012). *Educational research: Planning, conducting, and evaluating quantitative and qualitative research (4th ed.)*. Boston, MA: Pearson.

Czerniak, C. M., & Johnson, C. C. (2014). *Interdisciplinary science teaching*. Handbook of research on science education (pp. 395-411)

Davis, R., Shrobe, H., & P. Szolovits, P. (1993). What is a Knowledge Representation? *Al Magazine*, 14(1), 17-33.

Dolansky, M. A., Moore, S. M., Palmieri, P. A., & Singh, M. K. (2020). Development and Validation of the Systems Thinking Scale. *Journal of general internal medicine*, 35(8), 2314–2320. https://doi.org/10.1007/s11606-020-05830-1.

Dori, D., Sillitto, H., Griego, R.M., McKinney, D., Arnold, E.P., Godfrey, P., Martin, J., Jackson, S., & Krob, D. (2019). System definition, system worldviews, and systemness characteristics, *IEEE Systems Journal*, 1–11, https://doi.org/10.1109/JSYST.2019.2904116.

Easley, K. M. (2020). *Simulations and sense making in elementary project-based science*. Unpublished doctoral dissertation, University of Michigan.

Eilam, B. (2012). System thinking and feeding relations: learning with a live ecosystem model. *Instructional Science*, 40(2), 213–239. http://www.jstor.org/stable/43575411.

Ekselsaa, R. A., Purwianingsihb, W., Anggraenib, S., Ghofar, A., & Wicaksonoc, C. (2023). Developing system thinking skills through project-based learning loaded with education for sustainable development, *JPBI (Jurnal Pendidikan Biologi Indonesia)*, 9(1), 62-73. https://doi.org/10.22219/jpbi.v9i1.24261.

Elmas, R., Arslan, H. Ö., Pamuk, S., Pesman, H., & Sözbilir, M. (2021). Fen Eğitiminde Yeni Bir Yaklaşım Olarak Sistemsel Düşünme. *Türkiye Kimya Dernegi Dergisi*, 6(1), https://doi.org/10.37995/jotcsc.889340.

Evagorou, M., Korfiatis, K., Nicolaou, C., & Constantinou, C. (2009). An investigation of the potential of interactive simulations for developing system thinking skills in elementary school: a case study with fifth- and sixth- graders. *International Journal of Science Education*, 31(5), 655-674. https://doi.org/10.1080/09500690701749313.

Feltovich, P. J., Coulson, R. L., & Spiro, R. J. (2001). Learners '(mis) understanding of important and S. Sinha et al.22 | F L R difficult concepts. In K.D. Forbus & P. J. Feltovich (Eds.), *Smart machines in education: The coming revolution in educational technology*, 349–375. Menlo Park, CA: AAAI/MIT Press.

Fisher, D. M. (2011). Everybody thinking differently: K–12 is a leverage point. *System Dynamics Review*, 27(4), 394-411. https://doi.org/10.1002/sdr.473.

Fitzgerald, M. S. (2020). Overlapping opportunities for literacy learning and socialemotional learning in elementary-grade project-based instruction. *American Journal of Education*, 126(4), 573–601. https://doi.org/10.1086/709545.

Frank, M. (2006). Knowledge, abilities, cognitive characteristics and behavioural competences of engineers with high capacity for engineering systems thinking (CEST). *Systems Engineering*, 9(2), 91–103. https://doi.org/10.1002/sys.20048.

Gay, L. R., & Airasian, P. (2000). *Educational research competencies for analysis and application (6th Edition)*. Ohio: Merrill an imprint of Prentice Hall.

Goel, A. K., Gomez de Silva Garza, A., Grué, N., Murdock, J. W., Recker, M. M., & Govinderaj, T. (1996). *Towards designing learning environments -I: Exploring how devices work*. In C. Fraisson, G. Gauthier & A. Lesgold (Eds.), Intelligent Tutoring Systems: Lecture notes in computer science. NY: Springer.

Greene, M. T., Gonzalez, R., Papalambros, P.Y., & McGowan, A. R. (2017), *Design Thinking vs. Systems.Thinking for Engineering Design: What's the Difference?* Proceedings of the 21st International Conference on Engineering Design, Vancouver, British Columbia, Canada

Haas, A., Januszyk, R., Grapin, R., Goggins, M., Llosa, L., & Lee, O. (2021). Developing instructional materials aligned to the Next Generation Science Standards for all students, including English learners. *Journal of Science Teacher Education*, 32(7), 735–756. https://doi.org/10.1080/1046560X.2020.1827190.

Haatainen, O., & Aksela, M. (2021). Project-based learning in integrated science education: Active teachers' perceptions and practices. *LUMAT*, 9(1), 149–173. https://doi.org/10.31129/LUMAT.9.1.1392.

Hadgraft, R. G., Carew, A. L., Therese, S. A., & Blundell, D. L. (2008). *Teaching and assessing systems thinking in engineering*. Research in Engineering Education Symposium, 230–235.

Han, S., Yalvac, B., Capraro, M. M., & Capraro, R. M. (2015). *In-service teachers' implementation andunderstanding of STEM project-based learning*. EURASIA Journal of Mathematics, Science & Technology Education, 11(1), 63–76. https://doi.org/10.12973/eurasia.2015.1306a.

Hmelo-Silver, C. E., & Pfeffer, M. G. (2004). Comparing expert and novice understanding of complex system from the perspective of structures, behaviours, and functions. *Cognitive Science*, 28, 127–138. https://doi.org/10.1016/S0364-0213(03)00065-X.

Hmelo-Silver, C.E., & Azevedo, R. (2006). Understanding Complex Systems: Some Core Challenges. *Learning Sciences*, 15(1), 53-61. https://doi.org/10.1207/s15327809jls1501_7.

Hmelo-Silver, C. E., Marathe, S., & Liu, L. (2007). Fish swim, rocks sit, and lungs breathe: Expert-novice understanding of complex systems. *Journal of the Learning Sciences*, 16, 307-331. https://doi.org/10.1080/10508400701413401.

Jacobson, M. J. (2001). Problem solving, cognition, and complex systems: differences between experts and novices. *Complexity*, 6(3), 4-49. https://doi.org/10.1002/cplx.1027.

Jacobson, M., & Wilensky, U. (2006). Complex Systems in Education: Scientific and Education Importance and Implications for the Learning Sciences. *The Journal of the Learning Sciences*, 15(1), 11-34. https://doi.org/10.1207/s15327809jls1501_4.

Jagers, R., Rivas-Drake, D., & Williams, B. (2019). Transformative social and emotional learning (SEL): Toward SEL in service of educational equity and excellence. *Educational Psychologist*, 54(3), 162–184. https://doi.org/10.1080/00461520.2019.1623032.

Kingston, S. (2018). Project Based Learning & Student Achievement: What Does the Research Tell Us? *PBL Evidence Matters*, 1(1), 1-11.

Koral, K. S., Frank, M., & Nissel, M. A. (2018). Systems Thinking Education—Seeing the Forest through the Trees. *Systems*, 6(3), 29. MDPI AG. http://dx.doi.org/10.3390/systems6030029.

Liu, L., & Hmelo-Silver, C. E. (2009). Promoting complex systems learning through the use of conceptual representations in hypermedia. *Journal of Research in Science Teaching*, 9, 1023-1040. https://doi.org/10.1002/tea.20297.

Long, C. (2012). Teach Your Students to Fail Better with Design Thinking. *Learning & Leading with Technology*, 9(5), 16-20. https://files.eric.ed.gov/fulltext/EJ982832.pdf.

Markow, P. G., & Lonning, R. A. (1998). Usefulness of Concept Maps in College Chemistry Laboratories: Students' Perceptions and Effects on Achievement. *Science Teaching*, 35(9), 1015-1029. https://doi.org/10.1002/(SICI)1098-2736(199811)35:9<1015::AID-TEA4>3.0.CO;2-G.

Martin, D. (2004). Martin's Map: A conceptual framework for teaching and learning the medical interview using a patient-centred approach. *Medical education*, 37, 1145-53. https://doi.org/10.1111/j.1365-2923.2003.01719.x.

Mintzes, J. J., Wandersee, J. H., & Novak, J. D. (1998). *Teaching science for understanding: A human constructivist view*. San Diego: Academic Press.

Moore, S. M., Komton, V., Adegbite-Adeniyi, C., Dolansky, M. A., Hardin, H. K., & Borawski, E. A. (2018). Development of the Systems Thinking Scale for Adolescent Behaviour Change. *Western journal of nursing research*, 40(3), 375–387. https://doi.org/10.1177/0193945917697219.

Nagarajan, S., & Overton, T. (2019). Promoting Systems Thinking Using Project- and Problem-Based Learning. *Journal of Chemical Education*, 96(12), 2901-2909. https://doi.org/10.1021/acs.jchemed.9b00358.

National Education Association, NEA. (2002). *Preparing 21st Century Students for a Global Society: An Educator's Guide to the "Four Cs"*. Retrieved October 12, 2022, from https://www.nea.org/assets/docs/A-Guide-toFour-Cs.pdf.

NGSS Lead States (2013). *Next Generation Science Standards: for States, by States*. Washington, DC: National Academy Press.

Novak, J. D., & Musonda, D. (1991). A Twelve-Year Longitudinal Study of Science Concept Learning. *American Educational Research Journal*, 28 (1), 117-153. https://doi.org/10.3102/00028312028001117.

Novick, L. R., & Hmelo, C. E. (1994). Transferring Symbolic Representations across Nonisomorphic Problems. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 20(6), 1296-1321. https://doi.org/10.1037/0278-7393.20.6.1296.

Odegard, I., & van der Voet, E. (2014). The future of food—Scenarios and the effect on natural resource use in agriculture in 2050. *Ecological Economics,* 97, 51-59. https://doi.org/10.1016/j.ecolecon.2013.10.005.

Odom, A. L., & Kelly, P. V. (2000). Integrating Concept Map- ping and the Learning Cycle to Teach Diffusion and Osmosis Concepts to High School Biology Students. *Science Education*, 85(6), 615-635. https://doi.org/10.1002/sce.1029.

Ossimitz, G. (2000). *Systemisches Denken braucht systemische Darstellungsmittel, invited paper for the yearly conference of the Society for Social and Economic Cybernetics*. September 2000 in Mannheim. - Berlin: Duncker & Humblot, 161-173

Penner, D., (2000). Explaining systems: Investigating middle school students' understanding of emergent phenomena. *Journal of Research Science in Teaching*, 37, 784-806. https://doi.org/10.1002/1098-2736(200010)37:8<784::AID-TEA3>3.0.CO;2-E.

Plate, R. (2010). Assessing individuals' understanding of nonlinear causal structures in complex systems. *System Dynamics Review*, 26(1), 19–33. http://doi.org/10.1002/sdr.432.

Richmond, B. (2001). *An Introduction to Systems Thinking.* High Performance Systems, Inc. Lebanon, NH.

Rotherham, A. J., & Willingham, D. (2009). 21st Century Skills: the challenges ahead. *Educational Leadership*, 67(1), 16-21.

Ruiz-Primo, M. A., & Shavelson, R. J. (1996). Problems and issues in the use of concept maps in science assessment. *Journal of Research in Science Teaching*, 33(6), 569–600. https://doi.org/10.1002/(SICI)1098-2736(199608)33:6<569::AID-TEA1>3.0.CO;2-M.

Rye, J. A., & Rubba, P. A. (1998). An Exploration of the Concept Map as an Interview Tool to Facilitate the externalization of Students' Understandings about Global Atmospheric Change. *Science Teaching*, 35(5), https://doi.org/10.1002/(SICI)1098-2736(199805)35:5<521::AID-TEA4>3.0.CO;2-R.

Sabelli, N. (2006). Complexity, technology, science, and education. *Journal of the Learning Sciences*, 15, 5-10. https://doi.org/10.1207/s15327809jls1501_3.

Semiz, G. K., & Teksöz, G. (2019). Developing the systems thinking skills of pre-service science teachers through an outdoor ESD course. *Journal of Adventure Education and Outdoor Learning*, 20, 1-20. https://doi.org/10.1080/14729679.2019.1686038.

Shaked, H., & Schechter, C. (2019). Systems Thinking for Principals of Learning- Focused Schools. *Journal of School Administration Research and Development*, 4, 18-23. 10.32674/jsard.v4i1.1939.

Shepardson, D. P., Roychoudhury, A., Hirsch, A., Niyogi, A., & Top, S. M. (2014). When the atmosphere warms it rains and ice melts: seventh grade students' conceptions of a climate system. *Environmental Education Research*, 20(3), 333-353, https://doi.org/10.1080/13504622.2013.803037.

Shepardson, D. P., Roychoudhury, A., & Hirsch, A. S. (Eds.). (2017). *Teaching and Learning about Climate Change: A Framework for Educators (1st ed.)*. Routledge. https://doi.org/10.4324/9781315629841.

Sinha, S., Gray, S., Hmelo-Silver, C. E., Jordan, R., Eberbach, C., Goel, A., & Rugaber, S. R. (2013). Conceptual representations for transfer: A case study tracing back and looking forward. Frontline Learning Research, 1(1), 3–23. https://doi.org/10.14786/flr.v1i1.14.

Sommer, C., & Lücken, M. (2010). System competence–Are elementary students able to deal with a biological system? *Nordic Studies in Science Education*, 6(2), 125-143. https://doi.org/10.5617/nordina.255.

Songer, C. J., & Mintzes, J. J. (1994). Understanding Cellular Respiration: An Analysis of Conceptual Change in College Biology. *Science Teaching*, 31(6), 621-637. https://doi.org/10.1002/tea.3660310605.

Sterman, J. D. (2000). *Business Dynamics Systems Thinking and Modelling In A Complex World*. Mcgraw-Hill, New York.

Sweeney, L. B., & Sterman, J. D. (2000). Bathtub dynamics: initial results of a systems thinking inventory. *System Dynamics Review*, 16(4), 249–286. http://doi.org/10.1002/sdr.198.

Tabachnick, B. G., & Fidell, L. S. (2013). *Using multivariate statistics (6th ed.)*. Boston: Allyn and Bacon

Tamir, R., Ben-Zvi Assaraf, O., & Maman, S. (2023). System-thinking progress in engineering programs: A case for broadening the roles of students. *Frontiers in Education*, 8. https://doi.org/10.3389/feduc.2023.1138503.

Tripto, J., Ben-Zvi Assaraf, O., Snapir, Z., & Amit, M. (2017). How is the body's systemic nature manifested amongst high school biology students? *Instructional Science,* 45, 73–98. https://doi.org/10.1007/s11251-016-9390-0.

Verhoeff, R. P., Waarlo, A. J., & Boersma, K.T. (2008). Systems Modelling and the Development of Coherent Understanding of Cell Biology. *International Journal of Science Education*, 30(4), 543-568. https://doi.org/10.1080/09500690701237780.

Verhoeff, R. P., Boersma, K. T., & Waarlo, A., J. (2013). *Multiple representations in modeling strategies for the development of systems thinking in biology education, in Multiple Representations in Biological Education*. eds D. F. Treagust and Chi-Yan Tsui (Dordrecht; Heidelberg; New York, NY; London: Springer), 331–348

White, R., & Gunston, R. (1992). *Probing Understanding*, Falmer. London

Whitner, P. A. (1985). *Gestalt Therapy and General System Theory*. The University of Toledo, Toledo, Ohio 43606. (419), 537-2426.

Yin, Y., Vanides, J., Ruiz-Primo, M. A., Ayala, C. C., & Shavelson, R. J. (2005). Comparison of two conceptmapping techniques: Implications for scoring, interpretation, and use. *Journal of Research in Science Teaching*, 42(2), 166–184. https://doi.org/10.1002/tea.20049.

Zele, E. C. (2004). Improving the Usefulness of Concept Maps as a Research Tool for Science Education. *Science Education*, 26(9), 1043-1064. https://doi.org/10.1080/1468181032000158336.