IMPLEMENTATION OF SYSTEMS THINKING SKILLS MODULE FOR THE CONTEXT OF ENERGY

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ABSTRACT

IMPLEMENTATION OF SYSTEMS THINKING SKILLS MODULE FOR THE CONTEXT OF ENERGY

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The aim of this dissertation is to explore how pre-service science teachers develop their systems thinking skills in the context of energy. Qualitative methodology is followed through the research. The study conducted in stages that consist of development of systems thinking module for implementation, development of tools to collect data, implementation of the module, and data collection procedure before, during and after the implementation and data analysis. Nine preservice science teachers at the faculty of education from a state university in Turkey are participated the study. Data were collected with real life scenario, interviews and audio and video recordings during the sessions. Content analysis was held to make sense of data. Results of the study indicated that overall, the developmental trajectory of pre-service science teachers changed with their individual interest and motivation towards the implementation, their knowledge level about the issues, the complexity level of the systems or events depicted during the implementation. Specifically, systems thinking skills regarding mindset domain developed in the case of energy issues. Pre-service science teachers' skills development regarding content, structure and behavior domains stayed limited. In the content domain they have difficulties with maintaining boundaries skill. Pre-service science teachers harbor some doubt in recognizing complex interactive relationships and feedback mechanisms between the events in structure domain and describing and predicting system behavior in behavior domain. The results of the study supported the Arnold and Wade (2017)'s domain approach as means of identifying structure of systems thinking skills.

Keywords: Systems Thinking Skills, Pre-service Science Teachers, Energy, Systems Thinking Module, Systems Thinking Development

ÖZ

SİSTEMSEL DÜŞÜNME BECERİSİ MODÜLÜNÜN ENERJİ BAĞLAMINDA UYGULANMASI

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Bu çalışmada, fen bilimleri öğretmen adaylarının sistemsel düşünme becerilerinin enerji konusu bağlamında araştırılması ve geliştirilmesi amaçlanmıştır. Araştırmada nitel yöntem kullanılmıştır. Çalışma, uygulamaya yönelik modülün geliştirilmesi, veri toplama araçlarının geliştirilmesi, modülün uygulaması, uygulama öncesinde, sırasında ve sonrasında verilerin toplanması ve analizi aşamalarından oluşmaktadır. Araştırmaya Türkiye'de bir devlet üniversitesinde öğrenim gören dokuz fen bilimleri öğretmen adayı katılmıştır. Veriler gerçek yaşam senaryosu, görüşmeler ve modül uygulaması sırasındaki ses ve video kayıtları ile toplanmıştır. Verinin anlamlandırılması sürecinde betimsel analiz ve içerik analizi kullanılmıştır. Araştırmanın sonuçlarına göre öğretmen adaylarının sistemsel düşünme becerilerindeki gelişim örüntülerinin, uygulamaya yönelik kişisel ilgileri ve motivasyonlarına, konularla ilgili bilgi düzeylerine ve ele alınan konuların karmaşıklık düzeyine göre değişim gösterdiği saptanmıştır. Öğretmen adaylarında, sistemsel düşünme becerileri alanlarından düşünce yapısı alanı gelişim göstermiştir. Sistemsel düşünme becerilerinin yapı alanında, karmaşık ilişkilerin anlaşılmasına ve olaylar içindeki geri besleme mekanizmalarının çözümlenmesine yönelik becerilerin gelişimi sınırlı kalmıştır. Ayrıca öğretmen adaylarının, sistemsel düşünmenin davranış alanındaki becerilerden olayları ya da sistem davranışını bütünlük içinde açıklama ve sistem davranışının tahmin edilmesi konusunda zorluk yaşadıkları görülmüştür. Çalışmanın sonuçları Arnold ve Wade (2017)'in alan yaklaşımının sistemsel düşünme becerilerinin belirlenmesinde kullanılabileceğini destekler niteliktedir.

Anahtar Kelimeler: Sistemsel Düşünme Becerileri, Fen Bilimleri Öğretmen Adayları, Enerji, Sistemsel Düşünme Modülü, Sistemsel Düşünmenin Gelişimi

To My Family

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LIST OF ABBREVIATIONS

AI	After STS Module Implementation
BI	Before STS Module Implementation
ESD	Education for Sustainable Development
IS	Stage of Implementation
MoNE	Turkey Ministry of National Education
NA	Not Applicable
NRC	National Research Council of USA
PST	Pre-Service Science Teacher
SDG	Sustainable Development Goals
STS	Systems Thinking Skills
STS Module	Systems Thinking Module for Energy Context
UNDP	United Nations Development Program

CHAPTER 1

INTRODUCTION

In 21st century, science, technology and knowledge developed rapidly. This rapid development affected our lives and expectations from individuals. The changing direction of education goes hand in hand with technological advancements and societal needs. People, who produce knowledge, use this knowledge functionally, solve problems, think critically, contribute culture and society and who are entrepreneur, decisive, communicative, and emphatic are defined as expected profile of the century in many countries (A Framework for K-12 Science Education, 2012; National Curriculum in England: Science Programs of Study, 2013, 2014; Tukey Ministry of National Education, 2013, 2018). It is seen that abilities related to scientific thinking, experimental skills, scientific attitudes, analysis, science and engineering practices are advocated besides core concepts related to scientific disciplines in these curricula. Specifically, in Turkish Science Curriculum developing students' who are qualified as means of mentioned skills are emphasized similarly. Also, analytical thinking is frequently advocated in the last curriculum (MoNE, 2018). Analytical thinking is an ability that target to understand the events, phenomenon or a whole by breaking them down into small pieces and understanding the function of the pieces (Mella, 2012). However, analytical thinking alone is not enough to understand the events around us. Global climate crisis, energy choices, consumption and management, human behavior related to energy and environment, environmental issues, economy, and development issues are all complex and intertwined (Meadows, 2009). Understanding, evaluating and decision making related to these issues are beyond the boundaries of analytical thinking. Analytical perspective which aims to understand issues by breaking down them into pieces does not seem to be enough to solve complex issues surrounding us. Systems thinking perspective is offered to handle with complex issues such as health issues, environment, management, economy, human behavior, societal issues, climate change and education (Daellenbach & McNickle, 2005; Meadows, 2009; Mella, 2012; Higgins, 2015).

1.1 Systems Thinking

When it is wanted to understand systems thinking; it is possible to talk about systems initially. A system is a regularly interacting or interdependent group of items forming a unified whole (Merriam Webster Online Dictionary, 2019). A system consists of three kinds of things: elements, interconnections, and function or purpose. Some examples of systems include economy of a country, a power plant, a tree, an ecosystem, the Earth, atmosphere, human body, a sport game, a molecule and a faculty (Meadows, 2009). Some of these systems are natural systems while some of them are contrived or human-made. Sometimes the elements of the systems themselves are also systems and they are called subsystems. All these subsystems have a purpose and connected to each other. For instance, while the Earth is a natural system that is composed of several sub-systems such as forests, matter cycles, biological organisms or oceans, a car or a power plant is a human-made system with several subsystems. Some of the systems, especially human-made systems have mechanical, fixed structure and once they are understood they may be programmed for a desired behavior. Some of systems are hard to understand since they respond the changes differently under different conditions.

When systems structure are considered, it should be asked that if it is possible to identify; the parts, the interaction between these parts, the difference between the behavior of the parts alone and all together as a system, and the persistence of the behavior of the whole structure over time under a variety of conditions (Meadows, 2009). Parts of a system can be either visible or invisible and they are the least effective component of the systems behavior. Interconnections have the potential to change system behavior. If interconnections among the parts of the system change, the system may greatly change. If any change in the parts of the system, changes the interconnections among the parts of the system, the system behavior may also change. The most obvious part of the system, function or purpose of the system is the most effective part of the system behavior. Change in function of the system alters the structure of the system and interconnections of the system.

System behavior results in an emphasis on many thinking habits that are powerful tools to understand the issues and problems around us. Like systems; events, problems and issues around us have different developmental trajectory and usually people want to carry them over a desired state. In this process; initially it is very important to make decision about boundaries (Frank, 2012; Arnold & Wade, 2017). Deciding boundaries means understanding what is more related to our issue, what is inside it, what is not related to it. When the boundaries are determined first, it may be possible not to spend time with unrelated issues. It is also important to realizing historical context of events (Jackson, 2003). The history gives us an understanding of flow of events at different times. Therefore, it becomes possible to see the way of systems behavior through understanding patterns. Individual focus on events in current time does not give us a full comprehension of flow (Kim, 1999). When events are followed for a while, it is possible to understand the purpose of the system. These are all necessities for being a fine problem solver and at the same time necessities for being a systems thinker.

Systems thinking is a way of thinking including understanding the structure of systems from a holistic framework by understanding the relationships between systems components, feedbacks and the way systems behave, in their own context by taking into consideration of change and dynamism (Arnold & Wade, 2017; Meadows, 2009; Sweeney & Sterman, 2000). It is very important to understand complex structure of economies, individuals, companies, illnesses, environmental problems to cope up with all these issues (Daellenbach & McNickle, 2005; Meadows, 2009; Higgins, 2015). When handling with complex issues, usually there are lack of information and knowledge to solve these problems. Meadows (2009) told about the inadequacy of classical reductionist approach to understand complex issues and advocated systems thinking as a holistic way of understanding complex phenomena. Systems thinking is valuable in complex problems that have many actors, recurring problems that are not fixed in the past by attempts, problems that do not have obvious solutions and issues contextualized in their environment (Aronson, 1996; Daellenbach & McNickle, 2005; Higgins, 2014). Systems thinking requires understanding the situations or events in their full systems context (Yurtseven & Buchanan, 2016). It is beyond linear thinking. Systems thinking skills are mentioned to be as higher order thinking skill and to be related to scientific thinking, problem solving, and critical thinking by many researchers (Assaraf & Orion, 2005; Hung, 2008).

1.2 Defining Systems Thinking

Systems thinking is defined by many authors in the research literature. For instance, according to National Research Council (2010), the ability to understand how a system work; how an action, change or malfunction in one part a system affect the rest of the system is defined as systems thinking. Definitions in literature are resulted in many elements which try to characterize systems thinking. For example, Richmond (2000) listed a set of skills that characterizes a good systems thinker in a non-hierarchical manner. Richmond's skills of systems thinking are; dynamic thinking, system as cause thinking, 10.000 meters thinking, operational thinking, closed-loop thinking, non-linear thinking, scientific thinking, and emphatic thinking. Each of these skills refers to different constructs that characterizes systems thinking. Sweeney and Sterman (2000, p.2) define system thinking as "ability to assess and represent dynamic complexity" and lists a variety of abilities about systems thinking. They also emphasize some basic skills underlying system thinking such as creating and interpreting graphs, creating a graph of behavior over time, identifying units of measure and basic understanding of probability, logic and algebra. Similarly; Behl and Ferreira (2014) listed a variety of individual systems thinking elements from different authors' framework. Different from Richmond (2000)'s work, they showed the relationships between these elements. Their systems thinking elements are given in Table 1.1.

Another characterization of systems thinking elements is Assaraf and Orion (2010)'s systems thinking hierarchical model framework that they used in explaining students systems thinking. Hierarchy of systems thinking skills framework is a specific framework in the context of earth sciences including the topics such as carbon cycle and water cycle. The framework included eight elements organized in three levels; analysis, synthesis and implementation. The framework is given in Table 1.1. Similarly, Stave and Hopper (2007) proposed a hierarchical model of systems thinking skills. Their model showed systems thinking skills in a continuum from lower level of skills including recognizing interconnections, identifying feedback, and understanding dynamic behavior, followed by intermediate level skills; differentiating types of variables and flows and using conceptual models to higher level skills including creating simulation models and testing policies.

Arnold and Wade (2015) criticized these definitions as being reductionist in nature. They defined systems thinking as "a set of synergistic analytical skills used to improve the capability of identifying and understanding systems, predicting their behaviors, and devising modifications to them in order to produce desired effects" (Arnold & Wade, 2015, p.676). According to their definition system thinking skills work together as a system. They developed a systems thinking systemigram showing the relationships among the components of systems thinking and explained the elements of systems thinking with the help of literature synthesis. In their paper (Arnold & Wade, 2017), they extended their definitions of systems thinking and proposed systems thinking skills categorized in four domains. These four domains are mindset, content, structure, and behavior domains. They classified these four domains under two areas namely, gaining insight and applying insight. Content, structure and behavior domains are more relevant to applying systemic insight, while mindset domain is more relevant to gaining systemic insight domain. They target to assess systems thinking of individuals in more generic terms. Their systems thinking elements are given in Table 1.1.

While Assaraf and Orion (2010)'s framework is a framework to assess systems thinking skills in earth sciences context, it is also possible to see adaptation of systems thinking skills in education for sustainable development context. Karaarslan (2016) emphasized the importance of systems thinking in Education for Sustainable Development and built up a framework consisting twelve multifaceted skills to assess systems thinking in ESD context.

In summary, it is possible to say that system thinking refers to understanding the presence of a phenomenon or event from a whole perspective by realizing its structure and behavior and use this understanding to predict the behavior of the system in changing conditions. Therefore, systems thinking allows us not to focus just one event and its effects instead it allows us to see more events related to the whole structure and assess their roles in the whole context. Systems thinking skills assessment frameworks are different from each other by their structure and contextual aspects. While Assaraf and Orion (2010) and Karaarslan (2016) target to assess systems thinking skills by using frameworks adapted to their own contexts, other authors Richmond (2000), Sweeney and Sterman (2000), Stave and Hopper (2007), and Arnold and Wade (2015, 2017) use general frameworks that are not specified for their own context. Besides context dependency of these frameworks, their structural differences are also an important aspect of these frameworks. In some of these frameworks the relationships among systems thinking skills are not defined; such as Richmond (2000) and Sweeney and Sterman (2000). In another group of frameworks hierarchical structure of systems thinking skills are emphasized such as Stave and Hopper (2007) and Assaraf and Orion (2010). Some of systems thinking skills frameworks emphasize the importance of connection between systems thinking elements, such as Behl and Ferreira (2014) and Arnold and Wade (2015; 2017).

Table 1.1: Systems Thinking Elements Defined by Researchers

Researchers	Model of Systems Thinking	Systems Thinking Elements in Model
Sweeney and Sterman (2000, p.2)	Systems Thinking Abilities	Understand how behavior of the system arises from the interaction of its agents over time Discover and represent feedback processes (both positive and negative) hypothesized to Underlie observed patterns of system behavior Identify stock and flow relationships Recognize delays and understand their impact Identify nonlinearities Recognize and challenge the boundaries of mental (and formal) models
Stave and Hopper (2007, p.12)	Hierarchical Model of Systems Thinking Elements	Recognizing interconnections Identifying feedback Understanding dynamic behavior Differentiating types of variables and flows Using conceptual models Creating simulation models Testing policies
Assaraf and Orion (2010, p.541)	Hierarchical Model of Systems Thinking Elements	The ability to identify the components of a system and processes within the system. The ability to identify relationships among the systems components. The ability to identify dynamic relationships between or among the systems components. The ability to organize the systems' components, processes, and their interactions, within a framework of relationships. The ability to identify cycles of matter and energy within the system- the cyclic nature of system. The ability to recognize hidden dimensions of the system- to understand natural phenomena through patterns and interrelationships not seen on the surface. The ability to make generalizations- to solve problems based on understanding systems' mechanisms. The ability to think temporally: retrospection and prediction.
Behl and Ferreira (2014, p.107)	Individual Systems Thinking Elements	Understanding the whole system Understanding interconnections Consider and use multiple perspectives Thinking creatively Not getting lost in details Curious Ask good questions Analytical Create, build and use models Good interpersonal skills

Table 1.1 (continued)		
Behl and Ferreira (2014, p.107)	Individual Systems Thinking Elements	Good listening skills Good communication skills Have self confidence Disciplined Abstract thinking Initiative/Motivation Systems engineering education Wide and varied experienced Outgoing/Extrovert Tolerance for uncertainty Open minded
Arnold and Wade (2015, p.676)	Connected Systems Thinking Elements	Recognizing interconnections Identifying and understanding feedback Understanding systems structure Differentiating types of stocks, flows, and variables Identifying and understanding non-linear relationships Understanding dynamic behavior Reducing complexity by modeling systems conceptually Understanding systems at different scales
Karaarslan (2016)	Multifaceted Systems Thinking Elements	Identifying aspects of sustainability Seeing nature as a system Identifying components of a system Analyzing interconnections among the aspects of sustainability Recognizing hidden dimensions Recognizing own responsibility in the system Considering the relationship among past, present and future Recognizing cycling nature of the system Developing empathy with other people Developing empathy with non-human beings Developing a sense of place Adapting systems thinking perspective to one's personal life
Arnold and Wade (2017)	Domain approach	Explore multiple perspectives Consider the wholes and parts Effectively respond to uncertainty and ambiguity Consider issues appropriately Use mental modeling and abstraction Recognize systems Maintain boundaries Differentiate and quantify elements Identify relationships Characterize relationships Identify feedback loops Characterize feedback loops Describe past system behavior Predict future systems behavior Respond to changes over time Use leverage points to produce effects

1.3 Systems Thinking in Education

Many countries make educational reforms to adapt the changing world and grow individuals who can adapt this change. In this process, the importance of thinking skills and abilities increased. Education is inevitably the reflection area of systems thinking in schools. One of the most extensive efforts of integrating systems thinking elements in school is seen in Next Generation Science Standards (NRC, 2011). In their report: A Framework for K-12 Science Education, NRC (2011) emphasizes the importance of three main dimensions in Science Education, namely; scientific and engineering practices, crosscutting concepts and core ideas. In these three dimensions; except disciplinary core ideas, the reflections of systems thinking elements are clearly seen, especially in crosscutting concepts dimension. Crosscutting concepts are the main concepts used when dealing with systems thinking including; patterns, cause and effect: mechanisms and explanation, scale, proportion and quantity, systems and systems models, energy and matter: flows, cycles and conservation, structure and function and stability and change. In each of disciplinary core ideas; crosscutting concepts take place and find an implementation area. While crosscutting concepts are closely tied to systems thinking, another main dimension; scientific and engineering practices also connected to systems thinking. For example; asking questions and defining problems, developing and using models, designing solutions are also related to systems thinking. Developing these skills in K-12 level science courses has a great value for a country to take place in the international area of technology and communication era.

In addition to the importance of systems thinking in K-12 education, the role of these skills in teacher education should not be neglected. Systems thinking is also emphasized as a key competency for Education for Sustainable Development in the area of teacher education (Sleurs, 2008). In Comenius-2-project report (Sleurs, 2008), systems thinking competencies for ESD educators are defined as; ability to create conditions for systems thinking in the classroom, school and community, ability to understand the presence of different systems and understand the interrelations between social sciences, environment and economics, ability to deal with uncertainty in the classroom by the cooperation with other teachers, ability to explore multiple cause and effect relationships in social situations.

The recent revised science curriculum in Turkey (MoNE, 2018) emphasized analytical thinking, decision making, creative thinking, entrepreneurship, communication and team work as life skills; innovative thinking as engineering and design skill; and observation, measurement, classification, data recording, hypothesizing, modelling, changing and controlling variables, experimentation as science process skills. According to G. Karaarslan (personal communication, February 18, 2020) most of systems thinking elements either does not take place in science curriculum or implicitly take place. When the learning outcomes are examined, it is seen that there are learning outcomes related to understanding relationships, classification, model building (not modelling) prevalently. Also, there are some outcomes related to design and engineering practices. In the elementary level science curriculum, it is seen that, although engineering and design practices are clearly require systems thinking, systems thinking elements do not take place. This situation seems to be similar for high school science curriculum including physics, biology, and chemistry. Contrarily, some clues about the elements related to systems thinking system are emerged in core topics, including Ecology of Ecosystems and Current Environmental Problems in Biology, Energy Resources and Scientific Advances in Chemistry, or Conservation of Energy and Energy Transformations in Physics. However, both students and teachers need systems thinking skills not only to reach the general and specific goals of the curriculum but also to deal with the complex issues they encountered in their daily life as citizens. Therefore, specifically science education and teacher education and in a more broad sense all educational attempts need systems thinking perspective to keep up with constant change in the World.

1.4 Energy in Science

Energy is a complex topic with its abstract nature on the conceptual aspect and it takes place everywhere. It is not possible to define energy in a simple sentence. According to Bevilacque (2014) it is not clear that various meanings of energy are the result of the polysemic nature of the concept or the result of a deep confusion. When we try to ask the question of “What is energy?” we may mean the essence of energy or operational definition of energy as a physical quantity (Besson & Ambrosis, 2014). Linguistic analysis of energy result in five definitions from the dictionaries (Jin & Wei, 2014); a person’s physical or mental strength or power, life energy of living things, vital power of places, energy sources utilized by people, the ability to do work. Also, three categories arise from dictionary definitions; (1) sources of energy: people, living things including people, living and non-living things, (2) nature of energy: energy as a psychological entity, energy as a physical entity, and energy as an abstract quantity, (3) causal reasoning: energy as a cause and energy as a constraint. In the history of science, it is seen that sometimes energy is threat as a substance which often defined through conservation principle, and sometimes energy is used as an abstract quantity or a general explanatory tool for describing events in science. In current textbooks, energy is defined as *capacity to do mechanical work*. This definition is still advocated in textbooks and used as a main definition for energy. However, this definition excludes the other traits of energy and is used in mechanics to explain processes.

In conceptual physics Hewitt (2006, p.71) introduces energy as followed:

> *Although energy is familiar to us, it is difficult to define, because it is not only a "thing" but both a thing and a process-similar to both a noun and a verb. Persons, places, and things have energy, but we usually observe energy only when it is being transferred or being transformed. It comes to us in the form of electromagnetic waves from the Sun, and we feel it as thermal energy; it is captured by plants and binds molecules of matter together; it is in the foods we eat, and we receive it by digestion.*

Even matter itself is condensed, bottled-up energy, as set forth in Einstein's famous formula, $E = mc^2$…

Another definition includes physical and biological processes as *the ability to drive a system transformation* (Ulgiati & Bianciardi, 2004, p.7). Similarly with and emphasize on systems, energy is defined as following (Kostic, 2007, p. 15):

a fundamental property of a physical system and refers to its potential to maintain a systems identity or structure and to influence changes with other systems (via forced-displacement) or heat (forced chaotic displacement/motion of a system molecular or related structures).

Energy exists in many forms; electromagnetic (including light), electrical, magnetic, nuclear, chemical, thermal, and mechanical (including kinetic, elastic, gravitational, and sound).

Conceptualization of energy varies depending on the context in which it is used. Lancor (2014) identifies six types of substance metaphors for energy concept in textbooks and science education literature. In each of these metaphors, while some characteristics of energy highlighted, some characteristics of energy concept obscured. According to Lancor (2014) energy can be accounted for metaphor highlights conservation of energy principle while it obscures transformation and source. Energy can change forms metaphor emphasizes transformation of energy and conservation of energy and obscures transfer of energy. Energy can flow metaphor highlights transfer of energy and source however obscures transformation of energy principle. Energy transfer is emphasized with energy can be carried metaphor, but it obscures energy transformation. While degradation and source of energy is highlighted with energy can be lost metaphor, conservation principle is obscured at the same time. Last metaphor energy can be an ingredient, product or can be stored metaphor emphasizes source and transfer of energy, however obscures energy conservation and energy degradation. These metaphors are prevalently used in physics, chemistry and biology textbooks.

When we look at history of science we see that first discussions related to energy is shaped through becoming or being and elementary substance or principle of action (Bevilacque, 2014). Initial debates are followed by other issues about perpetual motion machine, pendulum, causality, force and work concepts, conservation principle, degradation of energy, entropy, thermodynamics, the importance of potential energy, mass-energy equivalence of Einstein, Feynman's famous statement and turning back of becoming in 1977, respectively (Bevilacque, 2014). Thus, history of science and endeavors to define and characterize energy in scientific disciplines indicates complexity and many faces of energy concept.

1.5 Energy in Society

Today, energy is one most the most important topics in our daily lives. Energy production is needed to conduct our daily activities including heating, cooling, cooking, cleaning, and lightning; in industry energy is needed for production; and also for transportation. In fact, a small malfunction in energy production systems has really big economic consequences since all daily activities depend on energy production.

In the history of human civilization, especially after the Industrial Revolution human population and energy use increased almost exponentially as a result of developing technologies and life quality. Today, we are nearly totally dependent on the access of electricity to conduct our daily activities. While in the 1970, 51.5% of population had access to electricity, today total of our population have access to electricity (Dilaver, 2009; World Data Bank, 2019). When 1990s examined, it is seen that Turkey's total energy consumption was 1,565,313 TJ. In 2015 this value exceeded doubled and reported as 3,629,552 TJ (World Data Bank, 2019). Just this indicator shows the importance of energy in our lives, including electricity as a form of energy. The importance of electricity is clearly the same for the all World countries like Turkey. In Europe, a typical house consumes 60 kWh energy in a day and that equals boiling water with a kettle for 24 hours (McLeish, 2013). Lack of energy including electricity, affects people from meeting basic needs to education, health, water and all areas mentioned as Sustainable Development Goals by United Nations Development Programme. 1.2 billion people still do not reach electricity in the World (UNDP, 2016). That is an important issue as means of equality among people all around the World. On the other side, dependency of energy bring environmental crisis together, since energy production processes strictly connected to environment. Global climate crisis, degradation of water sources, environmental pollution are all connected to processes related to energy use. Domestic energy use constitutes one part of total energy consumption. Research pointed out the presence of a possible link between domestic energy use and global greenhouse gas emission (Abrahamse & Shworm, 2018; Kurz, Gardner, Verplanken & Abraham, 2015; Poortinga, Steg & Vlek, 2002). These studies indicated that by utilizing significant amount of fossil fuels, households contribute substantially to global warming. Thus, similar to other environmental problems we faced today, energy scarcity mainly results from individuals' daily behaviors (IPCC, 2007; Shi, Wang & Wang, 2019). Research about individuals' energy related behaviors indicated various factors are effective in determining energy use and energy saving behaviors. Theories related to individuals' energy related behaviors are summarized as utility based decisions and behavioral economics, technology adaptation and attitude based models, decision making theories in social and environmental psychology and theories related to social context of decision making in sociology (Lopes, Antunes & Martins, 2012). While energy consumption behavior is explained with socio-demographic variables such as income and house size, energy saving behavior mainly determined by psychological factors such as attitude, perceived ease or difficulty of behavior, personal responsibility for the behavioral consequences and personal norms (Abrahamse & Steg, 2009). Also, egoistic norms and biospheric value orientations have a role in in reducing energy consumption behavior (Şahin, 2013). Similarly in the case of acceptance of environmental policies related to energy behaviors, individuals' biospheric values, awareness of problems, general environmental awareness, personal norms and responsibility for problems are found to be effective in increasing acceptance of environmental policies (Steg, Dreijerink and Abrahamse, 2005). Therefore, in the case of energy related behaviors of individuals, it is important to take action to change people's personal norms, beliefs, attitudes, responsibility acceptance, environmental awareness and value orientations of people. However, it usually is not a very easy matter to change and improve these mentioned factors related to individuals' behaviors. People's beliefs and values are deeply rooted constructs that people create during their lives. The role of education and personal experiences are very important in this sense. Because, education and personal experiences shape people's thinking patterns that form their beliefs, values and attitudes. Changing people's thinking patterns through education may require long term effort.

1.6 Energy in Science Curriculum

Every people have an idea about energy since it is embedded in people's daily lives. Although the prevalence of ideas regarding energy and energy topics, people usually lack of scientific understanding of the topic. The research about learning energy indicates a variety of learning difficulties and alternative conceptions of energy (Dreyfus, 2014). Realizing the importance of energy concept and associated learning difficulties, it is advocated both as a disciplinary core idea and a crosscutting concept in Next Generation Science Standards (Achieve, 2013). It is emphasized that *energy and matter are essential concepts in all disciplines of science and engineering, often in connection with systems*. Also, the importance of energy transfers through systems in engineering is emphasized. The insight of energy transfer is given at 3^{rd} to 5^{th} grade. While at grades 6^{th} to 8^{th} students learn conservation of matter, at grades 9^{th} to 12^{th} students learn energy conservation in closed systems. Energy as a crosscutting concept framework seems to be including explanations about energy and energy relationships under core ideas. For instance, photosynthesis and aerobic cellular respiration is explained with energy processes. On the other hand, although energy concept is advocated as a crosscutting concept, teaching of the energy concept does not seem to be clear. Teachers also have a new challenge of teaching energy as a crosscutting concept (Eisenkraft, Nordine, Chen, Fortus, Krajcik, Neumann & Scheff, 2014).

Moving from the complexity of energy topic researchers offered main strands for learning energy from a unitary framework including; nature and forms of energy, transfer and transformations, dissipation and degradation and conservation principles (Lacy, Tobin, Wiser & Crissman, 2014). In another study; Tobin, Crissman, Doubler, Gallagher, Goldstein, Lacy, Rogers, Schwartz, and Wagoner (2012) explained key learning objectives for teachers in a workshop respectively; the nature of energy including forms, relationships with systems, importance of energy; conversion of energy including energy conservation principle; conversion of thermal to mechanical/electrical energy including second law of thermodynamics. These key learning objectives and strands sum up the characteristics of energy and energy related principles to explain the events related to energy and learn energy topics from scientific disciplines perspective.

Besides these conceptually focused efforts to teach energy, we need an understanding of energy from ecological, social, economic, and cultural aspects of energy to understand the problems associated with energy. Besson and Ambrosis (2014) emphasize the importance of teaching energy with progressive construction of meaning in different contexts and problem situations. They summarize the approaches to teaching energy as historical approach, science-technology-society-environment approach, gradual and progressive conceptual sequence, holistic approach and cross-sectional ideas. When physical content and the general social aspect of the energy are separated from each other it is not possible to get a true comprehension of the phenomenon (Besson & Ambrosis, 2014). Such a holistic understanding of the topic gives us insights about the most appropriate decisions regarding energy as citizens.

One of the curricula targeting learning about energy is developed by Wisconsin K-12 Energy Education Program researchers (KEEP, 2017). In this program's conceptual guide energy is given under four titles; we need energy, developing energy resources, effects of energy resource development and managing energy resource use. Under we need energy title, energy, concepts related to energy and principles related to energy are described and explained. Developing energy resources theme included the issues related to energy resource development, energy resource consumption, and specifically renewable energy. Effects of energy resource development theme consisted of human life and environmental issues. Managing energy resource use theme focused on human behavior, decision making and energy future. KEEP conceptual guide is an example of a guide to teach energy holistically by taking into consideration as many faces as possible including concepts, society, environment, resources, technology and future directions.

When Turkish context is considered teaching and learning of energy concept follows traditional discipline based progression. Despite, many curricula changes in last years, conceptual base of energy topics stay nearly the same as before (see Table 1.2 for learning progression of energy concepts). Students meet light, sound, force and electricity very before the energy concept, at 3rd grade is science course, without explicit connection to energy. First arise of energy explicitly, in the science curriculum is at 7th grade (MoNE, 2013, 2018). Energy is mentioned in relation with force and work concepts, it is classified as potential and kinetic energy, and conservation of energy principle is exemplified through kinetic-potential energy transformations. Friction and energy loss mentioned and energy loss due to friction is explained through heat energy. In high school physic curriculum, it is seen that mechanic, sound, light and heat considered as energy forms and conservation of energy principle is mentioned more detailed adding new energy forms. Energy degradation is mentioned at 11th grade. In earlier grades, first insight of degradation is given as energy loss. An analytical approach regarding energy concept takes place in Turkish science curriculum in K-12 grades. Some of these energy concepts used in curriculum are still issues of debate because of complex nature of energy. According to Millar (2014), mechanic, electricity, heat and radiation are the ways of energy transfer rather than being energy forms, and it is not very clear mentioning of kinetic, chemical, internal, elastic, electrostatic, magnetic and gravitational as forms of energy. He suggests that using these concepts as common energy stores. Besides, the conceptual presentation of the topic, there is a need to reconsider the energy issues from the social, economic and environmental aspects in Turkish science context.

Table 1.2: Learning Progression of Energy Concepts in Turkish Science Curriculum (MoNE, 2013)

<table>
<tr><th>Grade Level</th><th>Course</th><th>Unit</th><th>Topics and Concepts Related to Energy</th></tr>
<tr><td rowspan="2">7</td><td rowspan="2">Science</td><td>Force and Energy</td><td>Physical Work
Kinetic Energy
Potential Energy
Gravitational Potential Energy
Elasticity Potential Energy
Conservation of Energy
Loss of Kinetic Energy</td></tr>
<tr><td>Electrical Energy</td><td>Transformation of electrical energy to heat and light energy
Transformation of electrical energy to motion energy and transformation of motion energy to electrical energy
How to produce electricity in power plants
Using electrical energy consciously and economically</td></tr>
<tr><td>8</td><td>Science</td><td>Living Beings and Energy Relations</td><td>Food Chain and Energy Transfer
Photosynthesis and Respiration
Matter Cycles</td></tr>
<tr><td>9</td><td>Physics</td><td>Energy</td><td>Work, Energy and Power
Mechanical Energy
Conservation of Energy and Transformation of Energy
Efficiency
Energy Sources</td></tr>
<tr><td>9</td><td>Physics</td><td>Heat and Temperature</td><td>Internal energy
Energy Transfer Ways and Speed
Using Energy Economically</td></tr>
<tr><td rowspan="3">10</td><td>Biology</td><td>The Earth</td><td>Energy and Matter Transfer in Ecosystems</td></tr>
<tr><td>Physics</td><td>Electricity and Magnetism</td><td>Electrical Energy and Power</td></tr>
<tr><td>Chemistry</td><td>Energy in Industry and Living Beings</td><td>Obtaining Energy in Industry and Living Beings</td></tr>
</table>

Table 1.2 (continued)			
11	**Biology**	Energy Transformation in Living Beings	Life and Energy Photosynthesis Chemosynthesis Respiration
	Physics	Force and Motion	Energy and Motion Conservation of Energy Elastic Potential Energy
		Electricity and Magnetism	Electrical Potential Energy
	Chemistry	Chemistry and Energy	Thermodynamics Environment System Internal Energy Heat Temperature Mechanical Work Enthalpy Chemical Reactions Entropy Gibbs Free Energy
12	**Physics**	Modern Physics	Photoelectric Effect
	Chemistry	Chemistry and Electricity	The relationship between redox reactions and electrical energy

1.7 Theoretical Perspective: Developing Systems Thinking for Energy

Targeting to understand and evaluate pre-service science teachers' systems thinking skills Arnold and Wade (2017)'s domain approach for systems thinking skills is used as a framework for this study. According to Arnold and Wade (2017) systems thinking construct cannot be broken down to elements and this attempt may be a reduction that may break down systems thinking essence as a whole. Instead of breaking down systems thinking to elements, the skills that support systems thinking should be identified. For the aim of identification of the skills that support systems thinking, Arnold and Wade (2017) examined the concepts in systems thinking literature. They built their framework based on the systems thinking definitions of

Richmond (1994), Ossimitz (2000), Sweeney and Sterman (2000), Stave and Hopper (2007), Plate (2010), Bonnema (2012), Arnold and Wade (2015).

According to the definition of Arnold and Wade (2017) systems thinking has two distinct faces; gaining insight, namely; improving systemic insight of a particular system, and using insight, namely; applying systemic insight to a particular system. While gaining insight is characterized with reaching the system from the outside and understanding the behavior of the system in general, using insight is characterized with reaching system from the inside and understanding systems, systems structure and dynamic behavior. These two distinct faces of systems thinking support each other while exploring a system.

According to Arnold and Wade (2015) there are four basic principles of systems thinking as following; identifying systems, understanding systems, predicting system behavior, devising modifications to produce desired effects. The skills defined in Arnold and Wade (2017) definition, are the ones that support these four basic principles. They built their framework in four domains; mindset that is characterized by approaching systemic problems, content that characterized by understanding inside of the system, structure that characterized by the reaching the organization of the system and behavior that is characterized by understanding the results of interaction between content and structure. While mindset domain includes skills related to gaining insight, other three domains namely; content, structure and behavior are predominantly related to using insight skills. All of these skills together may affect gaining insight facet of the systems thinking. The summary of Arnold and Wade (2017)'s framework is given in Table 1.3.

In the systems thinking area, focusing on energy issues is valuable as means of coping with environmental issues. Today, environmental problems including global climate crisis, environmental pollution, and degradation of natural resources is interconnected with energy issues. Most of research in environmental education and energy education area focused on climate change and individual behavior related to energy (Jorgenson, Stephens & White, 2019). Research targeting development about renewable energy resources and collaborative action from educational area is rare. The dissertation focuses on these issues.

Energy is examined as a systemic construct that includes, energy resources; primarily renewable energy resources, energy generation processes comprising processes producing usable energy forms for needs of society, and the interrelationships between energy processes, economy, society, development and environment during this research. Researcher primarily focuses on social, environmental and scientific meaning of energy in today's World.

Table 1.3: Definition of the skills that support systems thinking (Arnold and Wade, 2017)

Domains	Skills that Support Systems Thinking	Definition
1. Mindset Domain	1.1. Explore Multiple Perspectives	A systems thinker investigates a problem by objectively examining multiple subjective perspectives although some of these perspectives might be non-obvious, unfamiliar, or even distressing.
	1.2. Consider the Wholes and Parts	A systems thinker considers both the forest and trees. An appreciation for both the wholes and parts, simultaneously, is a critical systems thinking skills.
	1.3. Effectively Respond to Uncertainty and Ambiguity	A systems thinker should be able to make decisions that guide a system towards a desired state. A systems thinker needs the ability to move forward while analyzing or designing a system, despite the uncertainty inherent in any complex system.
	1.4. Consider Issues Appropriately	An experienced systems thinker takes time to absorb the complexity of a situation rather than reacting immediately to (even stressful) stimuli. The ability to determine what appropriate means for a given system is also part of this skill.
	1.5. Use Mental Modeling and Abstraction	Systems thinkers mentally model systems and parts of systems as a way to simplify and understand structure and behavior.
2. Content Domain	2.1. Recognize Systems	At this point, the thinker has not yet defined the boundaries of the system, but has recognized that such a construct exists and may have a conceptual idea of its contents.
	2.2. Maintain Boundaries	The boundary defines the content of the system. The boundary is not defined once and then forgotten; rather, it is continuously maintained and updated over time and changing system contexts.
	2.3. Differentiate and Quantify Elements	Understanding and differentiating between the elements in a system, such as their properties, types, and natures, are critical to understanding systems.

Table 1.3 (continued)		
3. Structure Domain	3.1. Identify Relationships	Recognizing that two parts of a system are related in some way is a basic systems thinking skills. Relationships are often called interconnections, or just connections. Increasing levels of maturity in this skill are demonstrated by the ability to recognize increasingly non-obvious, more complex and less visible connections.
	3.2. Characterize Relationships	Characterizing relationships demonstrates an understanding of how two things are related. Characterizing, in this case, can be defined as describing distinctive nature or features of a relationship. Increasing levels of maturity result in an increasingly clear and accurate picture of how a relationship works, what its characteristics are, and how strong it is.
	3.3. Identify Feedback Loops	Relationships can form feedback loops. Although similar, and possibly an extension of the identification of relationships, the identification of feedback loops likely requires additional systems skills.
	3.4. Characterize Feedback Loops	Feedback loops must also be characterized in terms of their strengths and properties (reinforcing vs. balancing, as well as delays and other temporal properties).
4. Behavior Domain	4.1. Describe Past System Behavior	Describing past system behavior requires an understanding of how the system has worked in the past. Past system behavior refers not only to holistic system behavior but also to behavior of specific parts of the system at specific points in time.
	4.2. Predict Future System Behavior	Predicting future behavior is often more difficult than describing past system behavior. It requires all content and structure skills. Also, future behavior prediction also requires an appreciation for the way systems change over time and the way dynamic behavior manifests itself.
	4.3. Respond to Changes over Time	A key systems thinking skill is the ability to effectively respond the changes in a system over time, rather than treating a system as an unchanging entity. A systems thinker needs to continuously evaluate whether a given strategy is still valid, or whether system behavior has become fundamentally different due to changes that have occurred over time.
	4.4. Use Leverage Points to Produce Effects	A system thinker must be able to change a system to make it perform in desired ways. These changes always depend upon the system and context, but there are a set of commonly recognized leverage points in which to intervene in a system (low and high leverage points).

1.8 Aim and Research Questions

Current research aimed to develop a systems thinking module in the context of energy to develop pre-service science teachers' systems thinking and assess the changes in PSTs' systems thinking skills and general systems understanding through the implementation of the systems thinking skills module.

Following research questions are investigated in this dissertation:

1- What are the activities to be contained in the STS module for developing PSTs' systems thinking skills in the context of energy?
2- How pre-service science teachers' systems thinking skills in the context of energy can be developed through a systems thinking module?
3- How do pre-service science teachers' systems understanding change during the implementation of systems thinking skills module for energy?

1.9 Significance of Study

Keeping in mind the role of systems thinking about dealing with complex events, this study is planned to contribute a rarely mentioned area in systems thinking; issues related to energy.

Energy is a main topic to understand scientific processes and events. It is emphasized both as a core and crosscutting concept in Next Generation Science Standards (NRC, 2011). Besides the importance of energy as scientific concept, current issues related to energy also have a high value. Research about energy education, rarely focus on decision making about energy issues, renewable energy and collaborative action (Jorgenson, Stephens & White, 2019). This study aims to contribute energy education field for a transition phase. This transition includes a movement from the research about individuals' energy related behaviors to individuals' systems thinking about energy from the lens of energy. The relationship between systems thinking skills about energy issues and learning of energy is not clear.

However, understanding of energy and systems thinking about energy issues may be in an interaction. Also, understanding energy issues may have an important role about people's decision and behaviors regarding energy related behaviors. As a basic example, electricity consumption behavior may be related to individual's systems thinking. If an individual is not aware the systemic structure behind the events regarding energy production and consumption, it may be just an issue of economy for him/her to consume electricity. Today, most of individuals' behaviors regarding energy issues are superficial and aiming to save money. In fact, the importance of awareness about consumption behavior is remembered just in times of financial crisis. The relationships between the environment, economy, society, health, education and energy are often neglected by people. In fact, the main issue here is that it is not possible us to develop a unified perspective to understand the events around us even after people graduate from university. For example, people usually think that if they find new energy resources, their comfortable life continues; however it is late when they understand that more holistic solutions are necessary such as including consumption strategies with production strategies if they want to sustain energy. In another example, a decision about increasing electricity production to supply energy for household consumption, industrial aims, and commercial aims may have negative consequences in the process. As a starting point, economic development is taken into consideration. It means people find new areas for work and earn money. However, the way we produce energy effects environment and in turn, human health. Therefore, the money that we pay for our basic needs such as food and health increases, and we need more money. It is like a cycle that always needs to produce more and more money to maintain itself. If we understand the relatedness of far seemed issues and how these systems operate, we have a chance to change things to a better direction. Therefore, systems thinking is even more important than we may think, especially as means of energy issues, which are complex and undetermined issues.

In this process teachers' role as means of providing students' opportunities for developing their systems thinking, especially as means of science education, is a very important. In their 17 years longitudinal study that aims to investigate teachers' knowledge of energy, Arzi and White (2008) found that the curriculum was the most powerful factor effecting teachers' knowledge about energy. Therefore, to arrange learning environments for developing systems thinking about energy issues, initially teachers and curriculum developers should be aware of the importance of systems thinking in educational area. Taking into consideration of the role of curriculum in shaping teachers' knowledge, including current energy topics from the framework of systems thinking may be a beneficial way to support teachers' implementations of activities that could develop students' systems thinking. A top down movement regarding systems thinking may start with research and implementation about systems thinking in the science education divisions of faculties. Both as means of developing activities targeting systems thinking of individuals and applying these activities with new generations' science teachers, current research is expected to contribute teachers' education and science education area.

On the other side, one of the main aims of this research is to understand pre-service science teachers' development of systems thinking in the case of energy. It is targeted to understand how pre-service science teachers' systems thinking changes by creating an environment that pre-service science teachers' may use their systems thinking skills -so that their systems thinking skills may be apparent. Understanding the relationships between PSTs' systems thinking and other important factors such as students' knowledge and understanding of content area, students' active participation in the implementation process and other possible factors that may arise during the implementation is expected to contribute research in systems thinking area.

In the future, if it may be possible to integrate systems thinking skills to the science curriculum, studies are needed about systems thinking in Turkish context. This study may contribute curriculum development area, in the context of systems thinking regarding energy.

CHAPTER 2

LITERATURE REVIEW

In this chapter of the dissertation, literature including systems thinking skills, development of systems thinking and effects of implementations on systems thinking skills, reasoning in association with systems thinking, learning energy topics, development of students' conceptions related to energy and effects of implementation on students' energy understanding topics are presented and depicted. Since, it could not be possible to find research studies that bring together systems thinking with energy, research related to system thinking and research related to energy are given independently. Realizing the importance of structure of systems thinking, initially studies related to identification and conceptualization of systems thinking is examined. Studies related to individuals systems thinking levels and research studies targeting improvement in individuals' systems thinking skills are depicted. Finally, studies related to energy are examined.

2.1 What is Systems Thinking?

Understanding and defining systems thinking skills are the initial steps in systems thinking area. In the introduction part of the dissertation it is tried to clarify the description of systems thinking with the help of literature about systems thinking. It may be possible to say that systems thinking is about understanding the events from the whole perspective. However, it is needed to clarify this general definition. In this section initially literature related to defining systems thinking, development of assessment tools related to systems thinking frameworks, content dependency of systems thinking are reviewed.

One of the examples of understanding systems thinking skills from a general perspective is Jaradat (2014)'s study. This research also puts characteristics of systems and systems thinking from the articles of the researcher's literature review. Among 1000 systems based articles Jaradat (2014) established the characteristics of systems thinking and developed an instrument to assess individuals' systems thinking with dichotomous items. According to the author's analysis of published articles seven core codes arouse regarding systems thinking; interconnectivity, autonomy, evolutionary development, emergence, complexity, flexibility and holism. Interconnectivity is related to connectedness of a complex system including many heterogonous systems including human, technology, culture, information and multiple perspectives. All these systems interact to produce behavior. Autonomy refers to each individual systems own purpose. Some of these systems' own purposes are sacrificed to achieve overall purpose of the system. Evolutionary development is explained through the changes of systems due to interaction with environment. Emergence is related to unpredictable behavior of systems because of their constituent systems' different behavior. Complexity refers systems complex nature including uncertainty, ambiguity, and lack of knowledge. Flexibility is related to adaptiveness of the system in changing conditions. Holism refers to holistic solutions taking into consideration of related aspects. These seven characteristics applied to the individual level to assess systems thinking of individuals. Jaradat (2014) listed individual characteristics of a systems thinker based on these seven characteristics. For instance; having interdisciplinary knowledge, be able to negotiate under conflicting perspectives, take multiple perspectives into consideration, considering a range of different solutions, understand the limitations of reductionism, identify multiple aspects of a problem, take into consideration interactions among the system, thinking in a holistic way and choosing the most relevant aspects. These characteristics of a systems thinker assessed with dichotomous items and a scenario at the beginning of these items. In another study aiming to assess systems thinking skills by constructing a scale; researchers (Dolansky, Palmieri & Alemi, 2010) identified six theoretical dimensions of systems thinking through an expert panel as following; sequence of events, causal sequence, multiple causations possible, variation of different types, feedback and interrelations of factors, patterns of relationships. The items produced in the light of these theoretical dimensions a 5-point Likert type scale was developed to assess systems thinking skills.

Assessing systems thinking skills as a set of general skills is advocated by especially researchers in economics, health and management sciences. In educational area, especially in science education systems thinking skills are assessed content-dependently. The content specific examples of systems thinking assessment are more prevalent in educational area especially in the earth sciences. One of the aspects of these studies are it may not be possible to differentiate knowledge of area and skills related to thinking in these studies. Therefore, it is possible to say that when we take systems thinking skills as a set of skills related to any content, systems thinking skills are not distinguishable from knowledge. Hung, Chang and Hung (2019)'s research gives us an idea about differentiation of thinking skills and knowledge of area when used in a teacher's metavisualization process of carbon cycle. Hung, Chang and Hung (2019) investigated knowledge and skills used by an experienced science teacher when performing metavisualization about carbon cycle. Science teacher used both knowledge and skills in her visualization process. She frequently used content knowledge followed by metacognitive knowledge and metavisualization knowledge, respectively. Her content knowledge included formation of carbon compounds, components related to carbon cycling, reactions and interactions. On the other hand, teacher used cognitive skills frequently followed by metacognitive skills and metavisualization skills. Science teacher's cognitive skills included; understanding the content of the task, retrieving resources related to task, searching for the necessary resources and integration of the information. Metacognitive skills included comparing, evaluating and identifying, self-questioning, planning and monitoring. Visualization skills included using text representations, using symbolic representations and using different colors. Researchers provided internet and published sources to the science teacher in their study to see what is necessary for her to visualize carbon cycle. When compared with other research studies about earth systems in systems thinking area, in this study; aspects like identifying components related to carbon cycling and identifying interactions are classified as content knowledge. On the other hand, understanding the content of the task and retrieving sources related to task are evaluated as cognitive skills by Hung et al. (2019).

When these studies and before mentioned studies trying to conceptualize systems thinking such as Richmond (2000), Sweeney and Sterman (2000), Stave and Hopper (2007), Assaraf and Orion (2010), Behl and Ferreira (2014), Karaarslan (2016) and Arnold and Wade (2017) are evaluated, it is seen that operationalization of systems thinking changes by authors. Main issues arising from these studies are; knowledge relationships of these skills, the effectiveness of assessments with scales and analytical evaluation of each of these skills.

After identifying systems thinking following step may be evaluating individuals' systems thinking skills. Therefore the assessment studies took place in next section.

2.2 Systems Thinking Level of Individuals

Students', teachers' and public systems thinking levels are investigated by different researchers from various perspectives including assessing systems thinking skills as a set of general skills, adapting systems thinking skills to many different contexts and topics including earth sciences, ecosystems, and global warming.

Sweeney and Sterman (2000) investigated systems thinking abilities of business school students. They developed an inventory consisting of bath tub and cash flow tasks to investigate systems thinking concepts such as feedback, delays, and stock and flows. The results indicated that students understanding of stocks and flows, delays and feedback were poor. Students violated conservation of matter principle and used inconsistent ways to deal with tasks although many of them have background in mathematics, engineering and science. Their formal training and experience were not reflected on their systems thinking skills. The researchers emphasized that the tasks are not included any work beyond basic arithmetic. Sterman and Sweeney (2002) used the same systems thinking perspective to assess graduate students understanding of global warming. They used tasks including understanding of stock and flow relationships, requiring no mathematics, and including basic facts about climate change. Similar with their previous research, students violate conservation of matter and basic principles of physics in their choices of answers. Many of the students believe that CO_2 concentration changes immediately effects global temperate changes. This showed that they do not recognize delays in systems. Students do not think that the temperatures will increase; even the current CO_2 concentration levels are stabilized. These results reflect the poor levels of stock and flows understanding of the graduate students. Besides these studies, middle school students' and their teachers' systems thinking skills are also investigated as a set of general skills by Sweeney and Sterman (2007). In their research Sweeney and Sterman (2007) used similar methods as Sweeney and Sterman (2000)'s study. They used a variety of different scenarios including events related to; wolves and rabbits, teacher perception and students' achievement and self-esteem, hunger and eating, births/population, practice, performance and enthusiasm and room clean up and parents' attitude. Common results from these scenarios indicated that most students had a poor understanding of feedback processes. Just 15% of students and %32 of teachers recognized closed loop connections in these events. In time dimension most of teachers and students did not describe the impact of time delays. When it is compared to students their teachers were likely to describe time dimension higher. More than half of the students and 45% of teachers focused on just inflow and did not take into account of outflow rate. 24% of students and 18% of their teachers assumed that outflow and inflow were equal. When it comes to recognizing feedback structure approximately 25% of students and 50% of teachers were able to recognize and differentiate balancing and reinforcing feedback loops. Homologues reasoning is also advocated by researchers and referred to situations although seemed different from the surface that has same underlying structure. 33% of students and most of the teachers (77%) were able to recognize deep structural similarities. While Sweeney and Sterman prefer to focus on different contents to assess individuals' systems thinking abilities, common general results arise from their studies. It is seen that individuals have difficulties with understanding stock and flow relationships, time delays and feedback processes. To summarize it, understanding dynamic processes in systems is not an easy issue for individuals including both students from different levels and teachers.

On the other hand; Kuhn, Iordanou, Pease and Wirkala (2008) investigated students' scientific thinking, in terms of multiple causality and consistency. Identifying multiple causal relationships is related to understanding the systems boundaries and identifying relationships from the systems thinking perspective. Sixth grade students worked on a case of avalanche estimation with a limited set of variables on a computer program. The students were successful as means of identifying non-causal two variables. It means that they could understand what is outside of the system when the variables readily given to them. However, the students reasoning were inconsistent as means of labeling the same variables as causal or non-causal, when the same situation is presented them differently. This situation may be evaluated as the presentation context has a role while students use their thinking processes.

Students' systems thinking skills do not seem to be developed well according to the results of both context independent and context dependent research. In the context of earth sciences, systems thinking of individuals are investigated prevalently. In their study aiming to explore high school students understanding of cycling nature of the water cycle and issues related to human water cycle interaction, Assaraf and Orion (2005b) found that among 1000 high school students, most of them do not understand dynamic, cyclic and systemic nature of water cycle and do not have complete picture of it. Students recognize atmospheric part of the water cycle but do not recognize its underground water part. They saw underground water as static, sub surface lakes. Similarly, Lee (2015) investigated pre-service and in-service science teachers understanding of the components, processes and relationships of water cycle. In-service science teachers achieved 11.63 points on average from 20 points test while pre-service science teachers achieved 7.68 points. Most of the teachers' systems thinking were at recognition level. Teachers had difficulties when identifying components and processes in a system, identifying multiple relationships, recognizing hidden dimensions and understanding human impact on water cycle.

Even students from geology and geography background have some problems about achieving systems thinking. Batzri, Ben-Zvi Assaraf, Cohen and Orion (2015) investigated university students' dynamic thinking and cyclic thinking from systems thinking perspective. In their research, college students who have geography or geology background and students without background in geology were compared. Geography and geology students showed higher levels of dynamic and cyclic thinking than the students from natural sciences or agriculture. In the qualitative part of the study geology students systems thinking is investigated in details. Researchers found that geology students rely heavily on descriptions of structures and processes rather than of the systems behavior. They could not see the hidden parts of the systems. On the other hand students could realize the time dimension in geological processes. Also, students used different cognitive models to predict or explain the behavior of a system. The researchers could not identify the nonlinear thinking and feedback loops and hierarchy in students' cyclic thinking. Researchers also noted that there were almost no expressions of the transfer of energy in the system and students presented interactions in the ecosystem as linear chain of feeding processes.

Most of the literature about systems thinking in earth sciences indicates similar results with content-independent research studies as means of emphasizing the difficulties associated with achieving systems thinking. The research studies about systems thinking levels of younger students, teachers and graduate level students indicate that they have difficulties with understanding stock and flow relationships, cyclic nature of the systems, recognizing hidden parts of the systems, understanding dynamic behavior of systems, understanding feedback processes, and they use event based explanations rather than focusing on systems behavior in general. Seeing deep structural similarities and transfer to similar situations show differences between samples.

2.3 Research about Improving Systems Thinking of Individuals

Realizing the importance of systems thinking in educational area, other question arises: how is it possible to develop systems thinking of students? The answer of this question is not very easy however; it is possible to summarize some common findings from the research targeting improving systems thinking skills. The effects of knowledge integration activities, inquiry, using multimedia environments, outdoor education and engineering design activities are investigated by researchers. These studies summarized below.

In the case of earth systems; Kali, Orion and Eylon (2003) investigated the effectiveness of knowledge integration activities in 7^{th} grade students' systems thinking development process about rock cycle. Their knowledge integration activities included inquiry based activities. They assessed students' systems thinking with a test that includes four questions. They evaluated students' answers in a continuum of systems thinking development from low systems thinking to high system thinking. Low system thinking is characterized through the completely static view of system and high system thinking is characterized through understanding the cyclic and dynamic nature of the system. After the knowledge integration activities students' system thinking improved. Students' realized the dynamic and cyclic nature of the rock cycle after the implementation. According to the results of the study researchers suggested that a system based curricula design should consist of gradual knowledge building process from components to the whole depiction of the system and a conclusion stage with differentiation and reintegration activities.

In another study; Assaraf and Orion (2005) investigated development of systems thinking skills of junior high school students at 8^{th} grade. In this research, students studied the earth systems curriculum focused on the "hydro cycle". Researchers examined systems thinking in terms of 8 characteristics. The results showed despite the minimal initials systems thinking abilities, most of the students made progress in their systems thinking abilities during the period of implementation. The researchers concluded that conceptual understandings and amount of students' participation influenced students' development in systems thinking.

Computer and laboratory work supported with discussion, and instruction are also found to be effective as means of developing systems thinking skills of students. Yoon (2008) investigated the improvement students' knowledge of complex issue of reproduction at grade 9 in a summer school implementation of 40 hours in the case of genetic engineering. The activities included computer laboratory work, small group discussions, whole group online discussion, constructing risk and benefit charts about societal and environmental issues, developing concept maps related to political, economic, social and environmental stakeholders of the issue (Yoon, 2008). In the implementation two main topics were at the focus: animal use in genetic engineering processes for human needs, and plant use in genetic engineering processes for human needs. Students responses to complex genetic engineering issue is evaluated through Jacobson (2001)'s clockwork mental models and complex mental models framework. The results indicated an improvement in students' understanding of complex systems concepts. At the same time students' arguments were also developed as means of sophistication and reasoning. The implementation was effective as means of developing students' decision making patterns. The effects of computer based activities are also investigated by other researchers. Reiss and Mischo (2010) investigated the effectiveness of different teaching methods on promoting systems thinking in the field of Education for Sustainable Development. They used three different conditions which include a special lesson designed to promote systems thinking, a computer simulated scenario on the topic ecosystem forest and a combination of both special lessons and a computer-simulation. A total of 424 six grade students are participated the study. The results indicated that systems thinking can most effectively be promoted through a combination of specific lesson and exploring a computer simulation. Simulation alone led only to a small increase in students systems thinking. In the case of systems thinking about ecosystems; Grotzer, Kamarainen, Tutwiler, Metcalf, and Dede (2013) investigated 7^{th} and 8^{th} grade students reasoning about ecosystem dynamics. They listed novice and expert reasoning characteristics about ecosystems and assessed students reasoning through this framework. They found that initially, students mostly used event based causality in their explanations. Then, researchers investigated the effect of using a multiuser virtual environment which offers simulated experiences for students to help their learning about ecosystem dynamics. After using this learning environment, students increased process based change over time explanations about ecosystem dynamics. However, the students still had a tendency to use event based explanations. Evagorou, Korfiatis, Nicolaou and Constantinou (2009) investigated the effectiveness of an interactive simulation as means of developing fifth and sixth grade students in the case of a marsh ecosystem. After the implementation students' systems thinking skills including identification of elements of a system, recognition of the temporal and spatial boundaries of a system, conceive the existence of subsystems, identify the influence of specific elements of the systems on whole system and identify the necessary changes that have role in observing certain patterns are developed. Only one skill, identification of feedback effects in system ability did not developed. A common result arising from these studies is that computer based activities have a positive effect as means of developing systems thinking of students in varying degrees.

The effects of real life experiences including live models and outdoor learning experiences on systems thinking are investigated by researchers. Eilam (2012) discussed systems thinking in terms of learning ecology concepts and worked with fifty 9th grade students to reveal their systemic understanding in feeding relations. In the research study students worked with a live ecosystem model throughout one academic year, they receive formal instruction and laboratory support. As a result of the study, students identify components of the system, the operations inside of it and components' roles in the system and interactions within the components. On the other hand, the author noted that most of the students still present broken conceptions about feeding relations. Students have deficient understanding of dynamic equilibrium, feedback mechanisms, matter and energy, and process characteristics related to feeding relations and biosphere. In addition to live models, outdoor learning environments are also effective as means of developing students' systems thinking skills. To understand younger students' systems thinking skill development a study conducted with 4th grade Israeli students by Assaraf and Orion (2010), with using inquiry-based teaching activities and outdoor learning environments about hydro cycle concept. The research aimed to reveal whether students in elementary level can achieve system thinking skills. Authors find out that the systems thinking ability increased during the implementation even though students show low levels of systems thinking skills at the beginning of the study. They argued that real life experiences on a subject made students more competent in systems thinking and understanding the relationships between the parts of a system. However, they noted that most of the 4th graders could not complete all levels of systems thinking hierarchical model. This study indicated the importance of effectiveness of a well-designed course on even 4th grade students' systems thinking. Outdoor learning environments improve students' systems thinking for different age ranges. Long (2015) investigated the understanding of systems of youths aged 9-11 in the context of ecohydrological citizen science club after school and Karaarslan (2016) investigated pre-service science teachers systems thinking skills in education for sustainable development context. According to Long (2015) despite the initial fragmented understanding of ecohydrological systems, youth students developed their systems thinking in the outdoor learning implementation. Students focused on a local canyon to understand the water cycle in nature. The study contributed the knowledge that systems thinking of young students can be developed through authentic research context. Similarly, Karaarslan (2016) found that pre-service science teachers have lower levels of systems thinking skills initially. There were individual differences between their systems thinking skills. Lower level of system thinking skills were higher than higher level of systems thinking skills at the beginning. According to this situation the systems thinking skills seemed to be hierarchical and complex. At the end of the first phase of implementation including Eymir Lake discoveries, pre-service science teachers systems thinking skills developed to some degree. At the end of the second phase of implementation including work on sustainable solutions PSTs' systems thinking skills were at mastery level, except one skill; adapting systems thinking perspective to personal life. All of these studies that are including outdoor experiences contributed improvement of systems thinking skills of individuals.

Besides these studies Lammi (2011) depicted systems thinking skills of students' from a different perspective in a different context. Lammi (2011) investigated high school students systems thinking from structure-behavior-function framework in an engineering design. Researcher analyzed twelve high school students' verbal protocols in design process and a reflective group interview. The students in the study showed evidence for systems thinking from function-behavior-structure framework in their design process. Students focused on structure in their designs and they emphasized the expected and actual behavior their systems. Through the analysis of data following engineering themes are emerged in relation with systems: interconnected variables; that indicates students' consideration about multiple variables related to their design, optimization; that refers to finding solutions about best design product by comparing technical, functional, aesthetics, and cost aspects, unboundedness; that is about finding multiple ways of solutions and variations of final design, sketching; that is related to drawing of design during the process, analogical reasoning; that matching before known designs and processes to the current design, and relevance; focused on authenticity and everyday life connectedness of the design.

In another study from structure-behavior-function framework, Liu and Hmelo-Silver (2009) designed two experiments to investigate the effects of different ways of organizing hypermedia- one of them is function centered and the other one of them is structure centered- on pre-service teachers' and middle school students' understanding of human respiratory system. In their hypermedia designs, structure centered design emphasize on knowledge of structure mostly including factual knowledge. Function centered design focuses on the organization of the system, dynamic nature of the system and relationships between structure, function and behavior of the system. Hypermedia is used as medium in this study. The difference between the hypermedia groups is conceptual representations organizing knowledge. While the function centered hypermedia moves from function of the system to structure of the system, structure centered hypermedia moves from structure to function of the system. 82 pre-service teachers and 41 seventh grade students participated to this study. Half of these pre-service teachers (from educational psychology) assigned function centered hypermedia group and other half of the PSTs assigned structure centered hypermedia group. Same procedure is repeated for 7th grade students. Post assignment took place including the elements related to structure, function and behavior of the systems after PSTs and students worked on respiratory system in their hypermedia groups. The results of the study showed some differences for PSTs and 7th grade students. Two groups of PSTs differed from each other as means of identifying non-salient phenomenon that showed the superiority of function based hypermedia group on structure based hypermedia group. In the F-hypermedia group students identified more behaviors than students in h-hypermedia group. There were no difference as means of structures. As means of salient (macro) and non-salient (micro) phenomena F- group students had a better understanding of non-salient phenomena. The overall results showed that F-hypermedia students and pre-service teachers have better understanding of non-salient functions and behavior of the system.

Research studies indicate the difficulties of achieving higher levels of systems thinking and the importance of the design of the courses to develop students' systems thinking. Elementary and high school level students' systems thinking skills is not developed in the context of earth sciences including topics related to ecosystems, matter and energy cycles, and feeding relations. Especially, students have difficulties with understanding dynamic nature of the processes, hidden dimensions of the systems, and causal relationships between the events. This situation is nearly the same for university students, even geography or geology majors. They also could not see the hidden parts of a system and they could not realize nonlinear relationships. Students also do not realize transfer of energy in a system. On the other hand, it is possible to develop students systems thinking through a well-designed course including inquiry, virtual learning environments, outdoor environments and laboratory activities. Also students' use systems thinking skills through the engineering design processes. Therefore, it may be possible to contribute students' systems thinking development by a variety of implementation with taking into consideration content targeted and facilities.

In this dissertation, energy topics including; energy resources, production and consumption, effects of energy production and consumption, the relationships between energy choices and environment are chosen as content to investigate pre-service science teachers' systems thinking. Individuals understanding and learning of energy concept and issues related to energy are very important in education. Therefore, in the following section energy related research studies are summarized and discussed.

2.4 Individuals' Learning of Energy

Research in energy education area may be assessed mainly into two parts to stay in line with this dissertation's aims; individuals' understanding and conceptions of energy and implementations aiming to improve individuals' understanding of energy.

Studies about students' understanding of energy showed that individuals' usually have misconceptions about energy. Trumper (1997) investigated pre-service teachers' energy conceptions in Israeli. A total of 608 primary school teaching students, in their 1^{st}, 2^{nd}, 3^{rd}, and 4^{th} years, participated in the study. According to the results students hold a number of alternative conceptual frameworks. Most of the students think that energy is a concrete entity. They do not accept energy conservation and degradation. They cannot recognize different types of energy. In addition, students confuse the concepts of force and energy. Similar results were found by Megalakaki and Thibaut (2015). They investigated 5^{th} grade students' conceptions of energy and force for animates and inanimate objects. The results indicated that students cannot make distinction between force and energy concepts, do not differentiate force, energy, work and power concepts and do not use energy conservation and energy degradation while explaining events. They associated energy and force with objects height or weight or the agent (for e.g. human action on object), even though in the case of inanimate objects. Ninth graders also cannot differentiate two concepts. Only 11th grade students are successful as means of making distinction between two concepts. They see force concept interactionist or else from scientific point view. They understand energy as internal or acquired. Not all of 11th grade students take into account energy transfer and energy conservation. Also all students have difficulties with force and energy concepts for animates. They cannot differentiate force and energy and relate force and energy concepts to the effort of the agent.

Besides cross-sectional studies related to energy conceptions of individuals, there are some research studies aiming to understand developmental process of students' energy conceptions. For instance, Lee and Liu (2010) investigated learning progression of energy concepts across physical, life and earth sciences contexts in middle grades including a total of 2688 6th, 7th, and 8th grade students. They focused energy source, transformation and conservation topics. The results indicated that students' knowledge integration level is mediocre and the concept of conservation is more difficult than the other concepts. 8th grade students knowledge integration level is higher than 6th and 7th grade students. In addition, mean knowledge integration level of students who took a physical science course is significantly higher than that of students who took a life or earth science course. In another study, Liu and Keough (2005) investigated if students' understanding of energy is in line with developmental stages. They analyzed TIMMS items related to energy for the US sample to answer this question. Researchers compared data coming from students at 3rd, 4th, 7th, 8th grade and students at last year of high school. The results of the study put evidence on gradual increase in energy topics. Students' correct answer percentages increased from 3rd to 8th grade about activity/work and source/form topics. Students understanding of energy transfer increased from 7th to 8th grade and high school level, and their understanding of degradation increased from 7th grade to high school. Energy conservation topic is not understood by high school students, independent from their specialization of area. In general, specialized instruction is important in students learning about energy. Students' performance order from highest to lowest according to specialization fields are as follows: physics and math specialists, physics specialists, math specialists, and generalists. As a result of this study students' learning of energy is seen as a gradually expanding process and understanding energy degradation is an important component of understanding energy conservation. Also, Neumann, Viering, Boone and Fischer (2013) investigated students' conceptions of energy from learning progression framework. They developed an assessment tool by utilizing energy learning literature. 1856 students from grades 6, 8 and 10 answered assessment tool. The researchers emphasized that difficulty of items were in line with higher levels of energy conceptions. This situation has a meaning of item difficulty is associated with higher level of energy conceptions. According to the results of this study, sixth grade students mostly understand energy forms and energy sources. Eighth grade students understand energy source, forms and energy transfer and transformation. The deeper understanding of energy conservation is only achieved by some of all these students and 10^{th} grade students. The results of their study indicated that students initially develop an understanding of sources and forms of energy, they then understand transformation, transfer and degradation and they later develop their understanding of conservation of energy principle. Liu and Keough (2005), Lee and Liu (2010) and Neumann, Viering, Boone and Fischer (2013) provide evidence for developmental progression of energy concepts respectively; sources and forms of energy, transfer, transformation and degradation of energy and finally conservation of energy by their research studies.

From a different perspective Park and Liu (2016) focus on content domains that energy concepts are used. Researchers developed an instrument to assess students' energy understanding. According to their results, the most difficult topic for students is energy in atomic structure, while the easiest topic is energy in living things. Energy in chemical change and energy in photosynthesis and respiration topics nearly have same difficulty. Students' understanding of mechanical energy is better than their understanding of electromagnetic energy and energy in modern physics. Energy in living things, ecosystems, alternative energy and energy efficiency topics are easier than energy in photosynthesis and respiration processes. Different from the other research studies, in this study researchers emphasized that the energy concept as an embedded construct in science disciplines rather than an independent concept and a progression pattern is available among science contents rather than among science disciplines.

Apart from the studies aiming to draw a trajectory for development of energy conception by using cross sectional evidence from different age groups, a longitudinal study by Arzi and White (2007) explored change in teachers' knowledge of subject of energy through 17 years professional experience. They found that teachers' change in their content matter is multifaceted. The required curriculum is the single most powerful factor affecting teachers' knowledge as a source and organizer. Teachers' prior knowledge as school students shaped their interest for further learning. The study indicated that there are integration deficiencies about energy even among experienced teachers.

2.5 Research about Improving Energy Learning

Research about understanding energy indicated learning difficulties about energy principles and difficulties with applying students' knowledge related to energy to a variety of conditions. Even chemistry majors and pre-service teachers hold some alternative conceptions and have fragmented knowledge about energy. In addition, teachers also do not have a holistic understanding about energy topics. Taking into consideration of importance of energy concept as a core topic in science researchers conducted studies aiming to handle with learning difficulties from various perspectives. The effects of refutation texts, dynamic visualizations, and static illustrations, teaching-learning paths for energy principles, different contextualized environments and professional development programs on individuals understanding of energy are investigated by researchers. While some of these studies focused on the methods and techniques used while teaching energy, some of them focused on discipline based usage of energy concept.

Diakidoy, Kendeou and Ioannides (2003) investigated the effectiveness of refutation texts about overcoming misconceptions related to energy. Students from 6th grade in six rural schools in Cyprus participated to this study. Students randomly assigned to three conditions respectively; refutation text group, expository text group and standard instruction group. The expository text included main ideas related to energy such as definition of energy, energy sources and forms, energy transformation and storage. The refutation text included two main misconceptions, conceptualization of energy as a substance and confusion of force and energy concepts. Students who read refutation text outperformed students in two other conditions. There were no meaningful difference between students' performance in groups of standard instruction and expositor text.

Ryoo and Linn (2012) investigated how dynamic visualizations support 7th grade students' understanding of energy in photosynthesis process as compared with static illustrations. Both groups' activities shaped through the knowledge integration framework including activities targeting eliciting ideas, adding ideas, distinguishing ideas and sorting out ideas, respectively. In the activities, energy source, energy transformation, energy storage and energy transfer concepts are taken into consideration. The implementation continued 12 days in the groups. In both conditions, students developed more scientific and coherent understanding of energy. However students in dynamic illustration group were significantly more successful in understanding energy transformation process in chemical reactions during photosynthesis. Also these students could better able to connect their energy transformation ideas to other energy ideas in photosynthesis process as compared with students in static illustrations group. Students in dynamic visualizations group could better able to understand the role of energy in photosynthesis, how plants gets energy, transformation of energy during the photosynthesis process and where energy goes. Also, dynamic visualizations were effective as means of contributing students' understanding of molecular processes.

The importance of energy as means of cultural and environmental aspects is taken into consideration by researchers. Besson and De Ambrosis (2014) developed a teaching learning path for high school students about thermal phenomena, radiation energy, and greenhouse effect. They implemented their activities comprising learning path with the aim of understanding the energy concept and conservation principle. 121 students from high schools aged from 15 to 18 are participated the study. Students' answers show progressively more correct and appropriate use of concepts of heat, thermal conduction, radiation, temperature, and internal energy. Results indicated that students' explanations of greenhouse effect based on thermal isolation decreased and they showed more correct reasoning about phenomenon.

The context of energy principles used constituted focus point by some researchers. Podschuweit and Bernholt (2017) investigated students' learning about energy in different contextualized environments. One of the groups were homogenous that defined as means of one category power plants including different subcategories wind turbine, coal power plant, water power plant, solar power plant. The other group consisted different categories, wind turbine, photosynthesis, eco-fuel and power to gas. Students' learning was not significantly different in these two different contextualized learning environments. In details, homogenous environment increases the possibility of solving directly associated items to the environment. On the other hand students in heterogeneous contexts had higher achievement scores on contextualized items. Student achievement was similar as means of abstract items.

In addition to students' learning of energy, teachers' learning of energy also investigated by researchers. Daane, Vokos, and Scherr (2014) analyzed the episodes of teachers' discussions who participated in a professional development program about K-12 teachers as a part of Energy Project in Seattle Pacific University. The results of the analysis showed that teachers used productive resources for understanding energy. They considered both amount and forms of energy involved in physical processes without prompts and ideas related to energy availability and degradation that align with statements from the NGSS. Some teachers view energy as losing value during the certain processes, even as they explicitly recognize that the total amount of energy is constant. The other teachers mentioned that the quality, usefulness, or availability of the energy may decrease when the energy changes form or when the energy disperses in space. Although teachers have used productive resources for learning about energy, they do not have a holistic understanding of the energy degradation and second law of thermodynamics.

As a common point, in all of these studies energy learning is investigated as means of understanding energy resources and forms, learning and using energy transfer and transformation, and using conservation and degradation principles while explaining events. In a recent study, moving from the criticisms to the complex nature of energy including many related sub-concepts, a different approach to the nature of energy teaching is offered by researchers. Fortus, Kubsch, Bielik, Krajcik, Lehavi, Neumann, Nordine, Opitz and Touitou (2019) investigated the effectiveness of a new conceptually based approach. This new approach does not need energy forms concepts while explaining events. It emphasizes interactions between energy, systems and fields, meanly; novel approach focuses on energy transfers. In this study energy understanding is evaluated through NGGS-aligned knowledge in use framework to explain events. Two approaches, one of them is novel approach and other one is forms-based approach, compared in this study. Seventh grade students from three Midwestern schools participated to this implementation. Items to assess students understanding of energy in relation with learning performance are developed. In addition researchers interviewed with students after the implementation. After the implementation both groups of students gain significantly higher points as compared to before instruction situations. However, transfer-only approach (novel group) students' results were higher than forms-only approach group. Transfer-only group students' strongly focus on transfer idea while explaining events, on the other hand forms-only group focused on more than one core ideas including speed, force, forms, transformation and transfer in their explanations and their connections of ideas were not strongly linked. The researchers emphasize the superiority of this novel approach among classical approach to learning energy.

It is possible to see some common results of all the studies, although their scope and theoretical frameworks differ. To begin with individuals are more successful as means of identifying surface or in other terms salient aspects of events or topics examined. They have difficulties with understanding hidden, not seen, non-salient aspects of events. As a result of this, they may not use explanatory frameworks from scientific perspective. Direct instruction as a transmission of knowledge is not very effective as means of overcoming these problems. Even, individual time consumed on understanding systems or events has different effects on performance of individuals depending on the structure of activities individuals participated. In general, starting from the events that have real life connections seems to be more effective as means of improving individuals learning and thinking.

Also, a necessity arises as means of implementing different approaches in relation with energy concepts and systems thinking in Turkish context. In this dissertation, the researcher combines energy concepts and principles around energy related issues, focusing on pre-service science teachers' systems thinking skills.

CHAPTER 3

METHODOLOGY

3.1 Method

This research study follows a qualitative methodology. Since, it is aimed to understand pre-service science teachers systems thinking skills regarding energy topics including energy resources, energy production and consumption and role of energy processes in our lives for a sustainable future and to monitor PSTs in an implementation process; it may be classified as a qualitative case study. Case is defined as a type of phenomenon occurring in a bounded context. The case of a study may be a role, a single person, a program, an event, a group of people, an institution, a specific policy, an environment or a period of time (Miles, Huberman & Saldana, 2014; Merriam & Tisdell, 2015). According to the qualitative researchers the social world is complex and it is not possible to see events from the framework of linear cause and effect relationships. Moving from this idea, cases are seen as complex systems. Therefore, it is needed to understand this fuzzy realities by thinking them as a whole; constituted from complex configurations, including two directional causality or feedback loops, interaction effects, tipping points with many different outcomes (Schwandt & Gates, 2018). Qualitative case studies search for meaning and understanding and as an end its end product is rich descriptions of a bounded system (Merriam & Tisdell, 2015).

In this dissertation, an implementation conducted by the researcher to understand pre-service science teachers' systems thinking in this process. The implementation constituted the case of this research. Implementation is examined by pre-service science teachers' expressions, studies during the process, interviews, video and audio recordings and researcher notes. It is aimed to understand the process of development of pre-service science teachers' systems thinking skills.

3.2 Researcher’s Position

The researcher of the study has a background in environmental education. She earned her bachelor’s and master’s degree in science education. She studied environmental education in her master’s thesis. She is research assistant at the Department of Mathematics and Science Education at a state university in Turkey. She took several courses on environmental education during her bachelor’s, master’s and PhD programs. Researcher has experience about qualitative research. She took course on qualitative research in education and has two qualitative research articles and two conference papers.

The researcher knows the pre-service science teachers who participated the research from their laboratory courses. She participated core laboratory experiences of these pre-service science teachers in their first and second years at science education training including physics, chemistry and biology laboratory experiences.

According to the researcher’s worldview, the thinking patterns people look at the events around us shape our behaviors. As people think about the events and their connections, and they try to see the whole picture, they construct their own worldviews, beliefs and behavior patterns. If any of kind and useful idea, belief or worldview is not expressed as behavior, it is a lost opportunity for a better World. In the case of environmental behavior, teachers who are one of the most responsible people shaping next generations’ future, should have the ability of thinking in patterns, see the connections between the events, understand the issues and find ways to solve complex problems. Therefore, it becomes possible to provide opportunities for their students to gain these abilities. Nowadays, more and more people are needed who have systems thinking abilities. People need to use their abilities to understand the World, instead of believing the spurious ideas around them. Small but persistent attempts may have important consequences as means of solving problems. Individual thinking and behavior may have a collective transformative role regarding shaping society, politics, environment, economy and education. People may feel more responsible, conscientious and sensitive, when they widen their perspective through changing their thinking habits.

3.3 Participants

The participants of this study consisted of 9 pre-service science teachers (6 female and 3 male) participating science teaching laboratory course at a state university in Turkey. These pre-service science teachers were in their third year of science teaching undergraduate program. Their ages were at the range of 20-22 years. Their cumulative grade point were at range of 2.87-3.29 from 4.00. They completed their basic physics, chemistry, biology and laboratory courses. Therefore, they were familiar with energy concepts from their formal experiences.

Researchers own experiences in their laboratory courses indicated that they have difficulties during scientific experiments. Their basic laboratory skills and practical thinking habits were not developed well. They usually did not make preliminary preparation for the experiment and they were not willing for learning. There were negative group interactions and discussions between these pre-service science teachers. Some students did not communicate with each other.

3.4 Methods of Data Collection

Methods of data collection included before, during and at the end of STS module implementation tools in the research process. Data collection tools included written tests, interviews, and video and audio recordings of the class during the implementation. They are explained in details below.

Real Life Scenario (Geothermal Case): It is developed about a real local issue (see Appendix A). A text about geothermal crisis in Aydın is given to pre-service science teachers and they answer questions about the case. The questions target finding systems thinking components in PSTs' answers. The instrument is applied before and after the implementation to reveal PSTs' systems thinking skills.

Semi-Structured Interviews: At the beginning and at the end of the research, interviews were held with PSTs about energy and systems aiming to understand their systems thinking regarding energy and systems understanding. A total of 13 questions regarding energy topics -including concepts and issues- and 3 questions related to systems are prepared. The interview questions are given in Appendix B.

In Class Audio and Video Recordings: During the sessions PSTs' discussions are video and audio recorded to understand how their systems thinking change about issues.

In Class Student Notes and Reports: Pre-service science teachers take notes about the discussions and answer questions during the sessions to their notebooks. Their notes are used as a tool to support their video and audio recordings aiming to see their development.

Researcher Notes: Researcher takes notes about the implementation process immediately after the each session take place. These notes are helpful as means of understanding the process elaborately.

3.5 Procedure

In this research, it is aimed to understand systems thinking development of nine junior pre-service-science teaching students in the context of a designed STS module implementation. These candidate teachers were the ones who participate science teaching laboratory 1 course in fall semester. The research took place in their Science Teaching Laboratory Practice Course I in 2017-2018 year fall semester. All 55 members of the classroom participated module implementation process since it was not possible to take these nine students' to the outside of the classroom and implement the activities. Nine pre-service science teachers are monitored specifically in classroom context. Their video and audio recordings are taken during the course implementation. At the end of the course all students (complete of 55 students attending the laboratory course) take final examination about energy topics and laboratory practices. Researcher applied data collection instruments as soon as activities finish. After data collection procedure finished, researcher gave information about the assessment of the course and grading. Any of data collection tools were not used for grading.

In data collection process, written data collection tools were implemented to all 55 students to choose students who want to be voluntary data collection procedure. Instruments were assessed and 15 students from 55 of them were chosen according to variety of their answers to written data collection tools from basic to complex levels. It is asked them to participate detailed data collection phase of the study. Initially, 10 of the students accepted to participate the study. In the middle of the process, one of these students left from the research. All students (55 members of the class) participated implementation phase and before and after implementation written data collection tools application. Outline of research process is given at Table 3.1, flowchart of implementation is given at Figure 3.1 and detailed explanation of module implementation process is given at Table 3.2 below.

Table 3.1: Outline of the Research

Aim	Instrument	Data analysis
-To understand and explain changes in PSTs' systems thinking skills before, during and at the end of module implementation.	***Before and After the Implementation:*** Semi-structured interviews Real Life Scenario (Geothermal Case) ***During Implementation:*** Activities: 2.Energy Production-Consumption 3. Biogeochemical Cycles 4.Carbon-Based Production 5. Trip to a Geothermal Power Plant 7. Energy Production Systems	Content Analysis: Evidence from the GPP case assessed Content Analysis: Excerpts from the video and audio recordings and in-class student notes are examined and assessed
-To understand and explain changes in PSTs' systems understanding.	***Before and After the Implementation:*** *Semi-structured interviews*	Content Analysis

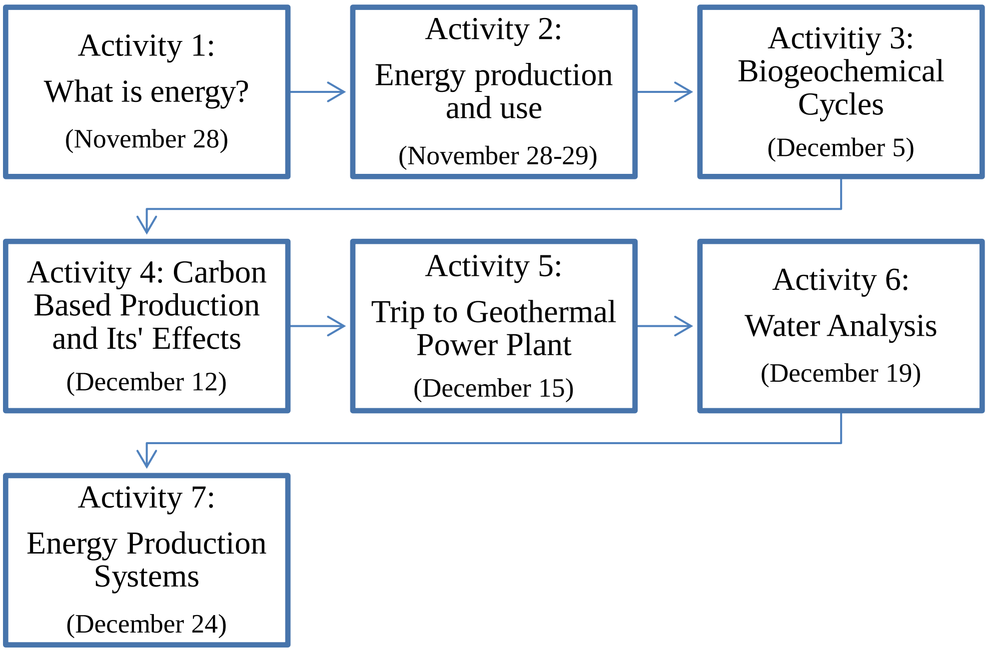

Figure 3.1: Flow Chart of Implementation of STS Module

3.6 Methods of Data Analysis

According to Miles and Huberman (1994), analysis of qualitative data may be summarized in three phases including data reduction, presenting data and making inferences and drawing conclusions and verification of data. At first stage, researcher examines data and makes coding. Data are summarized; important and related concepts and themes are chosen in this stage. At second stage data are presented with graphs, tables or other figures. Concepts, themes and relationships are compared and interpreted at final stage.

In the data reduction phase, data may be organized through the themes associated with research questions or taking into consideration dimensions coming from the interviews and questions. In content analysis main aim is to reach the concepts and relationships that may explain data collected (Yıldırım and Şimşek, 2008). In present dissertation both descriptive analysis and content analysis are held together in data reduction phase. In descriptive analysis, data are summarized and interpreted through the themes identified before.

Table 3.2: Module Implementation Process

Date	Activity Implemented	Data Collected
October 31	Data collected before implementation	
November 14	Data collected	Written data collection tools
November 21	Data collected	Written data collection tools
November 21, 23, 24, 25, 26, 27	Interviews conducted with chosen ten students.	
November 28	1st activity: What is energy? implemented with the whole class	Interviews, audio recordings, worksheets
November 28	2nd activity: Energy Production and Consumption implemented with the half of the classroom in the computer laboratory	Worksheets, Video recordings
November 29	2nd activity: Energy Production and Consumption implemented with the other half of the classroom in the computer laboratory	Worksheets, Video recordings
December 5	3rd activity: Biogeochemical Cycles implemented	Cycle drawings, worksheets Video recording
December 12	4th activity: Carbon Based Production and It's Effects implemented	Audio recording of group discussions, Laboratory Worksheet
December 15	5th activity: Trip to Geothermal Power Plant implemented	Student notes and photos taken at power plant
December 19	6th activity analysis of water	Laboratory worksheet
December 24	7th activity: Energy Production Systems	Video recording of the activity, Drawings and Presentations
December 26	Data collected with written tools after implementation	
28-29-30 December	Interviews conducted with 9 students	

Present study included categories both determined before the interviews and categories arising from the pre-service science teachers' statements. Initially, audio recordings from the interviews are transcribed verbatim. Pre-service science teachers' names are coded as PST1, PST2, PST3, PST4, PST5, PST7, PST8 and PST9 and researcher is coded as Q (indicating questions asked). Written statements are read and assessed at different times. For PSTS' systems understanding, codes are written and grouped under categories. These categories are derived from questions themselves. On the other hand, new categories sometimes arise from the dialogues between the interviewer and pre-service science teachers. Codes and categories arising from the data collection tools are presented as tables and graphs. In order to analyze pre-service science teachers systems thinking skills content analysis are held by the help of the framework proposed by Arnold and Wade (2017). Rubric adapted from Arnold and Wade (2017) definitions of systems thinking used for the aim of analyzing data under categories. The rubric presented researcher predetermined categories to evaluate systems thinking skills. These predetermined categories are presented as skills. Arnold and Wade (2017)'s rubric is modified through the data collected during this study. Some of the skills in original rubric are not evaluated since there was no evidence regarding these skills. The results arising from the data are discussed and interpreted.

3.7 Trustworthiness of the Study

Trustworthiness of a qualitative research deals with the issues such as researchers' interpretation of the phenomenon, the generalizability of the results, researchers as a data collection and analysis instrument, the confirmability of results by different researchers, researcher bias, researcher effect and adequacy of data (Merriam & Tisdell, 2015). These issues are explained under the following subheading as credibility, consistency, transferability in the study.

3.7.1. Credibility

The credibility issue is related to congruence of the research findings with reality. The methods to ensure credibility for a research study includes triangulation, member check, adequate engagement in data collection, discrepant case analysis, explaining researcher's position and peer examination (Merriam & Tisdell, 2015).

In this study, a variety of methods were used to ensure internal validity including triangulation, adequate engagement in data collection, explaining researcher's position and peer review. For one research question, more than one data collection tools are used. Meanly, pre-service science teachers' systems thinking skills examined with data coming from real life scenario, interviews, group discussions and classroom notes. The results arising from multiple data sources compared and explained.

Adequate engagement in data collection is ensured through the number of participants in the study and time spent on data collection process. Indeed, data collection procedure continued through the module implementation process, besides before and after the module implementation.

Another researcher experienced in systems thinking area examined data and checked the inferences made by the researcher. This procedure is held for systems thinking and system understandings of pre-service science teachers.

3.7.2. Consistency

Consistency or dependability refers to consistency of research process and stability of the research over time and across researchers and methods. The methods to ensure the dependability of a research are clear statement of research questions, the congruency of design of the study with research questions, stating the role of researcher in the study, specification of the connectedness of research to the theory, inter-coder agreements, and peer review (Miles, Huberman & Saldana, 2014).

In this research the congruence of research questions and research design ensured in the light of research literature. The connectedness of the research to the theory is controlled by checking the analysis through the lens of framework. A rubric adapted through the framework is used for understanding the development of systems thinking skills of pre-service science teachers. The rubric provided pre-determined categories that refer to the systems thinking skills. Two researchers, one of them is expert in the field of systems thinking, checked the excerpts coming from data collection tools and consistency between the inferences is ensured.

Inter-coder reliability by two researchers is used as a method to ensure validity for analysis of interviews. The formula used for coder-reliability is given below (Miles and Huberman, 1994 p: 64):

Reliability= number of agreements / (total number of agreements+ disagreements)

According to Miles, Huberman and Saldana (2014) an intra or inter-coder agreement should be within the range of 0.85-0.90. In this research, inter-coder reliability for the interviews is found to be 0.87 for categorical level.

3.7.3. Transferability

Some strategies including giving thick descriptions of the setting and maximum variation in sampling are offered by researchers to increase the transferability of the results of a study to other settings (Merriam & Tisdell, 2015). Detailed descriptions include detailed presentation of participants, method and setting of the study besides descriptions of findings with quotes from data collection tools during the research including interviews, notes, records and documents (Jensen, 2008; Merriam & Tisdell, 2015).

In this research to ensure transferability, researcher gave the details of the implementation process and data collection process by describing in details. The characteristics of participants and setting are presented. Descriptions of statements of pre-service science teachers are written in details.

3.8 Ethics

A series of issues considered related to ethics from beginning to the end of this research. These issues included consent, transparency, right to withdraw, harms arising from participation in research, and privacy (BERA, 2018). From the beginning of the research participants are informed about the research and assigned consent forms (Appendix E). They knew that they could give up the study if they wanted. The study did not include any potential harm or disadvantage. Since all of the students participated the implementation in the classroom, all participant in the classroom facilitated the potential benefits of the students. Participant pre-service science teachers' informations related to personal knowledge and their names are not used and shared. Instead anonymous coding is used to differentiate the participants. Besides individual consent forms, permissions from university's Human Ethics Committee (Appendix G) and implementation permission from the faculty administration are taken (Appendix F).

CHAPTER 4

RESULTS

This chapter is organized through the presentation of the STS module for energy, assessment of each pre-service science teachers' system thinking skills before, during and at the end of the module implementation trying to answer the following research questions:

1- What are the activities to be contained in the STS module for developing PSTs' systems thinking skills in the context of energy?
2- How pre-service science teachers' systems thinking skills in the context of energy can be developed through a systems thinking module?
3- How do pre-service science teachers' systems understanding change during the implementation of systems thinking skills module for energy?

4.1 Systems Thinking Skills Module for Energy

Systems thinking module for energy designed by taking into consideration of factors including; the topics should be consisted in the module in relation with energy, the instructional methods could be used in the module, the feasibility of the activities for pre-service science teachers. According to these three areas, the results of the systems thinking and energy learning literature shed light into the module development process.

Energy topics are rarely taken into consideration from the environmental, social, technological and economic aspects during the educational process of individuals. However, the connections between these aspects in relation with energy should be taken into consideration in a Systems Thinking Module. Therefore, topics including, energy concepts, energy production and consumption, biogeochemical cycles and energy production systems are included in the module. Each of these topics emphasizes the environmental, social, economic and technological aspects of energy issues and the topics included in the module explained in details below.

4.1.1. Energy Production and Consumption

Energy Production and Consumption is a system that consists of several factors affecting both consumption and production. Consumption is mainly shaped through production. Production is affected by several factors, including resources for production, economy, technologies, human force and engineers. Similarly, consumption is affected by many factors, such as population, industrialization, transportation, climate, technology, habits, and life standard (Annenberg Foundation, 2017). Taken together, all these factors act together as a system forming energy consumption. The nature of relationships between system components is usually not unidirectional and linear, but reciprocal and complex. Nearly, all human activities dependent on the energy availability formed through many of interrelated factors. Energy availability has social aspect; consisting of filling the gap in reaching reliable energy services that is related to peace and security, economic aspect; as means of job creation and economic growth and environmental aspect; related to threatens of biodiversity, climate and environmental destruction (UNDP, 2016). Solutions related to these problems are not obvious and require understanding the big picture (Aronson, 1996). Therefore, understanding energy production and consumption process is very important and requires systems thinking skills. Choosing energy consumption topic as a case for activities, it is targeted to develop pre-service science teachers, structural systems thinking skills including; identification of relationships in a system, characterization of relationships, and identification of feedback loops skills, besides mindset domain skills. On the other hand, it is expected for students to understand the role of humans about social, economic, and environmental aspects of the energy production and consumption.

4.1.2. Biogeochemical Cycles

Processes related to energy on the Earth are inextricable from environmental issues. Earth is a system that is composed of many subsystems. Deficiencies about students' thinking in relation with earth systems especially in relation with biogeochemical cycles pointed out by various researchers in the educational area (Gudovitch & Orion, 2001; Assaraf & Orion, 2005; Raia, 2005; Libarkin & Kurdziel, 2006; King, 2008; Assaraf & Orion, 2010; Lee, 2015) Therefore, students' systems thinking about biogeochemical cycles is important as a part of their systems thinking about energy issues. Pre-service science teachers are expected to be familiar with main topics such as water cycle and carbon cycle from their learning experiences. Their familiarity with these topics is assumed to serve as basis for their thinking about mechanisms governing the issues about energy and environment. Moving from these assumption, two of the cycles mostly emphasized in systems thinking literature, carbon cycle and water cycle, are added to the implementation as sample topics to make pre-service science teachers more familiar with environmental effects of energy processes.

4.1.3. Carbon-Based Energy Production

From the 1960s to 1970s; nearly 94% of total energy consumption in the World based on fossil fuels including; coal, oil, petroleum and natural gas products. After the 1970s to 1990s this ratio moved between 85-80% of total consumption, and in 2015; 79.6% of total energy consumption was based on fossil fuels (World Data Bank Statistics, 2019). Today, although intensive efforts take place to increase alternative and renewable resources for energy production, the World is still depends on carbon-based resources to produce energy for human needs. The costs of the dependency on fossil-fuels are now evident, especially when the World is in global climate crisis. Since Carbon-based energy production is a big part of energy issues, it is chosen as a topic for implementation.

4.1.4. Geothermal Energy

Geothermal energy topic is a controversial issue in the location of the implementation. Since, it is an issue that is closely connected to pre-service science teachers' lives and there are a lot of debates about the issue, it is chosen as a topic for the module.

Normally, geothermal energy is known as environmentally-friendly, sustainable and renewable energy source (Annenberg Foundation, 2017). Underground hot water resources are used for producing electricity, greenhouse cultivating, and heating in geothermal energy production process. Since the underground water resources are re-injected to underground after use, the resource is not consumed but sustained. However, the intensive agricultural practices, olive and fig production are prevalent in the location. It is claimed that farming and production practices, air quality and water resources are affected negatively from geothermal power plants. Non-governmental organizations, farmers, people in the location are showing reaction to the issue. In the long run, this situation changes the face of the location. The geothermal situation is a small part of a big change. Therefore, it is very important to understand geothermal case from the systems thinking framework. In the geothermal power plant case, nearly, all systems thinking skills including two areas of systems thinking gaining insight and using insight may be investigated. The rational for choosing geothermal power plants case for the implementation is based on these mentioned aspects of the issue.

After tasks were chosen activities were designed for STS module. Through the design process, the instructional methods and design principles chosen targeted PSTS' active participation to the implementation process. Different resources from systems thinking literature, energy learning literature and science education literature taken into consideration (Chen, Einsenkraft, Fortus, Krajcik, Neumann, Nordine & Scheff, 2014; Crowley, Schunn & Okada, 2008; Jonassen & Land, 2012; Karaarslan, 2016; KEEP, 2017). Activities in the module targeted developing systems thinking skills. The module comprised of seven activities. The activities, related teaching methods and outputs of activities as data collection tools are given at Table 4.1 below. Some samples from designed activities are given in Appendix C.

Table 4.1: Systems Thinking Module for Energy Context

SYSTEMS THINKING MODULE FOR ENERGY				
Activity	**Related Topic/Purpose**	**Teaching method**	**Activity output**	**Method of Analysis**
1st activity: What is energy?	Energy in science /determining students' knowledge of energy	Open ended questions, Discussion, watching videos, individual study	Interviews, audio records	Content analysis
2nd activity: Energy Production and Consumption	Energy production and consumption/developing PSTs' systems thinking skills	Data analysis	Student worksheets, video recording	
3rd activity: Biogeochemical Cycles	Biogeochemical Cycles, Energy and Environmental Relationships/developing PSTs' systems thinking and general understanding of systems	Direct instruction, in class assignment: drawing carbon and water cycle	Cycle drawings, worksheets	
4th activity: Carbon Based Production and Its Effects	Biogeochemical Cycles, Energy and Environmental Relationships/ developing PSTs' systems thinking	Inquiry based instruction, laboratory experiment: What are the impacts of carbon based energy production on environment?	Laboratory worksheet	
5th activity: Trip to Geothermal Power Plant	Geothermal energy, Energy and Environmental, Social, Economic, Technological Relationships/developing PSTs' systems thinking	Field trip	-	
6th activity analysis of water	Environmental Relationships/developing PSTs systems thinking skills	Laboratory experiment as demonstration	Lab worksheet	
7th activity: Energy Production Systems	Energy Production Systems/developing PSTs' general systems understanding	In class assignment: energy production systems	Drawings, presentations and discussion	

4.2. Pre-Service Science Teachers' Systems Thinking Skills

The instruments that aimed to understand student systems thinking skills were geothermal power plant real life scenario, PSTs' notes during the implementation and interviews conducted both before and after the implementation. In the scenario students read an article based on a real life event, and then they were allowed to answer written questions. In the interviews, the questions related to energy and energy issues are asked to them, and their answers are assessed. Also, PSTs write down some notes during the activities. The analysis of data coming from the data collection tools, are held by the help of rubric proposed by Arnold and Wade (2017). Some of the skills proposed by researchers are not used, since there is no evidence related to the skills coming from the data collection tools.

4.2.1 Mindset Domain

4.2.1.1. Explore Multiple Perspectives

According to Arnold and Wade (2017) definition of systems thinker, a system thinker investigates an issue or a problem objectively by taking into consideration multiple perspectives. Even these perspectives are unfamiliar or contradicting with the systems thinker's views, system thinker is able to use these perspectives while understanding the issue. Geothermal power plant case is used for assessing pre-service science teachers' skill about exploring multiple perspectives. In the case of geothermal power plants, the stakeholders of the problem include people living in the region, farmers, employees of the GPPs, policy makers, administrators and peasants. Different people may have different ideas about the issue. They may think of monetary issues, environment, or health. Therefore, it is important to understand if the pre-service science teachers are able to take into consideration of as many as ideas that they are able to use while understanding the issue or they are just assessing the issue from only one perspective. PSTs' levels of maturity regarding exploring multiple perspectives are assessed through the rubric in Table 4.2 below.

Table 4.2: Rubric for Evaluating Explore Multiple Perspectives Skill (Adapted from Arnold and Wade, 2017)

STS: Explore Multiple Perspectives		
Low Maturity	**Developing**	**High Maturity**
Considers issue from only one perspective, for example s/he makes emphasizes constantly on the problems of health.	Recognizes the presence of different perspectives regarding the issue. S/he tries to look at the event from more than one perspective including a difference between the ideas.	Actively emphasizes and compares many faces of the issue, although they may contradict with his/her own opinions. S/he does not ignore contradicting ideas.

According to the results of the assessment PSTs' Systems Thinking Skill levels are given at Table 4.3.

As means of considering multiple perspectives, before the implementation most of these pre-service science teachers think about geothermal power plants from only their perspective, indicating usually negative attitudes about the issue. In details, PST2 tries to explain the issue from the side of the people living the location and farmers. PST3 considers only effects of GPP on human health. She does not consider the other perspectives related to the issue. She gives detailed explanations on the importance of human health regarding with the GPP case. PST4 and PST6 consider the negative aspects of GPPs, as means of human health and environment. PST7 considers the issue from only his own perspective. He usually emphasizes environmental pollution. PST8 considers similar perspectives. He emphasizes economic and developmental aspects of the issue. Similarly, each of these pre-service science teachers considers only one aspect of the issue and this aspect is usually human health or environment. PST1 gives very limited explanations, usually emphasizes that he does not know GPPs. He prefers not to talk or think about the issue. PST5 and PST9 have different ideas about the issue from the other PSTs. PST5 is able to emphasize two different aspects of the issue, namely; growth in human needs and environmental issues. PST9 is able to look at the issue both from the dependency of foreign resources, health and natural damage at the same time.

After the implementation six of nine pre-service teachers including PST1, PST2, PST3, PST6, and PST7 take into consideration of contradictory perspectives in addition to their own ideas. In details, PST1 still gives limited explanations, however he takes into consideration of the two contradicting aspect of the issue. PST2 does not make certain claims about the issue. She takes into consideration two contradictory perspectives in the issue, tries to elaborate the different ideas. PST3 gives detailed explanations about the effects of GPPs as means of human health and also natural resources. On the other hand, she talks about the engineer's ideas working in the GPP. PST6 considers the positive aspects of the issue. While emphasizing positive aspects she considers the health and agricultural issues. Also, she considers the negative aspects of the issues to be investigated. PST7 considers different perspectives including unfamiliar ones for himself, similarly.

PST4 considers the negative aspects of GPPs, as means of human health and environment. She does not consider different aspects. PST8 emphasizes his own perspective regarding economic aspect of the issue although he recognizes the presence of different perspectives. However, he ignores the reactions and thinks that people have wrong ideas about the issue. PST5 considers the different aspects of the issue including both positive and negative ones. She takes into consideration of different ideas regarding the issue while trying to make a decision. PST9 forms her own ideas about geothermal after the implementation. While, before the implementation she took into consideration of different aspects of the issue, after the implementation she focuses on the renewable aspect of the resource and advocates the use of GPPs. She does not ignore the effects of GPPs, however she does not think that their affect may not be damaging as the other non-renewable resources. She does not add any new ideas to her view. She shows a more certain stance to the issue. PSTs mostly develop explore multiple perspectives skill after the implementation.

Table 4.3: Explore Multiple Perspectives Skill of Pre-Service Science Teachers

PST	IS	STS Level	Quotes
PST1	**BI**	**NA (Not Applicable)**	Q: What do you think about the GPP issue? A: I do not know the GPPs and their effects, if it is really harmful, I may react.
	AI	**Developing**	Although GPPs may be little harmful, its' effects may develop if the necessary hesitation is not shown. If the precautions are not taken it may negative effects as means of human and environment.
PST2	**BI**	**Low Maturity**	…I support people in the location. …The observers of the situation are people and farmers in the location. Mortality increases.
	AI	**Developing**	I am not a close witness of the issue. …A platform may be created to understand two sides of the issue… There is a tension between the people… If the regulations are taken into consideration, the harmful effects may be minimized.
PST3	**BI**	**Low Maturity**	I want to live in a healthy city. Otherwise, I apply to the authorities. In fact, GPPs do not work without their permission. However, they may do something if they hear the complaints of people.
	AI	**Developing**	When the waste materials are released to the water, human health is threatened. The balance of water is destroyed. Animals die. On the other hand, according to the engineer in the factory, no problematic issue arises. … At the GPP location we saw the people who work for greenhouse cultivating. The products seemed to be fine and water resources were clean.
PST4	**BI**	**Low Maturity**	This bad smells may affect human health. Agriculture and nature, also… Natural balance will be destroyed.
	AI	**Low Maturity**	This issue threatens human and nature. It may have negative results. Human, animals, plants may die. Remaining waste materials affect all living organisms.
PST5	**BI**	**Developing**	When the conditions are convenient and industry is developed, the population and human needs will increase. Then different methods will be required. … The gases may cause mutations and destroy environment permanently. Agriculture and trees may be affected negatively.
	AI	**High Maturity**	… Contrary to the known, the need for electricity may be supplied from GPPs. However if it is really harmful, it may be damaging for environment and human. … If it is not harmful, it may be fine to get energy from a renewable resource. Economy develops.

Table 4.3 (continued)			
PST6	BI	Low Maturity	…The gases released to the environment affect the soil and air and destroy balance. …I have certainly negative attitudes about this issue. We should use alternative resources, however if these resources are harmful for human health we should find other resources.
	AI	Developing	I think that when renewable resources are used, both financial loss and damage will be minimized. …I try to change the idea that GPPs are harmful, because I know that they do not have so prevalent negative effects. The reasons for agricultural damage and mortality should be investigated.
PST7	BI	Low Maturity	I have been living in the city for 20 years. In Sultanhisar air pollution increased. We cannot ignore it. I even do not want to mention Menderes River. …The GPPs should be closed down. …Nobody listens to us, the best solution is to move another city.
	AI	Developing	It may be a beautiful place, if owners of GPPs become conscious. It is important to take into consideration of nature, not just money. I am aware of people's complaints. I cannot keep silent. …Some GPPs affect nature and human negatively.
PST8	BI	Low Maturity	My idea is certain. GPPs are prevalent in developed countries. The most important issue is to control the GPPs. If I were a plant owner, I make speeches about the importance of GPPs as means of the economy and employment.
	AI	Low Maturity	We see that people have wrong knowledge about the issue. GPPs are very beneficial when used properly. People think that nature may be affected. However they are wrong. Using GPPs for politics come into fashion.
PST9	BI	High Maturity	Since geothermal energy is a renewable resource, it is a little harmful for the environment. Its usage will decrease the dependency on petroleum, coal and fossil fuels. However, if we think about the damages on fig and olive production, the agricultural quality will decrease and human health will be affected.
	AI	High Maturity	Geothermal energy is a natural source that is continuous. The water used in the process is reinjected. It is less harmful for nature. …If I were a farmer, I did not behave biased. I investigate the effects of GPPs and if they are not harmful, I support them.

4.2.1.2. Consider Issues Appropriately

Pre-service science teachers' consider issues appropriately skill is searched through the evidence from different parts of their answers about Geothermal Power Plant

Case. PSTs' levels are mainly assessed through their statements as stakeholders about the issue and their statements about results of the issue. As means of considering issues appropriately, high maturity is characterized as giving time to absorb the complexity in the event, while low maturity characterized as immediately reacting to the issue. Rubric at Table 4.4 used for assessing PSTs consider issues appropriately skill.

Table 4.4: Rubric for Evaluating Consider Issues Appropriately Skill (Adapted from Arnold and Wade, 2017)

STS: Consider Issues Appropriately		
Low Maturity	**Developing**	**High Maturity**
Takes a reactionary approach to the issue immediately.	Allows time to understand the issue and complexity, however sometimes still jumps to conclusions.	Allows time for complexity and does not directly jump to conclusion, without understanding the issue.

Before the implementation of the module most of these pre-service science teachers show immediate reaction to the issue without a detailed understanding of the issue. Their reactions included the issues regarding environment and health problems. They usually emphasize the importance of health problems related to energy production. They directly jump to conclusions and portray a pessimistic results pattern including increase in deaths, cancer and health problems. The maturity level of these PSTs namely; PST2, PST3, PST4, PST7 and PST8 are classified as low regarding consider issues appropriately skill. Three of nine pre-service science teachers namely; PST1, PST5 and PST6 do not give immediate reaction to the issue, while they sometimes go to the results. They do not quickly make judgment about the issue. Therefore, their level of maturity is assessed as developing. PST9 follows a different trajectory before the implementation from the other candidate teachers. She evaluated the issue from the perspective of advantages and disadvantages of GPPs and tries to find a solution. Her answers to questions indicated a high level maturity about consider issues appropriately skill.

After the implementation four of these nine pre-service science teachers PST2, PST3, PST7 and PST8 increased their maturity level from low level to developing level. While these pre-service science teachers showed immediate reaction the issue before the implementation, they try to evaluate the issue with information from different sources and do not react to the issue. PST6 increased her maturity level from developing to mastery after the implementation and PST9 expressed similar ideas both before and after the implementation indicating a high level of maturity as means of consider issues appropriately skill. Only one of these pre-service science teachers, PST4 stayed at low maturity level after the implementation. She does not use different information resources while telling the events and she directly does to conclusions with reaction, without an elaborated understanding. A general trend towards developing in these pre-service science teachers' consider issues appropriately skill is identified through their answers regarding GPP case. The quotations from their answers are given below.

Table 4.5: Consider Issues Appropriately Skill of Pre-Service Science Teachers

PST	IS	STS Level	Quotes
PST1	**BI**	**Developing**	I do not know geothermal energy and its effects. If it is really harmful, I have a reaction.
	AI	**Developing**	If GPPs are not used with attention, they may be harmful for environment. …No matter to what degree GPPs are harmful, if they are not used with sensibility, their harms may increase. …Everyone should do their job better.
PST2	**BI**	**Low Maturity**	…The use GPPs are harmful for the environment in their location. The mortality and tree deaths may increase. People may be obligated to immigrate. …The first hand observers are people in the location and farmers. Mortality, tree and animal deaths may increase. The observations support this.
	AI	**Developing**	When GPPs used properly, they may not have harmful effects. However, when the rules are not obeyed it may destroy the environment. …I probably do not want GPPs in my hometown. I may react against it. …I want to make a common decision with farmers if I was a director of a GPP, but this decision affects my benefits. I give information to farmers. …An environment may be established for stakeholders to listen and understand each of them …It increases the tension between the people and also as means of environment. I heard that one of my friends was obligated to uproot their olive trees.

Table 4.5 (continued)			
PST3	**BI**	**Low Maturity**	When there are fault lines, the fertility of the soil increases. GPPs decrease the fertility and change the climate. They have fatal effects. All of these are real, however these facts are told by ignorance. …In the future, life does not continue, climate is destroyed. The weather becomes either too cold or hot. All the living organisms die except bacteria. Even, bacteria die.
	AI	**Developing**	I could not understand the issue before. Now, I think that when some conditions are supplied, GPPs are not harmful. Near the GPP, we saw greenhouse cultivating, clean water, and fine agricultural products. Also, the workers in GPP seem to be healthy. …As mean of the ones that release their waste materials to the water, they threaten our health. They threaten to themselves, their children and next generations. They destroy nature. They affect the balance of water.
PST4	**BI**	**Low Maturity**	If GPPs are harmful for human health and agriculture, it would not be fine. Illness increases, economy gets worse …As a person living in this city, I am very disturbed with bad smells. Geothermal energy either should be reduced or should not be used.
	AI	**Low Maturity**	I think that our future will be affected negatively. As a person living in this city, I am disturbed with that smells. This issue threatens human and nature.
PST5	**BI**	**Developing**	…I understand that the alternative ways to improve workforce may be harmful for human and nature. For example in the history, the process related to industrial revolution that coal started to use by people, increased the workforce, however increased CO_2 emissions is harmful for health. The harmful materials or gases caused from the GPPs may result in mutations on the people in long term. They may destroy nature. …I did not investigate about the issue. If this information is proved to be true, GPPs may be harmful.
	AI	**High Maturity**	…Contrary to known, we may supply our electricity need from GPPs. On the other hand, if effects of GPPs are extensive, increase in cancer ratios, infertility and mortality may increase. …I have been informed after the GPP trip. GPPs are not very harmful when the precautions are taken. I am not a partisan of GPP; however I am also not an opponent of it. I still have doubts.
PST6	**BI**	**Developing**	If I have certain evidence that the trees are drying out because of GPP, I use my rights. …I have negative attitudes about this issue. Yes, we should use alternative resources, however if these resources are deleterious for our health, we should find other resources.
	AI	**High Maturity**	I would investigate the reasons of the deaths and natural destruction, there may be different reasons except GPPs. …Meetings may be arranged to raise consciousness. …It is hard to predict the results of GPPs in long term.

Table 4.5 (continued)			
PST7	**BI**	**Low Maturity**	Question: What would you do about GPPs if you were a farmer? Answer: It is not enough to complain municipality. In fact, I do not think that they listen to us. The only way is to move another city. Answer: If I were a director of a GPP I would think myself and my family and shut down the GPP.
	AI	**Developing**	…If inappropriate GPPs were closed down, harmful gases were not released, and people were informed, Aydın would be a beautiful place. …If we do not take events considerations from the monetary perspective and we see the harmful effects of GPPs, it would be better. I am aware of the complaints of the farmers, I cannot keep my silence.
PST8	**BI**	**Low Maturity**	If GPPs were continued to increase, city would be developed, employee ratio would increase. Industrialization would increase. However, agriculture would be affected negatively. People's reaction would affect energy production. If I would be a farmer living in the city I do not give up the truths I believe in, I hear the sounds "We are right, we will win". … …If I would be a director of a GPP I would make speeches to shut up people, "money and power will be ours!" … I am sorry, but as we continue to develop, nature will be damaged.
	AI	**Developing**	Initially we see that people have wrong knowledge about the GPPs. When geothermal used properly and controlled, it is very useful for the city. …People may boil over, however I do not think like that. It may be a chance for development.
PST9	**BI**	**High Maturity**	The advantages of GPPs should be reconsidered. GPPs are less harmful to the environment from the other resources such as coal and natural gas. However if it is harmful for the agriculture, it may affect economy. If the disadvantages are decreased and precautions are taken, GPPs may be used.
	AI	**High Maturity**	The disadvantages of GPPs are not very extensive. They release some sulphur gas to the atmosphere, and they cause some soil pollution. Only it requires large land. It is less harmful for atmosphere and nature. …If I would be a farmer, I investigate the effects of GPPs and I increase my knowledge about the issue.

4.2.2 Content Domain

Content domain is relevant to the boundaries of the system at hand; what it includes or what is outside of the system. Usually, it is not easy to make a decision about the boundaries of system since the boundaries change with the context and they are not clear.

4.2.2.1. Maintain Boundaries

A systems thinker is able to define the boundaries of a system. Also, when the context changed s/he is able to follow the changes about the boundary of a system. For instance, in the GPP case, necessity of energy, health issues, natural damage, and people's reaction stays in the boundaries of the system, while tourism and earthquakes stays far from the issue at hand. Pre-service science teachers' statements in relation with key words, big issue, events and explanations of their understanding of the issue are used as data sources for understanding their decisions about the boundary of the issue. Pre-service science teachers' ability to decide the boundaries of the system is assessed through the rubric given above at Table 4.6. The results are given at Table 4.7.

Table 4.6: Rubric for Evaluating Maintain Boundaries Skill (Adapted from Arnold and Wade, 2017)

STS: Maintain Boundaries		
Low Maturity	**Developing**	**High Maturity**
Cannot define the boundary of the system	Defines the boundary of the system including most of the relevant items.	Defines the boundary of the system with accuracy even the system changes over time and context.

Before the implementation PST1 gives very limited explanation about the boundaries of the issue. PST2 is able to talk about the elements of the issue with accuracy. PST3 focuses on events one by one, however she adds some far related elements to her explanations, and loses the main focus of the issue. PST4 focuses on some elements in the scenario, excluding some of the main others. PST5 mentions most of the elements while defining the situation from her own perspective. Both PST6 and PST7 take into consideration of negative elements while defining the situation. PST8 emphasizes the presence of both advantages and disadvantages of GPPs.

After the implementation nearly half of these pre-service science teachers namely; PST1, PST3, PST6, PST8 recognize people factor in the situation and emphasizes the reaction, consciousness or knowledge level of individuals. PST2, PST4, PST5 and PST7 emphasize the similar factors both before and after the implementation. PST9 is not able to decide the boundaries of the system after the implementation, as an interesting issue. It is possible to understand that she does not focus on the energy production process and issues related to this process after the implementation, since she does not attribute any responsibility to GPPs.

On the other hand, pre-service science teachers usually focus on the events that they think as advantage or disadvantage of GPPs. This situation makes it hard for them focus on flow of events and comprehend the boundaries of the issue in its context.

Table 4.7: Maintain Boundaries Skill of Pre-Service Science Teachers

PST	IS	STS Level	Quotes
PST1	**BI**	**Low Maturity**	Aydın is an important city, but geothermal is destroying the city.
	AI	**Developing**	The advantages and disadvantages of GPPs, people's consciousness and their reactions are interrelated.
PST2	**BI**	**Developing**	GPPs have both positive and negative aspects. Human need energy to continue their lives. Unconsciousness use of energy threatens human life.
	AI	**Developing**	People in the region do not like GPPs. They think that the source of the problems they faced is geothermal. The population increases and the need for energy increases. Drying out of trees and figs shows geothermal as target.
PST3	**BI**	**Low Maturity**	When there are fault lines, fertility increases. GPPs decrease fertility, change climate. They have fatal effects… Mortality, dried trees, changing climate are because of geothermal.
	AI	**Developing**	Is geothermal harmful for agriculture, is it the reason for mortality? Mortality, worsening in agriculture, infertility, and people's reactions are events.
PST4	**BI**	**Low maturity**	I understand that geothermal can be harmful for the environment. There are problems in agriculture. People have health problems.
	AI	**Low Maturity**	I understand that geothermal effect human health and agriculture negatively.

Table 4.7 (continued)			
PST5	**BI**	**Developing**	The alternative ways that increase human workforce may have negative impact on human health and environment. For example, the use of coal starting with industrial revolution increased workforce while it has negative impact on human health. Every new phenomenon may not have positive effects for humanity or environment.
	AI	**Developing**	When the power plant have positive impact as means of providing needs and making production easier, it is not understood well or it could not be possible to solve the problem.
PST6	**BI**	**Low maturity**	Geothermal energy is harmful for nature, it affects air and soil, production decreased and GPPs are blamed as reason for deaths and these events.
	AI	**Low maturity**	People's reaction towards geothermal resources. People think that geothermal is the reason for damage in agriculture and increase in mortality ratio.
PST7	**BI**	**Low maturity**	The issue is about the negative effects of geothermal on environment.
	AI	**Low maturity**	Some of the GPPs have negative effects on environment in the region we lived.
PST8	**BI**	**Low maturity**	We understand that Aydın is an important city because geothermal has increased. Geothermal has both positive and negative impacts.
	AI	**Developing**	People react to the GPPs. When Aydın continues to develop, people started to protect their city.
PST9	**BI**	**Low Maturity**	The gains of Aydın with GPPs and the negative effects of geothermal on agriculture and production.
	AI	**Low Maturity**	Aydın has both advantageous and disadvantageous situation because of its location.

4.2.2.2. Differentiate Elements

In line with the GPP scenario, pre-service science teachers' ability to differentiate the static components and processes are investigated. Following questions related to GPP scenario are asked to PSTs to understand if they are able to differentiate the elements in geothermal power plant scenario:

- What are the key words in this real event? (components)
- How many small events there are in this big event? (processes)
- What are the names of these small events? (processes)

In these questions while key words refers to static components, events refers to dynamic processes. Therefore it is important to understand if pre-service science teachers are able to differentiate events and key words. The components and processes as identified by researcher are given at Table 4.8.

Pre-service science teachers' answers to this three questions are evaluated through components and processes identified by researcher. Pre- service science teachers' levels of maturity regarding differentiate and quantify elements skill is assessed through the rubric given at Table 4.9. The total components and processes are counted, later appropriate answers are counted. They are given at Table 4.10.

Table 4.8: Components and Processes in the GPP Scenario (Identified by Researcher)

Components of GPP scenario	Processes of GPPS scenario
Agriculture Human Health Economy Energy Need Environment Society Technology City	increase in population increase in geothermal power plants people's reaction against GPPs intensive agricultural practices increase in pollution increase in mortality increase in environmental damage development of city increase in people's interest of the issue

Table 4.9: Rubric for Evaluating Differentiate Elements Skill (Adapted from Arnold and Wade, 2017)

STS: Differentiate and Quantify Elements		
Low Maturity	**Developing**	**High Maturity**
Unable to identify the elements in the system	Able to identify the elements in the system and starts to differentiate the events from static components	Able to identify the most of the elements and differentiate the static components from processes with high accuracy.

When the results are assessed, it is seen that PST2 is able differentiate components and processes characterized by key words and events before and after the implementation.

Table 4.10: Number of reasonable components and processes identified by pre-service science teachers

		Total Number of Components	**Reasonable Components** Number of Components Identified	Total Number of Processes	**Reasonable Processes** Number of Processes Identified
PST1	Before Implementation	1	1	3	0
	After Implementation	2	2	4	1
PST2	Before Implementation	6	6	5	4
	After Implementation	12	8	10	7
PST3	Before Implementation	5	1	5	2
	After Implementation	1	0	5	5
PST4	Before Implementation	2	1	2	2
	After Implementation	3	2	3	3
PST5	Before Implementation	6	5	6	4
	After Implementation	8	5	5	4
PST6	Before Implementation	5	1	3	3
	After Implementation	3	1	2	2
PST7	Before Implementation	3	2	2	2
	After Implementation	2	2	2	2
PST8	Before Implementation	2	2	3	3
	After Implementation	3	3	3	2
PST9	Before Implementation	7	4	4	2
	After Implementation	5	5	3	2

Additionally, after the implementation she adds new components and processes her explanations. Similarly, PST5 is able to identify half of the possible components and processes and able to differentiate the elements with accuracy. PST1 is not successful as means of identifying the elements. Although after the implementation he identifies more elements, the elements are not related to the issue. PST3 and PST4 are better able to differentiate components and processes after the implementation. While PST2 reaches complete understanding and differentiation of components and processes, other PSTs still have some deficiencies about differentiating the elements in the scenario. PSTs levels of maturity regarding differentiating and quantifying elements are given at Table 4.11.

Table 4.11: Differentiate Elements Skill of Pre-Service Science Teachers

	Before Implementation	After Implementation
PST1	Low Maturity	Low Maturity
PST2	High Maturity	High Maturity
PST3	Low Maturity	Developing
PST4	Low Maturity	Developing
PST5	High Maturity	High Maturity
PST6	Developing	Developing
PST7	Developing	Developing
PST8	Developing	Developing
PST9	Developing	Developing

4.2.3 Structure Domain

4.2.3.1. Identify and Characterize Relationships

It is possible to say that understanding that there are relationships between the elements of an issue is a core systems thinking skills. Recognizing non-obvious, complex and less visible relationships indicates high maturity as means of identifying relationships. Pre-service science teachers' ability to identify relationships assessed through geothermal power plant case and interviews. According to Arnold and Wade (2017) framework identifying relationships and characterizing relationships skills are assessed with two different rubrics. While identifying relationships is characterized by the maturity about identifying increasingly complex and less obvious relationships, characterizing relationships is characterized with finding answers to questions related to mechanism, e.g. how a relationship works. In the GPP case and interview questions usually these two kinds of evidence is intertwined in the answers of pre-service science teachers. Therefore, the rubrics for evaluating PSTs' identifying and characterizing relationships skills are taken together and adapted for current case.

Table 4.12: Rubric for Evaluating Identify and Characterize Relationships Skill (Adapted from Arnold and Wade, 2017)

STS: Identify and Characterize Relationships		
Low Maturity	**Developing**	**High Maturity**
Unable to identify the relationships with accuracy.	Able to recognize the relationships and tell these relationships with surface explanations that does not consist of answer to how questions.	Recognizes most of the relationships including non-obvious ones and explains the relationships in details giving answer to how it works questions.

Before the implementation PST1 is not able to clarify the relationships between the events. He gives surface explanations without clarification. PST2 explains the relationships in terms of cause and affect relationships without clarification of a mechanism. PST3 identifies causal one directional relationship pattern of relationships. However, she cannot identify the main relationships with accuracy. Her explanations do not focus on the main issues. PST4 gives explanations about the relationships between the events. She tries to clarify the mechanism there. On the other hand, she does not recognize some important relationships in the process. PST5 identifies and explains relationships about the issue. She mainly follow a linear trajectory while explaining the events, however she focuses on a part of the issue and does not focus on the whole events. Similarly, PST6 explains the relationships she realized. She does not recognize all relationships. She mainly focuses on environment and health relationships. PST7 relates the events, however with limited explanation and without focus on the main issues. PST8 also tells that the events are related; however his explanations are not related to the issue. PST9 gives explanations about the events; however her explanations are not related to the main issues. Before the implementation pre-service science teachers either give limited surface explanations about the issues, without indicating the mechanisms governing the processes, or their explanations are lack of a focus of main issues. They make explanations about the unrelated or far related issues. None of these pre-service science teachers are able to recognize the complex and non-obvious relationships between the events in the case before the implementation.

After the implementation PST1 tells the events and their relations, limitedly with an identification of a non-obvious relationship. He identifies an interactive relationship but does not explain it. He develops his identify and characterize relationships skill. PST2 gives explanations about the issue similar to before implementation situation with a differentiation in her interpretation of the issues. PST3 does not focus on the events in the scenario. She does not explain the relationships between the events. PST4 gives explanations about the relationships between the events. She does not give a complete picture of the issue; however she tries to indicate the mechanisms of the relationships. PST5 explains the events. She does not express the relationships clearly by sentences. Instead, she draws a schema to show relationships. She indicates linear relationships between the events with this schema consisting of limited elements regarding the issue. PST6 thinks that it seems to be relationships between the events. However, she believes that the effects of GPPs are not extensive. Therefore, she does not try to explain the events in details. PST7 relates the events. He still gives limited explanations while he is starting to reach the issue. PST8 gives limited explanation. His explanations are more related to the issue than before implementation situation; he starts to focus on the main issue. PST9's explanations about the relationships showed a different trajectory. She expresses her ideas as the events are seemed to be related on the surface, however, they are not related in fact. Her interpretation is similar to PST6's interpretations. Since, PST9 think that GPPs do not have prevalent damaging effects, she does not think about the relationships in the issue. PST2, PST4 and PST5's levels are still developing after the implementation, since they do not add any complex, non-obvious relationships to their explanations and they still do not make explanations about the mechanisms of the relationships. None of these pre-service science teachers is able to reach high maturity level as means of identifying and characterizing relationships skill after the implementation.

Table 4.13: Identify and Characterize Relationships Skill of Pre-Service Science Teachers

PST	IS	STS Level	Quotes
PST1	**BI**	**Low Maturity**	The events are; Aydın, geothermal energy, Aydın's location. The events are related.
	AI	**Developing**	The pros and cons of geothermal energy, consciousness of people and their reactions are all related. They are affected from each other.
PST2	**BI**	**Developing**	These events are related. Fertile soils allow immigrants→ crowded→ people need energy to continue their lives. → Unconscious use of energy threatens environment and human life→ human death, trees death
	AI	**Developing**	These events are related. Fertile soil allow immigrants, the city becomes a metropolis. The need for energy increases. Increase in mortality ratio and drying out of trees cause geothermal power plants become target of people.
PST3	**BI**	**Low Maturity**	Everything is related. Migration to Aydın increases rapidly. Why? Aydın is an earthquake location. Electricity generation, heating, greenhouse cultivation, fisheries are increased. Why? There is geothermal. Mortality ratio increased. Fig and olive trees dry out. Why? It is because of geothermal power plants and global warming.
	AI	**NA**	No answer
PST4	**BI**	**Developing**	These events are related. Agricultural problems affect nature. People lose their health because of agriculture and nature. This may affect national economy. Aydın is a city of fig and olive.
	AI	**Developing**	These events are related. If agriculture is affected, people and animal are affected, too. Because, they are feeding with agricultural products.
PST5	**BI**	**Developing**	These events are related. Because when the soil is fertile and industry is developed migration to the city will increase. When population is increased, the needs will also increase. Then different ways of solutions will be investigated.
	AI	**Developing**	Energy→ energy production→ is given for use→ human→ used energy→ human and environment affected negatively
PST6	**BI**	**Developing**	The events are related. GPPs pollute soil, then agriculture and trees are affected negatively. Polluted air and soil effect people, since we use them.
	AI	**NA**	It seems that agriculture is damaged and mortality is increased because of GPPs. However, we learned that the effects of GPPs are not so extensive.
PST7	**BI**	**Low Maturity**	These events are related. They are about losses of geothermal.
	AI	**Low Maturity**	These events are related. They are about gains and losses of geothermal.

Table 4.13 (continued)			
PST8	**BI**	**Low Maturity**	These events are of course related, they are all about the city.
	AI	**Developing**	These events are related. Increase in population helps the city to develop. People start to protect their city.
PST9	**BI**	**NA**	These events are related. The intensity of agricultural practices increases the migration to the city.
	AI	**NA**	Since, the city is located in the fertile soils and agricultural practices are intense, population is increased, in a short time.

4.2.3.2. Identify and Characterize Feedback Loops

Identifying feedback loops is mainly related to recognition of relationships between the events. The relationships between the events in a system may form feedback loops. It means that the relationships are not unidirectional, but reciprocal and more complex. Especially in the case of geothermal issue, complex relationships may arise. For instance, the reaction of the people to the GPPs may affect development of GPPs in the location, or the constant increase in GPPs may reach the top level that energy produced cannot be managed and in turn, the GPPs will be decreased.

The questions regarding the relationships between the events have an evidential value for assessing pre-service science teachers' identify and characterize relationships skills. Arnold and Wade (2017) proposed an assessment for identifying feedback loops and another assessment for characterizing feedback loops skills with two rubrics. In current issue, there is no evidence that pre-service science teachers recognize the feedback loops in the relationships (see Table 4.10). They tell the relationships in causal linear manner. There is no evidence that they form a feedback loop while explaining events. Both before and after implementation these nine pre-service science teachers cannot make explanations regarding relationships in the events which in turn affect the events in cycles. They completely explain the relationships between the events in a linear cause and effect relationship pattern. Since, their identify feedback loops skill is evaluated in a degree of low maturity.

Characterization of feedback loops is not possible and no evidence is found in this case, since pre-service science teachers' skill of identifying feedback loops is low matured. A hierarchy is present between these two skills, indicates that identifying feedback loops skill is a base skill for characterizing feedback loops.

4.2.4 Behavior Domain

4.2.4.1. Describe and Predict System Behavior

A system thinker describe the events or system in its own context, considering time dimension and makes prediction about future events or system behavior by taking into consideration of past and present behaviors (Assaraf & Orion, 2010; Karaarslan, 2016; Arnold and Wade; 2017).

In the geothermal power plant case, it is asked to pre-service science teachers "what will happen if geothermal power plants are continued to rise in the future?" to understand if they are able to describe and predict system behavior in the future. Their answers are assessed through the rubric given at Table 4.14 below.

Table 4.14: Rubric for Evaluating Describe and Predict System Behavior Skill

STS: Describe and Predict System Behavior		
Low Maturity	**Developing**	**High Maturity**
Considers only one time dimension while talking about system behavior. Does not predict system behavior by taking into consideration of past or present time. Do not use evidence for predictions.	Considers two time dimensions while talking about system behavior, for example uses present time observations predict system behavior. Tries to justify predictions based on evidence.	Uses both past and present time situations of the system while talking about future behavior of the system, connects past-presents and future clearly. Justifies predictions based on evidence.

Before the implementation PST1 focuses on future events without giving reasons for his predictions. PST2 connects two time dimension; present time to future. She talks about her own observations and the speculations about the event. She focuses on the negative sides of GPPs and makes prediction about future based on some events such as mortality, increased health problems and death of trees. She talks about observations of farmers as a source of evidence for future events. It is seen that her predictions are in general terms based on current events. PST3 focuses on negative events such as mortality, climate and global warming. She does not give reasons for her predictions. PST4 focuses both negative and positive situations from the scenario given. She makes assumptions and predictions based on the events.

Table 4.15: Describe and Predict System Behavior Skill of Pre-Service Science Teachers

PST	IS	STS Level	Quotes
PST1	**BI**	**Low Maturity**	The soil may become infertile, ecosystem may be destroyed.
	AI	**Low Maturity**	If necessary precautions are not taken into consideration, it may be harmful for environment.
PST2	**BI**	**Developing**	The uses of geothermal energy destroy its location. Mortality and health problems and death of trees increase. People may be obligated to migrate. People in the location and farmers are the basic observers of the situation. Death of people and trees may increase. First hand observations are in line with this situation.
	AI	**Developing**	When geothermal power plants are used properly, they may not be harmful however when the regulations are not taken into consideration, GPPs may be harmful to the environment. The situation increases the tension between people. I heard from one of my friends that they become obligated to uproot the trees.
PST3	**BI**	**Low Maturity**	GPPs decreased fertility. They change climate, they have fatal effects. Geothermal have negative effects as means of climate, global warming, and increased mortality.
	AI	**NA**	As means of the GPPs that release their waste materials to the water, they play with our health; they play with their own health and with their children’s health. Otherwise, everything is normal.
PST4	**BI**	**Developing**	In the future both positive and negative aspects may be evident. If it destroys agriculture and health, this will not be fine. Health problems increase, economy may be affected negatively. Human health may be affected from the gases released. The natural balance may be destroyed.
	AI	**Developing**	GPPs in Aydın will affect our future negatively, because the gases released from GPPs affects air and threatens all living creatures.
PST5	**BI**	**Low Maturity**	The waste materials and gases released from the GPPs may affect human health, environment and agriculture negatively.
	AI	**Developing**	Contrary to known, electricity need may be supplied from GPPs in the future. That develops national economy; and environment positively. On the other hand if GPPs are harmful it may have negative results as means of environment and human; cancer, increased illness, agricultural production decrease, economic loss.

Table 4.15 (continued)			
PST6	**BI**	**Developing**	When we think about its negative effects on air and water, in future I think that we feel its negative effects more than today. When geothermal power plants are generating energy, harmful gases are released to the environment. Balance is destroyed (If you destroy nature, it answers you!
	AI	**Developing**	Supplying energy needed for people, from renewable sources, is less harmful and losses are decreased. I do not think it has very harmful consequences in short terms, also in long terms. The reason for this is the past of geothermal in Turkey reach out 2006s. We cannot predict its long term effects.
PST7	**BI**	**Developing**	The effects of GPPs are evident. In the past in River Büyük Menderes there were a variety of fish species. Nowadays, most of them died, and most of the species are endangered. Air is polluted. While we are generating energy, we lose our energy of life.
	AI	**Developing**	GPPs that release gases to the environment negatively effects nature and human health. If GPPs without precaution are closed, poisonous gases are not released and awareness of people is increased, here may be a beautiful place.
PST8	**BI**	**Developing**	The city will be developed faster. Employment increases. Industrialization increases. People who deal with agriculture will be affected negatively.
	AI	**NA**	People think that nature will be affected. When geothermal is controlled and used properly, it is very useful for the city.
PST9	**BI**	**Developing**	Since geothermal is a renewable resource, environmental damage of it, is lower. It decreases the dependency on coal, petroleum and fossil fuels. When we think that it is harmful for olive and fig production, the agricultural quality decreases, and human life will be threatened in next years.
	AI	**Developing**	Since we do not observe the damages of GPPs, they are not harmful. They result in large land use. There are some air pollution due to sulphur release and some soil pollution. We give less harm to the atmosphere and nature when we use GPPs. Also, our dependency on foreign resources decreases as a result of not using fossil resources.

PST5 focuses on negative events, however does not give reasons for her predictions. Similarly, PST6 talks about negative events with justification from moving current issues to the future. PST7 focuses on negative events. He moves from past to present however does not make prediction about future. PST8 takes into consideration of both positive and negative aspects of the issue, however does not give reasons for his predictions. PST9 takes into consideration of different aspects of the issue as means of dependency on fossil resources and environmental aspects. She moves from the current events to make predictions about the future events.

After the implementation PST1 makes a prediction about the future in relation with environment, moving from the assumption of precautions are not taken. He does not indicate the reasons for his prediction. PST2 focuses on two aspects of the event. One of these is that the environmental aspect and the other is the social aspect of the event. Similarly, she talks about harms of the GPPs in the future, based on the assumption of the regulations are not taken into consideration. She considers the other people's experiences about the situation. Different from the other pre-service science teachers, she considers tension between the people. PST3 focuses on health issues, however she does not make prediction about the future. PST4 mentions negative ideas about the future, because of the gases released from GPPs. She does not give any details related to the events about future. PST5 develops her prediction ability after the implementation. She focuses on more than one aspect of the events. She makes prediction about the future events based on current situations. After the implementation PST6 thinks differently. She focuses on positive events and take consideration of past, present dimensions into consideration, however she is still not able to make predictions about future behavior. She emphasizes uncertainty without making predictions. PST7 makes a prediction about future based on some conditions. He gives general explanations about the events in conceptual terms. Similarly, PST8 makes simple explanations such as usefulness of the resource instead of trying to predict future behavior. He denies the other people's ideas about the issue. PST9 bases predictions about the future on her observations. She takes into consideration environmental and economic aspects of the issue. Instead of making predictions about future by taking into consideration of events of flow, pre-service science teachers usually focus on the sole events by trying to talk about future. They make conceptual explanations such as "future will be fine, GPPS are useful, or future will be worse". These explanations are not clear and they usually rely on pre-service science teachers feelings.

4.3 Pre-service Science Teacher's Systems Thinking Skills during Implementation

Pre-service science teachers' discussions and classroom works are recorded to track changes in their systems thinking skills regarding energy. Three activities (at the beginning, in the middle and at the end of the implementation) are chosen to understand pre-service science teachers' progress namely; Activity 2, Activity 4 and Activity 7.

4.3.1 Activity 2: Energy Production and Consumption

The second activity included an internet based investigation with groups about energy production and consumption in the World and specifically in Turkey. Pre-service science teachers study in the computer laboratory and downloaded data from the World Data Bank. Downloaded data is chosen by the researcher before the activity, and pre-service science teachers are guided while they download the data from the internet. They have handouts that included questions about energy production and consumption. Some of the PSTs prefer to work alone while some of them work in groups. They try to find answers to their questions and make sense of data they have. They write their answers to their computer and give them to the researcher at the end of the activity. Some of the examples of answers from the computer laboratory activity are examined in details below.

Q: What are the factors effecting energy production?
Answer (PST2): I think that density of population, the location of the country on the Earth, the need of the energy, the area that the countries have (square meters), economic development of the country effects energy production.

Q: How can we show the relationship between population change and energy consumption?

Answer (PST2): Energy consumption of developed countries are high, however their renewable sources lower compared to the other countries of the Earth. One of the reasons for this situation is that they want to make profit. Developed countries like

China have a high renewable energy production; however their renewable consumption stays lower in their total energy use.

Q: Is there any relationship between use of renewable resource in energy production and developmental status of the countries?

Answer (PST2): There may be a linear relationship. However it is not a certain relationship. When we look at use of energy ratios, the situation cannot be compared.

PST2 identifies five factors that may affect energy production. While she explains the relationship between population and energy consumption she expresses developmental status of countries as a factor in this relationship. This explanation goes beyond a linear cause and effect relationship. As means of identifying relationships between development level of the countries and renewable energy use, she is not sure. She expresses a possibility of linear relationship, however tells that she cannot compare the situation for countries. She emphasizes the uncertainty in the relationship. Her expressions indicate a developing maturity regarding identifying relationships skills. On the other side, she recognizes the uncertainty and give time to understand the issue. Therefore, it is possible to say that her consider issues appropriately skill is also developing.

Another excerpt from answers of PST1 and PST8 is given below:

Q: What are the factors effecting energy production?
Answer (PST1 and PST8): Energy consumption is in relationship with development level of the country and population. It may change with geopolitical location and per capita net income of the country.
Q: How can we show the relationship between population change and energy consumption?
Answer (PST1 and PST8): When population increase, energy consumption increases too. In relation with the population increase development becomes difficult, that problem may be overcome with renewable resources.

PST1 and PST8 identify four factors affecting energy consumption. They do not give reasons for their explanation. They see a directly proportional relationship between population increase and energy consumption. They do not explain other factors role in this relationship. They talk about renewable sources when the others come to an end.

Excerpt from PST4's explanations are as following:

Q: What are the factors effecting energy production?
Answer (PST4): Population, geographic structure, climate, developmental status, technology, transportation, industry, trade, economic conditions, living conditions.

Q: Is there a relationship between renewable energy use and developmental status of countries?
Answer (PST4): There is inverse proportion. Some of the developed countries use nonrenewable sources, therefore they change the situation.

Q: How does energy use change in Turkey in years?
Answer (PST4): Generally, it increases. The reason of this increase is technological developments and unconsciousness of people.

PST4 indicates ten factors affecting energy production. She claims that when developmental level of the countries increase their renewable energy use decreases. She expresses some of the countries as a reason of this situation. She relates energy use raise to unconsciousness of people and technological developments. In this example excerpt, it is possible to understand that PST4 thinks differently from the other PSTs. In fact, while trying to find an answer to the question about the relationships between the elements, she moves from a limited example of developed countries using non-renewable resources. It is a weakness in her systems thinking to stick on a situation rather than following a pattern. On the other hand, she indicates some important factors in relation with Turkey's energy consumption.

In second activity, energy production and consumption, in general PSTs can identify many factors related to both production and consumption. In the excerpts above, it is seen that they usually use pattern of if … increase… increases or decreases while identifying the relationships in the system. Only PST2 states a mediating relationship between the factors she choose. This activity can be assessed as an evidence for students' limited use of data.

4.3.2. Activity 3: Biogeochemical Cycles

Activity 3 is helpful as means of understanding how pre-service science teachers use their systems thinking skills during the implementation regarding the issues they work on. As an instance, an excerpt from PST9's in class notes showing her systems thinking clearly, is given below:

> *PST9 (during implementation of Activity 3): Energy may be produced with different methods. However, the effects of these methods to environment, soil and water cycle should not be ignored. For instance, although GPPs are little harmful for environment, some of the GPPs do not inject water to the underground or release sulphur to the air. Water that is not injected to the underground mixes to the soil and environment. These affect the water cycle, and in turn all living organisms since this process is nested in nature.*

In this excerpt, PST9 uses her systems thinking while explaining the effects of energy production to the environment. She sees the big picture as energy production and moves between the connections of production process with environment. She does not forget the big picture. She indicates the processes in the energy production in relation with environment. She explains the mechanisms that interaction takes place between the elements. Therefore, in this situation she shows an example of high maturity in using systems thinking skills while explaining effects of energy production to the environment.

In another example during Activity 3, PST2 tries to identify the relationships between c-cycle and human-activities. The excerpt taken from her in-class notes is given below:

> *Human participate carbon cycle by respiration in simplest terms. However, they also participate c-cycle by mining, for example with coal drawing or drilling for oil. The*

effect of people on c-cycle is increased with the development in technology, machines and human force.

In this excerpt, she mentions the natural and human-made processes regarding c-cycle. She mentions respiration at the beginning. She does not explain the mechanism in details. Then, she talks about energy-related activities of people. She again does not give a detailed explanation about how these processes occur. Although, her explanations are not very detailed, she grasp the main idea. She is able to use her systems thinking skills while explaining human contribution in c-cycle.

As another example, PST3s' drawing in her notebook is given at Figure 4.1. It is possible to see that PST3 broadens her perspective during the activity. Her drawing includes many elements, both processes and components. She combines natural and human-made processes in her drawing. She recognizes the role of people in her drawing. She gives place to a plant, a car, energy resources and war in her drawing. She also gives place to animals and plants both living on the terrestrial, atmospheric and aquatic systems. She also indicates the relationships between these elements with arrows and explanations. For example, the processes of respiration and photosynthesis are emphasized in her drawing, with cyclic arrows. It is possible to say that she uses her systems thinking skills while working on this drawing. She is able to use her maintain boundaries, differentiate elements, identify and characterize relationships, and identify feedback loops skills according to her drawing. Although it is not possible to see the use of pre-service science teachers' identify feedback loops skill in geothermal power plant case, in this drawing PST3 uses her skill limitedly when remarking CO_2-O_2 relationships.

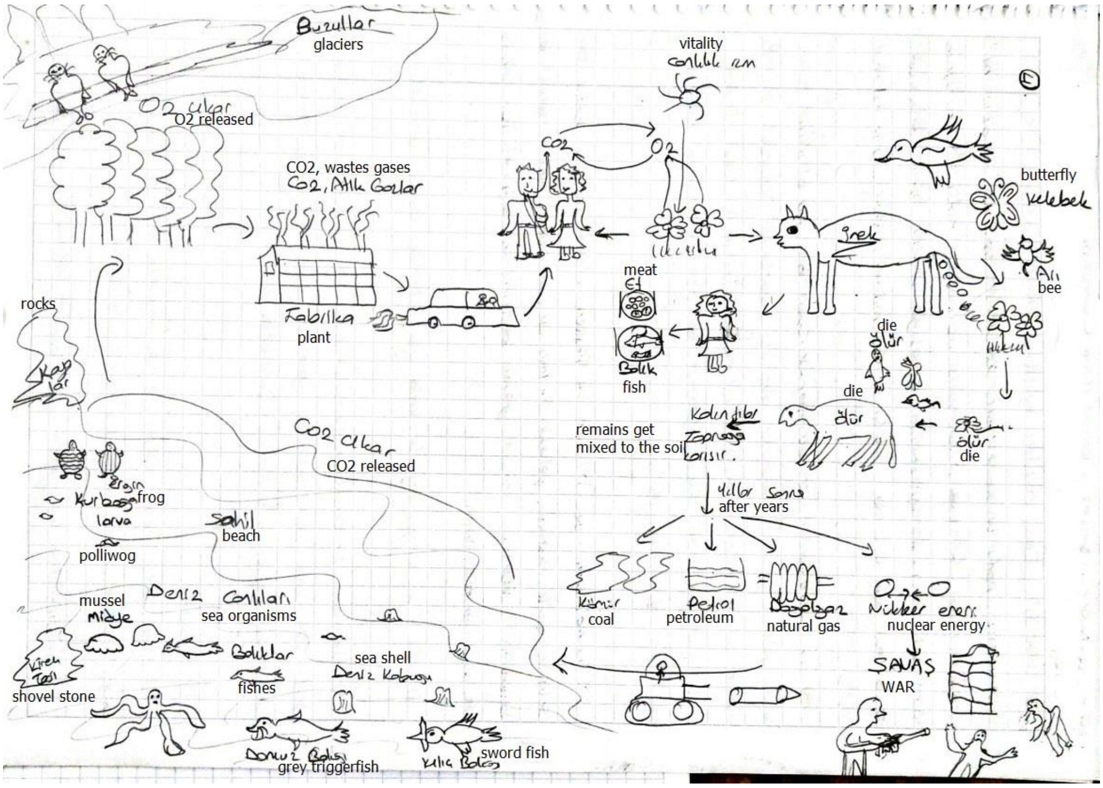

Figure 4.1: PST3's ecosystem drawing during Activity 3

4.3.3. Activity 4: Carbon Based Production

Pre-service science teachers' fourth week activities are chosen for detailed examination to understand their learning and thinking during the implementation process. 4th activity hold place at 12th of December in a four hours session in the laboratory classroom. There were 25 PSTs in the session. Half of the total students did not participate the activity. PSTs work with groups to investigate a given research problem about carbon dioxide concentration increase in the atmosphere (Activity 4). A hand out is distributed each group to instruct PSTs about their activity. They read a small text about fossil fuel based energy production and carbon dioxide increase in the atmosphere. They discussed and tried to clarify how they may plan to investigate given research problem. In the other three hours, they conducted their planned activities and reported their results. Their group discussion process at the beginning of the session is examined in details. The quotation from their group discussion is given below:

PST3 (is reading the question): When fossil fuels are preferred in energy production process atmospheric CO_2 increases. What may happen when atmospheric CO_2 increases?

PST7 (trying to understand): I think she is talking about carbon cycle deterioration.

PST8 (thinks in terms of cause and effect relationship): When CO_2 increased C-cycle is deteriorated.

PST1 (asks for reason): Why?

PST2 (gives an explanation based on a general idea in systems language): It is increased from one side while it is decreased from the other side. Since it is not balanced, it is deteriorated.

PST1 (asks for reason): Why?

PST8 (gives an explanation in terms of cause and effect relationships): When CO_2 increased in the atmosphere, ozone layer depleted.

PST1 (refuses the explanation): It is not right.

PST3 (puts another argument): The increase in CO_2 is very harmful for living organisms.

PST2 (agrees and gives an example from her own life experiences): Yes, it is very harmful, in Muğla Milas it damages trees. There is not filter at factory chimneys. It damages birds. Not just CO_2, increase in carbon concentration is also harmful.

PST3 (puts another argument about human and adds carbon mono oxide to the discussion): When we think about ourselves high CO_2 concentration may kill us by respiration. In addition, there is CO.

PST8 (remembers his knowledge about carbon mono oxide, turns back his own argument about ozone layer depletion): Carbon monoxide, heater poisoning.. Deterioration of C-cycle is the most important reason for ozone layer depletion.

PST3 (elaborates her knowledge and adds methane to the discussion): After the Carbon, the most effective gas is greenhouse gases. CH_4 from the dump…

PST1: Forest fires…

When the dialogue between students before reaching a consensus about the investigation is examined, it is seen that many arguments arise as a result of student participation. However, most of them are not clear and not related to the topic closely. They are not able to clarify the boundaries of the system at hand. Also, pre-service science teachers sometimes do not have enough knowledge to make sense of research questions. While they talk about carbon dioxide, they pass ozone layer depletion, and carbon monoxide. They relate human, tree and animal deaths directly to the carbon dioxide emissions to the atmosphere. They do not give explanation about the mechanisms governing the process. When PST8 gives an explanation and relates ozone layer depletion to carbon dioxide, PST1 refuses his explanation, however he also does not give any explanation and PST8 also does not ask any reasons why he refuses that claim. PST3 shares her knowledge about the topic, and sometimes they start to talk about topics that are not closely related to research question. However, there are some cues about systems language in the explanation phase of the dialogue. PST2 gives an explanation based on systems language to PST1's *why* question about C-cycle deterioration. The summary of PSTs' discussion process is given in Figure 4.2 below.

4.3.4. Activity 7: Energy Production Systems

The activity takes place at December 25th. Pre-service science teachers worked with a friend in this activity. Pre-service science teachers directed towards to draw a model of energy production system. They are completely free to make choice about their drawings. After they decide what to do, they used internet and books to take as a reference. When they finish their work with groups, they tell their study and drawings to the other groups and they presented advantages and disadvantages of their energy production methods. Their drawings with their group friends are given below.

PST1 worked with a different partner from his usual partner in this activity. They choose a fossil fuel based energy production process to work on and present their friends. They start with how fossil fuels formed and tell their friends this formation process initially as they investigated before.

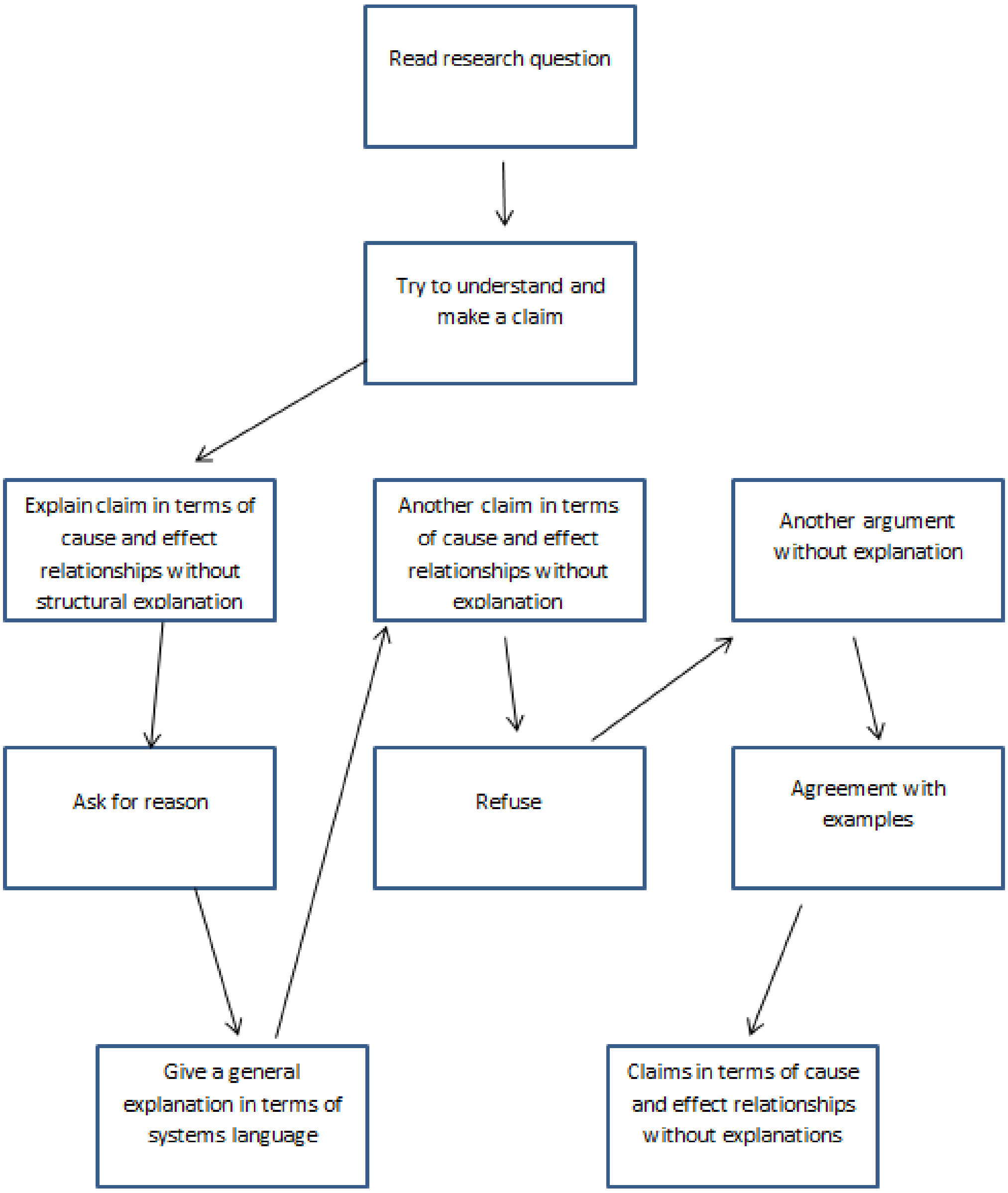

Figure 4.2: The Discussion Process of PSTs about Carbon-Based Energy Production

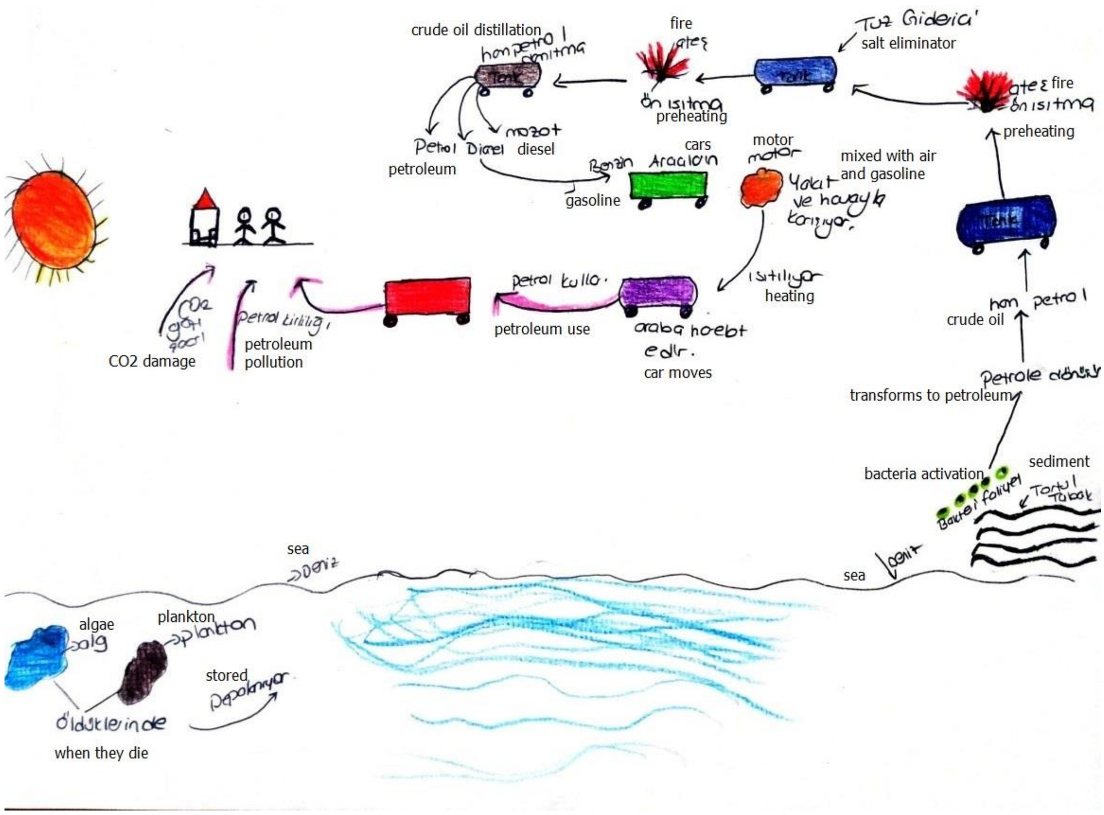

Figure 4.3: Drawing of PST1 and his Group Friend about an Energy Production System

They searched for crude oil processing, and draw this process to their papers. Then, they choose cars to use fuel. In the end they emphasized the environmental aspect by indicating fossil fuel pollution and CO^2 emission from the car. Their drawing consisted of many components and processes, including humans, cars, fossil fuels, and their environment. Processes and their relationships take place in drawing and explained to the other friends. However, their drawing is not completed to a cycle.

PST4 and PST9 work together and they choose electricity generation in hydroelectric power plants. They focus on mechanic structure and processes in electricity generation. They do not give place any other components except the system structure of a hydroelectric power plant. They express the advantages and disadvantages of a hydroelectric power plant to their friends while they present their energy production process.

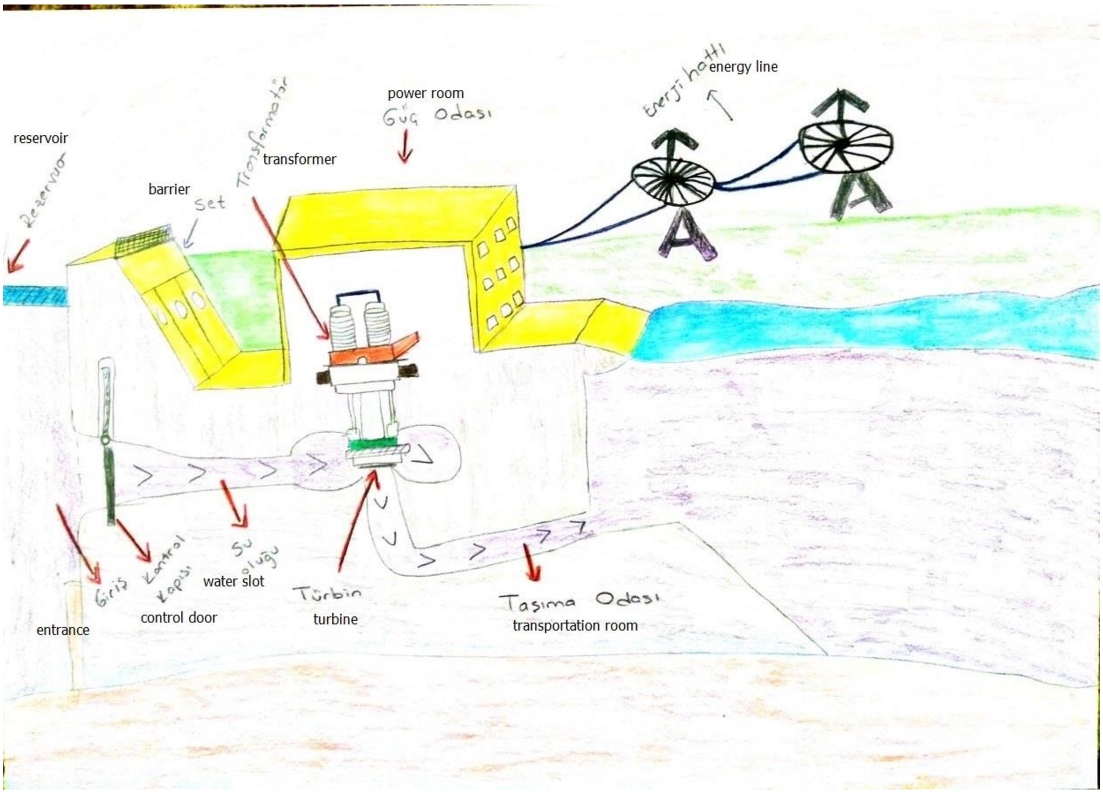

Figure 4.4: Drawing of PST4 and PST9 about an Energy Production System

PST2 and PST8 work on wind turbines for electricity generation. Similar to PST4 and PST9, they focus on mechanical structure and system of a wind turbine while they work on drawing. In their presentation, they focus on environmental effects of wind turbines, advantages and disadvantages of this electricity generation method.

In general, PSTs are well-aware of some energy production methods and systems. They also understand mechanical systems of these structures. However they do not give place other factors in these processes except PST1 and his friend. It is possible to say these pre-service science teachers were not familiar with energy production processes, therefore the time consumed in this activity used for increasing their knowledge about some of these systems. Therefore, this activity was helpful as means of contributing their understanding about the structure of these systems.

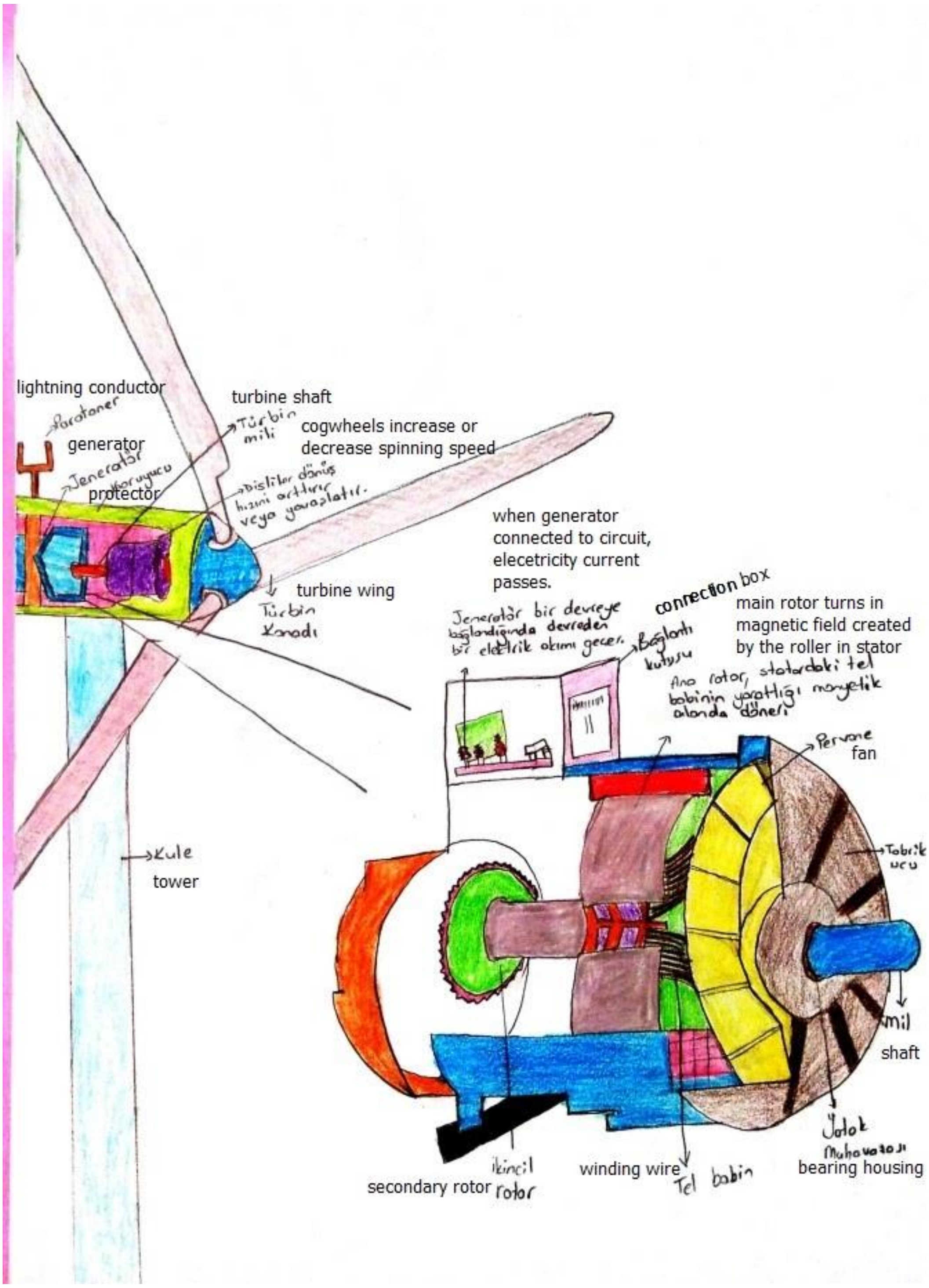

Figure 4.5: Drawing of PST2 and PST8 about an Energy Production System

4.4 Pre-service Science Teachers' Systems Understanding

Second research question is related to pre-service science teachers' systems understanding. The questions related to systems were asked students during the interviews before and after the implementation to reveal how they understand systems in general. These questions included:

- What is a system?
- Can you give examples of systems?
- How do you understand if there is system at hand?

When pre-service science teachers' answers before the interview are examined, it is seen that words; harmony, order and whole are mostly emphasized by PSTs. After implementation PSTs mostly emphasize words; interaction, order and parts. While PSTs try to characterize and define systems before the implementation, they emphasize function, structure and relationships in systems after the implementation. Examples of codes in relation with categories, mostly mentioned categories and codes by PSTs both before and after the interview are given at Table 4.16, Figure 4.6 and Figure 4.7 below.

Table 4.16: Codes and Categories about Systems Understanding of PSTs

Categories	Example Codes
Component	part, more than one thing, elements, part
Function	working together, aim, cycle, responsibility
Relationship	connection, interaction, related
Structure	regular work, whole, harmony, hierarchy

In Table 4.17 it is seen that all pre-service have an idea about systems in changing amounts before the implementation. After the implementation they give more details about systems in the interviews. They both emphasize structure of a system and its functions. Nearly, it is possible to say they grasp systems clearly. They realize dynamic nature of the systems. Different from the other pre-service science teachers, PST5 also emphasizes presence of energy input and output in the systems. Although, definitions, characteristics and examples of systems are not explicitly emphasized during the implementation, pre-service science teachers' understanding of systems developed during the process according to the interview results.

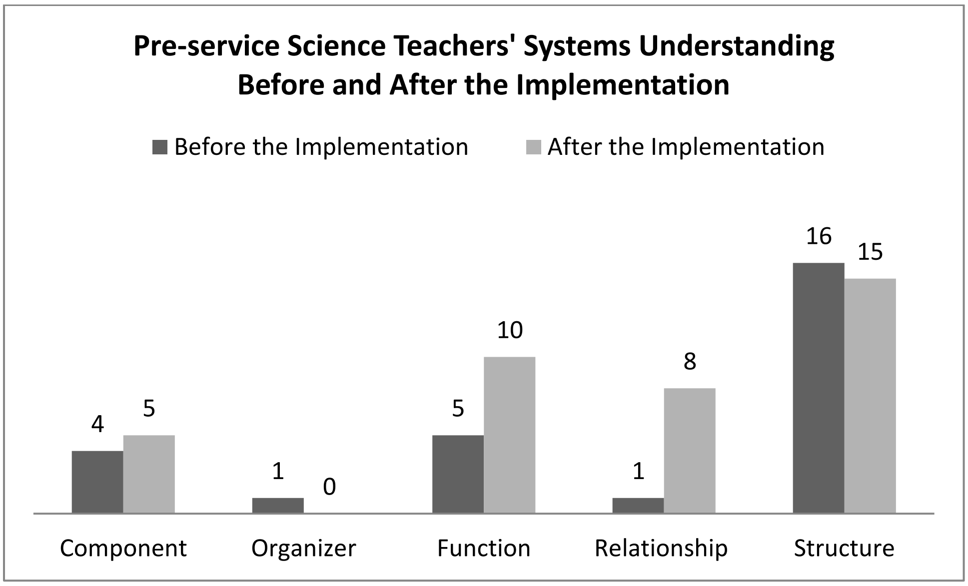

Figure 4.6: Mostly mentioned categories by PSTs before and after the implementation

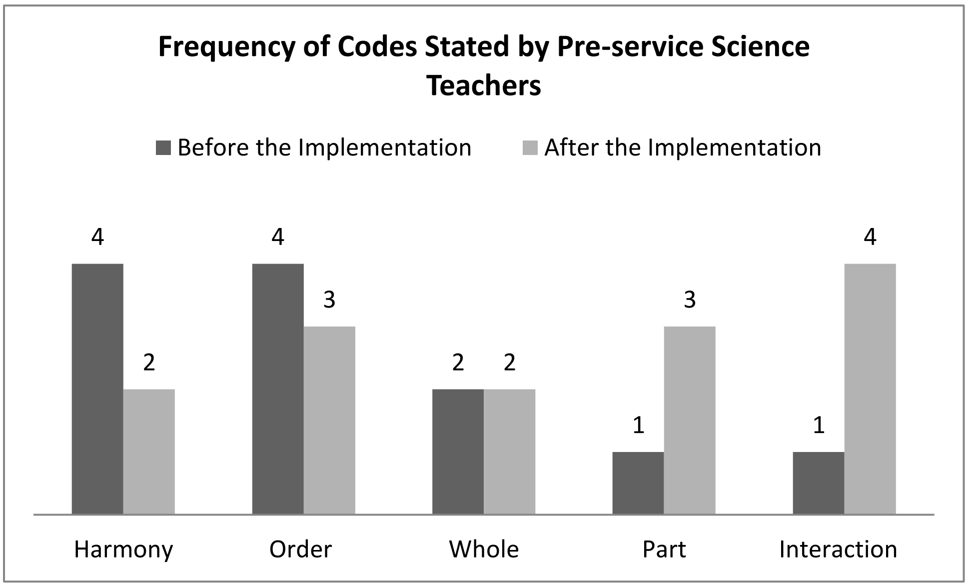

Figure 4.7: Mostly mentioned codes by PSTs before and after the implementation

The examples of excerpts from the interview and the system examples given by PSTs in the interviews are given in Table 4.17.

Table 4.17: Pre-service Science Teachers' Systems Understanding Before and After Implementation

	IS	Examples from Interviews	Codes	Examples of Systems
PST1	**BI**	Q: What is the meaning of the system? A: It is a group working in harmony. It should contain more than one component.	Harmony Component	Mobile Phone Solar Panels Systems in Human Body
	AI	Q: What is the meaning of the system? A: It is an organized group working together, related to each other. Everybody knows their missions and they work.	Harmony Relationship Mission	Circulatory System Geothermal Power Plant
PST2	**BI**	Q: What is the meaning of system in general? A: It means a constituted organization. A system should have branching including; input, output, receiver and message… If we talk about communication, it is a system. It is a system based on transmitter, receiver and message. It has an order. When it also has feedback it is certainly a system.	Order Branching Feedback Distribution of Work Input Output Receiver Message	Communicatio n Digestive System Excretory System
	AI	Q: What is a system? A: A working organization with parts coming together. These parts should be related and in harmony. Q: When we change parts of the system, does this system change or not? A: Yes, but to what extend it change… If it is machine, it breaks down. However if it is the universe, I don't think so. Q: How does it continue? A: Probably, it recovers broken part. But, it takes time. For example, oil resources have been consumed for a long time. It takes too much time to recover themselves. Q: What are the parts of a system? A: They may be other systems. They should be working and interrelated.	Parts Order Harmony Connection Systems in System Interaction	Environmental Pollution Machines Universe
PST3	**BI**	Q: What do you understand from a system? A: I understand coordinated work, for example; machines, school, program… In science, everything is developing, it is systematic. … System is events happening when certain data is obtained. Some opportunities should be supplied. …There should be parts and their director.	Regular work Systematic Parts Organizer	School Program Human Body Science Machine

Table 4.17 (continued)				
PST3	**AI**	Q: What is system? A: A mechanism working in an order. It may be human body, machine parts or a natural event. It is an organized event. Q: What is order? A: For example, everybody has responsibilities. When they do not work, problems arise. For example, people who suffer from renal illness. Their kidneys do not work properly. Normally, urine should be collected in bladder; however their urine is collected in a different place with the help of a hose through dialysis.	Regular event Mechanism Responsibility	Human Body Machine Natural Phenomenon Respiratory System Excretory System Digestive System
PST4	**BI**	Q: What is system? A: It is a particular order, or harmony of something. For example the order of planets, like the order of the Sun and planets around it. When we say systems I think of systems in human body.	Order Harmony	Harmony of Planets Systems in Human Body
	AI	Q: What is the meaning of system? A: System is events that are related to each other, it is an order. The order means working together that is to say, affecting each other. Every part is a member of the system. These parts constitute system by coming together.	Working together Order Related Effect each other Part Interaction	Respiratory System
PST5	**BI**	Q: What is system? A: It is an interaction regarding an event. For example digestive system, circulatory system, systems in nature; ecosystem. .. There are rules and cycles of a system. It happens in the course of an event. At least it has certain rules and flow of events.	Interaction Regular Cycle Flow of Events	Musculoskeletal System Circulatory System Digestive System Ecosystem Systems in Nature
	AI	Q: What is a system? A: It happens in the course of events or a phenomenon. System is the environment of everything that are effected from each other. …It should include energy input and output and something effected from this situation.	Energy Interaction Environment Event/phenomenon	Pressure Cooker Respiration Energy Production-Consumption
PST6	**BI**	Q: What should a system include? A: It should have a source, and sub-things. It should distribute from a source. I can give ecosystem as an example. A system should be a whole inside itself. Being a whole means being in harmony with each other.	Source Wholeness Parts Harmony	Solar System Ecosystem Musculoskeletal System
	AI	Q: What is a system? A: System are the whole of things which are in interaction to each other. For example ecosystem. … A system should produce something; it should be in a cycle. In an ecosystem there are some cycles. As a result of the cycles vital activities continue.	Interaction Whole Produce Cycle	Ecosystem

Table 4.17 (continued)				
	BI	Q: What is system? A: There is a system of human body, for example digestive system, respiratory system. Esophagus, mouth, laryngeal are its subtitles. All of these constitute system. It may be moving from parts to whole. Parts that constitute whole are necessary for being a system.	From Parts to Whole Whole	Digestive System Respiratory System Computer
	AI	Q: What is system? A: It means holism. When parts come together and complement each other, a system is formed… The meaning of complementing is function. Their functions should be same. Parts constitute a system.	Wholeness Parts Mission Same mission	Digestive System Excretory System
	BI	Q: What is system? A: It means the presence of order. Order equals system. For example car is a system… There should be a system for cars to move. Similarly, TV… Systems require this. There should be a system in plants. Systems should include harmony, tactic and discipline.	Order Harmony Tactic Discipline	Cars Plants TV Soccer Game
	AI	Q: What is system? A: System means mechanism. System is a whole of parts that have an aim and an order.	Mechanism Order Aim Whole of Parts Level	Digestive System Excretory System Endocrine System Reproductive System Ecosystem
	BI	Q: What is system in general? A: System is a mechanism that works in a certain order. This mechanism includes elements that run the system. They work in a division of labor.	Parts Order Mechanism Distribution of Work	Machines Ecosystem Solar System
	AI	Q: What is system? A: It is mechanism that produces something, for e.g. plants. Everything has a different function … Systems are the things that have both inputs and outputs or are succession of things… There should be more than one thing, anything cannot be a system by alone, and there should be movement.	Production Mechanism Input-Output Movement A Certain Way More than One Thing	Plants Machine Digestive System Excretory System

4.5. Summary of Results

In this study, pre-service science teachers' systems thinking skills and system understanding during the module implementation process are examined. Arnold and Wade (2017)'s systems thinking model is used for the aim of understanding PSTs' systems thinking development during the module implementation process. Systems thinking skills identified during this research are given in Table 4.18.

Table 4.18: Systems Thinking Skills Identified in This Research

Skills Proposed by Arnold and Wade (2017)	**Skills identified in Current Study**
Explore Multiple Perspectives	+
Consider the Wholes and Parts	-
Effectively Respond to Uncertainty and Ambiguity	-
Consider Issues Appropriately	+
Use Mental Modeling and Abstraction	-
Recognize Systems	-
Maintain Boundaries	+
Differentiate and Quantify Elements	+
Identify Relationships	+
Characterize Relationships	+
Identify Feedback Loops	+
Characterize Feedback Loops	+
Describe Past System Behavior	+
Predict Future System Behavior	+
Respond to Changes over Time	-

In this research study some of these systems thinking skills proposed by researchers are not identified. The skills identified in this study according to interpretation of evidence from the data sources, are evaluated with a rubric adapted from Arnold and Wade (2017). The rubric used in this study is given in Table 4.19 below.

Table 4.19: Rubric Used for Evaluating Pre-service Science Teachers' Systems Thinking Skills Before and at the end of Module Implementation

Domain	STS Skills	Levels		
		Low Maturity	**Developing**	**High Maturity**
Mindset	**1.1. Explore Multiple Perspectives**	Considers issue from only one perspective, for example s/he makes emphasizes constantly on the problems of health.	Recognizes the presence of different perspectives regarding the issue. S/he tries to look at the event from more than one perspective including a difference between the ideas.	Actively emphasizes and compares many faces of the issue, although they may contradict with his/her own opinions. S/he does not ignore contradicting ideas.
	1.2. Consider Issues Appropriately	Takes a reactionary approach to the issue immediately.	Allows time to understand the issue and complexity, however sometimes still jumps to conclusions.	Allows time for complexity and does not directly jump to conclusion, without understanding the issue.
Content	**2.1. Maintain Boundaries**	Cannot define the boundary of the system	Defines the boundary of the system including most of the relevant items.	Defines the boundary of the system with accuracy even the system changes over time and context.
	2.2. Differentiate and Quantify Elements	Unable to identify the elements in the system	Able to identify the elements in the system and starts to differentiate the events from static components	Able to identify the most of the elements and differentiate the static components from processes with high accuracy.
Structure	**3.1. Identify and Characterize Relationships**	Unable to identify the relationships with accuracy.	Able to recognize the relationships and tell these relationships with surface explanations that does not consist of answer to how questions.	Recognizes most of the relationships including non-obvious ones and explains the relationships in details giving answer to how it works questions.
	3.2. Identify and Characterize Feedback Loops	Unable to recognize feedback loops	Recognizes some feedback loops, however does not characterize their properties	Recognizes most of the feedback loops and characterizes their properties

Table 4.19 (continued)				
Behavior	**4.1. Describe and Predict System Behavior**	Considers only one time dimension while talking about system behavior. Does not predict system behavior by taking into consideration of past or present time. Do not use evidence for predictions.	Considers two time dimensions while talking about system behavior, for example uses present time observations predict system behavior. Tries to justify predictions based on evidence.	Uses both past and present time situations of the system while talking about future behavior of the system, connects past-presents and future clearly. Justifies predictions based on evidence.

PSTs' systems thinking skills before the module implementation and at the end of module implementation are evaluated with the help of the rubric. The results of these assessments are given in Figure 4.8 below as a summary.

Before the module implementation PSTs' systems thinking skills were mostly low matured. At the end of the module implementation their STS levels were developing. PSTs' systems thinking skills in mindset domain including explore multiple perspectives and consider issues appropriately were mostly developed skills through the implementation. In structure domain, identify and characterize feedback loops skill did not show any development and stayed at low maturity level. Content domain skills followed mindset domain skills as means of their development. At the end of the implementation, structure and behavior domain skills stayed nearly the same as before the module implementation.

All activities may be effective as means of developing PSTs' mindset domain skills, especially Activity 5 (field trip), Activity 7 (Energy Production Systems) and Activity 3 (Biogeochemical Cycles) seemed to be fruitful according to the evidence coming from PSTs' in class discussions and notes during the sessions.

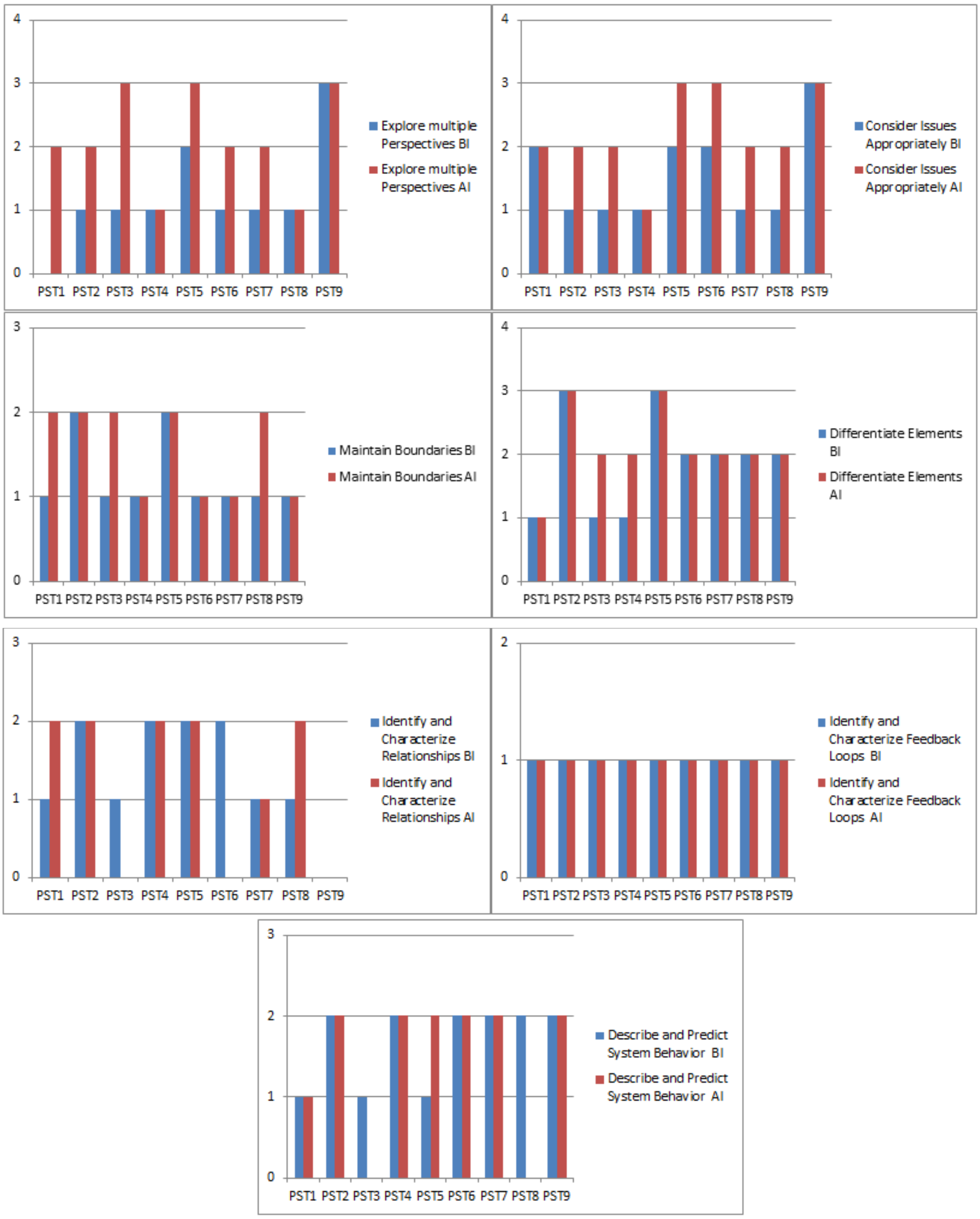

Figure 4.8: The Comparison of PSTs' STS Before and After Module Implementation

PSTs' systems understanding evaluated before the module implementation and at the end of module implementation. PSTs' could define systems both before and after the implementation, however focusing on different aspects of systems. Before the implementation they emphasized harmony, order and whole that classified as structure of systems. At the end of module implementation, they emphasized interaction and parts classified under relationships and structure. Also, they talked about function of the systems. PSTs were able to give system examples both before and after the module implementation. They usually realize systems in human body when systems mentioned. Different examples of systems were found in their explanations including, solar panels, machines, school, science, energy production-consumption, pressure cooker, plants, and soccer game. Their explanations were more extensive including parts, relationships, and function of the systems at the end of the module implementation. This is an evidence for deeper understanding about systems after the module implementation.

CHAPTER 5

DISCUSSION AND RECOMMENDATIONS

5.1. Discussion of the Results

In this dissertation it is aimed to develop and implement a module in the context of energy and understand the role of this module in developing PSTs' systems thinking skills and general systems understanding. Pre-service science teachers' systems thinking development may be evaluated as a complex system. It includes components of the nature of activities in the STS module, PSTs' motivation towards implementation, the duration of implementation, PSTs' prior knowledge about systems and energy issues and PSTs' skills. These factors are discussed in relation with each other in this part of the dissertation.

Pre-service science teachers' systems thinking assessed with written data collection tools, interviews both before and after the interview and classroom discussions and PSTs' notes during the implementation. Content analysis, with the help of rubric developed through the framework offered by Arnold and Wade (2017), was held to make sense of data collected. The reason for adopting this framework for the aim of investigating PSTs' systems thinking skills was framework's novelty, holism and applicability of complex issues when compared with individual systems thinking elements approach (Richmond, 2000; Behl and Ferreira, 2014) and hierarchy of systems thinking skills approach (Stave and Hopper, 2007; Assaraf and Orion, 2010).

The results of the study support the domain approach by Arnold and Wade (2017) as means of identifying structure of systems thinking skills. Most of the skills identified by the researchers appeared during the research process in different phases of data collection processes. Therefore, the results of this research have evidential value of supporting researcher's starting point as systems thinking approach.

Pre-service science teachers' STSs' in mindset domain including explore multiple perspectives and consider issues appropriately skills change during the module implementation. After the implementation, pre-service science teachers were more able to look at the issue from multiple perspectives while before the implementation they were stuck in some issues such as human health. They recognized the environment, economy, energy need, and consciousness after the implementation. As means of consider issues appropriately skill, PSTs' reactionary approach at the beginning is decreased at the end of the implementation. PSTs were more able to give time to understand the issues and complexity. Pre-service science teachers' STSs' development in mindset domain may be attributed to the activities during the module implementation process. Outdoor learning environments are found to be effective developing systems thinking skills of students by different researchers at different age groups from elementary level to undergraduate students (Assaraf and Orion, 2010; Long, 2015; Karaarslan, 2016). Assaraf and Orion (2010) found outdoor learning environments effective as means of developing elementary school students' systems thinking about water cycle. Long (2015) found similar results for high school students in an after school ecohydrological citizen club and Karaarslan found Lake Eymir discoveries effective for developing pre-service science teachers' systems thinking about sustainability issue. In this study, field trip may be effective as means of developing pre-service science teachers' explore multiple perspectives and consider issues appropriately skills. Indeed, in field trip, PSTs' had a chance to talk to engineers and see the location around the geothermal power plant. Before the trip PSTs heard some bad news related to GPPs and they usually have a tendency to take these talks into consideration while making a decision about the issue. During the trip, they learned about the structure of geothermal power plants, electricity generation, cautions for protecting environment, and other applications of geothermal resources besides electricity generation. Pre-service science teachers increased their knowledge of energy resources. They listen to the people working in geothermal power plant and realized the economic, environmental and developmental value of geothermal sources besides the disadvantages of GPPs. Therefore, geothermal field trip is thought to be effective in developing PSTs' systems thinking skills.

In content domain, differentiating elements in a system is one of the components of systems thinking. Pre-service science teachers identified energy, the city, problems, and activities characterizing the city before the implementation as components in this scenario. After the implementation, they mentioned energy less while they mentioned problems and activities characterizing the city more. When it is asked them to identify events, they focused on problems of the city, activities characterizing city and effects of geothermal before the implementation. After the implementation they mentioned problems less, while they mentioned effects of geothermal and activities characterizing city more. According to these results, it is possible to say that PSTs may relate problems of the city to the presence of geothermal power plants before the implementation. As means of differentiating components and processes PSTs have some difficulties both before and after implementation. As means of maintaining boundaries, it is seen that four of these nine pre-service science teachers relate distant components and events to the main events. It is understood that PSTs have difficulties to decide the boundaries of the event here. In content domain there were development in PSTs' skills, however it was less when compared with mindset domain. It may take time to understand the content of the issue especially in such a complex issue and also, it may be necessary to explicitly focus on the content of the complex issue.

Identifying and characterizing relationships and feedback loops skills are structural skills. In this research study, it is seen that PSTs usually were not very good at identifying complex relationships between society, economy, environment and energy production. Pre-service science teachers usually look at events as a linear chain of causes and effects. After the implementation the situation was similar. However, there are some new elements added to explanations. These new elements were people's consciousness, knowledge level and reactions. In the end of the implementation, just one of the pre-service teachers explains the events as a relationships web, by saying all of these events are affected from each other. However he did not give any explanatory details about the relationships structure. No evidence was found regarding the development of identify and characterize feedback loops skill of PSTs. This skill is an important of understanding complexity inherent the system. Pre-service science teachers stayed at the low maturity level as means of identifying feedback loops. Similar results were found by researchers in systems thinking area regarding the structural skills. For example Lee (2005) found that most of the teachers had difficulties when identifying relationships, recognizing hidden dimensions and understanding multiple relationships in the case of water cycle. Also, in the context independent assessment of systems thinking, Sweeney and Sterman (2000), Sterman and Sweeney (2002) investigated university students and graduate students' systems thinking skills and found that students' understanding of stocks and flows, and delays and feedbacks were poor. In the case of global warming students violated basic physical principles such as conservation of matter (Sterman and Sweeney, 2002). In their study, Assaraf and Orion (2005b) found that most of the high school students in their sample do not understand the dynamic and cyclic nature of water cycle. Also, Evagorou et al. (2009) found that identification of feedback loops in a system skill was not easy to develop even in a case which students' other systems thinking skills showed development. It is usually hard for students to understand the relationships in systems especially when events or systems are complex. The laboratory experiments also favor problems' of individuals in association with understanding relationships and complexity. People usually try to use simplistic explanations rather than focusing on complexity and unidirectional explanations are favored over multicausal explanations (Sweeney & Sterman, 2007; Dunbar, 2008).

Pre-service science teachers preferred to use flow diagrams and schemas to explain events before the implementation. However, some of them were not able to draw anything even a figure or diagram. These PSTs were the ones with limited ability to as means of differentiating elements and identifying and characterizing relationships. After the implementation, pre-service science teachers' picture drawing preferences increased. They give more details in pictures than in diagrams or figures. Some of them add mechanism to their explanations. The mechanisms and indicators of relationships are important. It also may be a sign of increasing systems thinking abilities of PSTs. Three of these pre-service science teachers add indicators of relationships and explanatory mechanism to drawing. Another three of PSTs do not draw anything. Other three of them draw schemas showing the effects of geothermal. Pre-service science teachers drawing abilities are also in a relationship with their structural skills. When they could not present their ideas, it was not possible to understand if their abilities were developing. Activity 3: Biogeochemical Cycles seems to be effective as means of developing PSTs' structural skills. Because, this activity included investigation, discussion and drawing processes. While the development in PSTs' structural skills was not very explicit in geothermal real life scenario, during the module implementation, drawings were powerful tools to show PSTs' skill development. Indeed, drawings are known to be powerful cognitive tools in research literature (Tversky, 1999; Brooks, 2003).

Description and prediction as a systems thinking ability focuses on PSTs descriptions of systems current situation and predictions of future behavior of systems in changing conditions based on time dimensions and justification. Description and prediction ability of PSTs is assessed through the question of what may happen in the future if geothermal power plants are continue to increase and what may be the results of this event in relation with human and nature. The preferred answers include the observations of systems behavior in the past and present. Through the knowledge of these two dimensions PSTs may make predictions about the future. However, PSTs usually use present time without taking into consideration of past behavior of the system while making predictions about the future. After the implementation one PST clearly talk about both past and present while predicting future. Other PSTs focus on two time dimensions. Pre-service science teachers use negative events such as increase in cancer ratio, drying out of trees and decrease in agricultural practices to make predictions about the future before the implementation. After the implementation they use these situations with more uncertainty, because they their own ideas about geothermal power plants change in some degree. They usually emphasize necessary precautions for geothermal power plants while talking about future after the implementation. When talking about future pre-service science teachers also reflect their feelings to their predictions instead of thinking about other important factors which are in continuous change that may affect the situations in the future such as increase in population, development, regulations, government promotion, environmental destruction except from caused by GPPs, and economic facilities. It may not be just related to limitedness of their description and prediction ability, it may be related to their thinking just from limited dimensions of the issue. On the other hand, some PSTs mention the needs of humans, role of renewable resources in producing energy and economic development in their other expressions. Ben-Zvi Assaraf (2004) mentions this systems thinking skill as retrospection and prediction and classifies it as a higher-order systems thinking skill. After an earth system instruction she found limited development (only 10-30% of students) in junior high school students' abilities of retrospection and prediction, similarly.

Pre-service science teachers systems thinking skills in the domains of content, structure and behavior showed different patterns for students as explained above. Limited development in pre-service science teachers systems thinking may be attributed to the nature of the activities. The design of activities in the module was based on several important principles such as; consisting of domain related activities, adopting the inquiry process, coaching of thinking skills, ill-structured situations, social construction of process and collaboration, providing motivating learning context (Barab & Duffy, 2012). In the first activity, it is aimed to introduce the concept energy to the pre-service science teachers and motivate them to for the sessions. Questions related to energy are given to them. Initially, they tried to answer these questions individually, and then they discussed their answers as a group. They used reference books and internet to answer the questions. In the last stage of the session, the questions are evaluated as a whole group discussion. The answers of the questions are not given by the researcher. According to the observations of the researcher and researcher notes taken during the activity, pre-service science teachers had difficulties with basic concepts related to energy; such as forms of energy, energy resources and basic principles of energy. Also, during the process, pre-service science teachers could not communicate well to each other and have difficulties with investigating questions from resources; rather they tried to seek the right answers for their questions from the instructor. Pre-service science teachers have some difficulties as means of adopting student-centered learning process.

In the energy production and consumption activity, it is expected to develop pre-service science teachers' skills related to maintain boundaries, differentiate elements and identifying and characterizing relationships in the systems. Energy production and consumption issue is an abstract system when we compare it to a power plant system or ecosystems. Also, this issue is a complex system and contains a lot of relationships with issues such as technology, economy, resources, human behavior and ecological concerns. In this activity, pre-service science teachers are expected to make sense of data about, countries' energy consumption, population, developmental status and production. It was a difficult activity for pre-service science teachers as indicated by their statements. During the sessions, from starting to the end, they have difficulties with dealing with data sets through the questions. The best implementation of the activity included one to one guidance of researcher with groups of three or four students. In this activity, both practical difficulties and deficiencies of limited thinking arouse. Practical difficulties included pre-service science teachers' skill deficiencies about computer use. To deal with these deficiencies, the data is downloaded by the researcher from the internet and distributed to the students. On the other hand, the way to reach data is shown to students by making a practice by the researcher. Groups wrote down their work on the computer and their answers are collected by the researcher. The practical difficulties are tried to be overcame with these implementations. Other difficulties included trying to find answers to general questions by using limited data, reaching a conclusion by comparing extreme cases, and difficulties with understanding relationships and differentiating distant and close relationships; namely, maintaining boundaries. When pre-service science teachers tried to understand the relationships between the factors such as developmental level of the countries, their population and their energy use, they mainly focus on most and least developed countries, most and least use of energy. Comparing extreme cases made difficult to see the whole picture for them. They could not recognize the whole trajectory for these factors. They usually concentrate on certain parts of data. A similar situation arose during activity four, carbon based production and its' effects. In this activity it is expected to PSTs to realize the effects of human impact on environmental systems. Therefore, this activity targets to develop pre-service science teachers' description and prediction and considering multiple perspectives skills in addition to structural systems thinking skills. Activity four included an investigation process based on an experiment. The importance of scaffolding, role of argumentation, presentation and modeling through the experimentation process were taken into consideration in the design of the activity (Lehrer, Schauble & Petrosino, 2008). During this activity students had difficulties with each phase of the activity starting from argumentation. It was hard for the PSTs to continue their dialogue when a new idea is proposed by a group member. Instead of trying to elaborate and support their arguments, they prefer to pass the argument when another group member told about some new ideas. Their dialogues simply turned out to be saying you are wrong or that is true. Pre-service science teachers needed guidance in their discussion process. When pre-service science teachers asked questions of how and why to each other during the group discussions, they could form a fertile investigation process. These group discussions have a role of developing pre-service science teachers' presentation abilities and give them chances to realize their own reasoning processes. During the activity, they needed help both as means of making a decision about their research questions and during the implementation of the process of investigation. They mostly have difficulties with deciding and limiting their problems as a researchable question. With the guidance and help of the researcher they find their way to investigate. Most of the students choose to do experiments and they used plants for their experiments. The discussion and setting up the experiment took four hours to study. After they set up their experiments they observed their plant with time intervals and recorded their findings. In the end of their experiment, they find some results as they predicted before setting up the experiment. They usually state that because of CO_2 concentration increase plants and if there are any animals in the location they could die. However, they have difficulties with understanding their experiments' weaknesses such as absence of necessary control groups. Therefore, as a result of their experiment when their plant died, they could not interpret it from a systemic perspective. During the activity it is seen that pre-service science teachers do not realize the other factors affecting plant grow. They are not able to realize light, structure of the soil, and atmosphere moisture. They only focus on CO_2 during their experiment. The limitedness of PSTs systems thinking skills reflected on this experiment during the process. They could not recognize plant growth as a system, they focus on some of the parts, therefore; they could not grasp the whole picture similar to the process in activity two. PSTs' engagement and motivation in the activity stayed at lower levels. The reason for lower engagement may be PSTs' abilities during the process. Student-centered learning-environments bring together some challenges as means of students' motivation (Adler, Schwartz, Madjar & Zion, 2018). Students' abilities associated with doing inquiry activities are found to an important factor in sustaining their motivation (Edelson, Gordon & Pea, 1999; Veermans & Järvelä, 2004).

Between these two activities, activity three took place. In this phase of the module implementation, it is expected to increase the pre-service science teachers understanding of matter cycles, energy and ecosystems. Pre-service science teachers watched videos related to biogeochemical cycles. Then, they work in groups and tried to answer questions related to C-cycle and water cycle. They draw pictures to reflect their understanding. During the session they were free to use internet and reference books. Reference books were supplied by the researcher. In this session PSTs' drawings were more detailed as means of showing components and relationships as compared with their interview drawings both before and at the end of the module implementation. Some of the students also showed human impact on ecosystems adding energy related activities. Pre-service science teachers' structural systems thinking skills show progress in this session in the context of ecosystems. Drawing process and knowledge were helpful as means of developing PSTs' systems thinking skills. It is seen that he changes pre-service science teachers' systems thinking skills were complex and intertwined with a variety of other skills and knowledge. For example, during the activity three and other parts of the implementation, it is seen that pre-service science teachers' have difficulties while making drawings. Hung, Chang and Hung (2019) identified an experienced teacher's skills in metavisualization process about carbon cycle. In this article, they list a variety of skills and knowledge that teacher used. In our case, our pre-service science teachers tried to visualize energy production and consumption process in relation with c-cycle during the session. Even if they were aware of the complexity of relationships, they sometimes have difficulties with expressing them. In fact, their skills of using symbolic representations and using text representations are effective as means of expressing themselves. Also, pre-service science teachers' knowledge of these specific systems is important as means of applying their systems thinking. During the implementation of the module, it is seen that pre-service science teachers' understanding of topics such as water cycle, carbon cycle, electricity generation, ecosystems, energy resource formation were limited. They were giving surface explanations about the events. These limited level of knowledge made it hard to see pre-service science teachers systems thinking skills. In their study, Assaraf and Orion (2005), found similar results that conceptual understanding of eighth grade students' influenced their systems thinking development. In addition to these findings, Lyons (2014) found that students who have lower levels of knowledge also have lower levels of reasoning, while students who have highest knowledge level, have higher levels of reasoning in the case of earth systems. Therefore activity three was helpful as means of providing PSTs to increase their knowledge besides increasing their presentation skills by drawings. Another activity, geothermal power plant trip was expected to be helpful as means of developing pre-service science teachers systems thinking skills in four domains. Students usually have a tendency to think that harmful gases are released by the GPPs are the reason for health problems with the respiration process according to their statements. In this study, this situation is evident by participants' statements. That may be in relation with the students' tendency to not to realize the mechanisms and hidden dimensions of the systems. Difficulties associated with understanding hidden dimensions and mechanisms of systems are detected by various researchers (Sibley et al., 2007; Assaraf, Dodick and Tripto, 2013; Batzri et al., 2015; Rodriguez, Kohen and Delval, 2015). Claims related to GPPs' effects also include water pollution besides air pollution. Another activity in the module, water analysis activity targets to collect evidence and interpreted this evidence in relation with systems. During this activity water from different locations including Büyük Menderes River, artesian water near the GPPs, tap water and irrigation water are compared as means of different parameters including physical and chemical parameters. Activity is done as a demonstration because of high student participation to the session. Pre-service science teachers write down the findings about values of parameters and try to make sense of the values. In the end of the sessions, during the interviews, it is seen that pre-service science teachers usually do not remember this activity and it was not as effective as their own observations of river and environment in the location. Also, there was no evidence of PSTs systems thinking skills in relation with water analysis activity. The reason for this may be that PSTs could not actively participate the activity from the preparation to the end of the activity. The sample waters were supplied by the researcher. If PSTs were involved this activity from the collection phase of the water samples, and they could do the analysis with their own groups, it would be more effective. The last activity in the module, energy production systems activity is planned to be flexible to focus on how energy, used as electricity or other purposes, is generated and used. During the implementation it is aimed to guide PSTs to focus on any system they choose and work on it. Therefore it would be possible to develop PSTs structural systems thinking skills. PSTs work in groups of two people. They were responsible for their partner and other students to talk about the system they work on. They worked together and identify their system initially. They did not choose geothermal power plants, since they were familiar with GPPs from the field trip. They presented their system to the other PSTs. They asked questions to the other groups about the systems they presented. This activity is helped them to comprehend the structure of any physical system and they are better able to understand methods of energy generation both in specific and general perspective. Especially, energy production systems activity and biogeochemical cycles activities are thought to be helpful as means of developing PSTs' systems understanding besides other activities in the STS module. The analysis of the interviews at the beginning and at the end of the module implementation showed the development of systems understanding of PSTs. Also, there were systems embedded in the content of the module such as economy, technology, energy production-consumption, environment, and their experimental set up. Therefore, all activities had a contribution of developing PSTs systems understanding.

5.2. Recommendations

This dissertation is shaped through a module implementation that focused on energy issues and systems thinking skills in energy related issues. Therefore both implications for implementation and further research arising from the results of the study discussed below.

5.2.1. Recommendations for Module Implementation

In this research through the STS module implementation process some issues appeared. These issues shed light into recommendations part. One of them is duration of module implementation. According to the results of this study, systems thinking skills take time to develop. The current research is implemented in four weeks duration and four to eight hours in a week. The duration of the implementation may be extended to a semester to see the development of these skills.

The implementation took place in a science laboratory. Sometimes difficulties arise due to physical deficiencies such as absence of ventilation, and the configuration of the laboratory. Therefore, this study may be repeated in more feasible and healthy conditions.

The participants were 3rd grade science teaching students. It is thought that they would better able to deal with issues of doing experiment and they could have basic knowledge related to the issues of energy. However, the results are different from expected. Therefore, this study also may be repeated with freshman, sophomore and senior science teaching students. In addition to these, the course independency of this STS module gives change to implement the module for different students from various levels and back grounds in addition to undergraduate science teaching students. The participatory group may include high school students and other undergraduate school from various divisions.

Some of the activities may be extended by adding some elements. These activities include water analysis, energy production and consumption, geothermal power plant trip and energy production systems. PSTs participation of water analysis activity was not as high as expected. In this study, water samples were prepared before the activity by the researcher. Instead of prepared samples, pre-service science teachers may collect these samples themselves with a guidance of the researcher if possible. Therefore, they may involve each phase of the process from the preparation to the end. It may give the participants chance to communicate with other people from the location and see the water samples in their resource and environment. This would be very helpful for them to understand the situation from a holistic framework and increase their motivation through the activity. One of the activities which may be extended is geothermal power plant trip. The trip was limited to experts' guidance in the power plant. It may be extended as means of including the other sides of the issue such as interviews with farmers, activists, directors and people from the location. Energy production and consumption activity may be extended to be as including visualization of data and analysis of the data from different countries. The participants' knowledge and experience of dealing with data should be reconsidered and guidance should be consistently supplied. Therefore, an implementation that focuses on only this aspect of systems thinking skills may take place. Also, building a model of an energy production system, though included in the current research, may be added to energy production systems activity.

Each of these activities arranged through a rationale that starts from providing resources for gaining knowledge to understand the nature of issues. In each phase of the module, participants knowledge level and other skills should be reconsidered that could be helpful through the module implementation process. It is clearly seen that the improvement in various skills such as argumentation, presentation, visualization and experimental skills have important contributions to pre-service science teachers' systems thinking skills. Therefore, these skills should be reconsidered in any implementation about systems thinking.

5.2.2. Recommendations for Research

The current research contributed to the research as means of understanding pre-service science teachers' systems thinking skills development and interaction between these skills and module implementation. Also, it is the first effort to test the model proposed by Arnold and Wade (2017). Results showed that this model is applicable and it seems to be effective as means of identifying systems thinking skills of PSTs. Therefore researchers may use this model in their investigation and test the applicability of this model at different contexts for further research.

According to the results of this study, PSTs systems thinking skill may be shaped by nature of the systems. It means that their systems thinking skills used during the process are embedded in the context. It arises as an issue to understand the interaction between various definitions of systems thinking and students' skills used in the process. As an example, it is seen that PSTs realized the dynamic and cyclic nature in the water cycle while they did not realize complex nature of geothermal issue. Besides, cyclic relationships, more complicated relationships and uncertainty took place in geothermal issue. That may be a reason for difficulties associated with understanding relationships in this issue. Natural systems, social systems and contrived systems may be tested and compared as means of skills used in the process. The complexity inherent in these systems may result in differentiation between skills used. These issues should be reconsidered.

This study provides researchers valuable STS module which include the activities related to energy issues from various perspectives. The issues that have social, cultural, environmental and technological value should be further investigated in instructional process. Science education may include more connections to social values besides scientific values. Individuals who have more comprehensive perspectives are needed. This issue should be reconsidered.

The researchers may use this module in their research with modifications for their participatory groups. The results may be different for various groups in relation with their background knowledge and motivation towards learning energy issues.

This study indicated that pre-service science teachers' systems thinking skills are not well developed. This result highlights the importance of integrating systems thinking skills in education faculty programs and middle school programs. The importance of systems and system related abilities are emphasized in science education in United States Next Generation Science Standards. Emphasize on systems thinking abilities is needed in Turkish curriculum, especially for science courses. It may be helpful to develop various modules targeting development of systems thinking of individuals for various topics and test these modules.

There were some skills that could not be detected in this research. Therefore, STS module may be extended with additional activities focusing on these elements. Modeling activities may be a part of this module, so that it may be possible to increase individuals' description and prediction abilities.

In addition to science course content, other disciplines for instance geography and history are very suitable contents for integrating systems thinking. Therefore, research about systems thinking in other educational disciplines may have very important contributions increasing individuals' abilities. This issue should be reconsidered.

Another critical result arising from the study is low motivation of pre-service science teachers to students-centered learning environments in the module implementation process. Education faculty students have an important role in shaping future education. In this case, pre-service science teachers have troubles while working in group, they have deficiencies as means of expressing themselves and they have low motivation to very important issues about our future. Their values may be investigated in association with their systems thinking skills. More research is needed as means of understanding the motivational issues in relation with pre-service science teachers' systems thinking skills.

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APPENDICES
A. GEOTHERMAL REAL LIFE SCENARIO

Adı-Soyadı:

Tarih:

Aşağıda jeotermal enerji ile ilgili küçük bir tanıtım yazısı verilmiştir. Verilen metni okuyunuz. Metnin sonunda verilen soruları kendi düşünceleriniz doğrultusunda cevaplayınız.

Görsel http://cleanenergy.ucoz.net/ adresinden alınmıştır.

Aydın Türkiye'nin tarım, sanayi ve dış ticaret ile turizm faaliyetlerinin bir arada bulunduğu, ekonomisi en gelişmiş bölgelerden olan Ege Bölgesi içindedir. Aydin ili ilk çağlardan beri verimli toprakları, elverişli, iklimi, ticaret yolları üzerinde bulunması nedeniyle önemli bir yerleşim merkezi olmuştur. Günümüzde de tarımsal faaliyetlerin yoğunluğu ve çeşitliliği, turizm olanaklarına sahip bulunması ilin önemini giderek artırmaktadır. Kuzey ve güneyi dağlık, engebelidir, iki bölüm arasında iki yandan faylarla sınırlanmış ve sonradan alüvyonlarla örtülmüş genç bir çöküntü alanı olan Büyük Menderes ovası yer alır. Aydın ilinde meyvelikler özellikle zeytin ve incir ağaçları geniş alan kaplar.

Son yıllarda Aydın ilinin nüfusu hızla artmaya başlamıştır. Türkiye'nin büyükşehirleri kapsamına alınmıştır. Aydın Türkiye'nin hızlı göç alan şehirleri arasındadır. Tüm bunlarla birlikte birinci dereceden deprem bölgesidir ve aynı zamanda jeotermal kaynaklar yönünden de oldukça zengindir. Jeotermal kaynaklar dünyada Amerika Birleşik Devletleri, İtalya, Yeni Zelanda, İzlanda ve Türkiye'de elektrik üretimi, konut ısıtma, seracılık, su ürünleri yetiştirilmesi, sıcak su elde edilmesi, endüstri ve kaplıcalarda kullanılmaktadır. Aydın'da son yıllarda jeotermal enerji üretimi hız kazanmıştır. Ancak hız kazanan bu üretimle birlikte çiftçilerin ve sivil toplum kuruluşlarının da jeotermal enerjiye tepkisi artmıştır. Bu tepkilerinin sebebini insan sağlığının ve tarımın olumsuz etkilendiği iddialarına dayandırmaktadırlar. İddialarını ise Aydın'da son üç yılda artan ölüm oranları ve kuruyan incir ve zeytin ağaçlarını gerekçe göstererek desteklemeye çalışmaktadırlar.

Bu bilgilere ve konu hakkındaki düşüncelerinize dayanarak aşağıdaki soruları cevaplayınız.

Sorular

1. Bu olaydan ne anlıyorsunuz?
2. Bu gerçek olaydaki anahtar sözcükler ne olabilir?
3. **a.** Bu olayda kaç tane küçük olay bulunmaktadır?
b. Bu olayların başlıkları neler olabilir?
c. Bu olaylar birbiriyle ilişkili midir, nasıl?
4. Bu büyük olay içerisinde birbiriyle ilişkili olayları ve ilişkileri açıklayan bir şema/resim çizip açıklayınız?
5. Aydın'da jeotermal enerji santrallerinin kullanılmasının gelecekte ne gibi etkileri olabilir?
6. **a.** Bir jeotermal enerji santralinde nasıl enerji üretilir?
b. Enerjiyle ilgili bildiğiniz ilkeler doğrultusunda jeotermal enerji santralindeki enerji üretim süreçlerini açıklayınız.
7. **a.** Aydın ilinde çiftçilik yapsaydınız, jeotermal kaynakların kullanımı konusunda ne düşünürdünüz?
b. Nasıl bir davranış sergilerdiniz?
8. **a.** Siz Aydın ilinde bir jeotermal enerji firması işletiyor olsaydınız nasıl düşürdünüz?
b. Nasıl bir davranış sergilerdiniz?
9. **a.** Siz Aydın'da yaşayan biri olarak bu olayla ilgili ne düşünüyorsunuz?
b. Bu problemin çözümünde nasıl bir yol izlenebilir?
10. Siz Aydın'da yaşamayan biri olsaydınız, bu konuda ne düşünürdünüz, nasıl bir davranış sergilerdiniz?
11. Sizce bu olay, insan ve doğa açısından nasıl sonuçlar ortaya çıkarabilir, neden?

B. INTERVIEW QUESTIONS

Enerji ve enerji üretim sistemleri

1. Enerji üretimi deyince aklınıza ne geliyor, tanımlar mısınız?
    a. Örnek verir misiniz?
    b. Enerji üretimi nasıl gerçekleşir?
2. Dünyada bazı ülkelerin enerji tüketimi fazladır, bunun nedeni ne olabilir?
3. Enerji tüketimi nelerden etkilenir?
4. Dünyada ne tür ülkeler fazla enerji üretebilir, neden?
5. Enerji üretimi nelerden etkilenir?
6. Enerji üretimi ile tüketimi arasında ilişki olduğunu düşünüyor musunuz?
    a. evet ise, nasıl?
    b. hayır ise neden?
7. Enerji üretim süreçlerinde son yıllarda yenilenebilir kaynakların kullanımı artmaktadır.
    a. Yenilenebilir kaynaklar ne anlama gelir?
    b. Yenilenebilir kaynak kullanımı neden artış göstermektedir?
8. Termodinamik yasaları nelerdir, açıklar mısın?
9. Enerjinin etkili kullanımı ne anlama gelir?
10. Bir elektrik santralinin %35 verimle çalışması ne anlama gelir?
11. Enerjinin sürdürülebilirliği ne anlama gelir?
12. Enerjinin sürdürülebilirliğini sağlamak için hangi yollar izlenebilir?
13. Enerjinin dünya genelinde tüm insanlara adil dağılıyor mu, cevabınızı gerekçeleriyle açıklayınız?

Sistemler

1. Fen bilimleri içinde düşünerek bir sistemi nasıl tanımlarsınız?
2. Fen bilimlerini düşünerek bir sisteme örnek verebilir misiniz?
3. Bir sistemi oluşturan öğeler nelerdir?

C. SAMPLE ACTIVITIES

Activities in STS Module Activity 1: What is Energy (Teacher Guide)

Etkinlik 1: Enerji Nedir? (Önerilen Süre: 4 ders saati)

Hedefler:

1. Bu etkinlikte temel amaç öğrencilerinin enerji konusundaki bilgilerinin açığa çıkarılması ve öğrencilere temel enerji kavramlarının hatırlatılmasıdır.

Öğrenme Çıktıları
Öğrenci,

1. Enerjinin ne olduğunu açıklar.
2. Enerji türlerini ve enerji kaynaklarını ayırt eder ve tür ve kaynaklara örnekler verir.
3. Enerjiyle ilgili temel yasaları açıklar.

İşleyiş:

Dersin girişinde öğrencilere aşağıdaki sorular yöneltilerek enerji konusunda sınıfça tartışma yapılır:

- Enerji nedir?
- Enerjinin korunumu nedir?
- Enerji dönüşümü ne demektir?
- Enerjinin tüketilmesi ne anlama gelir?
- Enerji nereden gelir?
- Enerji üretilir mi, nasıl?
- Enerji üretmek için ne gerekir?
- Enerji üretimi sonucunda ne oluşur?
- Teknoloji ve enerji üretimi arasında nasıl bir ilişki vardır?
- Enerji üretiminin çevreye etkisi var mıdır, nasıl?
- Enerji üretiminin sürdürülebilir olması ne anlama gelir?
- Enerji üretim sistemi dediğimizde aklınıza ne geliyor?
- Bir enerji üretim sisteminin bileşenleri neler olabilir?
- Enerji üretim sisteminde hangi olaylar meydana gelir?

Öğrencilere bu sorular yöneltilerek enerjiyi nasıl düşündükleri ve temel enerji ilkelerini ne düzeyde anladıkları ortaya çıkarılmaya çalışılır. Öğrencilerin bu sorulara toplu değil, sırayla cevap vermeleri sağlanır. Öğrenciler bu aşamada düşüncelerini ifade ederken yönlendirilmezler ancak, süreç boyunca enerji konusunu enerji krizi ve enerji üretimi başlığı altında ele alacağımız ifade edilir. Bir saat sınıf tartışması yapıldıktan sonra öğrencilere ikinci ders saati için okuma ve derste sorulan sorular basılı olarak dağıtılır. Öğrencilerin sorulara verdikleri cevapları defterlerine not etmeleri istenir.

Not: Öğretmen, öğrencilerin konu ile ilgili temel kavramları hatırlamamaları durumunda hatırlatma amacıyla bir ders saatini aşmamak kaydıyla konu anlatımı, video ve örneklerle açıklamalar yapabilir.

Öğrenciler için kısaca inceleyebilecekleri kitaplar:

McLeish, Ewan (2013). Dünya Sorunları: Enerji Krizi. Tübitak Popüler Bilim Yayınları

Activity 1: What is Energy? (Student Handout)

Aşağıda verilen soruların cevaplarını kaynaklardan ve bilgilerinizden yararlanarak, cevaplayınız, cevaplarınızı defterlerinize yazınız.

- Enerji nedir?
- Enerjinin korunumu nedir?
- Enerji dönüşümü ne demektir?
- Enerjinin tüketilmesi ne anlama gelir?
- Enerji nereden gelir?
- Enerji üretilir mi, nasıl?
- Enerji üretmek için ne gerekir?
- Enerji üretimi sonucunda ne oluşur?
- Teknoloji ve enerji üretimi arasında nasıl bir ilişki vardır?
- Enerji üretiminin çevreye etkisi var mıdır, nasıl?
- Enerji üretiminin sürdürülebilir olması ne anlama gelir?
- Enerji üretim sistemi dediğimizde aklınıza ne geliyor?
- Bir enerji üretim sisteminin bileşenleri neler olabilir?
- Enerji üretim sisteminde hangi olaylar meydana gelir?

Activity 2: Energy Production and Consumption (Teacher Guide)

Etkinlik 2: Enerji Üretimi ve Tüketimi (Önerilen Süre: 4 ders saati)

Öğrenme Çıktıları
Öğrenci,

1. Bir enerji üretim-tüketim sürecindeki ilişkileri belirler.

World Data Bank web sitesi üzerinden ülkelerin enerji kullanımı, elektrik kullanımı, enerji sağladıkları kaynakların dağılımı ve benzer verilere ulaşılabilmektedir. Bu veriler renkli haritalar, grafikler ve excell formatında verilerin bilgisayara kaydedilmesi şeklinde elde edilebilmektedir.

Bu etkinlikte öğrenciler bilgisayar laboratuvarında çalışacak ve çalışmalarını flash bellek üzerinde kendi adlarına açacakları klasörlere kaydedeceklerdir. Aynı zamanda not defterlerine yönlendirici soruların cevaplarıyla ilgili notlar alacaklar. Öğrenciler aşağıda bulunan sorular doğrultusunda web sitesinden aldıkları verileri tarayacak, grafikleri inceleyecek ve veriler doğrultusunda enerji tüketimi, enerji üretimi, alternatif enerji üretimi, enerji kaynaklarının dağılımı arasındaki ilişkileri tespit etmeye çalışacaklar.

Öğrencilerin verileri kullanarak cevap arayacağı sorular:

1. Enerji tüketimi en yüksek ve en düşük beş ülke hangileridir?
2. Nüfusu en fazla ve en az olan beş ülke hangileridir?
3. Enerji tüketimini etkileyen faktörler neler olabilir?
4. Nüfus değişimi ve enerji tüketimi arasındaki ilişkiyi nasıl gösterebiliriz?
5. Yenilenebilir enerji kaynaklarının kullanımı dünya genelinde nasıl değişmektedir?
6. Yenilenebilir enerji kaynaklarının toplam enerji kaynakları içindeki payı nasıl değişmektedir?
7. Yenilenebilir enerji kaynaklarının toplam enerji tüketimi içinde en büyük ve en küçük paya sahip olduğu ülkeler hangileridir?
8. Yenilenebilir enerji kaynaklarının kullanımı ile ülkelerin gelişmişlik düzeyleri arasında ilişki olabilir mi, nedeni açıklayınız?
9. Yenilenebilir enerjinin toplam üretim içindeki payının değişmesinin nedenleri nelerdir? Gerekçeleriyle açıklayınız.
10. Elektrik kullanımı dünya genelinde nasıl dağılım göstermektedir?
11. Elektrik kullanımını etkileyen faktörler neler olabilir? Gerekçeleriyle açıklayınız.
12. Dünya genelinde elektriğe erişim nasıldır? Nüfusunun çoğunluğu elektriğe erişemeyen ülkeler hangileridir?
13. Türkiye'de enerji kullanımı yıllara göre nasıl değişmektedir?
14. Türkiye'de enerji hangi kaynaklardan üretilmektedir?
15. Türkiye'de yenilenebilir enerji kaynaklarının kullanımı toplam enerji kaynakları içinde nasıl bir paya sahiptir?

Yansıtma:

Öğrencilerden verileri kullanarak buldukları cevapları not defterlerine yazmaları istenir. Dört veya beş kişilik gruplar oluşturulur ve bu gruplardan bir araya gelerek buldukları cevapları tartışmaları istenir.

Tartışma bittikten sonra not defterlerine başlangıçta soruların cevapları hakkında ne düşündükleri, veri analizi ve tartışma sonucunda fikirlerinde değişme olup olmadığını olduysa neler düşündüklerini yazmaları istenir.

Activity 2: Energy Production and Consumption (Student Handout)

World Data Bank web sitesi üzerinden ülkelerin enerji kullanımı, elektrik kullanımı, enerji sağladıkları kaynakların dağılımı ve benzer verilere ulaşılabilmektedir. Bu veriler renkli haritalar, grafikler ve excell formatında verilerin bilgisayara kaydedilmesi şeklinde elde edilebilmektedir.

Bu çalışmada sizlerden bu web sitesinden indirilip flash belleğe kaydedilen verileri sorumlu öğretim elemanından alarak, bilgisayarlarınıza kaydetmeniz ve bu verileri kullanarak aşağıda verilen soruları cevaplamanız beklenmektedir. Cevapladığınız soruları bilgisayarda word programında yazıp öğrenci numaranızla kaydetmeniz gerekmektedir. Ders bitiminde sorumlu öğretim elemanı sizlerden kaydettiğiniz dosyaları alacaktır.

Sorular:

1. Enerji tüketimi en yüksek ve en düşük beş ülke hangileridir?
2. Nüfusu en fazla ve en az olan beş ülke hangileridir?
3. Enerji tüketimini etkileyen faktörler neler olabilir?
4. Nüfus değişimi ve enerji tüketimi arasındaki ilişkiyi nasıl gösterebiliriz?
5. Yenilenebilir enerji kaynaklarının kullanımı dünya genelinde nasıl değişmektedir?
6. Yenilenebilir enerji kaynaklarının toplam enerji kaynakları içindeki payı nasıl değişmektedir?
7. Yenilenebilir enerji kaynaklarının toplam enerji tüketimi içinde en büyük ve en küçük paya sahip olduğu ülkeler hangileridir?
8. Yenilenebilir enerji kaynaklarının kullanımı ile ülkelerin gelişmişlik düzeyleri arasında ilişki olabilir mi, nedeni açıklayınız?
9. Yenilenebilir enerjinin toplam üretim içindeki payının değişmesinin nedenleri nelerdir? Gerekçeleriyle açıklayınız.
10. Elektrik kullanımı dünya genelinde nasıl dağılım göstermektedir?
11. Elektrik kullanımını etkileyen faktörler neler olabilir? Gerekçeleriyle açıklayınız.
12. Dünya genelinde elektriğe erişim nasıldır? Nüfusunun çoğunluğu elektriğe erişemeyen ülkeler hangileridir?
13. Türkiye'de enerji kullanımı yıllara göre nasıl değişmektedir?
14. Türkiye'de enerji hangi kaynaklardan üretilmektedir?
15. Türkiye'de yenilenebilir enerji kaynaklarının kullanımı toplam enerji kaynakları içinde nasıl bir paya sahiptir?

Yansıtma:
Dört kişilik gruplar oluşturunuz. Sorulara verdiğiniz cevapları karşılaştırınız. Arkadaşlarınızla farklı cevaplarınızın nedenlerini tartışınız. Fikirlerinizde değişme oldu mu, nedenlerini açıklayınız.

Activity 4: Carbon Based Production and Its' Effects (Teacher Guide)

Etkinlik 4: Karbona Dayalı Enerji Üretimi (Önerilen Süre: 4 ders saati)

Öğrenme Çıktıları
Öğrenci,

1. Fosil yakıta dayalı enerji üretiminin çevre açısından sonuçlarını tartışır.
2. Karbona dayalı enerji üretiminin sonuçlarını değerlendirmeye yönelik bir araştırma tasarlayıp uygular.

Öğrenci bu çalışmada grup arkadaşlarıyla tartışarak konuyla ilgili önbilgilerini ve araştırma amacıyla neler yapılabileceğini belirler. Bu süreçte aşağıda verilen işlem basamaklarına uygun hareket edip etmediği sorumlu öğretim elemanı tarafından takip edilir.

1. Merak edilen araştırma konusunun saptanması
2. Nedensel bir araştırma sorusu oluşturulması
3. Öngörülen açıklama
4. Araştırma sorusuna nasıl cevap verileceğinin planlanması
5. Tahmin edilen sonuçların tartışılması
6. Gözlemlenen sonuçlar
7. Sonuçların rapor edilmesi (araştırmanızı defterlerinize rapor olarak yazınız).
8. Araştırmadan hareketle gelecekte yapılabilecek olası araştırma konularının tartışılması

Öğretim elemanı öğrencileri süreç boyunca izleyerek sistemsel düşünme becerilerini tasarım ve uygulama sürecinde nasıl kullandıklarını takip eder. Gerekli durumlarda yönlendirmek için sorular sorar.

Activity 4: Carbon Based Production and Its' Effects (Student Handout)

Enerji üretim sürecinde fosil yakıtlar tercih üretildiğinde (örneğin; elektrik üretiminde termik santraller kullanıldığında, ısınma amaçlı veya taşımada fosil yakıtlar kullanıldığında…) karbondioksit gazı açığa çıkar.
Atmosferik CO2 (karbondioksit) gazının artması karbon döngüsünde ne gibi değişikliklere sebep olabilir?
Bu temel soru çerçevesinde merak ettiğiniz bir konu saptayıp aşağıdaki süreçleri takip ederek bu konuyla ilgili grup arkadaşlarınızla birlikte bir araştırma yapınız.

Aşağıdaki işlem basamaklarını takip ediniz.

1. Merak edilen araştırma konusunun saptanması
2. Nedensel bir araştırma sorusu oluşturulması
3. Öngörülen açıklama
4. Araştırma sorusuna nasıl cevap verileceğinin planlanması
5. Tahmin edilen sonuçların tartışılması
6. Gözlemlenen sonuçlar
7. Sonuçların rapor edilmesi (araştırmanızı defterlerinize rapor olarak yazınız).
8. Araştırmadan hareketle gelecekte yapılabilecek olası araştırma konularının tartışılması

Yukarıda belirtilen işlem basamaklarını uygularken basılı kaynaklardan (kitap/dergi ya da internet) faydalanınız. Önceki derslerde grupça oluşturduğunuz karbon döngüsü modellerini göz önüne alınız.

Activity 6: Analysis of Water (Teacher Guide)

Etkinlik 6: Suyun Analizi (Önerilen Süre: 4 ders saati)

Hedefler:

1. Bu etkinlikte öğrencilerin Menderes Nehri'nden alınan su, artezyen suyu, musluk suyu ve damacana suların fiziksel ve kimyasal özelliklerini karşılaştırarak, nehrin kirliliğine yönelik iddialara yanıt araması hedeflenmektedir.
2. İddialara deney yoluyla cevap arama süresince öğrencilerin sistemsel düşünme becerilerine yönelik anlayış kazanma ve bu anlayışı kullanmaları beklenmektedir.

Öğrenme Çıktıları
Öğrenci,

1. Ekosistemdeki bileşenler arasındaki ilişkileri tespit eder.
2. Ekosistemdeki bileşenler arasındaki ilişkilerin niteliğini ifade eder.
3. Ekosistemdeki döngüsel yapıyı fark eder.
4. Menderes Nehri'nin geçmişteki durumunu araştırır ve açıklar.
5. Menderes Nehri'nin gelecekteki durumuna yönelik tahminlerde bulunur.

İşleyiş:

Öğrenciler bu etkinlikte grup olarak çalışırlar. Farklı kaynaklardan gelen su numunelerinin fiziksel ve kimyasal özelliklerini su test kitleriyle belirleyip, karşılaştırma yaparlar. Bu karşılaştırma sonuçlarına göre suyun özelliklerini; içilebilirlik, canlılar için yaşam alanı sağlayabilme, sulamada kullanım gibi işlevleri yönünden değerlendirirler.

D. PHOTOS FROM MODULE IMPLEMENTATION

E. AN EXAMPLE OF ASSIGNED CONSENT FORM

Araştırmaya Gönüllü Katılım Formu

Bu çalışma Prof. Dr. Ceren ÖZTEKİN danışmanlığında ve Prof. Dr. Gaye TEKSÖZ eş-danışmanlığında yürütülen bir tez araştırmasıdır. Çalışmanın amacı Adnan Menderes Üniversitesi Fen Bilgisi Öğretmenliği Anabilim Dalı'nda öğrenim gören öğretmen adaylarının sistemsel düşünme becerilerini incelenmesi ve geliştirilmesidir.

Bu çalışma FBÖ309 Fen Öğretimi Laboratuvar Uygulamaları I ve FBÖ310 Fen Öğretimi Laboratuvar Uygulamaları II dersi kapsamında yürütülecektir. Çalışmaya katılımınız geleceğin öğretmenlerinin, enerji konusundaki sistemsel düşünme becerilerini geliştirme ve inceleme olanağı sağlayacaktır. Çalışma fiziksel ve ruhsal herhangi bir risk taşımamaktadır. Sizlerden beklenen çalışmanın başında ve sonunda verilecek olan soruları ve değerlendirme araçlarını içtenlikle yanıtlamanızdır. Bu araçları yanıtlamanız toplam 60-90 dakikanızı alacaktır. Çalışmanın ilerleyen safhalarında sizlerle değerlendirme araçları ile ilgili görüşmeler yapılacaktır. Görüşmeler toplam 90-120 dakikanızı alacaktır.

Bu araştırmada yer almak tamamen sizin isteğinize bağlıdır. Araştırmada yer almayı reddedebilirsiniz ya da herhangi bir aşamada araştırmadan ayrılabilirsiniz; bu durum herhangi bir cezaya ya da sizin yararlarınıza engel duruma yol açmayacaktır. Araştırmanın sonuçları bilimsel amaçla kullanılacaktır; size ait kimlik bilgileri gizli tutulacaktır ve araştırma yayınlansa dahi kimlik bilgileriniz verilmeyecektir.

Araştırma hakkında ek bilgiler almak için ya da çalışma ile ilgili herhangi bir sorun, istenmeyen etki ya da diğer rahatsızlıklarınız için Adnan Menderes Üniversitesi Matematik ve Fen Bilimleri Eğitimi Bölümü'nden Araştırma Görevlisi Hediye CAN' a (hediye.can@adu.edu.tr) başvurabilirsiniz.

Bu çalışmaya tamamen gönüllü olarak katılıyorum ve istediğim zaman yarıda kesip çıkabileceğimi biliyorum. Verdiğim bilgilerin bilimsel amaçlı yayımlarda kullanılmasını kabul ediyorum. (Formu doldurup imzaladıktan sonra uygulayıcıya geri veriniz).

İsim Soyad	Tarih	İmza	Alınan Ders
[redacted]	26/11/2017		Fen Öğretimi Lab Uygulamaları I

F. PERMISSION FROM FACULTY ADMINISTRATION

Evrak Tarih ve Sayısı: 24/11/2017-E.65943

T.C.
ADNAN MENDERES ÜNİVERSİTESİ REKTÖRLÜĞÜ
Eğitim Fakültesi Dekanlığı

Sayı : 57629817-605.01
Konu : Veri Toplama

Sayın Araş.Gör. Hediye CAN
Araştırma Görevlisi

Fen Bilimleri Öğretmen Adaylarının Sistematik Düşünme Becerilerinin Bütünleştirilmiş Enerji Eğitimi Programıyla Geliştirilmesi konulu doktora teziniz kapsamında 2017-2018 Eğitim-Öğretim Yılında Fakültemiz Fen Bilgisi Öğretmenliği Lisans Programı öğrencilerine ölçek uygulama/ders uygulama isteğiniz Dekanlığımızca uygun bulunmuştur.

Bilgilerinizi ve gereğini rica ederim.

e-imzalıdır
Yrd.Doç.Dr. Soner ALADAĞ
Dekan a.
Dekan Yardımcısı

G. HUMAN SUBJECTS ETHICS COMMITTEE PERMISSION

UYGULAMALI ETİK ARAŞTIRMA MERKEZİ
APPLIED ETHICS RESEARCH CENTER

ORTA DOĞU TEKNİK ÜNİVERSİTESİ
MIDDLE EAST TECHNICAL UNIVERSITY

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10 EKİM 2017

Konu: Değerlendirme Sonucu

Gönderen: ODTÜ İnsan Araştırmaları Etik Kurulu (İAEK)

İlgi: İnsan Araştırmaları Etik Kurulu Başvurusu

Sayın Prof.Dr. Ceren ÖZTEKİN ;

Danışmanlığını yaptığınız doktora öğrencisi Hediye CAN'ın **"Fen Bilimleri Öğretmen Adaylarının Sistematik Düşünme Becerilerinin Bütünleştirilmiş Enerji Eğitimi Programıyla Geliştirilmesi"** başlıklı araştırmanız İnsan Araştırmaları Etik Kurulu tarafından uygun görülerek gerekli onay **2017-EGT-165** protokol numarası ile **24.10.2017 – 30.09.2018** tarihleri arasında geçerli olmak üzere verilmiştir.

Bilgilerinize saygılarımla sunarım.

Prof. Dr. Ş. Halil TURAN
Başkan V

Prof. Dr. Ayhan SOL
Üye

Prof. Dr. Ayhan Gürbüz DEMİR
Üye

BULUNAMADI
Doç. Dr. Yaşar KONDAKÇI
Üye

Doç. Dr. Zana ÇITAK
Üye

Yrd. Doç. Dr. Pınar KAYGAN
Üye

Yrd. Doç. Dr. Emre SELÇUK
Üye

H. CURRICULUM VITAE

PERSONAL INFORMATION

Surname, Name: Can, Hediye
Nationality: Turkish (TC)
Date and Place of Birth: 9 June 1987, Akçaabat
Marital Status: Single
Phone: +90 5374295968
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EDUCATION

Degree	Institution	Year of Graduation
MS	Adnan Menderes University	2012
BS	Dokuz Eylul University	2009
High School	İzmir Anatolian High School	2005

WORK EXPERIENCE

Year	Place	Enrollment
2009- Present	Adnan Menderes University	Research Assistant

FOREIGN LANGUAGES

English

PUBLICATIONS

Articles

1. Can Hediye (2015). Sources of Teaching Efficacy Beliefs in Pre-service Science Teachers. İlköğretim Online (Kontrol No: 1678356)

2. Hiğde Emrah, Can Hediye (2015). Eğitim Fakültesi Öğrencilerinin Çevre Sorunlarına Yönelik Sorumluluk Algılarının İncelenmesi. Anadolu Doğa Bilimleri Dergisi (Kontrol No: 1678358)

3. Can Hediye, Akar Vural Ruken (2011). Fen Bilgisi Öğretmen Adaylarının Kromozom Kavramı Bilgi Düzeyleri ve Kavramın Öğretimine İlişkin Görüşleri. Hasan Ali Yücel Eğitim Fakültesi Dergisi (Kontrol No: 1678362)

Proceedings

1. Can Hediye, Öztekin Ceren, Teksöz Gaye (2018). Enerji Kavramına Yönelik Anlayışta Karmaşık Nedensel Modellerin Rolü. UFBMEK 2018 (Özet Bildiri)

2. Can Hediye, Özdemir Adem (2016). İlköğretim Bölümü 1. ve 4. sınıf Öğrencilerinin Doğa Haberlerini Takip Etme Durumlarının Araştırılması. VI. Uluslararası Eğitimde Araştırmalar Kongresi (Özet Bildiri)

3. Can Hediye, Öztekin Ceren (2016). A Closer Look at Pre-service Science Teachers Resource Consumption. 14th International Teacher Education for Sustainable Development, Culture and Education (Özet Bildiri/)

HOBBIES

Fitness, Social Latin Dances, Argentina Tango

I. TURKISH SUMMARY/TÜRKÇE ÖZET

1. GİRİŞ

Çağımızda bilim, teknoloji ve bilgi birikimi hızla gelişmektedir. Bu hızlı gelişim insan hayatını kolaylaştırmakla beraber küresel boyutta yaygın etkileri olan karmaşık sorunları da beraberinde getirmektedir. Günümüzdeki hızlı gelişim ve değişimin sonuçları dünya çapında pek çok ülkede bireylerden beklentileri ve eğitimin yönünü değiştirmektedir. Birçok ülkede bilgiyi üreten, kullanan, problem çözebilen, girişimci, eleştirel düşünebilen, iletişim becerileri yüksek, empati kurabilen, karar verme becerilerine sahip ve kültüre ve topluma katkı sağlayabilen bireyler yetiştirmek yüzyılın beklenen profili olarak öne çıkmaktadır (A Framework for K-12 Science Education, 2012; National Curriculum in England: Science Programs of Study, 2013, 2014; Milli Eğitim Bakanlığı, 2013, 2018). Ülkemizde de öğretim programlarında bireylere bu becerilerin kazandırılmasının önemi vurgulanmaktadır. Aynı zamanda güncel fen bilimleri dersi öğretim programında analitik düşünmenin önemi de bu becerilerle birlikte yer almaktadır (MEB, 2018). Analitik düşünme olayları, olguları ya da bir bütünü bileşenlerine ayırarak ve bu bileşenlerin işlevlerini anlayarak olayın ya da olgunun anlaşılmasını hedefleyen bir beceridir (Mella, 2012). Ancak günümüzde bunu çevreleyen olayları anlamak için analitik düşünme yeterli olmamaktadır. Küresel iklim krizi, enerji üretimi, tüketimi ve yönetimi, enerjiyle ilgili davranışlar, çevre sorunları ve ekonomi gibi konuların tamamı bağlantılı ve karmaşık konulardır. Bu konuları anlamak, değerlendirmek ve bu konularla ilgili karar vermek analitik düşünme perspektifinin ötesine geçmektedir. Sistemsel düşünme bize karmaşık konularla baş etmede bir yol sunar (Daellenbach & McNickle, 2005; Meadows, 2009; Mella, 2012; Higgins, 2015).

Çevre sorunları, hastalıklar, ekonomi ve bireysel davranışlar gibi konular karmaşıktır ve konuları anlamaya ve karar almaya çalışırken her zaman bilgi eksikliği vardır. İndirgemeye dayalı yaklaşım bu konuları anlamaya çalışırken yetersiz kalır ve bu durumda bütüncül perspektife ihtiyaç duyarız (Meadows, 2009; Higgins, 2015).

Sistemsel düşünme olayları bağlamında anlamayı gerektirir (Yurtseven & Buchanan, 2016) ve doğrusal düşünmenin ötesindedir. Sistemsel düşünmeyi anlamak için sistemlere değinmek faydalı olabilir. Sistem düzenli şekilde etkileşim gösteren birbiriyle bağlantılı bir elemanlar bütünüdür (Merriam Webster Dictionary, 2019). Bir sistem; elemanları, bağlantıları ve işlevi ile şekillenir (Meadows, 2009). Hücre, madde döngüleri, ekosistemler, Dünya, bir araba ya da ülke ekonomisi sistemlere örnektir. Bu sistemlerin bazıları mekanik, sabit bir yapı gösterirken bazıları karmaşık ve değişken yapıya sahiptir. Sistemsel düşünme ise bir yapının nasıl işlediğini, yapının bileşenleri işlev kaybına ya da değişime uğradığında neler olduğunu ya da sisteme bir müdahale olduğunda sistem davranışının nasıl etkilendiğini anlama becerisi olarak tanımlanmaktadır (NRC, 2010). Literatürde sistemsel düşünme araştırmacılar tarafından bir seri düşünme becerisi (Richmond, 2000; Sweeney & Sterman, 2000), hiyerarşik üst düzey düşünme becerileri seti (Stave & Hopper, 2007; Assaraf & Orion, 2010) ya da ilişkili düşünme becerileri seti olarak tanımlanmıştır (Behl & Ferreira, 2014; Arnold & Wade, 2017).

Günümüzde eğitimde beklentilerin değişmesiyle birlikte sistemsel düşünme becerileri son yıllarda önem kazanmaya başlamıştır. Amerika'da öğretim programında sistemler ve sistemlere ilişkin birçok beceri ana kavramlar olarak yer bulmaktadır (NRC, 2010). Bu kavramlar, örüntüler, neden-sonuç ilişkileri, mekanizmalar ve açıklamalar, ölçek, oran ve nicelik, sistemler ve sistem modelleri, enerji ve madde kavramları olup sistemsel düşünmeyle ilişkili kavramlardır. Aynı zamanda bilim ve mühendislik uygulamaları sistemlerle doğrudan ilişkilidir. Öğrencilerle birlikte öğretmenlerin sistemsel düşünme becerileri de oldukça önemlidir. Öğretmenlerin sistemsel düşünme becerileri sürdürülebilir kalkınma bilinci kazandırma bağlamında araştırılmakla birlikte farklı bağlamlarda araştırmaların sınırlı olduğu görülmektedir. Sistemsel düşünme becerileri özellikle fen eğitiminde önemli olabilir. Ülkemizde fen öğretim programında sistemsel düşünme becerileri açık olarak yer almamakla beraber kazanımların bazılarında örtük olarak ilişkili beceriler bulunmaktadır (MEB, 2013; MEB, 2018).

Enerji konusu sistemsel düşünme becerileri gerektiren, hem bilimde hem de günlük hayatımızda büyük öneme sahip bir konudur. Günümüzde enerji sorunları karmaşık ve çok yönlüdür. Günlük faaliyetlerimizi devam ettirebilmek için her alanda enerjiye bağımlıyız. Enerji ile ilgili konular çevre problemleri, ekonomi, toplum, siyaset ve teknolojiyle yakından ilişkidir. Bireylerin enerji ile ilgili davranışları sosyoloji ve çevre psikolojisinde karar verme kuramları, tutuma dayalı modeller, davranışsal ekonomi ve faydacı kararlar yönünden araştırılmıştır (Lopes, Antunes & Martins, 2012). Ancak bireylerin davranışlarının şekillenmesinde eğitim ve bireysel deneyimlerinin yeri önemlidir. Bireylerin enerji konularındaki sistemsel düşünme biçimlerinin geliştirilmesi belki de eğitim ile mümkündür ve bu uzun bir süreç olabilir. Bu konudaki araştırmalar oldukça sınırlıdır. Fen eğitimi açısından bakıldığında enerji konuları öğretim programında disiplin temelli yer almakta, temel eğitimde fen bilimleri dersinde, ortaöğretimde fizik, kimya ve biyoloji derslerinde bilimsel yönüyle ele alınmaktadır. Fen öğretim programlarında, enerji konularının günlük hayattaki önemi; enerji kaynakları, kullanımı, çevresel, ekonomik, teknolojik ve sosyal boyutlarıyla bütüncül şekilde yer almamaktadır. Enerji konularının öğretimine yönelik tarihsel yaklaşım, çoklu bağlamlar, fen-teknoloji-toplum-çevre yaklaşımı, gelişimsel kavramsal yaklaşım ve bütüncül yaklaşım olmak üzere farklı yaklaşımlar önerilmektedir. Enerji konusunda fiziksel bağlam ve genel sosyal bağlam birbirinden ayrıldığında enerji anlayışının yeterli düzeye ulaşamayacağı vurgulanmaktadır (Besson & Ambrosis, 2014).

Enerji konularının karmaşık ve çok boyutlu olması gerçeğinden hareketle sistemsel düşünme becerilerinin enerji bağlamında önemli ve sınırlı çalışma olan bir alan olduğu görülmektedir. Bu tezin konusu enerjinin sistemsel düşünmenin enerji bağlamındaki önemi ve bu alandaki çalışma eksikliğinden yola çıkarak belirlenmiştir.

Bu araştırma, enerjinin; enerji kaynakları, çevre ve enerjinin toplumsal boyutlarıyla ele alındığı bir bağlamda sistemsel düşünme becerilerini geliştirmeyi hedefleyen bir dizi etkinlik tasarlanarak oluşturulan bir sistemsel düşünme becerileri modülü uygulanmasıyla, fen bilimleri öğretmen adaylarının sistemsel düşünme becerilerinin ve sistem anlayışlarının nasıl değiştiğini anlamayı hedeflemektedir. Bu amaçla aşağıda belirtilen araştırma sorularına cevap aranmıştır:

1. Fen bilimleri öğretmen adaylarının enerji bağlamında sistemsel düşünme becerilerinin geliştirilmesi amacıyla tasarlanan sistemsel düşünme becerileri modülü hangi etkinlikleri içermektedir?
2. Fen bilimleri öğretmen adaylarının enerji konularındaki sistemsel düşünme becerileri sistemsel düşünme becerileri modülüyle nasıl geliştirilebilir?
3. Fen bilimleri öğretmen adaylarının genel sistem anlayışları sistemsel düşünme becerileri modülünün uygulanmasıyla nasıl değişmiştir?

Bu araştırma sorularına cevap aranırken Arnold ve Wade (2017) tarafından geliştirilen sistemsel düşünme becerileri modeli araştırmanın bağlamına uyumlu hale getirilerek kullanılmıştır. Bu model sistemsel düşünme becerilerinin sezgi kazanma ve bu sezgiyi uygulama olarak iki temel alanda ayrıldığını ve sezgi kazanmaya eşlik eden becerilerin genel ve alandan daha bağımsız iken, sezgiyi uygulamaya eşlik eden becerilerin bağlamla daha ilişkili ve özel beceriler olduğunu iddia etmektedir. Sezgi kazanmaya eşlik eden becerilerin alanı düşünce yapısı ile tanımlanmakta, sezgiyi uygulama becerileri ise içerik, yapı ve davranış alanları olarak tanımlanmaktadır. Bu dört alan içeriğinde birbiriyle ilişkili beceriler bulundurmaktadır. Bu modelin ve enerji konularının ele alınmasıyla uygulamaya yönelik etkinlikler içeren bir modül oluşturulması, fen bilimleri öğretmenlerinin sistemsel düşünme becerilerinin nasıl geliştirilebileceğinin araştırılması ve sistemsel düşünme becerileri modelinin işlevselliğinin enerji bağlamında irdelenmesiyle bu tezin fen bilimleri eğitimi alanına, araştırmacılara ve eğitimcilere katkı sağlanması hedeflenmiştir.

2. YÖNTEM

Bu tez fen bilimleri öğretmen adaylarının sistemsel düşünme becerilerinin belirlenmesi ve gelişiminin nasıl olduğunun araştırılması amacıyla tasarlanmış nitel bir durum çalışmasıdır. Durum sınırlandırılmış bir bağlamda ortaya çıkan bir olay olarak tanımlanabilir. Nitel bir araştırmada durum bir rol, bir kişi, bir program, bir olay, bir grup insan, bir politika, bir çevre ya da belirli bir zaman aralığı olabilir (Miles, Huberman & Saldana, 2014; Merriam & Tisdell, 2015). Nitel araştırmacılar sosyal dünyanın karmaşık yapısında olayları doğrusal neden-sonuç ilişkilerine dayandırarak yorumlamanın mümkün olmadığını ifade ederler. Bu görüşten yola çıkılarak durumlar karmaşık sistemler olarak görülebilir. Bu karmaşık gerçekliği anlamak için onu çift yönlü nedensellik ve geri besleme mekanizmalarından, etkileşimlerden ve farklı sonuçlar üreten kırılma noktalarından oluşan bir bütün olarak görmek gerekir (Schwandt & Gates, 2018). Nitel durum çalışmaları bu sınırlı sistemin zengin açıklamalarından oluşan bir ürün ortaya koyar (Merriam & Tisdell, 2015).

Bu tezde araştırmacı tarafından enerji bağlamında sistemsel düşünme becerilerinin geliştirilmesine yönelik bir dizi etkinlik içeren bir modül oluşturulmuş ve modül fen bilimleri öğretmen adaylarında uygulanmıştır. Öğretmen adaylarının sistemsel düşünme becerileri modül uygulanmadan önce, uygulama süresince ve modül uygulaması bitince değerlendirilmiş ve sistemsel düşünme becerilerindeki değişim araştırılmıştır.

Araştırmaya Türkiye'de bir devlet üniversitesinde fen bilgisi öğretmenliği anabilim dalında üçüncü sınıfta öğrenim gören dokuz fen bilimleri öğretmen adayı katılmıştır. Öğretmen adaylarının yaşları 20-22 arasında, not ortalamaları ise 2.87-3.29/4 arasında değişmektedir. Araştırmaya üçüncü sınıf öğrencilerinin dahil edilmesinin nedeni teorik ve uygulamalı fizik, kimya ve biyoloji derslerini almış olmaları ve enerji ile ilgili konuları üniversite öğrenim sürecinde de görmüş olmalarıdır. Sınıfın dezavantajlı yönleri ise sınıf içi olumsuz iletişim ortamı ve gruplaşmalardır. Öğrenciler toplam elli beş kişilik sınıf içinden modül uygulaması öncesi kullanılan veri toplama araçlarına verdikleri cevaplardan sistemsel düşünme becerilerindeki varyasyonlara göre ayrılmış ve araştırmacı tarafından yirmi kişi belirlenmiştir. Bu yirmi kişiye araştırma açıklanmış ve araştırmaya katılma istekleri sorulmuştur.

İçlerinden on kişi katılmayı kabul etmiştir. Bu on kişiden biri araştırma başladıktan sonra çekilmiştir. Toplam dokuz kişi veri toplama sürecine dahil olmuştur.

Araştırmada veri toplama süreci sistemsel düşünme becerileri modülünün uygulanması başlamadan önce yazılı ve sözlü veri toplama araçlarıyla başlamış, modül uygulaması süresince ve modül uygulaması sonunda devam etmiştir. Yazılı veri toplama araçları, gerçek yaşam senaryosu, araştırmacı notları, sınıf içi öğrenci notları ve çizimlerden; sözlü veri toplama araçları, modül uygulama öncesi ve sonrası görüşmelerden, sınıf içi video ve ses kayıtlarından oluşmaktadır.

Araştırmada sistemsel düşünme becerilerinin anlaşılabilir hale gelmesi ve geliştirilmesini hedefleyen modül enerji öğretimi ve sistemsel düşünme becerilerine ilişkin alan yazın temel alınarak ve uzman görüşlerine başvurularak hazırlanmıştır. Modülde temel olarak enerji kaynakları, kullanımı ve bu süreçlerin çevre bağlantıları dikkate alınarak konu temeli oluşturulmuştur. Enerji üretimi-tüketimi, madde döngüleri, karbona dayalı enerji üretimi ve jeotermal enerji modülün konu kapsamına alınmıştır. Konu kapsamı seçiminin yanı sıra etkinlikler bir dizi öğretim tekniğiyle harmanlanmıştır. Bu teknikler düz anlatım, video izleme, soru-cevap, deney, veri analizi, çizim yapma, kaynak taraması, grup içi tartışma ve araştırmayı içermektedir. Öğretmen merkezli yaklaşımlar asgari düzeyde tutulmuş, genel olarak öğrenci merkezli yaklaşımlar kullanılmıştır.

Modülün uygulaması 2017-2018 yılı güz döneminde Fen Öğretimi Laboratuvar Uygulamaları I dersinde yapılmıştır. Elli beş kişilik sınıfın tamamı modül uygulama sürecine katılmıştır. Araştırmaya katılan dokuz öğrenciden modül uygulama esnasında detaylı veri toplanmıştır. Uygulama bir ayda yaklaşık 26 ders saati sürede tamamlanmıştır.

Araştırma sırasında toplanan verinin sistemsel düşünme becerileri ile ilgili bölümü, Arnold ve Wade (2017) tarafından önerilen sistemsel düşünme becerileri modeli dikkate alınarak içerik analizine tabii tutulmuştur. Gerçek yaşam senaryosu ve görüşmeler öğretmen adaylarının modül uygulaması öncesinde ve bitiminde sistemsel düşünme becerilerinin belirlenmesinde kullanılmıştır ve araştırmacı tarafından Arnold ve Wade (2017) modeline bağlı kalınarak uyarlanan rubrikle değerlendirme yapılmıştır. Uygulama süresinde açığa çıkarılmaya çalışılan beceriler yine temel çerçeveye ve beceri tanımlarına bağlı kalınarak betimsel olarak incelenmiş ve yorumlanmıştır. Öğretmen adaylarının genel sistem anlayışları, modül uygulaması öncesi ve sonrası yapılan görüşmelerle belirlenmiştir. Bu görüşmeler de içerik analizine tabii tutulmuştur ve kategorik düzeyde analiz edilmiştir. Alan yazın katkısıyla belirlenen kategoriler kapsamında sonuçlar yorumlanmıştır. Araştırmanın güvenirliğini ve geçerliğini sağlamak için araştırma sürecinde yeterli veri toplanması, araştırmacının araştırma sürecindeki rolü, farklı veri toplama araçlarının kullanılması yoluyla veri çeşitlemesi, başka bir araştırmacının yapılan analizleri ve yorumları gözden geçirmesi ve öğretmen adaylarının ifadelerine ve çizimlerine örnekler sunulması konularına özen gösterilmiştir. Ayrıca analizlerde kodlayıcılar arası tutarlık kategorik düzeyde hesaplanmıştır. Araştırma sürecince aynı düzeydeki tüm sınıfın modül uygulamasının potansiyel avantajından yararlanabilmesi için tüm sınıf uygulamaya katılmıştır. Öğrenciler gönüllü katılım formunu okumuş, imzalamış ve istediklerinde araştırmadan çekilme hakları olduğunu öğrenmişlerdir. Uygulama süresince yapılan etkinlikler ders değerlendirmesi amacıyla kullanılmamıştır. Araştırma için etik kurul izni ve modül uygulamasının yapılacağı üniversiteden fakülte izni alınmıştır.

3. BULGULAR

3.1. Modül İçeriği

Fen bilimleri öğretmen adaylarının sistemsel düşünme becerilerinin belirlenmesini ve nasıl geliştirileceğinin anlaşılmasını amaçlayan modül enerji öğretimi ve sistemsel düşünme becerileri ile ilgili alan yazınından ve enerjiye yönelik tasarlanmış programlardan fikir edinilerek oluşturulmuştur. Modül biri okul dışı öğrenme etkinliği olmak üzere toplam yedi etkinlikten oluşmaktadır. İlk etkinlik "Enerji nedir?" etkinliği olup, soru-cevap, grup tartışması, video gösterimi ve bireysel çalışmadan oluşmaktadır. Bu etkinlik fen bilimleri öğretmen adalarının enerji kavramı hakkındaki ön bilgilerini açığa çıkarmayı hedeflemektedir. 2. Etkinlik “Enerji Üretimi-Tüketimi adlı etkinlik olup, bilgisayar ortamında küçük grup çalışması şeklinde tasarlanmıştır. Bu etkinlik Dünya Veri Bankası’ndan indirilen 20 kadar ülkeye ilişkin toplam enerji üretimi, tüketimi, fosil yakıt temelli enerji üretimi-tüketimi, elektrik üretimi-tüketimi, ülkelerin yenilenebilir enerji kullanımı, nüfus, gayri safi milli hasıla gibi verileri içermektedir. Öğretmen adaylarının, bu verileri gözden geçirip analiz ederek, enerji üretimi ve tüketimi arasındaki ilişkileri ekonomi, çevre ve teknoloji açısından bütüncül olarak ele alması beklenmektedir. Bu amaçla hazırlanan sorulara grup arkadaşlarıyla tartışarak cevap bulmaları ve bu cevapları kaydetmeleri beklenmektedir. 3. Etkinlik “Biyojeokimyasal Döngüler” adlı etkinliktir. Bu etkinlik 4. etkinlikle yakından ilişkilidir. 3. Etkinlik öğretmen adaylarının enerji ile ilgili süreçleri çevre boyutunda ele almaları ve doğanın insan faaliyetlerine nasıl cevap verebileceğini fark etmeleri için zemin hazırlamaktadır. Aynı zamanda öğretmen adaylarının sistem anlayışlarını da geliştirmeyi amaçlamaktadır. Bu hedefle iki temel döngü olan karbon ve su döngüleri ele alınmıştır. Etkinlik düz anlatım, soru-cevap, video gösterimi ve çizim yapma çalışmalarını içermektedir. 4. Etkinlik “Karbona Dayalı enerji Üretimi ve Etkileri” adlı etkinliktir. Öğretmen adaylarından onlara verilen bir metin üzerinden araştırma-sorgulamaya dayalı bir etkinliği gerçekleştirmeleri beklenmektedir. Bu metin karbona dayalı enerji üretimi faaliyetleriyle birlikte atmosferde bulunan karbondioksit gazının artmasının ne gibi etkileri olabileceğine yönelik bir araştırma problemi çerçevesinde oluşturulmuştur. 5. Etkinlik okul dışı öğrenme etkinliği olup, jeotermal enerji santraline yapılan bir geziyi içermektedir. Santral gezisi bulunulan yöreye özgü yerel bir durumla ilişkili olup farklı bölgeler için uyarlanabilir. Bu gezide amaç öğretmen adaylarının insanların enerji ile ilgili faaliyetlerinin sosyal, ekonomik, çevresel, teknolojik ve sağlıkla ilgili boyutlarını fark etmelerini ve duruma yönelik kavrayışlarını ve sistemsel düşünme becerileri ile sistem anlayışlarını geliştirmeleridir. 6. Etkinlik benzer şekilde insanların hem enerji üretim faaliyetlerinin hem diğer üretim faaliyetlerinin çevresel boyutunu daha iyi anlamak ve sistemsel düşünme becerilerini geliştirmek için tasarlanmıştır. Nehirden, artezyen sularından, şehir şebekesinden ve damacana sularından alınan su örneklerinin test edilmesi, fiziksel ve kimyasal değerlerinin belirlenmesi ve karşılaştırılmasını içermektedir. Bu etkinlikle su kaynakları kullanılarak insanların çevrede oluşturduğu etkilerin neler olduğunun ve bu etkilerinin mekanizmalarının araştırılması ve anlaşılması amaçlanmaktadır. 7. Etkinlik son etkinlik olup öğretmen adaylarının sistem anlayışlarının geliştirilmesini hedefleyen "Enerji Üretim Sistemleri" etkinliğidir. Bu etkinlik öğretmen adaylarının küçük gruplarda çalışarak kendilerinin belirlediği bir enerji üretim sistemini araştırması ve tanıtıcı bir sunum hazırlamasını içermektedir. Bu enerji üretim süreci bir elektrik santrali olabileceği gibi, bir aracın çalışmasını sağlayan kaynağından başlayan enerji dönüşüm süreçleri de olabilir. Bu etkinlik sürenin ve imkanların uygunluğuna göre enerji üretim sisteminin bir modelinin oluşturulması şeklinde genişletilebilir. Bu araştırmada etkinlik, enerji üretim sistemi ile ilgili araştırma ve tanıtım sunumu ile sınırlı tutulmuştur.

3.2. Fen Bilimleri Öğretmen Adaylarının Sistemsel Düşünme Becerileri

Fen bilimleri öğretmen adaylarının sistemsel düşünme becerileri modül uygulaması öncesinde ve bitiminde gerçek yaşam senaryosu ve görüşmeler ile belirlenmiştir. Uyguma süresince sistemsel düşünme becerilerinin değişimi, ses ve video kayıtları ile öğretmen adaylarının ve araştırmacının notlarından oluşan verilerle değerlendirilmiştir.

Sistemsel düşünme becerileri Arnold ve Wade (2017) tarafından öne sürülen Sistemsel Düşünme Becerileri Alanları Modeli ile araştırılmıştır. Bu çalışmada elde edilen veriler kapsamında özgün modelde bulunan dört alandan tespit edilen beceriler değerlendirilmiştir. Araştırma sürecinde belirlenen beceriler; Düşünce Yapısı alanında; farklı bakış açılarının keşfedilmesi, olayların uygun biçimde ele alınması, İçerik Alanında; sınırların belirlenmesi, bileşenlerin belirlenmesi ve ayırt edilmesi, Yapı Alanında; ilişkilerin belirlenmesi ve açıklanması, geri besleme mekanizmalarının belirlenmesi ve açıklanması, Davranış Alanında; sistem davranışın açıklanması ve gelecekteki sistem davranışının tahmin edilmesi becerilerini içermektedir. Bu becerilerin düzeyleri düşük, orta ve üst düzey olgunluk olarak üç dereceli sınıflandırılmış ve özgün model çerçevesinde rubrik oluşturularak değerlendirilmiştir.

Farklı Bakış Açılarının Keşfedilmesi becerisinde düşük seviye; olayı tek boyutla ele alma, sürekli aynı boyuta vurgu yapma ile ifade edilirken, orta seviye farklı boyutların varlığı anlamak ve olaya birden çok yönden bakmaya çalışmak ile ifade edilmiştir. Yüksek seviyede olgunluk ise olayın birçok boyutunu etkin şekilde kişinin kendi görüşleri ile çelişse bile vurgulamak ve göz ardı etmemek olarak tanımlanmıştır. Bu tanımlamalara göre modül uygulamasında önce öğretmen adaylarından yedi tanesi farklı bakış açılarının keşfedebilme yönünden düşük düzeydeyken, bir aday orta seviyededir. Bir aday da yüksek seviyededir. Modülün uygulanmasından sonra becerisi düşük seviyede olan adaylardan beş tanesi orta seviyeye ulaşmış, orta seviyedeki bir aday ise yüksek seviyeye ulaşmıştır. Adayların farklı bakış açılarını keşfetme becerileri modül uygulamasından sonra gelişim göstermiştir.

Olayların Uygun Biçimde Ele Alınması becerisinde düşük seviye olaylara hemen tepki gösterme ile ifade edilirken, orta seviye olayın karmaşık doğasının anlaşılması için zamana ihtiyaç duymakla birlikte bazen direkt sonuçlara odaklanma olarak belirlenmiştir. Yüksek seviye is konuyu anlamak için gerekli zamanı verme ve konuyu anlamadan sonuçlara atlamamak olarak ifade edilmiştir. Bu tanımlamalara göre modül uygulamasında önce öğretmen adaylarından beş tanesi olayları uygun biçimde ele alabilme yönünden düşük düzeydeyken, üç aday orta seviyededir, yüksek seviyede bir aday bulunmaktadır. Uygulama sonrasında düşük seviyede beceri gösteren adaylardan dördü orta seviyeye ulaşmış, orta düzeydeki adaylardan iki tanesi ise yüksek seviyeye ulaşmıştır. Bir düşük, bir orta ve bir üst düzey beceriye sahip aday ise değişim göstermemiştir. Modül uygulamasından sonra genel olarak öğretmen adaylarının olayların uygun şekilde ele alınması becerisi gelişim göstermiştir.

Sınırların Belirlenmesi Becerisi düşük seviyede öğretmen adayının olayın sınırları içine giren bileşenleri belirleyememesi, orta seviyede olayla ilgili bileşenlerin birçoğunu saptayabilmesi ve yüksek seviyede sistem değişse bile olayların sınırlarını doğrulukla saptayabilmesi olarak tanımlanmıştır. Modül uygulamasından önce öğretmen adaylarından yedisi bu beceri yönünden düşük, iki tanesi de orta seviyededir. Yüksek seviyede aday bulunmamaktadır. Modül uygulaması sonrasında düşük düzeyde olan adaylardan üçü orta seviyeye yükselmiştir. Diğer öğretmen adaylarının becerisinde değişim olmamıştır.

Bileşenlerin Ayırt Edilmesi becerisi; düşük seviyede bileşenleri ayırt edememe, orta seviyede olayları, değişken olmayan bileşenlerden ayırt etmeye başlama ve yüksek düzeyde bileşenlerin çoğunu belirleme ve durağan bileşenleri ve olayları yüksek doğrulukla ayırt edebilme olarak tanımlanmıştır. Modül uygulaması öncesinde öğretmen adaylarından üç tanesi bu beceri yönünden düşük düzeydeyken, dört kişi orta ve iki kişi de yüksek düzeydedir. Uygulama sonrasında düşük seviyedeki adaylardan ikisi orta seviyeye ilerlemiş, diğer öğretmen adayları değişim göstermemiştir.

İlişkilerin Belirlenmesi ve Açıklanması becerisi düşük seviyede, ilişkileri doğru saptayamama, orta seviyede ilişkileri fark etme ancak yüzeysel açıklamalar geliştirme ve yüksek düzeyde ilişkilerin görünür olmayanları da dahil olmak üzere birçoğunu fark etme ve bu ilişkilerin nasıl olduğuna dair detaylı açıklamalar yapabilme olarak ifade edilmiştir. Modül uygulaması öncesinde öğretmen adaylarının dördü beceri yönünden düşük seviyede, dördü orta seviyede olup, bir adayın seviyesi belirlenememiştir. Uygulama sonunda beceri yönünden düşük seviyede olan iki aday orta seviyeye yükselmiştir. Diğer öğretmen adaylarında değişim görülmemiştir.

Geri Besleme Mekanizmalarının Belirlenmesi ve Açıklanması becerisi bütün olaydaki döngüsel ilişkilerin fark edilmesi ile tanımlanmaktadır. Modül uygulaması öncesinde ve sonrasında öğretmen adaylarının konuya ilişkin açıklamalarında döngüsel ilişkileri fark ettiklerine yönelik bulguya rastlanmamıştır. Olayları doğrusal neden sonuç ilişikleri şeklinde açıkladıkları görülmüştür. Öğretmen adayları bu beceri yönünden düşük seviyede kalmıştır.

Sistem Davranışının Açıklanması ve Gelecekteki Sistem Davranışının Tahmin Edilmesi becerisi, düşük seviyede sistem davranışı açıklanırken sadece tek bir zaman boyutunun dikkate alınması ve gelecek tahminlerinde kanıt sunulmaması olarak tanımlanır. Orta düzeyde beceri iki zaman boyutunun dikkate alınması ve tahmin yaparken kanıt kullanılması olarak tanımlanır. Yüksek düzeyde beceri ise sistem davranışının tanımlanırken geçmiş zaman, şimdiki zaman ve gelecek zamanın her biri göz önünde bulunarak, kanıtlara dayalı tahminlerde bulunmak olarak tanımlanır. Modül uygulaması öncesinde öğretmen adaylarının üçü bu beceri yönünden düşük seviyede, diğer altı aday ise orta seviyede bulunmuştur. Uygulama sonrasında adaylardan düşük seviyede olan adaylardan biri orta seviyeye yükselmiş, diğer adayların beceri düzeyinde değişiklik olmamıştır.

Özet olarak fen bilimleri öğretmen adaylarının modül uygulaması öncesi ve sonrası sistemsel düşünme becerileri gerçek yaşam senaryosu dikkate alınarak karşılaştırıldığında, öğretmen adaylarının sistemsel düşünmenin düşünce yapısı alanındaki becerilerde gelişme gösterdiği, içerik, yapı ve davranış alanlarında gelişimin sınırlı kaldığı görülmektedir.

Öğretmen adaylarının sistemsel düşünme becerilerini kullanma durumları modül uygulama sürecinde etkinlikler sırasında gözlemlenebilir hale gelmiştir. Etkinlik 2, Etkinlik 3, Etkinlik 4, Etkinlik 5 ve Etkinlik 7 öğretmen adaylarının sistemsel düşünme becerilerinin gözlemlenebildiği etkinlikler olmuştur.

Etkinlik 2: Enerji Üretimi-Tüketimi etkinliği sırasında öğretmen adaylarının sistemsel bir yapıyı oluşturan bileşenleri belirleyebildikleri görülmüştür. Ancak bu bileşenler arasındaki ilişkilerin açıklanması konusunda gerçek yaşam senaryosundakiyle benzer şekilde doğrusal neden-sonuç ilişkilerinden öteye geçmekte zorluklar yaşadıkları görülmüştür. Öğretmen adaylarının karşılaştıkları bu zorluğu kısıtlı veriden hareket ederek çıkarımlarda bulunma, genelin dışında kalan veriyi tahminlerde ve açıklamalarda kullanma, örüntünün tamamına ulaşacakları yolları görememe gibi etmenler oluşturmaktadır. Öğretmen adayları sistemdeki bileşenlerin karşılıklı etkileşimlerini de algılamakta güçlük çekmektedir.

Etkinlik 3: Biyojeokimyasal Döngüler öğretmen adaylarının karbon ve su döngülerini gözden geçirerek enerjiyle ilişkili faaliyetlerin çevre bağlantısını fark etmelerini sağlamakta katkıda bulunmuştur. Öğretmen adaylarının etkinlik süresince sorulan sorulara verdikleri cevaplar ve çizimleri öğretmen adaylarının doğal bir sistem söz konusu olduğunda döngüsel ilişkileri fark ettiklerini, bileşenleri belirleyebildiklerini ve sistem davranışını açıklayabildikleri göstermiştir. Etkinlik esnasında öğretmen adayları aynı zamanda insanların enerjiyle ilgili faaliyetlerinin çevrede gömülü olduğunu ve faaliyetlerin hangi mekanizmalarla etkileşime girdiğini belirleyebilmiştir.

Etkinlik 4: Karbona Dayalı Enerji Üretimi ve Etkileri tartışma ve deney kısımlarıyla şekillenmiştir. Öğretmen adayları tartışma kısmında görüşlerini genişletirken nasıl ve neden sorularının işlevsel olduğu görülmekle beraber öğretmen adaylarının küresel ısınma, ozon tabakasının delinmesi gibi çevresel sorunlarda yanlış ve sınırlı bilgiye sahip olduğu görülmüştür. Öğretmen adayları çoğunlukla neden sonuç ilişkileri üzerinden görüş açıklamıştır. Araştırma problemi için bir deney tasarlamışlar ancak deney sürecinde sıkıntılar yaşamışlardır. Deneyde oluşturdukları sistemi etkileyen bileşenleri göz önüne alırken sınırlı bölüme odaklanmışlar ve ortaya çıkan sonucu yanlış çözümlemiştir. Bu durum öğretmen adaylarının deney esnasında sistemi bütün olarak göremediklerini ve sınırlı bir alana odaklandıklarını göstermiştir.

Etkinlik 5: Jeotermal Santral Gezisi öğretmen adaylarının olayları farklı açılardan ele alma ve olaylara uygun şekilde ele alma yönünden ilerlemelerine katkıda bulunduğu düşünülmektedir. Öğretmen adayları, santral sistemiyle ilgili bilgilerini arttırmış, mühendislerin yaptığı açıklamalar ve santral civarındaki çevrenin ve etkinliklerin gözlemlemesiyle olayın çevresel boyutuna ek olarak sosyal ve ekonomik boyutunu da fark etmişlerdir.

Etkinlik 7: Enerji Üretim Sistemleri Etkinliği öğretmen adaylarının enerji üretimi ile ilgili bilgilerini ve sistem anlayışlarını arttırmıştır. Bu süreçte fen bilimleri öğretmen adayları seçtikleri enerji üretim sistemi konusuna odaklanmış, çizimler yapmış ve yaptıkları çalışmaya diğer gruplara sunmuştur. Bireysel araştırma ve grup çalışması süreçleri olumlu etki oluştururken, öğretmen adaylarının sistemi bütün olarak ele almak yerine yine parçalara odaklandığı durumlar oluşmuştur. Sıklıkla ortaya çıkan bu durumun öğretmen adaylarının geçmiş öğrenme yaşantılarında analitik düşünme becerilerinin desteklendiği ve geliştirildiği öğrenme ortamlarında bulunmalarıyla ilişkili olduğu düşünülmektedir.

3.3. Fen Bilimleri Öğretmen Adaylarının Sistem Anlayışındaki Değişimler

Öğretmen adaylarının sistem anlayışları modül uygulaması öncesi ve sonrasında görüşme sorularıyla değerlendirilmiştir. Uygulama öncesinde öğretmen adaylarının cevapları incelendiğinde sistem denildiğinde en çok vurgulanan kelimelerin uyum, düzen ve bütün olduğu görülmektedir. Öğretmen adayları sistemleri tanımlamaya ve tarif etmeye çalışmaktadır. Uygulamadan sonra öğretmen adayları en çok etkileşim, düzen ve bileşen sözcüklerini vurgulamaktadır. Aynı zamanda sistemlerin işleyişine, yapısına ve sistem içindeki parçaların ilişkilerine vurgu yapmaktadırlar.

Öğretmen adaylarını uygulama öncesinde sistemlerle ilgili değişen oranlarda bilgi sahibidirler. Uygulamadan sonra bilgilerinin derinlik kazandığı anlaşılmaktadır, sistemlerin yapısına ve işleyişine daha fazla vurgu yapmaları buna kanıt oluşturmaktadır. Öğretmen adaylarının cevaplarından oluşan kategoriler bileşen, yönetici, işleyiş, ilişkiler ve yapı kategorileridir. Uygulama öncesi ve sonrası karşılaştırıldığında işleyiş ve ilişkiler kategorilerinin uygulama sonrası yüksek oranlarda vurgulandığı görülmektedir. Modül uygulaması süresince sistemler açık olarak vurgulanmamıştır ancak uygulamada her etkinlikte sistemlerle ilgili konular yer almıştır. Uygulama sonrasındaki görüşmeler öğretmen adaylarının sistem anlayışının geliştiğine işaret etmektedir. Bu durum modüldeki etkinliklerle ilişkili olabilir.

4. TARTIŞMA

Öğretmen adaylarının sistemsel düşünme becerilerinin gelişimi, modülde bulunan etkinliklerin yapısı, öğretmen adaylarının uygulamaya yönelik motivasyonları, uygulama süresi, öğretmen adaylarının enerji ve sistem konularıyla ilgili ön bilgilerinden oluşan karmaşık bir sistem gibi düşünülebilir. Bu faktörler birbirleriyle karşılıklı etkileşim içindedir. Bu karşılıklı etkileşimler araştırmanın bulguları ışığında değerlendirilmiştir.

Araştırmada Arnold ve Wade (2017) tarafından önerilen sistemsel düşünme becerileri alanları yaklaşımı verilerin değerlendirilmesinde analizlere yön vermiştir. Bu yaklaşım sistemsel düşünmeyi bir beceriler paketi olarak ele alan yaklaşımlara (Richmond, 2000; Behl ve Ferreira, 2014) ve sistemsel düşünme becerilerini hiyerarşik olarak ele alan yaklaşımlara (Stave ve Hopper, 2007; Assaraf ve Orion, 2010) kıyasla daha bütüncül, karmaşık konulara uyarlanabilir ve daha yeni olduğu göz önünde bulundurulmuştur. Araştırmada elde edilen bulgular da bu düşüncelere kanıt oluşturur nitelikte olmuştur.

Öğretmen adaylarının sistemsel düşünme becerilerinden düşünce yapısı alanındaki farklı bakış açılarının keşfedilmesi ve olayların uygun şekilde ele alınması becerileri gelişim göstermiştir. Bu becerilerdeki gelişim sistemsel düşünme becerileri modülünde yer alan etkinliklerle açıklanabilir. Özellikle beşinci etkinlik, jeotermal santral gezisi bu konuda etkili olmuş olabilir. Sistemsel düşünme becerilerinin geliştirilmesi konusunda çalışan araştırmacılar okul dışı öğrenme ortamlarının ilkokul düzeyinden üniversite düzeyine geniş bir yaş aralığındaki öğrencilerin becerilerinin geliştirilmesine katkıda bulunduğunu ortaya koymuştur (Assaraf ve Orion, 2010; Long, 2015; Karaarslan, 2016). Bu araştırmada jeotermal santral gezisinde öğretmen adayları jeotermal santralde enerjinin nasıl dönüştürüldüğünü, ekonomik, teknolojik ve çevresel etkilerini uzman mühendislerle konuşmuş ve santralin her kısmını gezmişler aynı zamanda jeotermalin elektrik üretimi dışındaki kullanım alanlarını da tanımıştırlar. Bu bağlamda farklı bakış açılarının keşfedilmesi ve olayların uygun şekilde ele alınması becerileri açısından gelişim gösterdikleri düşünülmektedir.

Öğretmen adayları içerik, yapı ve davranış alanındaki beceriler yönünden karmaşık örüntülerle beraber sınırlı gelişim göstermişlerdir. Yapı alanında, geri besleme mekanizmalarının belirlenmesi ve açıklanması becerisi tüm öğretmen adayları için hem uygulama öncesinde hem uygulamadan sonra düşük düzeyde kalmıştır. Geri besleme mekanizmalarının belirlenmesi ve açıklanması sistemlerin dinamik yapısının anlaşılması açısından önemli bir beceri olup, bu becerinin kazanılmasındaki zorluklar çoğu araştırmacı tarafından vurgulanmıştır (Sweeney ve Steman, 2000; Sterman ve Sweeney, 2002; Assaraf ve Orion, 2005b, Evagorou, 2009). Örneğin, Lee (2005) su döngüsü konusunda öğretmenlerin bile çoklu ilişkilerin anlaşılması konusunda sıkıntı yaşadığını belirtmiştir. Benzer şekilde Dunbar (2008) kişilerin genelde olayları açıklarken karmaşık ve çok yönlü ilişkileri bulmak yerine basit ve tek tönlü açıklamaları tercih ettiğini ifade etmiştir.

Bu araştırmada öğretmen adaylarının kendilerini ifade etme ve iletişim konularında sıkıntı çektiği gözlemlenmiştir. Öncelikle, düşüncelerini ifade etme konusunda sembol kullanma ve çizimleri yapma konularında yaşadıkları güçlükler açıkça görülmüştür. Bu güçlüklere rağmen özellikle üçüncü etkinlik biojeokimyasal döngüler öğretmen adaylarına gelişim fırsatı tanımıştır. Öğretmen adaylarının sistemsel düşünme becerilerinin yapı alanındaki gelişimi uygulamadan önce ve sonra toplanan verilerde gözlemlenemezken, bu etkinlikte becerilerini nasıl kullandıkları görülmüştür. Çizimler öğrenmeye ilişkin alanyazında da güçlü bilişsel araçlar olarak yer etmiştir (Tversky, 1999; Brooks, 2003).

Bu tezde geliştirilen modüldeki etkinlikler tasarlanırken alana ilişkin etkinlikler olması, araştırma ve sorgulama sürecinin öğrenci tarafından benimsenmesi, düşünme becerilerinin uygulayıcı tarafından yönetilmesi ve güdüleyici bir öğrenme ortamının oluşturulması gibi tasarım ilkeleri dikkate alınmıştır (Barab ve Duffy, 2008). Bu bağlamda etkinlikler öğretmen adaylarının süreçte en etkin bileşen olarak yer alacağı şekilde tasarlanmıştır. Ancak uygulama sırasında öğretmen adaylarının etkinlikleri öğrenci merkezli bir sistemden öğretmen merkezli bir sisteme doğru yönlendirmeye çalıştığı ve düz anlatıma dayalı bir uygula beklentisi içinde olduğu görülmüştür. Bu duruma süreçte öğrencilerin tartışma, açık uçlu sorulama ve deney yapma becerilerindeki eksiklikler eklenince motivasyon yönünden düşüşler gözlemlenmiştir. Sorgulamaya dayalı öğrenme ortamlarında öğrencilerin motivasyonun sağlanmasındaki zorluklar diğer araştırmacılar tarafından da belirtilmiştir (Adler vd., 2018). Ayrıca öğrencilerin sorgulama becerileri sorgula sürecinde motivasyonlarının sürmesi yönündeki en önemli etkenlerden biri olarak belirlenmiştir (Edelson, Gordon ve Pea, 1999; Veermans ve Järvelä, 2004). Bu çalışmada da öğretmen adaylarının uygulama sürecindeki motivasyonlarının sürdürülmesi konusunda güçlükler olduğu görülmüştür.

Öğretmen adaylarının sistemsel düşünme becerilerinin gelişimiyle ilgili bir değer etmen ise uygulama bağlamındaki konulara ilişkin bilgi düzeylerinin düşük olmasıdır. Bu güçlük öğretmen adaylarına etkinlikler içinde konularla ilgili kaynak sunularak çizim yapmaları ve soru cevaplamaları sağlanarak, bazı temel konularla ilgili videolar izletilerek ve açıklamalar yapılarak giderilmeye çalışılmıştır. Ancak, bu eksikliklerin ve var olan yanlış bilgilerin öğrencilerin tartışma süreçlerini ve sistemsel düşünme becerilerinin gelişimini etkilediği görülmüştür. Assaraf ve Orion (2005) ve Lyons (2014)'da çalışmalarında öğrencilerin kavramsal anlama ve bilgi düzeylerinin sistemsel düşünme becerilerini etkilediği yönünde benzer bulgulara ulaşmıştır.

Özetle, öğretmen adaylarının sistemsel düşünme becerilerinin düşünce yapısı alanındaki gelişimin Arnold ve Wade (2017) tarafından da belirtildiği gibi daha kapsayıcı ve genel olduğu ve öğretmen adaylarının bu alanda önce gelişim göstermeye başlayabileceği görülmüştür. İçerik, yapı ve davranış alanındaki becerilerin gelişiminin ise içeriğin kendisi (olayların karmaşık yapısı) ve ele alınış biçimiyle yakından ilişkili olduğu, öğrenci merkezli öğrenme ortamında motivasyon, uygulama süresi ve öğrencinin konu alanı bilgisiyle yakından ilişkili olduğu görülmüştür.

5. ÖNERİLER

Bu tezde sistemsel düşünme becerilerinin geliştirilmesine yönelik bir modül oluşturulmuş ve öğretmen adaylarının sistemsel düşünme becerileri bu modül kullanılarak enerji bağlamında araştırılmıştır. Sonuçlar öğretmen adaylarının karmaşık ve çok yönlü konularda sistemsel düşünme becerilerinin geliştirilmesinin zaman aldığını ve konu alanına ilişkin bilgi ve becerilerle ilişkili olduğunu göstermiştir. Bu sonuçlar doğrultusunda araştırmacılara ve eğitimcilere şu önerilerde bulunulmaktadır:

Arnold ve Wade (2017) sistemsel düşünme becerileri modeli araştırma sonuçlarına göre öğretmen adaylarının enerji bağlamında sistemsel düşünme becerilerinin belirlenmesinde kullanılabilir görünmektedir. Bu modelin farklı bağlamlarda ve farklı seviyelerde test edilmesi önerilmektedir.

Sistemlerin karmaşık, doğal ye da mekanik olması öğrencilerin becerilerinin ortaya çıkarılmasında farklı sonuçlar üretiyor olduğu görülmüştür. Sistemsel düşünme becerileri karmaşık sistemler bağlamında daha çok araştırılmalıdır.

Öğretmen adaylarının sistemsel düşünme becerileri düşük seviyededir. Bunun sebebi önceki öğrenme yaşantılarında analitik yöntemlerle ilerlemiş olmaları olabilir. Öğrenme yaşantılarının sistemsel düşünme becerilerine önem veren bir şekilde düzenlenmesi için öğretim programlarında sistemsel düşünme becerileri yer almalıdır.

Öğretmen adaylarının sistemsel düşünme becerilerinin gelişiminde iletişim becerilerinin, dinleme becerilerinin, sembol kullanma becerilerinin, bireysel motivasyonlarının ve değerlerinin rol oynadığı görülmüştür. Bu konular için daha detaylı çalışmalara ihtiyaç duyulmaktadır.

Tezde geliştirilen enerji modülü fen bilimleri öğretmen adaylarında uygulanmıştır. Modül ders içeriklerinden bağımsız şekilde geliştirildiği için farklı seviyede öğrencilerde ve gruplarda uygulanabilir. Modülün farklı gruplarda uygulanması sırasında yöreye özgü bileşenleri uygulandığı bölgeye uyarlanabilir, öğrencilerin ihtiyaç duyacağı süre doğrultusunda uygulama süresi arttırılabilir. Modüldeki etkinliklere uygulamayı arttıracak şekilde eklemeler yapılabilir.

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