ANALYSIS OF PRE-SERVICE SCIENCE TEACHERS' SYSTEMS THINKING SKILLS IN THE CONTEXT OF CARBON CYCLE

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I certify that this thesis satisfies all the requirements as a thesis for the degree of Master of Science.

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This is to certify that we have read this thesis and that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.

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I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

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ABSTRACT

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The main purpose of this study is to analyze pre-service science teachers' systems thinking skills in the context of carbon cycle. The eight systems thinking skills that is previously defined by Ben-Zvi Assaraf and Orion (2005) were used to investigate the participants' systems thinking skills concerning the carbon cycle. Data was collected from four senior-year pre-service science teachers from elementary science education department of a state university. The data obtained through word association test, concept map, drawings alongside with the interview questions. It was expected from participants to view carbon cycle in a systematic way with its integrated parts identified as terrestrial system, hydrosphere and the atmosphere in this research. This study was designed as multiple case study that the data gathered from each participant with different backgrounds analyzed separately. Interviews were analyzed via a rubric specifically developed for examining systems thinking skills in the context of the carbon cycle.

This study aims to provide an insight view of systems thinking skills of pre-service science teachers' in the context of carbon cycle and inspire science teacher educators and science teachers an idea concerning the systems thinking education. Results demonstrated that participants systems thinking skills were appeared as non-hierarchical and generally low especially in identifying dynamic and cyclic relationships as well as identifying hidden dimensions in the carbon cycle system. In addition, participants mainly focused on the terrestrial part and ignored the hydrosphere and the atmosphere parts of the carbon cycle. In general, systems thinking should be emphasized more in the teacher education programs.

Keywords: Systems Thinking, Carbon Cycle, Pre- Service Science Teachers

ÖZ

FEN BİLİMLERİ ÖĞRETMEN ADAYLARININ KARBON DÖNGÜSÜ KONUSUNDAKİ SİSTEMSEL DÜŞÜNME BECERİLERİNİN ANALİZİ

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Bu çalışmanın amacı fen bilimleri öğretmen adaylarının karbon döngüsü konusundaki sistemsel düşünme becerilerini incelemektir. Bu çalışmada Ben-Zvi Assaraf ve Orion (2005) tarafından tanımlanan sekiz sistemsel düşünce becerisi karbon döngüsü konusu içerisinde kullanılmıştır. Veriler bir devlet üniversitesinin dört son sınıf fen bilimleri öğretmen adayı ile toplanmıştır. Bu çalışmadaki veriler kelime çağrışım testi, kavram haritası ve çizimlerin görüşme soruları ile birlikte kullanılarak toplanmıştır. Katılımcıların karbon döngüsünü oluşturan karasal sistemler, hidrosfer ve atmosfer boyutlarının bütünleişk yapısını sistematik bir şekilde görmesi beklenmektedir. Bu çalışma çoklu durum çalışması olarak hazırlanılmış olup katılımcıların verileri ayrı ayrı analiz edilmiştir. Görüşmeler ile toplanan veriler, karbon döngüsü konusundaki sistemsel düşünce becerilerini analiz için geliştirilen bir rubrik kullanılarak analiz edilmiştir.

Bu çalışma öğretmen adaylarının karbon döngüsü konusundaki sistemsel düşüncelerine bir bakış sağlaması ayrıca, eğitimcilere ve öğretmenlere sistemsel düşünce eğitimi açısından bir fikir vermesi amaçlanmıştır.

Sonuçlar, katılımcıların karbon döngüsü konusunda hiyerarşik olmayan ve genel olarak özellikle dinamik, döngüsel ve gizli boyutlar becerilerinde düşük sistemsel düşünce becerilerine sahip olduğunu göstermektedir. Ek olarak, katılımcıların, genellikle, karbon döngüsünde karasal sistemler üzerine yoğunlaşırken atmosfer ve hidrosfer sistemlerini göz ardı ettikleri görülmüştür. Sonuç olarak, bu çalışma karbon döngüsü konusunda son sınıf öğretmen adaylarının genel olarak düşük sistemsel becerilerine sahip olduğunu ve öğretmen eğitim programlarının sistemsel düşünceye daha fazla ağırlık vermesi gerektiğini göstermiştir.

Anahtar Kelimeler: Sistemsel Düşünme, Karbon Döngüsü, Fen Bilimleri Öğretmen Adayları

To my parents

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STS	Systems Thinking Skills
STH	Systems Thinking Hierarchical Model
NRC	National Research Council
NGSS	Next Generation Science Standards

CHAPTER 1

INTRODUCTION

1.1. Background Information

The world that we share with the other living creatures is made up of complex systems from ecosystems which consists interactions of various components at different levels to more-larger scale-systems such as Earth cycles that move the matter on the Earth while energy flows (i.e. water cycle, or carbon cycle) (Lee, 2015). Therefore, it was vital for understanding the complex systems to develop an understanding concerning our globe (Raia, 2005; Lee, 2015). On the other hand, it is not easy to handle the complex systems since they include multiple levels of interactions among their sub-levels. Such interactions mostly include causal relationships among the components of the systems which occurs at various scales such as time, that further increase the complexity in a system (Ben-Zvi Assaraf, 2003). Moreover, this complexity may encompass serious issues such as hunger, poverty, water scarcity, global warming or climate change that requires people to consider the interactions among the different problems from multiple perspectives to view the issues as a whole (Mohan, Chen, & Anderson, 2009).

Moxnes (2004) emphasized that current young generation is facing and will continue to face with the today's global issues (i.e. global warming, climate change) in a way that will have more impact on their daily life in the future. Therefore, it was needed an educational approach to raise their awareness and give them a chance to deal with the global problems considering the interactions among various variables on the Earth at different levels. It was suggested that developing a framework in students' minds which considers the interactions among the variables on the Earth, students will be able to overcome the global environmental problems that the world confronted today (Meadows, 2008). Therefore, systems thinking was introduced by Barry Richmond (1993) as a key skill to deal with the complex global issues of current world and make students more intellectual concerning the world around them. Accordingly, the studies emerged in the various fields of education to investigate the systems thinking levels of students from medicine (i.e. Faughman & Elson, 1998) to social sciences (i.e. Senge, 1990) including science education (i.e. Jacobson & Wilensky, 2006; Kali et al., 2003; Sabelli, 2006; Ben-Zvi Assaraf & Orion, 2005; Hmelo- Silver & Azevedo, 2006; Ben-Zvi Assaraf & Orion, 2005; Zangori et al., 2017).

After enormous efforts on the systems thinking in the field of education, Hmelo-Silver (2000) described the main properties that each complex system should hold. First, she stated that complex systems made up of hierarchical integrated sub-levels which revealed as outcomes or functions in the systems. Secondly, there should be causal relationships among the components in a complex system. These causal relations then, are used to describe the mechanism in a system. Lastly, she stated that the causal interactions are not independent from the time dimensions which includes thinking in past, present and future state of the system. Relying on those characteristics, for example, Ben-Zvi Assaraf and Orion (2005) designed a model, systems thinking hierarchical (STH) model which developed specifically for complex Earth systems such as water cycle (see Table 1.1.). This model includes three level defined as analysis, synthesis and implementation level in a hierarchical order. The focus of the model is to examination of a persons' understanding of dynamism and cyclic perception in an Earth cycle which does not only examine the relationships among the components of system, but investigates the causes of such relationships including feedback processes and indirect causes (Batzri et al., 2015).

Systems thinking were analyzed through mainly two frameworks in the context of education. The other framework was called as Structure-Function-Behavior (SBF) Model which has been created after examination of differences in systems thinking abilities among students and adults and has been suggested as a "pedagogical model" (Batzri, Ben-Zvi Assaraf, Cohen, & Orion, 2015).

Table 1.1.

Systems Thinking Hierarchical Model (Ben-Zvi Assaraf & Orion, 2005, p.523)

Definitions	System thinking skills	Level
The ability to identify the components of a system and processes within the system	STS-1	Analysis
The ability to identify simple relationships between or among the system's components	STS-2	Synthesis
The ability to identify dynamic relationships within the system.	STS-3	
The ability to organize the systems' components, processes, and their interactions, within a framework of relationships	STS-4	
The ability to recognize hidden dimensions of system—to understand natural phenomena through patterns and interrelationships not seen on the surface	STS-6	Implementation
The ability to make generalizations—to solve problems based on understanding systems' mechanisms.	STS-7	
The ability to think temporally: retrospection and prediction. Understanding that some of the presented interaction within the system took place in the past, while future events may be a result of present interactions.	STS-8	

This (SBF) model was widely used especially considering the system thinking studies in the science education (i.e. Hmelo-Silver, 2007; Libarkin, Anderson, Dahl, Boone, & Beilfuss, 2005; Sweeney, & Sterman, 2000). The model includes three characteristics including Structure, the physical elements of the system such as components, Behavior, the entities or phenomena that makes structures to perform their functions, and the Functions, the result of the system, output (Hmelo-Silver, 2000). The model mainly concentrated on the interrelationships among a systems' three characteristics in the SBF model.

Sweeney and Stermann (2007) suggested that middle school students and the teachers had lack of systems thinking abilities in the context of natural and social systems. They revealed that experts in specific disciplines showed weak understandings in the context of systems thinking (Sweeney & Stermann, 2000). Moreover, they proposed that current education systems directed students to consider complex systems which are consisting of unrelated parts. Consequently, students struggled to view interrelationships among the structures, functions and behaviors in a given complex system. Therefore, they called for a new approach in education with considering the systems thinking education.

On the other hand, Ben-Zvi Assaraf and Orion (2005) proposed a new model, Systems Thinking Hierarchical (STH) Model, which investigates the systems thinking understanding in the context of Earth science education. The model is similar to SBF model, considers the structures, behaviors and functions in a complex system, but specifies some properties and proposed a model for suitable for examining complex Earth systems such as Earth cycles (Batzri et al., 2015). The model mainly includes three levels including eight hierarchical characteristics. The first level was analysis level which encompasses the first skill in the STH model described as identify components and processes within a system. The second level was described as synthesis level, which includes the ability to identify relationships among the components of the system, dynamic relationships in the system, organizing framework of interactions among the components and processes within the system and understanding cyclic nature of the system. The third and last level defined as implementation level which covers making generalizations, identify hidden dimensions and think retrospectively and prediction in the system (Table 1.1).

The systems thinking approach in the Earth systems meaning that seeing the Earth’s components and processes from multiple perspectives as a whole, singular unit which contains the interactions of four main spheres encompasses the geosphere, the hydrosphere, the atmosphere and the biosphere (Post, 1990). The Earth systems in education was designed to make students to understand the Earth as a singular, complex system (Raia, 2005). Then, it was suggested that students will be able to deal with the complex global issues that they are and will be facing (Orion, 2002). Therefore, in order to develop understanding on the Earth systems and deal with the global issues concerning the today’s world such as climate change, system thinking was proposed as a tool which provides detailed comprehension about the complex Earth systems such as water or carbon cycle

Carbon is one of the most abundant elements on the universe. Almost every living and non-living organism is made up of carbon from larger scale to small scales such as from rocks that forms the planets and from to cells that enable life on the Earth. Moreover, Carbon is one of the best joining element which it binds nearly every element in the periodic table including nitrogen, oxygen, hydrogen (Kump, Kasting, & Crane, 2004). Therefore, carbon is present almost every space on the various Earth spheres from atmosphere to biosphere and from hydrosphere to geosphere.

The spaces that where large amount of carbon is present on the Earth called as carbon pools (or reservoirs) such as atmosphere, Earth’ crust and ocean. (Post, 1990). Carbon move and change among these pools continuously which called as fluxes that relate those pools. For example, plants use carbon in the carbon dioxide to produce organic material (i.e. glucose) through the process of photosynthesis, which in a macroscopic scale, defines a cycle. Such fluxes of carbon among the pools come together and forms lots of sub-cycles or (mini- cycles) which carbon move and change between reservoirs. At a global scale, carbon cycle is made up of these sub-cycles among the carbon pools. Those pools of carbon cycle were defined as the Earth’s crust (sedimentary rocks), oceans, atmosphere, terrestrial systems (plants, animals, soil, fossils, fossil fuels and bacteria). The fluxes or processes in the carbon cycle were identified as photosynthesis, respiration, soil respiration (including decomposition), litterfall, diffusion of carbon among the atmosphere and ocean, combustion (of fossil fuels), geological processes including various processes at in larger scale including sinking of dead-marine organisms, precipitation of calcium-carbonate, formation of limestone, plate tectonics) (Post, 1990; Kump et. al, 2004).

Thorough the processes that occur in different time scales such as fast (i.e. photosynthesis) and slow (i.e. formation of limestone), carbon is in a movement among the pools which is considered as a balanced state with input and output to the pool is relevantly equal. Thus, carbon cycle is in balance meaning that the amount of carbon in the pools do not significantly change (Mohan, & Chen, 2009). On the other hand, the excessive amounts of input or output to the pool distort the balance in the carbon cycle. Therefore, the challenges we faced today such as greenhouse effect or global warming occur (Zangori et al, 2017). Hence, carbon cycle is one of the utmost important bio-geo-chemical cycles on the Earth since especially considering the global issues that we faced today such as green-house effect, global warming and climate change which are caused by the imbalances among the processes in the carbon cycle. Mohan et al (2009) stated that it is impossible to solve the issues we confronted in nowadays without comprehending the carbon cycle in a systematic way, seeing as a whole.

One of the global problems that was advocated by the researchers is climate change which should be investigated in terms of interactions among the natural systems including people (IPCC, 2014). It was suggested that in order to reason concerning the climate change, it was required to consider the complex Earth systems such as carbon cycle in a systematic way (Mohan et al., 2009). This means investigating interactions among the components of the carbon cycle as well as relationship between carbon cycle and various other Earth cycles alongside with the global issues such as climate change. Accordingly, carbon cycle represented as a key Earth system to develop an understanding on the mechanisms behind the climate change (Mohan et al., 2009; Zangori et al., 2017). As it was stated in the Next Generation Science

Standards (NGSS) (2013), science education in the 21st aims for students to inquire concerning the complex global problems about the Earth.

Carbon cycle was described by the Zangori et al. (2017) as;

> Carbon cycle consists of carbon being generated, transformed and oxidized through several natural processes such as photosynthesis, cellular respiration, and digestion. Anthropogenic processes such as combustion also outputting carbon into the carbon cycle. When carbon outputs exceed carbon inputs, the system loses its balance. The excess carbon leads to climate change which in turn leads to effects such as global warming (Zangori et al., 2017, p. 1256).

To reach such an understanding, a person should consider the relationships among the various components and processes in the carbon cycle as well as the interrelationships between carbon cycle and climate change (McNeill & Vaughn, 2012). That means, it was vital to trace the carbon flux (transformation and transportations) of carbon through the carbon cycle (Shepardson, Niyogi, Roychoudhury, & Hirsch, 2012). In addition, carbon cycle processes that make carbon flow among the carbon pools, and the location of the process is important. It was noted that understanding their natural mechanism and locations of processes results to reason concerning the dynamism and cyclic relations in the carbon cycle give persons a chance to consider the causes of imbalances in the system (Mohan et al., 2009). Moreover, in a global scale, considering the imbalances as a cause for the climate change (IPCC, 2014; Melillo, Richmond, & Yohe, 2014).

To improve such systems understanding in the context of carbon cycle, it is needed to teach students with instructional strategies that are purposively developed to improve systems understandings (Hmelo-Silver & Azevedo, 2006). It was suggested that students can improve their systems thinking with the support of appropriate instructional methodologies or tools (Ben-Zvi Assaraf & Orion, 2005; Evagorou, Korfiatis, Nicolaou, & Constantinou, 2009; Mohan et al., 2009; Lee, 2015; Zangori et al., 2017). For this reason, teachers are a very vital factor to promote systems thinking. On the other hand, in the literature, there are few studies investigated pre-service science teachers' understandings of complex systems. (Kali, 2003; Lee, 2015).

Systems thinking was not studied using only the STH model in the context of science education. Structure-Function-Behavior (SBF) was proposed as an alternative framework to the researchers in the context of systems thinking area. In this alternative model, structures defined as components of the system, function means mechanisms that permit structures to perform, and behavior means the product of the function or output (Hmelo-Silver, 2000). SBF model appears various studies in the context of Earth systems education (i.e. Mohan et al., 2009; Zangori et al., 2017; Hmelo-Silver 2017; Cox, Elen, & Steegen, 2017).

On the other hand, Scherer, Holder and Herbert (2017) conducted a study which includes various frameworks that investigates people' understandings of complex systems including SBF and STH model. They compare the weaknesses and strengths of the frameworks and proposed several sets of skills that is called as "Earth systems skills" which was addressed by Ben-Zvi Assaraf and Orion (2005). Scherer et al. (2017) suggested that STH model is more fruitful to investigate the systems thinking understanding in the context of Earth systems such as carbon cycle in the context of this study.

1.2. Purpose of the Study

This study was to examine the systems thinking levels of pre-service science teachers in the context of carbon cycle. The research question was developed as followed:

(1) "What are the systems thinking levels of the pre-service science teachers in the context of carbon cycle as a complex system?"

It was noted that to deal with the today's challenging global issues, it is important for students to be more equipped to about the complex Earth systems through systems thinking (Orion, 2002). Therefore, teachers who are considerable understandings related with the systems thinking are required in the schools (Lee, 2015). Thus, it was vital to find out our pre-service teachers' system thinking levels in the context of carbon cycle as a complex system.

1.3 Significance of the Study

The world we live and share today, becoming more complex and interdependent as the societies developed. Accordingly, there is a need to educate students to be more engaged with the world (Booth Sweeney & Sterman, 2007). It is the teachers who make students more equipped with the complex world and its issues around them. At this point system thinking proposed as a key 21st century skill by NGSS (2013) to develop students as system thinkers who can solve the current issues we faced today and future problems we will be faced with. Therefore, it was vital to understand the future teachers' systems understandings of the Earth systems.

Various studies have shown that there is a strong connection between the undergraduate courses that students have taken during their academic years and the systems thinking abilities of the students (i.e. Raia, 2005). Therefore, this thesis was presented the current state of pre-service science teachers' understandings of disciplinary knowledges and their ability to think in systematic way considering the Earth system. This may give ideas about the adequacy of pre-service science teachers regular undergraduate curriculum in developing systems thinking for the pre-service science teachers in Turkey.

Another significance of this thesis is to present an adopted assessment technique in the context of Earth systems. This framework for the analysis of pre-service science teachers' systems understandings were adopted using the different studies in the literature encompassing systems thinking as well as carbon cycle.

CHAPTER 2

LITARATURE REVIEW

2.1. System Thinking in Education

We are living a world that is governed by complex systems. It is vital to understand the complex systems if we want to understand the world. Therefore, to understand the complex systems, we need an approach to evaluate events, phenomena, issues or systems from various perspectives. This approach is called as “systems thinking” (Lee, 2015).

Researchers from different disciplines believed that the one of the ways to solve the global issues that humanity faced today are complex problems (i.e. global warming, water scarcity, climate change, population growth). Therefore, the researchers agreed that to have solutions of the issues, systems thinking is prior to understand them. Therefore, systems thinking were studied in the context of various fields such as engineering (i.e. Monat & Gannon, 2018), Mathematics (i.e. Chowdhury, Norton, & Salado, 2018), social sciences (i.e. Senge, 1990) and medicine (Kappagoda, 2014).

Hmelo-Silver, Marathe and Liu (2007) stated that comprehending systems thinking is prior to realizing science. Various countries all around the world try to adapt the idea of systems thinking in the science courses such as in America (Jin, Shin, Hokayem, Qureshi, and Jenkins in 2019) in Israel (Assaraf and Orion 2005) which investigated the system thinking abilities of the students.

Systems thinking investigated on different systems concerning natural systems (i.e. Ben-Zvi Assaraf, &Orion, 2005; Sibley et al., 2007), social systems (i.e. Senge, 1990) and considering both natural and social systems (i.e. Mohan et al., 2009; Karakaya, 2016). Considering these systems, importance of studying on natural systems had been underlied by the Mohan et al. (2009). They argued that in order to understand the social systems and interactions of natural and social systems, first one should understand the natural systems in a systematic way. From that point, systems thinking research in the science education gain acceleration. There were studies emerged in the field of biology, chemistry and Earth systems in general.

In the context of biology education systems thinking were studied including the human body. A study concerning the human body as a complex system included analysis elementary students' understandings of human respiratory systems by using analogy as an instructional method (Han, & Kim, 2018). This study was conducted with thirty fifth and sixth grade elementary students in the South Korea. The researchers gave students forty hours of lesson to make students more eligible for modelling and arguing in advance. During the research, they divided students into two groups and give students tasks such as constructing a human respiratory system. The researchers mainly used the Structure-Mechanism and Function (SMF) model, developed from Structure-Behavior-Function model, which is generally advisable for the human body system. They wanted students to explain the integrated nature of human respiratory system as; organs that is responsible in the respiratory system (S), the role of diaphragm while air goes in and out (M), and the air movement in and out through the respiratory system (F). During this explanation, they wanted students to use analogies. After that, the researchers using analogy that was described as human-balloon analogy model which shows how lungs function in the human respiratory system. While analyzing students' understandings of hidden mechanism in the human respiratory system, they used video tapes taken during the classroom activities, their observation reports, and students' drawings. In their study, they found that using analogy while investigating the human respiratory system helps students to visualize the hidden mechanism of the human respiratory system. They found that students were able to create links structures (i.e. organs in the respiratory system) and the functions (i.e. air coming through the lungs) with using balloon-lung analogy which identified as hidden in the context of human respiration system. Moreover, they suggested that using modelling would help students to make visualize hidden components to the eye considering the complex biological systems. In addition, they stated that using analogy with modelling aids students' scientific explanations which promotes a room for higher-order thinking in the context of biological systems.

A study conducted by Snapir, Eberbach, Ben-Zvi Assaraf, Hmelo-Silver, and Tripto (2017) with using Components Mechanisms and Phenomena (CMP) for investigating the high school biology students' understandings of human body as a complex system. They stated that the systems understanding in the context of a complex system should encounter three main characteristics which are comprehending components of the system, realizing interrelationships among the components at micro-and macro levels (Mechanisms), and events that entails processes at macro scale and patterns in the system (Phenomena). They suggested that at first glance, students were struggled to identify the mechanisms and the phenomena in the human body as a complex system. In addition, students were unable to comprehend the complexity of the interactions among the systems at multiple scales. The students mainly concentrated the macro level interactions with omitting the micro level relationships (such as tracing oxygen through blood vessels). Therefore, students were found to be inadequate in terms of considering human body as a complex system.

Another study in the context of biology were conducted on the Teachers' and Educators' views on systems' thinking. This study was presented by Gillisen, Knippels, Verhoeff and Joolingen (2019) on the participants' perspectives on the systems' thinking and using systems thinking in the context of biology education. The researchers studied with the seven experts in the field of biology, eight biology teachers and nine biology teacher educators in Germany. The researchers mainly focused in the three systems views which are identified as General Systems Theory (GST) that concentrated on the hierarchy in the complex open-systems, Cybernetics which is concentrating on the self-regulating complex webs in the complex systems and Dynamical Systems Theories that is focused on the Complex, non-linear dynamic systems. The researchers collected their data through interviews and questionnaires. The results showed that biology experts indicated the equal importance of all-three systems models in the context of biology education. On the other hand, the authors underlied that teachers in the study, did not know all-three systems views in the context of biology. Therefore, teachers were found to be first educated concerning the systems thinking in general. The researchers found that teachers were unaware the importance of the systems thinking in general. Moreover, the teacher educators in the biology education mainly focused the importance of General Systems Theory and ignored the other two perspectives. The teacher educators mainly argued the necessity of systems thinking in the biology education and found it difficult for students to understand. Therefore, some of them stated that because of its difficult nature to understand, they would not choose to embedded systems thinking in their lesson. On the other hand, after the interviews, the others stated the importance of systems thinking in biology education, especially in complex biological systems such as human body and cell. However, the general view on systems thinking in the biology teacher educators was on the complexity of systems thinking in practice and their lack of time in teaching it during their classrooms. Therefore, researchers stated that even though teacher educators give importance to systems thinking in the field of biology education, they choose not to implement it in the classrooms because of the complexity of systems thinking. They stated that because of not choosing systems thinking as a teaching approach in the classroom, there is a big gap among the research in systems thinking and its practice of the field of science education.

Another study in the context of human body as a complex system were conducted by Hmelo-Silver et al. (2007) in the context of human respiratory system. They wanted to investigate the differences among experts' and novices' understandings of human respiratory system using Structure- Behavior- Function (SBF) model. They found that there were minor differences among the understandings of the human respiratory system as a complex system both novices and adults with using interviews and questionnaires. They suggested that the difference was emerged from identifying the casual relationships among the structures (i.e. components) of the system (behavior) among the experts and the novices understandings of human respiratory system. Therefore, the participants were unable to identify the functions of the human respiratory system in terms of complex system.

In the context of Earth systems thinking were examined various researches. A study conducted by Ben-Zvi Assaraf and Orion (2005) in the context of water cycle as a complex system. They investigated the systems perception of middle school students in Israel concerning the water cycle using the STH model alongside with the qualitative and quantitative research tools. They concluded that there are a hierarchy among the levels in the systems thinking skills (see Table 1.1.). They stated that the skills that students developed in each level formed a platform for the improvement of the next skill. They concluded that most of the students could not reached the highest level in the STH model which caused by students' knowledge concerning the water cycle which includes the location of components and processes as well as the explanations of the processes.

Moreover, in a more recent study, Ben-Zvi Assaraf and Orion (2009) examined the middle school students' understandings of complex systems in the context of water cycle in Israel. They used STH model alongside with the lab simulations and experiments which enables students to observe directly the interactions and relationships among the components of the water cycle. Although they suggested that computer simulations were limited to the given scenario, they stated that students were unable to identify the interactions among the different Earth systems which mainly resulted from the lack of organizations among the systems' components.

Another study conducted by the Lee (2015) considering pre-service and in-service science teachers systems thinking understandings in the context of water cycle in USA. She used visual representations as an assessment tool to investigate the systems understandings of both pre-service and in-service science teachers in water cycle alongside with the interview questions using STH model. She pointed out that without exception pre-service science teachers and in-service science teachers selected the similar representations and demonstrated similar reasons on why they have chosen the representation for an imaginary lesson. She stated that the selection criteria of both teacher groups were considered on the aesthetic issues rather than representing systems understandings such as dynamism, cyclicality or hidden dimensions. She also stated that the reason behind their choice was their lack of identifying components and processes in the water cycle, identifying multiple interactions among the components of the system as well as difficulty in identifying hidden dimensions within the water cycle.

In addition, another study conducted by Raia (2005) investigated the relationship between students' understandings of systems thinking in complex dynamic Earth systems and their knowledge considering the undergraduate courses that they have taken. She designed her study by using the interview questions which measures the geography students' ability to identify complexity, dynamism and the hidden dimensions considering the Earth systems. She concluded that students mainly tended to perceive Earth systems as static rather than dynamic. They also tended to focus on mono-causal-thinking rather than multiple causes while investigating an event (i.e. rock cycle) related with the Earth systems. Students also have shown difficulties in analyzing systems at multiple scales which is required to see the connections among the various Earth systems. After all, she pointed out that, the regular undergraduate curriculum is inadequate for students to learn the Earth systems' characteristics such as dynamism, complexity and hidden dimensions.

Moreover, a study conducted by Batzri, Ben-Zvi Assaraf, Cohen and Orion (2015) which includes undergraduate geology students' and non-geology major students' systems thinking understandings in the context of Earth systems (water, carbon and rock cycles) with using a questionnaire designed in the STH model framework. They compared the answers obtained from the two groups of students to found out the effect of disciplinary knowledge on the systems understandings in the Earth systems in terms of cyclic and dynamic thinking. They found that geology students demonstrated higher levels of dynamic and cyclic thinking in the context of all Earth systems compared to the non-major students which supported a significant link among the disciplinary knowledge and the expression of dynamic and cyclic understandings for the Earth systems.

Another study conducted by Cox, Elen and Steegen (2017) in the context of Earth systems considering the complex geographical problems (i.e. earthquakes). They studied with the high school students (16-18 years age) in Belgium with using the paper-pencil test that investigating interconnections among the various Earth systems. The findings demonstrated that students generally showed lack of systems thinking abilities in the context of complex geographical issues. They have difficulties in identifying the interconnections among the components of the Earth systems, as well as feedback relations in the complex global issues. Additionally, they shown significant gender differences in terms of students' understandings of complex global issues in a systematic way. Moreover, they suggested that systems thinking in the context of Earth systems greatly influenced by the personal experiences on a given phenomenon.

Another study that cover Earth systems topic was conducted by Sibley et al (2007). They investigated carbon, water and rock cycles by using the Systems Thinking Hierarchical Model. They examined the systems thinking abilities of geology education course for non-major students by using box-diagrams. They found that regardless of the cycle that is under investigation, participants demonstrated lack of transportation and transformation of matter (i.e. carbon) throughout the carbon and rock cycle. They noted that movement and change of carbon included chemical reactions (i.e. formation of carbonate shells) which could not be defined by the participants. In the case of the water cycle, since no-biochemical reaction processes (i.e. decomposition) were included in the cycle, students were able to identify the transportation and transformation of water. Moreover, it was also noted that most of the students were unable to recognize the hidden dimensions among the various cycles (rock-water-carbon cycles). They underlied the conclusion that lack of understanding the chemical processes in the carbon and rock cycle, results in lack of systems understandings in the context of those cycles.

Another study is conduct by Mohan et al (2009) which investigated the pupils' and teachers' systems understandings in the context of carbon cycle in a multi-year implementation. They described biogeochemical processes in the carbon cycle including photosynthesis, respiration, digestion, combustion, decomposition, food webs, carbon sequestration. In the study, they investigated the identification of those processes in the context of carbon cycle over interview questions. One of the results that they found was most of the students including teachers were unable to trace the matter through various components in the carbon cycle referring the transformation of carbon during the processes. Another result was a few participants (only included teachers) were able to connect the imbalances in processes of carbon cycle as a cause for the climate change. On the other hand, they also noted that with implementation students were able to identify the transformations of carbon in a degree.

In a more recent study, Zangori, Peel, Kinslow, Friedrichsen, and Sadler (2017) examined the relationship between carbon cycle and climate change through SBF model in the context of systems thinking. They found that students were unable to relate the how the changes in processes of the carbon cycle effects the climate change and vice versa. Throughout the interviews, they noted that students were tended to focus on linear mono-casual thinking rather than causal relationships among the carbon cycle components that transform and transfer the carbon to create the connection between carbon cycle and the climate change.

Moreover, the studies in the complex systems covers the field of education for sustainable development. One of the studies in that perspective conducted by Oztas (2018) that is analyzing pre-service science teachers' systems thinking skills with using real-life scenarios. The participants of the study included six senior year students from a state university in Turkey. She used real-life scenarios with interview questions related with the case. The context of the scenario includes one of the environmental issues including water in the Turkey which encompasses three tenets of the sustainability that are economy, environment and social. She analyzed her data with rubric that is developed by Karaarslan (2016) which emerged from the System Thinking Hierarchical Model developed by Ben-Zvi Assaraf and Orion (2005). Their model adopted for analyzing sustainability understandings in the context of systems thinking with reorganizing nine systems thinking skills for the research in sustainability in the field of education for sustainable development. She found that the participants in the study mainly focused on the environmental aspects in the given scenario with mostly ignoring the social aspects. In addition, she found that identifying relationships among those three tenets is a challenging event, therefore, most of the participants demonstrated poor skills in that systems thinking skill. As in the first skill in the model, since participants mainly focused on the environmental aspects in the scenario, they could not identify the relationships among the different aspects of the sustainability during their interviews. In this study, participants generally struggling the making generalizations. She stated that because of the participants lack of identifying different aspects of the sustainability, they could not extent the tenets to the new sustainable aspects in the given scenario. Additionally, most of the participants was observed as failed to develop “a sensing place” skill during the study by the author. She stated that most of the participants could only be able to describe the environmental view while describing the given real-life scenario.

In general**,** there are various studies conducted in the context of systems thinking. Accordingly, there are several issues were noted concerning the systems thinking characteristics. Firstly, it was noted that students showed difficulties in identifying the relationships in the system. It was suggested while investigating the complex systems, although students identify the components in the system, they are not able to identify relationships within the system. Ben-Zvi Assaraf and Orion (2005) stated that students could not be able to identify the interrelationships among the processes in the water cycle. Instead, they defined processes as unrelated parts without any interaction. Moreover, they stated that no interactions among the different Earth cycles were observed as well. In their study, they observed that students tended to perceive water cycle as separated parts which mainly concentrated on the atmosphere, ignoring the other parts such as geosphere. They claimed that because of the inability to identify the relationships among the water cycle’ components and processes, students showed poor systems understandings.

In addition, most of the students could not be able to identify interactions among the human and the environment. Similar results were also revealed in the various studies. For example, a study conducted by Cox, Elen, and Steegen (2017) suggested that students demonstrated difficulties in identify relationships among the components in the geographical systems. Moreover, in the context of systems thinking Hmelo-Silver (2017) analyzed middle schools students ecosystems’ understanding using SBF model. Similar with Cox et al. (2017), she stated that even though the students could be able to identify primary structures (i.e. components) in the Earth systems, they could not be able to identify the interrelationships among with the behaviors or functions of the Earth systems.

Studies showed that students concentrated on the linear, or single cause and effect relationships instead of describing multiple interactions caused by non-linear different causes (Hogan & Thomas, 2001; Lee, 2015). It was noted that students and adults (including pre-service and in-service teachers) focused on the simple, mono-casual relationships while examining various complex systems such as matter cycles which demonstrates lack of systems understandings in the context of systems thinking (Hogan & Fisherkeller, 2001; Booth Sweeney & Sterman, 2007; Grotzer & Bell-Basca, 2003).

Secondly, it was observed that students struggled to identify the components and processes and their interactions within an organized framework (Ben-Zvi Assaraf et. al., 2005). Batzri et al (2015) defined cyclic thinking as to reason about the indirect causes for a phenomenon which includes explaining the components and processes showing their relationship in a framework. On the other hand, Ben-Zvi Assaraf et al (2005, 2010) stated that students tended focus on non-cyclic relationships in the complex systems. Similarly, it was noted that students understood Earth cycles as unrelated parts with no relationship among sub-systems which indicates poor dynamic understanding (Kali et al, 2003; Lee, 2015). Additionally, researchers stated that pre-service teachers are not significantly different from elementary students in terms of explaining the components and processes in a framework of relationships alongside with the multiple causes (Lee, 2015).

Lastly, it was noted that students and teachers were not able to examine complex systems at multiple scales. It was observed that students tended to focus on the descriptive surface components or processes rather than hidden mechanisms which takes place under the surface (Tretter, Jones, Andre, Negishi, & Minogue, 2006). Identifying such hidden mechanism is vital for seeing Earth as a whole systems with interrelationships among the different Earth systems (Batzri et al. 2015). Therefore, lack of examining a complex system at multiple scales leads to poor understandings of systems thinking in the context of Earth systems (Lee, 2015).

STH model used in various Earth systems education studies such as water cycle (i.e. Ben-Zvi Assaraf, & Orion, 2005; Lee, 2015) and carbon, water and rock cycle (Sibley, Anderson, Heidemann, Merrill, Parker, & Szymanski, 2007). Ben-Zvi Assaraf and Orion (2005) suggested that the levels in the STH model represents of the characteristic of the complex systems which is hierarchy. They suggested that without being successful in the first level, one cannot go beyond into the following level. On the other hand, Sibley et al. (2007) suggested that in the context of carbon, water and rock cycle, the model lost hierarchy among its levels especially in the first two level in the STH model. Therefore, they suggested that second system thinking level which is described as identifying relationships in the system was redundant of the first level which is ability to identify components and processes in the system. They noted the reason behind it as relationships between the components of the cycles were identified through processes that explains the transportation and transformation of the matter. In addition, they suggested that third system thinking skills, which identifying dynamic relationships in the systems, covers the STS-1 and STS-2 since dynamism was identified via the flux of matter among the components of the cycle through the processes. Therefore, hierarchy lose its meaning in the STH model in the context of carbon, water and rock cycle. On the other hand, although the usability of hierarchy is questionable in the STH model, Ben-Zvi Assaraf and Orion's model were suggested as the most suitable model after covering the different levels in the context of systems thinking in the Earth systems (Scherer, Holder, & Helbert, 2017).

Studies suggested that with using of appropriate instructional strategies a significant improvement were observed in the development of systems thinking in the students (Ben-Zvi Assaraf & Orion, 2005; Batzri et al., 2015; Sibley et al., 2007). On the other hand, there are very few studies to investigate the pre-service science teachers' understandings of complex systems (Ateskan & Lane, 2017).

CHAPTER 3

METHODOLOGY

In this section, the information is presented related to the research design, participants of the study, pilot study, instrumentation, data collection, data analysis, validity, reliability and ethical and moral issues were presented. Additionally, limitations of the study were presented under methodology section.

3.1. Research Design

In this thesis, it was intended to investigate the senior year pre-service science teachers' understandings of system thinking levels in the context of carbon cycle. As it was reported by Sibley et al. (2007) as well as Batzri et al. (2015), participants study background is an important component in the systems thinking understanding. Although they passed though the same undergraduate curriculum, since understandings of the courses that they had taken throughout the undergraduate years might differ from one participant to another, they were analyzed as separate cases. Moreover, all participants had taken courses related with the sustainability which their significant life experiences were different from each other.

Multiple case study design was included in a part of the qualitative research in the context of this study. Meriam (2009) stated that cases in a multiple case study design the participants generally shares common properties, such as in this case, participating from one of the major universities in Turkey. Participants' systems thinking levels were analyzed as different cases accordingly with the data acquired from them.

In addition, Fraenkel et al. (2012) stated that multiple case studies give researchers an opportunity to present more persuasive results. Moreover, such studies enhance the validity and reliability of the conclusions. In addition, multiple case studies support the generalizability of the results (Meriam, 2009).

3.2. Participants

Four (4) female senior year preservice science teachers were purposively selected to participate in this study. Participants were students at the one of the major universities in Turkey. Participants in the study were purposively selected according to following properties they hold. Firstly, all the participants participate the study from the same academic in the same university which have passed through the similar undergraduate curriculum so far. Second, participants were suggested to participate the study by the advisor of this study. Volunteers (4) were selected to proceed during the data collection.

All the participants were in between 23-25 age range with passed through the similar undergraduate curriculum. Except for the courses that they have taken during undergraduate, no other personal information is presented.

The participants of the study had the basic understandings concerning the carbon cycle and related topics such as photosynthesis, respiration, and decomposition since such topics were been studied through middle and high school as well as during university.

In order to respect the participants' confidentiality, pseudo -names were created to represent the participants. In the following table (see Table 3.1), participants properties and the necessary courses that they passed to require disciplinary knowledge in the context of carbon cycle were presented.

3.3. Instrumentation

In the context of this study, semi-structured interviews were used alongside with the drawing and concept map.

3.3.1. Interviews

Meriam (2009) suggested that interviews are one of the most used instruments while collecting data in qualitative studies since it creates a chance to deeply investigate thoughts or ideas in a case. Since this study aims to analyze the understandings of systems thinking abilities of the participants in the context of carbon cycle in detail, interviews were used.

Semi-structured interviews were used in this study. Moreover, purposively prepared interview questions were asked so as to give no space to direct the participants during the interviews (Fraenkel et al., 2012). Moreover, in order to obtain more data concerning systems thinking skills, different interview questions were asked related with the same systems thinking skill. In this study, four (4) participants was interviewed accordingly with the questions that were proposed by Ben-Zvi Assaraf et al (2005) and Lee (2015). There are almost forty interview questions thirty (30) interview questions were intended to be asked in order to analyze the participants' understandings in the context of carbon cycle. On the other hand, if participant could not able to identify a component or process in the carbon cycle on her own, then, the interview questions related with this unidentified components or processes were not be asked to not to manipulate the participants (Ben-Zvi Assaraf et al, 2005; Mohan et al., 2009; Zangori et al., 2017). For example, if a participant could not be able to identify the water as a component then, interview questions related with water would not be asked. The interview questions and the related STS levels were presented in (See Table in p. 32).

Interview protocol also consisted of word association test, concept map, and drawing which are used in order to obtain more evidences to elaborate the results (Ben-Zvi Assaraf, 2003). Lastly, questions regarding demographic or background information were asked in order to present a general view of the participants including age and the courses that they passed through their undergraduate semesters (See Table 3.1). In the following part a brief portrayal was presented related with these three instruments:

Table 3.1

Properties of the Participants in the Study

Name	Age	Courses	Country	GPA (out of 4.00)
Canan	23	Organic chemistry, analytic chemistry, biology, physiology, physics, geology and environmental education. she took two additional elective courses related to sustainability	Ankara	3.86
Melisa	24	Organic chemistry, analytic chemistry, biology, physiology, physics, geology and environmental education. In addition, she took two elective courses related to sustainability	İzmir	2.35
Mehtap	25	Organic chemistry, analytic chemistry, biology, physiology, physics, geology and environmental education. In addition, she took one elective course related to sustainability.	Ankara	2.40
Berfin	24	Organic chemistry, analytic chemistry, biology, physiology, physics, geology and environmental education. In addition, she took one elective course related to sustainability.	Antalya	2.86

3.3.1. Word Association Test (WAT)

Ben-Zvi Assaraf (2003) stated that word association test opens "windows" to how one's perceives the set of concepts (p. 13). In this study, this test were used to investigate the connections among the concepts related with the carbon. The carbon was chosen to ask in the WAT in order to visualize in what degree participants familiar with the concept of carbon such as locations and processes or chemical properties to trace it in the carbon cycle. Moreover, if participants struggled to identify the concepts related with the carbon, the researcher would help them to ask questions like "try to consider the chemical characteristic of carbon" or "on the Earth where is carbon present?".

During the beginning of the interviews it was asked participants to write down 12 concepts related with the carbon. These concepts later categorized into three-sub-sphere of the carbon cycle including the terrestrial system, the hydrosphere and the atmosphere in the concept map.

3.3.2. Concept Map

Concept Maps are commonly used in system to investigate the system thinking skills of students, regardless of their ages (Bradstadter, Harms, & Grobschedl, 2012). In the context of this study, concept map was used to analyze the connection of concepts that is defined in the word association test. It was suggested that describing such relations among the concepts in the concept map give researcher to a chance to analyze participants' understandings of components and processes of carbon cycle in a framework of relationships (White, & Gunstone, 1992; Ben-Zvi Assaraf, 2003). In addition, it was proposed that non-hierarchical maps are more fruitful in demonstrating various patterns among concepts (Ben-Zvi Assaraf, 2003). Therefore, in the current study, it was not expected from participants to create hierarchical concept maps. Instead, participants were asked to connect the concepts to as many concepts as possible to create a organize framework which makes possible for carbon to trace in the carbon cycle. Participants were asked to write as many linkage words as possible for the relations in the concept maps. However, as suggested by

Bradstadter et al. (2012), sometimes students could not be able to write any linkage words. In such cases, only the links were analyzed.

After WAT, it was asked participants to draw a concept map which relates the concepts that they identify in the word association test in relation with carbon. In this study, the results of the interview limited with investigating the multiple interactions among the subsystems of the carbon cycle and cross-links among the concepts (Ben-Zvi Assaraf, 2003).

3.3.4. Drawings

After concept maps, it was asked participants to draw a carbon cycle, and then, interview questions were conducted on the components and processes on their drawing.

Participants drawings can give hints related with their knowledge concerning the Earth Systems (Ben-Zvi Assaraf, 2003; Ben-Zvi Assaraf, & Orion, 2008). On the hand, drawings sometimes cannot be identified as a valuable instrument during data collection since its limited with one's drawing skills (Novick, & Nussbaum, 1978). Therefore, interview questions asked alongside with the drawing.

In the current study, it was asked participants to draw a carbon cycle. The researchers give time to participants as much as possible to give them an opportunity to identify more components and processes in the carbon cycle. The drawings were analyzed according to three criteria:

a) The components and processes identified on the three sub-systems of the carbon cycle
b) Cyclic perception in the carbon cycle, meaning connections among the carbon pools in the drawing in terms of tracing carbon exchanges as inputs and outputs.
c) Identifying the four sub-cycles of the carbon cycle on drawing (Ben-Zvi Assaraf, 2003; Kump et al., 2004; Mohan et al., 2009; Zangori, et al., 2017)

3.4. Pilot Study

Pilot study in the context of this study were conducted with two participants in order to test the interview questions to investigate the systems thinking understandings of participants in the context of carbon cycle. Moreover, pilot study was also used in developing the rubric for system thinking skills in the carbon cycle.

Two volunteer female participants were used in the pilot study during 2017-2018 fall semester. The interviews were recorded in an audio recorder with the allowance of the participants. Each interview lasted for approximately one-and-a half hour. After transcribing the interviews, the interview questions were re-organized in order to examine the systems thinking levels more accurately. Advisor’s opinion had taken into consideration during the re-organization process of interview questions.

After pilot study, some of the interview questions were removed in order not to take any unclear and not intended answers. The answers of some interview questions were similar. Therefore, they were removed in the main study. There were forty-three interview questions in the pilot study, but after re-evaluating the interview questions, thirty-three interview questions were used in the main study to obtain more clear and accurate results.

3.5. Main Study

Main study was conducted on the participants that were descriptively described in the Participants section (see; Table 3.1). The instrumentation process and descriptions of the instruments that were used were presented in the Instrumentation section in 3.3. The data were obtained relying on those instruments in the main study.

3.6. Data Collection

Creswell (2008) stated that the researcher is one of the most important factors in collecting data in the qualitative research studies. Therefore, during this thesis, researcher was also data collector throughout the interviews.

Table 3.2

Interview Questions and the Measured Systems Thinking Levels

Interview questions	Measured STS Level
1. Can you define what is a system?	No STS is measured. It was expected from participants to show their basic understandings of the systems.
2. Is carbon cycle a system or not? Why?	
3. Which courses did you take until this your senior year?	
4. How old are you?	
5. Can you write down the 12-concepts when I say carbon?	STS-1
6. Where in carbon present on the Earth? Can you draw a carbon cycle based on this knowledge?	
7. What are the components of the carbon cycle?	
8. What are the processes in the carbon cycle?	
9. What is the main reservoir of carbon on the Earth?	
10. What is the relationship among the components in the carbon cycle?	STS-2
11. Which components affects each other. Can you explain?	
12. What happens to carbon in the atmosphere?	STS-3
13. What happens to carbon in the soil?	
14. What happens to carbon in the organism when it died?	
15. What happens to carbon in the decomposers?	
16. What happens to carbon in the plants?	
17. What happens to carbon in the water?	STS-3

Table 3.2 (cont'd)

Interview questions	Measured STS Level
18. What happens to carbon in the animals?	STS-3
19. Can you relate the concepts you identified in the WAT in a concept map?	STS-4
20. Is there any starting point in the carbon cycle?	STS-5, STS-7
21. Is there any ending point for the carbon cycle?	
22. What makes carbon move in the carbon cycle?	
23. How carbon reaches to the atmosphere?	
24. How carbon reaches to the soil?	
25. How carbon reaches to the plants?	
26. How carbon reaches to the animals?	
27. How carbon reaches to the water?	
28. How carbon reaches to the rocks?	
29. Have you ever heard of the climate change? If so, what is climate change?	STS-6
30. Is climate change related with carbon cycle? If so, how?	
31. Is there a relationship among the different Earth cycles with carbon cycle?	STS-7
32. What is the effect of humans on the carbon cycle?	STS-8

The data was collected in the spring semester of 2017-2018 academic year with senior year students at the science education department. The last semester of pre-service science teachers was selected in order to be ensure that all the participants had passed the mandatory undergraduate courses to be able to have adequate disciplinary knowledge considering the carbon cycle. Interviews were lasts for two-week span, and they were approximately one-and-half hours each.

Participants were informed concerning the context of the study and have right to feel free to leave the interview process whenever they want in advance. Moreover, before each interview participants consent on volunteer participation were taken. In addition, it was asked whether they were comfortable with audio-recording or not.

Interviews were conducted in silent places to make both interviewee and interviewer more concentrated on the topic. In addition, interviews were conducted in Turkish language to make participants more comfortable while answering the interview questions. It also gave researcher a chance to obtain more clear data.

The interviews started with word association test concerning the carbon. Later, this test followed by concept map which it was asked participants to connect the concepts in the word association test. After that, it was asked participants to draw a carbon cycle which traced the carbon among the components of the carbon cycle.

3.7 Data Analysis

In this study, data obtained from the interviews, word association test and concept map and drawing were analyzed accordingly with rubric that is developed to measure the systems thinking skills of the participants in the context of carbon cycle. The data obtained from the interviews were re-evaluated many times for each participant. The interviews were coded concerning the systems thinking skills in the carbon cycle. The rubric was presented in Table 3.7.1.

3.7.1. Carbon Cycle in the Context of System Thinking Hierarchical Model

In this thesis, participants' understandings of systems thinking abilities were analyzed accordingly with the System Thinking Hierarchical Level that was proposed Ben-Zvi Assaraf and Orion in 2005. The meaning of the levels in the carbon cycle were formed from various studies. The summarized table of meaning of STH model levels in the context of carbon cycle were presented in the Table 3.7.1.1.

In this first level of STH model, it is expected from participants to identify the components and processes within the Carbon Cycle. This level is analyzed accordingly with the data obtained from the interviews and drawing in terms of three categories that is described in the context of carbon cycle as the atmosphere, the hydrosphere and the terrestrial systems (biosphere and the geosphere) since the major exchanges of matter and energy takes place on those three sub-systems (Post, 1990).

In the context of carbon cycle, the first skill of system thinking is to ability to identify the components of the system such as plants, animals, carbon dioxide, methane, volcanoes, rocks, ocean etc. and processes such as photosynthesis, cellular respiration, digestion, rock weathering, formation of sedimentary rocks, volcanism, food webs, decomposition and combustion (Mohan et al, 2009; Zangori, 2017).

The components that the participants identified categorized as terrestrial system, hydrosphere and atmosphere. Terrestrial system includes the components such as plants, trees, animals, humans, soil, coal, volcanoes, rocks and so on. Hydrosphere components includes water, glaciers, rivers, lake, aquatic plants and so on. Atmosphere components may contain atmosphere, carbon dioxide, carbon mono-oxide, atmospheric temperature, air and so on. These categories (terrestrial, hydrosphere, atmosphere) were used since carbon cycles through terrestrial, hydrosphere and atmosphere (Post, 1990). The main intention to perform such categorization is to investigate focus point of the participants' perception of the carbon cycle as a system. In other words, it is intended to understand participant's perception of carbon cycle as a complex system through components whether she could define multiple components on the three categories including terrestrial, hydrosphere and atmosphere or not.

Table 3.3

Meaning of STH Model Levels in the Context of Carbon Cycle

STS Levels	Definition	References
1. The ability to identify the components of a system and processes within the system	Describes carbon cycle is to identify the components among three sub-systems; 1. Terrestrial systems such as plants, humans, fossil fuels, animals, rocks, volcanoes, factories etc.; 2. Hydrosphere system such as oceans, rivers, lakes, aquatic plants, glaciers etc.; 3. Atmosphere system such as air, carbon dioxide, methane, atmospheric temperature, CFCS and so on. In addition to the components, this level includes ability to identify processes within the carbon cycle among three sub-systems; 1. Terrestrial system: photosynthesis, respiration, decomposition, decay, litterfall, animal digestion, volcanism, combustion, sedimentation of carbonates, weathering (by water) plate tectonics, food web, carbon sequestration, 2. Hydrosphere system: photosynthesis, respiration, decomposition, dissolving (of CO_2), precipitation of carbonate, diffusion, sedimentations of carbonates. 3. Atmosphere system: dissolving (of CO_2), precipitation, weathering (by wind)	Ben-Zvi Assaraf (2003) Ben-Zvi Assaraf, & Orion (2005, 2010) Finley, Nam, & Oughton (2011) Kump, Kasting, & Crane, 2004 Mohan, Chen, & Anderson (2009) Post (1990) Zangori, Peel, Kinslow, Friedrichsen, & Sadler (2017)
2. The ability to identify simple relationships between or among the system's components.	In relation with the carbon cycle, the meaning of this level is to ability to identify relationships among the components on the three sub-systems of carbon cycle described as Terrestrial, atmosphere and hydrosphere systems such as understanding the connection between plants' presence and the CO2 in the atmosphere via the process of photosynthesis.	Ben-Zvi Assaraf (2003) Ben-Zvi Assaraf et al (2005; 2010) Finley et al (2011)

Table 3.3 (cont'd)

STS Levels	Definition	References
3. The ability to identify dynamic relationships within the system.	In relation with the carbon cycle, the meaning of this level is to consider carbon cycle as dynamic. The participants' understandings of transformation of matter (carbon) among the three sub-systems of the carbon cycle represents their understandings of dynamic nature of the carbon cycle. Carbon transferred and transformed among the different sub-systems through dynamic processes such as; CO2 dissolves into water OR carbonate forms sedimentary rocks at the bottom ocean Or, carbon (organic) is transformed through food chains etc.	Batzri et al (2015) Ben-Zvi Assaraf (2003) Ben-Zvi Assaraf et al (2005; 2010) Kump, Kasting, & Crane, 2004 Finley et al (2011) Zangori et al (2017)
4. The ability to organize the systems' components, processes, and their interactions, within a framework of relationships.	In the context of the carbon cycle, this level means organizing the components and processes of carbon cycle within a framework of relationships. The components that are related more than two components gives the cycle a system characteristic. (Ben-Zvi Assaraf, 2003). Therefore, connections among the components among all three sub-systems of carbon cycle were vital for carbon cycle to organize components and processes within a framework of relationships.	Ben-Zvi Assaraf (2003) Ben-Zvi Assaraf et al (2005; 2010) Bradstadter, Harms, & Grobschedl (2012) Finley et al (2011)

Table 3.3 (cont'd)

STS Levels	Definition	References
5. The ability to identify cycles of matter and energy within the system—the cyclic nature of systems.	In relation with the carbon cycle, this level means understanding that we live in a cyclic world which matter (carbon) cycles via exchange of energy (Ben-Zvi Assaraf, 2003). That means carbon cycles through in a series of small sub-cycles which represents carbon transformation among the main reservoirs of carbon located in subsystems of carbon cycle including terrestrial system, hydrosphere and atmosphere. Such sub-cycles include; a) Atmosphere-plants-animals-soil via photosynthesis, respiration (plant, animal, soil) and litterfall while solar energy turns into chemical; chemical to thermal. b) Dead organism-fossils-ocean (wetlands, lake)- fossil fuels- human activity (driving cars, or industry)- atmosphere-rain via burial, fossilization-combustion, precipitation while solar energy turns into chemical; chemical to thermal. (material carried through gravitational potential energy) c) Atmosphere-ocean via diffusion includes aquatic photosynthesis and respiration while solar energy turns into chemical, kinetic energy turns into potential; potential energy turns into kinetic. d) Atmosphere-ocean- rocks (sedimentary) via dissolution ,precipitation, plate tectonics-volcanism while gravitational potential energy (e.g. sediments and water) turns into kinetic; geothermal energy powers plate tectonics which transferred to atmosphere and the space.	Batzri et al (2015) Ben-Zvi Assaraf (2003) Ben-Zvi Assaraf et al (2005; 2010) Finley et al (2011) Sibley et al (2007)
6. The ability to recognize hidden dimensions of the system.	The meaning of this level is to understand carbon cycle through patterns and interrelationships not seen on the surface. In the context of carbon cycle, considering multiple scales (such as macroscopic; carbon cycle movement of carbon across terrestrial system, hydrosphere and atmosphere as well as microscopic scales such as molecule movements across the carbon cycle) are vital to see the interrelationships among the Various Earth cycles which are hidden to observable eye such as sedimentation	Ben-Zvi Assaraf (2003) Ben-Zvi Assaraf et al (2005; 2010) Finley et al (2011)

Table 3.3 (cont'd)

STS Levels	Definition	References
7. The ability to make generalizations	Generalization might be expressed within the carbon cycle system by the understanding that this system is dynamic and cyclic. In the context of carbon cycle, that understanding implemented on discussing the how environmental issues (i.e. global warming) occurred such as the current imbalances among the processes within the carbon cycle's sub-systems terrestrial, hydrosphere and atmosphere systems) referring to the feedback processes explaining that the imbalances among the sub-systems.	Batzri, Ben-Zvi Assaraf et al (2015) Ben-Zvi Assaraf (2003) Ben-Zvi Assaraf et al (2005; 2010)
8. The ability to think temporally: retrospection and prediction.	Understanding that some of the presented interaction within the system took place in the past, while future events may be a result of present interactions. In the context of carbon cycle, such understandings could be implemented in cases such as industrial revolution effect on the increasing concentration of CO_2 throughout the decades or predict consequences of population growth on the CO_2 concentration in the atmosphere for the upcoming ages.	Batzri et al (2015) Ben-Zvi Assaraf (2003) Ben-Zvi Assaraf, & Orion (2005, 2010) Zangori et al (2017)

The first level of system thinking model includes the ability to identify processes of in a system additional to its components. Carbon cycle as a system includes processes such as photosynthesis, cellular respiration, combustion, decomposition, food webs, rock weathering, sedimentation, soil respiration, volcanism, decay, run off, plant respiration, litter fall, diffusion (of CO_2), dissolution (of CO_2), formation of carbonate shells. The processes were analyzed on where they were identified on encompassing terrestrial system, hydrosphere or atmosphere, which are the sub-systems of carbon cycle. This level analyzed through the interview, word association test, and drawing.

The second level is described as the ability to identify simple relationships between or among the system's components. In this level, it is expected from participants to identify the relationships within the carbon cycle. The relationships analyzed on three categories such that include interactions of the components belonging to the terrestrial, hydrosphere and atmosphere systems of the carbon cycle. The investigation focused on the weather the participant identified relationships among three categories which are the sub-systems that forms carbon cycle. In addition, cause and effect relationships were analyzed over the identified relationships which give carbon cycle a system characteristic (Lee,2015). The second systems thinking skill which is described as the ability to identify dynamic relationships among the components in the carbon cycle analyzed by the interview questions.

In third level, it is expected from participants to identify the dynamic relationships within the carbon cycle. In this study, dynamism in the carbon cycle interpreted as having an awareness that material (carbon or carbon-based matter) is on flux among the carbon pools in the carbon cycle (Kump, Kasting, & Crane, 2004). The carbon pools on the Earth was investigated under three sub-systems of carbon cycle including the terrestrial system, the hydrosphere and the atmosphere. The flux among the carbon pools such as from plants to atmosphere or from plants to soil includes transformation and transportation of matter (carbon) (Ben-Zvi Assaraf, 2003; Mohan et al., 2009). Therefore, dynamic relationships in the carbon cycle were analyzed on the fluxes of carbon among the carbon pools with referring to the transformation and transportation of the matter (Kump et al., 2004; Zangori et al., 2017). The third systems thinking skill which is described as the ability to identify dynamic relationships among the components in the carbon cycle analyzed by the interview questions.

In the fourth level of STH model, it is expected from participants to identify organizing the components and processes of carbon cycle within a framework of relationships. As defined in the previous sections, carbon cycle includes three main sub-systems which are terrestrial system, hydrosphere and the atmosphere. It was vital for participants to organize the components belongs to the three sub-systems of carbon cycle. As Ben-Zvi Assaraf (2003) suggested it is important to note that connections among the components related with the more than two components since such relations gives the cycle a system characteristic. Therefore, this level was analyzed over the concept maps which investigated interaction of parts of the carbon cycle to understand the whole (Brandstädter, Harms, & Großschedl, 2012).

In the fifth level, it is expected from participants to identify the cyclic nature of the carbon cycle system. This means that we live in a cyclic world which matter (carbon) cycles via exchange of energy and matter (Ben-Zvi Assaraf, 2003). In the context of the study this level was interpreted as carbon cycles through in a series of small sub-cycles which represents carbon and energy transformation among the main reservoirs of carbon located in subsystems of carbon cycle including terrestrial system, hydrosphere and atmosphere (Batzri, et al., 2015; Finley et al., 2011; Kump et al., 2004). These small sub-cycles were identified as;

a) among atmosphere-plants-soil via photosynthesis, respiration (plant, soil, animal) and litterfall while solar energy turns into chemical; chemical to thermal.

b) Dead organism-soil-fossils-ocean (wetlands, lake)- fossil fuels- human activity (driving cars, or industry)- atmosphere-rain via burial, fossilization, combustion, precipitation while solar energy turns into chemical; chemical to thermal and material carried through gravitational potential energy.

c) Atmosphere-ocean via diffusion and includes aquatic photosynthesis and respiration while solar energy turns into chemical.

d) Atmosphere-ocean- rocks (sedimentary) via dissolution, precipitation, plate tectonics, volcanism while gravitational potential energy (e.g. sediments and water) turns into kinetic; geothermal energy powers plate tectonics which transferred to atmosphere and the space (Finley et al., 2011; Kump et al., 2004, Zangori, et al., 2017).

The fifth system thinking skill which is described as understanding the cyclic nature of the carbon cycle system were analyzed by the interview questions and the drawings.

In the sixth level, it is expected from participants to recognize the hidden dimensions of the carbon cycle system. This ability means that identifying relationships that are not seen on the surface (Ben-Zvi Assaraf, 2003; Ben-Zvi Assaraf et al., 2010). In the context of this study, while analyzing the hidden dimensions in the carbon cycle mainly focused on the recognizing interrelationships among the various Earth cycles such as water cycle or nitrogen cycle. Because the relationships of carbon cycle with the other Earth cycles are occurred in multiple scales from macroscopic to microscopic, they are invisible to the human eye (Batzri et al., 2015; Lee, 2015). Therefore, this level analyzed via through the interview questions that investigated the interrelationships among the various Earth cycles from multiple scales.

The seventh level in the STH model was described as ability to make generalizations. Generalization might be expressed within the carbon cycle system by the understanding that this system is dynamic and cyclic. In the context of carbon cycle, that understanding implemented on discussing the how environmental issues (i.e. global warming, climate change) occurred such as the current imbalances among the processes within the carbon cycle's sub-systems including terrestrial system, hydrosphere and atmosphere [*dynamism*] (Batzri et al., 2015; Ben-Zvi Assaraf et al., 2010; Mohan et al., 2009). Imbalances among the processes within the carbon cycle encompasses the feedback relationships among the components of carbon cycle [*cyclicality*] (Ben-Zvi Assaraf, 2003; Batzri et al., 2015; Mohan et al., 2009). Therefore, in this level, it was analyzed the participant's ability to identify current imbalances of the carbon cycle process with referring the feedback mechanisms among the components in three sub-systems of carbon cycle while discussing the global environmental issues. The seventh system thinking skill which is described as the ability to make generalizations was analyzed by the interview questions.

The last system thinking skill was described as ability to think retrospectively and make predictions. In the context of the carbon cycle, this level means that understanding that some of the presented interaction within the system took place in the past, while future events may be a result of present interactions (Ben-Zvi Assaraf, 2003). In the context of carbon cycle, such understandings could be implemented in cases such as industrial revolution effect on the increasing concentration of CO_2 throughout the decades or predict consequences of population growth on the CO_2 concentration in the atmosphere for the upcoming ages (Batzri et al., 2015; Zangori, et al., 2017). The eighth system thinking skill which is described as the ability to think temporally: retrospection and prediction was analyzed by the interview questions.

3.8.1 Rubric Development

A rubric was developed to measure the systems thinking levels of the participants in the context of carbon cycle. During the development process, the results of the pilot study were used alongside with the opinions and suggestions of the advisor of the study.

Four levels were determined for each systems' thinking skills. These levels are pre-aware, emerging, developing and mastery. Levels are descripted in the Table 3.4.

3.8. Validity, Reliability and Ethics

Content related evidence was one of the best ways to make researchers assured concerning the convenience of the instruments with ensuring the relatedness between the content and the format of the instrument (Fraenkel et al., 2012). In the context of this study, the interview questions were evaluated by the advisor of the study, a professor from science education department who had studies concerning the systems thinking in the science education. Moreover, researcher bias is one of the threats to the internal validity.

Table 3.4

Analysis of the Rubric

STS Level	Mastery	Developing	Emerging	Pre-aware
1.Identify the components of a system and processes within the system.	Multiple components and processes are identified on all three sub-systems of carbon cycle including terrestrial system, hydrosphere and the atmosphere.	Multiple components and processes are identified on at least two sub-systems (i.e. terrestrial system and hydrosphere)	Multiple Components and processes are identified but only in one sub-system (i.e. terrestrial system)	No components are identified. Identifying no processes.
2. Identify relationships between or among the system.	Relationships are identified among all three sub-systems. Includes cause and effect relationships among all three.	Relationships identified among at least two sub-systems. Includes cause and effect relationships. No casual relations.	Relationships identified among just two sub-systems.	No relationship is identified.

Table 3.4 (cont'd)

STS Level	Mastery	Developing	Emerging	Pre-aware
3. Identify dynamic relationships within the system.	Transportation and Transformation of carbon among all three sub-systems explicitly. The fluxes kept limited with the carbon pools (globe, 2017)	Transformation of carbon among at least two sub-systems with both referring transportation and transformation of carbon.	Transformation of carbon covers at least two sub-systems with only referring transportation of carbon	Non-dynamic, stable perspective of carbon cycle.
4. Organizing systems' components, processes, and their interactions, within a framework of relationships.	Includes interaction among the concepts to an organized framework that covers all three sub-systems of the carbon cycle.	Connecting concepts related more than two concepts which describes an organized framework on at least two sub-systems of the carbon cycle.	Connecting pairs of concepts but could not be able to connect an organized framework.	No indication of web of processes and relationships are identified in the carbon cycle.
5. Understanding the cyclic nature of the systems.	Understanding all sub-cycles of the carbon cycle with referring energy and matter exchanges within them.	Partially Understanding at least two sub-cycles of the carbon cycle, having an awareness and matter exchange	Partially understanding only one sub-cycle sub-cycles of the carbon cycle	No explanation about cyclic nature of the system.

Table 3.4 (cont'd)

STS Level	Mastery	Developing	Emerging	Pre-aware
6. Making generalization	While discussing environmental threats concerning carbon cycle, showing the understanding that the threats occurred such as the current imbalances among the processes within all the carbon cycle sub-systems (terrestrial, hydrosphere and atmosphere systems)	Showing the understanding the environmental threats occurred such as the current imbalances among the processes within at least two sub-systems of the carbon cycle with referring feedback mechanisms among components.	Showing the understanding environmental threats occurred such as the current imbalances among the processes in at least sub-systems without referring feedback mechanisms among components.	(Showing) no understanding concerning the Carbon cycle is dynamic and cyclic.
7.Understanding the hidden dimensions	Identifying inter-relationships among all Earth cycles at multiple scales (microscopic and macroscopic)	Recognizing inter-relationships among at least two Earth cycles referring at least one multiple scale (microscopic or macroscopic)	Aware of the inter-relationships among Earth cycles but could be able to explain.	No hidden dimension is identified.

Table 3.4 (cont'd)

STS Level	Mastery	Developing	Emerging	Pre-aware
8. Thinking temporarily; retrospection and prediction	Making relationship between past, present and future referring the cases such as industrial growth or glaciers meltdown.	Trying to make relationship between past, present and future; mostly consider two time spans (e.g., past and present).	Struggling to make relationship between past, present and future.	No relationship is identified connecting the past, present and future.

(Creswell, 2008). To deal with this threat, open-ended interview questions were used to compare the results of the various participants in the study. In this way, researcher bias could be eliminated (Patton,1990).

It was hard to provide reliability in the qualitative studies since people are not eager to behave in a consistent way (Merriam, 2009). On the other hand, to increase reliability of drawings, coding framework developed by Rennie and Jarvis (1995) were used. They analyzed the drawings and coded separately the same drawings. After discussing the results, they came of with a fruitful coding framework for the systems thinking in the context of Earth systems. For the other data collection instruments, transcriptions and coding processes were conducted various times to be sure that results of the participants were consistent to increase reliability.

In the context of ethical concerns, participants' consents that they admit volunteer participation to the study was taken. Moreover, while audio-recording, their permission was also taken. Additionally, instruments that were used in data collection were presented to the ethics committee in the university. After the approval, the current study was conducted (See approval form in Appendix C).

3.9. Limitations

There are several limitations that should be taken into consideration while analyzing the current study. First of all, in the current study, it was assumed that participants had adequate knowledge considering basic carbon cycle processes, and hence their disciplinary knowledge was not assessed. On the other hand, understanding systems thinking requires disciplinary knowledge on the investigated theme (You, Marshall, & Delgado, 2018). Therefore, if a participant had lack of disciplinary knowledge on the current issue, she demonstrated lack of systems understanding in the carbon cycle.

Secondly, there are other instruments that were used to examine in the context of systems thinking in Earth systems such as hidden dimension inventory, or cyclic thinking questionnaire (Ben-Zvi Assaraf, et al., 2005). On the other hand, such instruments were specifically developed to examine the water cycle which is a less complex Earth cycle compering with the carbon cycle. Therefore, they could not be used to provide extra evidences to the systems thinking levels of the participants in the context of the carbon cycle. Thirdly, all the participants of the study were female. On the other hand, it was not intentional. Since there are few male students in the science education department and they were not volunteers, male students could not be a part of this study. Lastly, the conclusions of the current study were not generalizable, since it is a qualitative study (Fraenkel et al., 2012).

CHAPTER 4

FINDINGS

In the context of the study, five participants were investigated as separate cases in terms of their systems thinking levels. For this purpose, interviews, concept maps and drawings were used. For each of the data collection tool, rubrics were presented (See Appendix B.). Based on the rubrics, the system thinking levels of the participants were analyzed. First of all, Canan's findings were reported followed by the other participants.

4.1. Case 1: Canan

4.1.1. Canan's Demographic Data

Canan is 23-year-old senior student from science education department in the one of the well-known universities in the Turkey. She grown up and currently live in capital city of Turkey.

Canan passed all the courses which are mandatory in the undergraduate curriculum including organic chemistry, analytic chemistry, biology, physiology, physics, geology and environmental education. In addition, she took two elective courses related to sustainability.

4.1.2. Canan's System Thinking Skills

Canan's system thinking levels were analyzed according to answers given to the three data collection tools which are interviews, drawings and concept map. Results were presented for each system thinking level separately.

4.1.2.1. STS-1 Identify system components and processes within the system In this level, it is expected from participant to identify the components and processes within the Carbon Cycle. This level is analyzed accordingly with the data obtained from the interviews and drawing in terms of three categories that is described in the context of carbon cycle as the atmosphere, the hydrosphere and the terrestrial system (biosphere and the geosphere). A summary table that include Canan's ability to identify both processes and components within the system was presented in the Table 4.1.2.1.1. The drawing that Canan draw were presented in Figure 4.1.

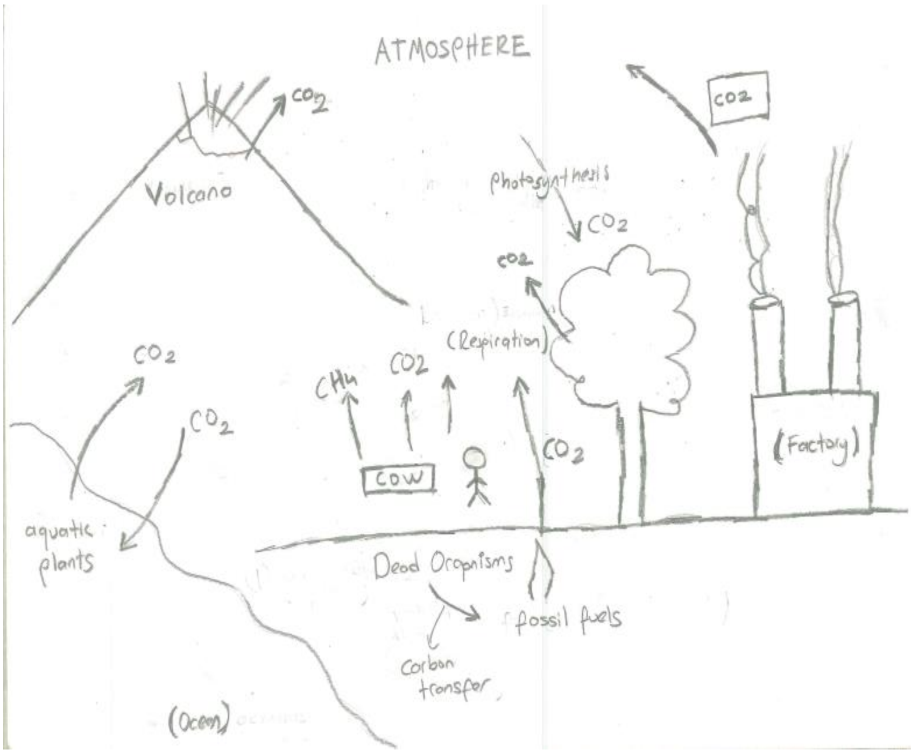

Figure 4.1. Canan's Drawing of Carbon Cycle

As it can be seen in the Table 4.2, Canan mainly focused on the Terrestrial part in the carbon cycle system (nine-teen components). Moreover, she identified six components in the Hydrosphere and seven components in the Atmosphere. Canan identified multiple components on the three category which shows that she considered all the sub-systems of the carbon cycle system. Therefore, she classified as mastery level for the components of the carbon cycle system.

Table 4.1

Canan's Ability to Identify Components and Processes within the Carbon Cycle

System thinking level	Categories			Level
STS-1- Ability to identify components and processes within the system.	Terrestrial System	Hydrosphere	Atmosphere	Developing level-identified components belonging to all three sub-systems of carbon cycle, however, identified processes only in two sub-systems.
Components of the carbon cycle	Plant, tree, humans, animals, cow, farm, food, agricultural products, nutrition (of humans), volcano, fossils, fossil fuels, soil, coal, sunlight, decomposers, organisms, dead organisms, carbon footprint, cars, factory	Aquatic plants, ocean, glaciers, contamination of water, chemical waste, pollution of water	methane, carbon dioxide, carbon mono-oxide, oxygen, greenhouse gases, temperature (atmospheric), air	Mastery—identify components includes all three sub-systems of carbon cycle.

Table 4.1 (cont'd)

System thinking level	Categories			Level
Processes of the carbon cycle	Photosynthesis, respiration, combustion, volcanism, decomposition, digestion	Photosynthesis, respiration	-	Developing—identified components only in two sub-system except for the atmosphere.

A brief summary of the components that Canan identified was categorized and listed in the Table 4.2. obtained by her responses to the interview and her drawing.

Table 4.2

Identified Components Within the Carbon Cycle by Canan

Categories	Components within carbon cycle		Number of components
Terrestrial System	Plant, tree, humans, animals, cow, food, farm, agricultural products, nutrition (of humans)	volcano, fossils, fossil fuels, soil, coal, decomposers, organisms, dead organisms, cars, factory	18
Hydrosphere System	Aquatic plants, ocean, glaciers		3
Atmosphere	methane, carbon dioxide, carbon mono-oxide, oxygen,	greenhouse gases, temperature (atmospheric), air	7

> Interviewer: “What are the components of the carbon cycle?”
>
> Canan: “There are living organisms such as plants, animals, decomposers humans in the carbon cycle. In addition, one can find fossil fuels such as coal. Moreover, fossil fuels formed by fossils which fossils formed by the dead organisms in the soil. In addition, volcanoes are present [in the carbon cycle]. Moreover, human activities such as cars, or factories are the components of the carbon cycle. I think these [human] activities include the agricultural products since we [humans] are eating them [agricultural products]. There are aquatic plants in the ocean as well. There are glaciers in the ocean too. In addition, there are gases such as carbon-monoxide and oxygen as well as greenhouse gases such as carbon-dioxide and methane which increase the atmospheric temperature in the air.”

The first level of system thinking model includes the ability to identify processes of in a carbon cycle system additional to its components. The processes, gathered through interviews and drawings, identified by Canan were listed in Table 4.3. Recall that findings were analyzed according to the data where the processes identified on encompassing terrestrial system, hydrosphere or atmosphere, which are the sub-systems of carbon cycle.

When it was asked about the processes in the carbon cycle, she identified the processes both on interview and drawing. The processes she identified were listed in Table 4. 3.

Table 4.3.

Identified Processes Within the Carbon Cycle by Canan

Category	Processes within the Carbon Cycle
Terrestrial System	Photosynthesis Respiration Combustion Volcanism Decomposition Digestion
Hydrosphere system	Photosynthesis Respiration
Atmosphere	-

> Interviewer: "Can you identify the processes within the carbon cycle?"
>
> Canan: "*Respiration* and *photosynthesis* are processes. [For example,] releasing methane [from cows] is a process [*digestion*]. When organism die, their organic material accumulates in the soil with the activities of the decomposers [*decomposition*]. Burning of [fossil] fuels is a process [*combustion*]. In oceans, there is *photosynthesis and respiration* that are performed by aquatic plants. *Volcanism* is a process as well."

Similar to the components, it was observed that she mainly identified processes related to terrestrial system (six processes). In addition, she defined two processes (photosynthesis and respiration) in the hydrosphere system. Even though she identified atmosphere components, processes included the atmosphere could not be defined. Since she identified processes on two sub-systems in the carbon cycle including terrestrial and hydrosphere system, she classified as developing level for the process within the carbon cycle.

All in all, it was obtained that Canan perceived carbon cycle mainly based on terrestrial system taking account for the components (18) and processes (6) she identified on it. She could be able to identify components on the three sub-systems of the carbon cycle includes terrestrial system, hydrosphere and the atmosphere. On the other hand, although she identified components on the all three sub-systems of carbon cycle, she could able to identify process only on two sub-systems, including terrestrial system (6) and the hydrosphere (2). She did not consider the processes in the atmosphere. Therefore, since Canan was not able to identify processes and the components within the all-three sub-systems of carbon cycle, she was classified as developing level for the ability to identify components and processes within the carbon cycle system.

4.1.2.2. STS-2 The ability to identify relationships among the components within the system

The second system thinking skill which is described as the ability to identify relationships among the components in the system analyzed by the interview questions. A brief summary of Canan's ability to identify relationships among the components of the carbon cycle were presented in the Table 4.4. The analysis demonstrated that Canan identified relationships among the terrestrial components and the atmosphere components on the carbon cycle.

Canan identified relationships three relationship among the terrestrial components and the atmosphere components of the carbon cycle. One relationship includes cause and effect relationship among the terrestrial system and the atmosphere over the excessive release of CO_2 as a cause for the carbon emission. On the other hand, the remaining relationships identified as a simple relationship without referring any causality.

The analysis continued with the interview questions investigating the relationship among the components that Canan defined in the STS-1.

> Interviewer: "What are the relationships among components in the carbon cycle? Can you tell me?"
>
> Canan: "When we talk about relationship, the interaction is among human, cow and plant. Moreover, there is an interaction between plant and atmosphere and between animals and atmosphere via respiration and photosynthesis. In photosynthesis, plant takes in CO_2 and gives out O_2. Then, O_2 and food are produced. Food contains carbon. Cow releases methane when they eat plants. Thus, there is a relationship between cow and plant."

Canan identified the relationship between terrestrial system components (plant, animals including humans) and atmosphere via photosynthesis and respiration. As a product of the process, food, was identified by the participant which were related with carbon. In addition, she related food with the "nutrition for cows" that is a small food chain identified. Digestion of food by cows related with the releasing of methane to the atmosphere. Therefore, she identified relationship among terrestrial components including plants, animals (including humans), food, nutrition, cow and atmosphere components consisting of sunlight, CO_2, O_2, methane via photosynthesis, respiration,

Table 4.4

Canan's Ability to Identify Components and Processes within the Carbon Cycle

STS level	Relationships	Level
STS-2 Ability to identify relationships among the components within the system		Developing Level--- Relationships linearly identified among two sub-systems including terrestrial system and the atmosphere referring a cause and effect relationship.
Among the terrestrial system components	-	
Among the hydrosphere components	-	
Among the atmosphere components	-	
Among Terrestrial System and the atmosphere components	- Plants-animals (human)-water-food-nutrition- cow-sunlight-CO_2 - O_2 -methane.	Linear relationship identified over the processes of photosynthesis and respiration as well as includes food chain, digestion. Did not include cause and effect relationships among the components.
	- Volcano-CO_2	Linear relationship identified over the processes of volcanism. Did not include cause and effect relationships.

	-		
	-	Humans-Cars-Factory-Agriculture-farms-food-CO_2.	Linear relationship identified over the process carbon emission as well as the processes of anthropogenic combustion (cars, factory), agricultural use (producing, harvesting and transporting food produced in farms) referring a cause and effect relationship which anthropogenic use (combustion and agriculture) causes carbon emission.
Among the Terrestrial System and hydrosphere components	-		
Among the hydrosphere and the atmosphere components	-		
Among Terrestrial System- the Hydrosphere and the atmosphere components	-		

digestion and food chain. She identified relationships among components in the terrestrial system and atmosphere including processes that forms the relationships. Canan continued to identify relationships with the questions in the interview which analyze the ability to identify relationships among the components of the carbon cycle that she described in the STS-1.

> Interviewer: "You identified volcano as a component of carbon cycle in your drawing. What is the relationship of volcano with the other components of the carbon cycle?"
>
> Canan: "I am not sure. Since there is a burning event, I mean... I am not sure exactly. I do not know the process of volcanism. However, I know, when it [volcano] exploded, CO_2 is released."

It was observed that even though she did not knowledgeable concerning the process of volcanic eruptions, she was aware of the relationship between terrestrial component (volcano) and the atmosphere component (CO_2) over the process of volcanism. Therefore, the relationship was identified included components belonging to two sub-systems; terrestrial system and the atmosphere over the volcanism.

> Interviewer: "Do you want to add anything about the relationships among the components of carbon cycle?"
>
> Canan: "Humans... human activities cause carbon emission."
>
> Interviewer: "What kind of activities are you talking about?"
>
> Canan: "Actually, everything. Factories release CO_2 to the atmosphere. For example, driving a car or transportation and nutrition, all of them cause carbon emission."
>
> Interviewer: "How nutrition causes carbon emission?"
>
> Canan: "Not nutrition itself, but all the processes that occurs during the food production such as how food is produced, harvested and delivered [to our houses]. For example, plants grow in the farms. Meanwhile, [while] they do photosynthesis and respiration. After that, food is harvested. Then, it is transported via driving vehicles. All of them cause carbon emission."

Canan mentioned an anthropogenic process causes carbon emission which were described as an effect for the human use of carbon by (driving) cars and use them for the transportation as well as combustion in the factories. In addition, she identified humans' agricultural use as a cause for the carbon emission. The agricultural use was described as producing, harvesting and transporting the food products by her which during the all the processes carbon dioxide is released to the atmosphere. Therefore, she identified relationship among the terrestrial system components; cars, factories, agriculture (includes food, cars) and the atmosphere component; CO_2 over the process of carbon emission referring cause and effect relationship among two sub-systems (terrestrial system- atmosphere) in the carbon cycle.

The overall analysis of second level of system thinking demonstrated that Canan could be able to identify relationships among the components located in the two-subsystems which are terrestrial system and the atmosphere. Relationship among the plants-animals (including humans)-water-food-nutrition- cow-sunlight and CO_2 -O_2 -methane, and volcano-CO_2 identified over the processes includes photosynthesis, respiration, digestion, food chain and volcanism without referring any causality among the components on terrestrial system and the atmosphere. On the other hand, she failed to identify interactions related with terrestrial system-atmosphere and the hydrosphere. Therefore, concerning the second system thinking level which was defined as the ability to identify relationship among the components within the system, Canan was classified as developing level (See Table 4.4).

4.1.2.3. STS-3 Identifying Dynamic Relationships in the System

In this level, it is expected from participants to identify the dynamic relationships within the carbon cycle. In this study, dynamism in the carbon cycle interpreted as having an awareness that material (carbon or carbon-based matter) is on flux among the carbon pools in the carbon cycle. The third system thinking skill which is described as the ability to identify dynamic relationships among the components in the carbon cycle analyzed by the interview questions. A series of interview questions asked to the participant to analyze her understanding of dynamism in the context of carbon cycle. According to the her answers, she was classified as pre-aware, emerging, developing or mastery.

In particular, the analysis demonstrated that Canan identified dynamic relationships on the among the terrestrial carbon pools (animals, plants, (dead) organisms, soil, fossils, fossil fuels) and the atmosphere mainly. On the other hand, she could not be able to identify any dynamic relationships related with the hydrosphere. A brief summary of Canan's ability to identify relationships among the components of the carbon cycle were presented in the Table 4.5.

The table demonstrated that Canan could be able to identify dynamic relationships in between terrestrial system carbon pools (plants, animals, (dead) organisms, soil) and atmosphere through the processes of photosynthesis and respiration. On the other hand, the dynamism she defined was limited with the transportation of the carbon only without considering the transformation of carbon among the pools. As she struggled to identify dynamic relationships considering hydrosphere, she was not able to define any. Moreover, carbon pools such as Earth curst, main reservoir of the carbon on the Earth (Kump et al., 2004), was not identified. Therefore, dynamic relationships considering major pool of the carbon in the Earth could not be observed in the interview.

The analysis continued with the interview questions investigating the relationship among the carbon pools that Canan defined in the STS-1.

> Interviewer: "What happens to carbon in the atmosphere?"
>
> Canan: "I do not have so much idea about it. Carbon in the atmosphere should be used by the plants for photosynthesis. I do not know what happens then. Something should happen to carbon, but I cannot explain what happens. CO_2 cannot stay in there [in the atmosphere] forever. It should be transferred to somewhere else like plants. On the other hand, I do not really have an idea about what happens to the carbon in the atmosphere."
>
> Interviewer: "What happens to carbon in the plants?"
>
> Canan: "Plants do photosynthesize. They take CO_2 from the atmosphere and water from the soil, to synthesize food…Hmm… However, I do not know what happens to carbon in the plants.
>
> Interviewer: "What happens to carbon in the soil?"
>
> Canan: "There are dead organisms in the soil. Organic materials accumulate in the soil when organisms die. After time pass, those organisms turn into fossils. I do not know what happens when organic material turns into fossils. Then, fossils become fossil fuels. However, I do not know which processes occur while fossils turn into fossil fuels."

Table 4.5.

Canan's Ability to Identify Dynamic Relationships Among the Components of the Carbon Cycle

STS Level	Relationships	Level
STS-3 Ability to identify dynamic relationships among the components within the system		- Emerging Level--- Relationships identified among two sub-systems including terrestrial system pools and the atmosphere focusing mainly on transportation of carbon without referring transformation of carbon explicitly.
Among the terrestrial system components	- (dead) organisms-Soil- fossils-fossil fuels	- Identified over process of fossilization, both transportation and transformation discussed, however, transformation could not be observed explicitly.
	- Dead organisms-Decomposers-Soil	- Identified over the process of decomposition. Only transportation of carbon could be identified intuitively.

Among the hydrosphere components	-	-
Among the atmosphere components	-	-
Among Terr. System and the atmosphere components	- CO_2 in the atmosphere-Plants	Identified over the process of photosynthesis, however, only referring the transportation of carbon from atmosphere to plants.
	- Animals-CO_2 in the atmosphere	Identified over the process of respiration, only referring the transportation of carbon from animals to atmosphere.
Among the Terr. System and hydrosphere components	-	
Among the hydrosphere and the atmosphere components	-	
Among Terr. System- the Hydrosphere and the atmosphere components	-	

Interviewer: "you mentioned decomposers when you identify the components of the carbon cycle? What is the role of decomposers in the carbon cycle?

Canan: "They [decomposers] take out carbon from dead organisms in the soil. I mean, dead organisms take role in returning carbon to the cycle. However, I do not know how this process [decomposition] occurs."

Interviewer: "What happens to carbon in animals?"

Canan: "Animals use food for synthesizing energy via respiration. Food contains carbon. At the end of the respiration, CO2 is released to the atmosphere. However, what happens to carbon…hmm… I cannot explain."

Interviewer: "you mentioned ocean as a component in the carbon cycle in your drawing. What happens carbon in the ocean?"

Canan: "I do not know; I cannot describe what happens."

Interviewer: "Do you want to add anything considering the dynamic relationships among the components that you identify?

Canan: "No, I think that's all."

To be brief, it was observed that Canan could be able to identify the dynamic relationship among the carbon pools. On the other hand, for most of the pools, the explanation of the relationships was limited with the transportation of carbon without explicit reference to the transformation of the carbon. For example, Canan could be able to identify dynamic relationships among the terrestrial system pools (soil, fossils, fossil fuels) and the atmosphere referring the transportation and transformation of carbon at some level without explicitly explaining the transformation of dead organisms to fossil fuels. The same phenomenon was observed when she tried to identify the dynamic relationship between the atmosphere and the plants. She identified the transportation of carbon (CO_2) from atmosphere to the plants with referring to the process of photosynthesis. However, she could not be able to identify the transformation of carbon (from CO_2 to glucose) in the photosynthesis. In addition, the analysis of dynamic relationships among the animals and atmosphere gave the similar results. Canan could be able to identify transportation of carbon to the atmosphere as in the form of CO_2 via respiration process. However, she failed to refer the transformation of carbon during the respiration from glucose to CO_2.

Moreover, it was observed that dynamic relationships considering decomposers (bacteria or fungi), she was aware that there should be transfer of carbon with the help of the decomposers in the carbon cycle. On the other hand, she was failed to identify the transformation of carbon (glucose to CO_2 or glucose to methane). In addition, for hydrosphere pools, it was observed that even though Canan identified as a component (ocean) in STS-1, she could not be able to identify any dynamic relationship including the ocean. Moreover, the terrestrial pools such as Earth crusts could not be identified by her. Hence, any relationship considering Earth crust could not be identified. Therefore, it was observed that Canan could be able to identify dynamic relationships among terrestrial pools, and also between the terrestrial pools and the atmosphere, with lack of referring to the transformation processes. As a result, she classified as emerging level for identifying dynamic relationships in the carbon cycle (see Table 4.5).

4.1.2.4. STS-4 Organizing the systems' components, processes, and their interactions, within a framework of relationships

In this level, it is expected from participant to identify organizing the components and processes of carbon cycle within a framework of relationships. As defined in the previous sections, carbon cycle includes three main sub-systems which are terrestrial system, hydrosphere and the atmosphere. This level was analyzed over the concept maps which investigated interaction of parts of the carbon cycle to understand the whole. For these purposes, it was asked participant to write the 12-words concerning carbon and to draw a concept map that relates the concepts to each other.

> Interviewer: "What comes in your mind when I say carbon?"
>
> Canan: "I can say livings and non-livings in the biosphere since they include carbon. Moreover, I can say carbon footprints of humans since we release carbon. In addition, I can say CO_2 and CO in the air which includes carbon inside. We measures the concentration of the carbon using ppm [parts per million]. Additionally, people cover their cars with carbon related something to protect cars from the sun, but I am not sure. Moreover, I can say there are organic compounds everywhere. While we said that, we can say carbon make 4-bonds. Moreover, I can say carbon is transported through the carbon cycle."
>
> Interviewer: "Can you draw a concept map that relates those concepts to each other?"

The concept map she had drew was presented in the Figure 4.2.

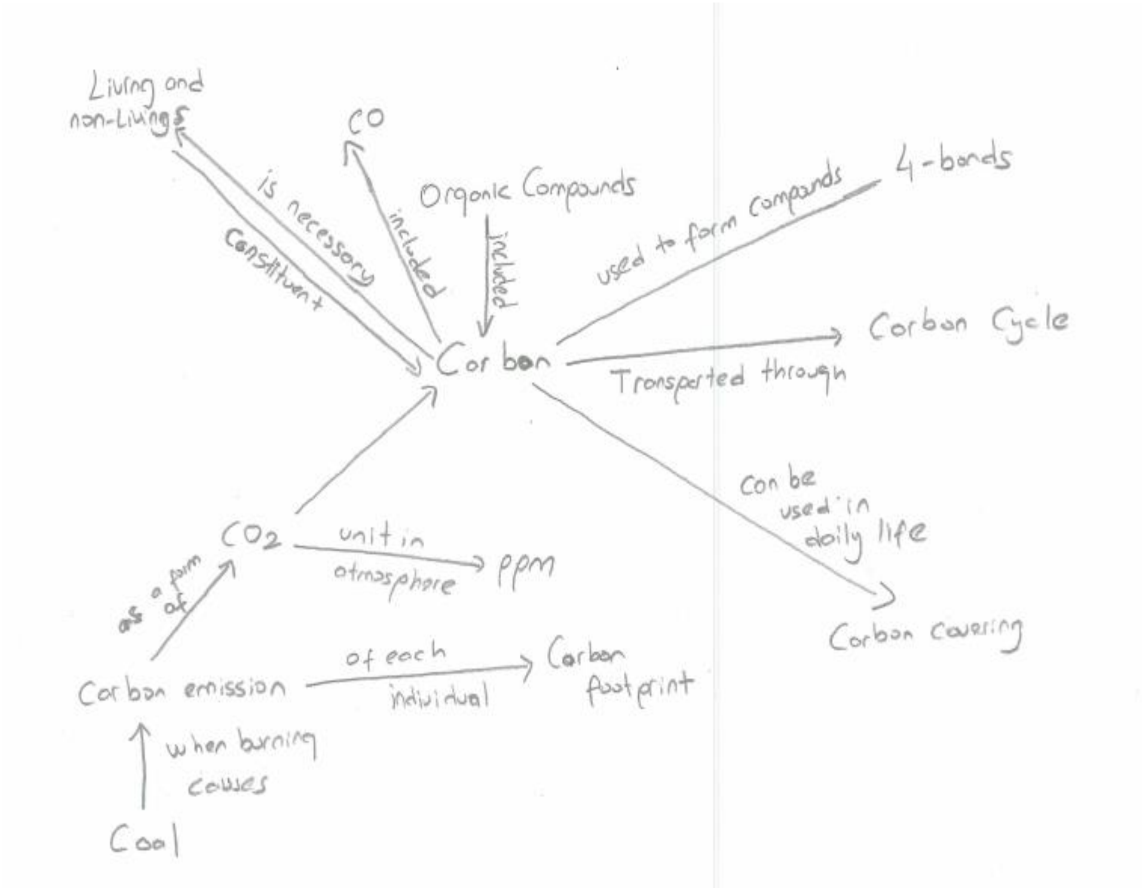

Figure 4.2. Canan's Concept Map

It was obtained that only two concepts (CO_2, carbon) were related to more than two concepts in the concept map. Her map mainly based on relating pairs of concepts (2-concepts) which is inadequate to form a framework with missing any cross-sectional arrows. It seemed she was aware of "*carbon [is] transported through [the] carbon cycle*".

The concepts that she discussed in the concept map was summarized in the Table 4.6.

Table 4.6

Canan's Ability to the Systems' Components, Processes, and Their Interactions, within a Framework of Relationships

Dimensions within the concept map	Examples	Number of the concepts
Terrestrial system	Living and non-livings, coal, carbon footprint (human), carbon covering (on cars)	4
Atmosphere	CO_2, CO, parts per million (ppm)	3
Hydrosphere	-	-
Miscellaneous	Carbon, carbon cycle, 4-bonds, organic compounds	4
Processes	Combustion (by humans), carbon emission (by humans)	2
Concepts related more than two concepts	CO_2, Carbon	2

However, she only related carbon cycle to carbon in this extent. No other interaction was observed on the carbon cycle in her concept map. Moreover, she mainly focused on the terrestrial part of the carbon cycle (4 concepts). Additionally, three concepts related to atmosphere were observed. However, the hydrosphere part of the carbon cycle could not be discussed. The processes that transport carbon in the carbon cycle was missing except from anthropogenic combustion (burning of coal) and carbon emission while she identified five other processes in the STS-1 including photosynthesis (also in hydro.), respiration (also in hydro.), volcanism, decomposition, digestion (See Table. 4.2). Even though she identified those processes in the carbon cycle, she failed to organize them in a framework of relationships in the concept map. Therefore, although she was aware of the carbon cycle processes and components (STS-1), the pairs she created was insufficient to describe an organized framework of relationships which characterize a system. In addition, the interaction of the concepts she discussed did not cover the terrestrial and atmosphere and the hydrosphere part of the carbon cycle which gave a "*fragmented perception to the system*" (Ben-Zvi Assaraf, &Orion, 2005). Hence, she classified as emerging level for the STS-4.

4.1.2.5. STS-5 Understanding the cyclic nature of the systems

In this level, it is expected from participants to identify the cyclic nature of the carbon cycle system. This means that we live in a cyclic world which matter (carbon) cycles via exchange of energy and matter (Ben-Zvi Assaraf, 2003). In the context of the study this level was interpreted as carbon cycles through in a series of small sub-cycles which represents carbon and energy transformation among the main reservoirs of carbon located in subsystems of carbon cycle including terrestrial system, hydrosphere and atmosphere. The fifth system thinking skill which is described as understanding the cyclic nature of the carbon cycle system were analyzed by the interview questions and the drawings. According to the answers, she was classified as pre-aware, emerging, developing or mastery.

The drawing that Canan drew was presented in the Figure 4.1 (See p. 45).

The components and the processes in the drawing was summarized in the Table 4.7.

Table 4.7

Components and Processes Identified by Canan in Her Drawing

Sub-systems of carbon cycle	Components	Processes
Terrestrial system	Cow, human, dead organism, fossil fuels, tree, factory, volcano, soil,	Photosynthesis, respiration, combustion, decomposition, volcanism
Atmosphere	CO_2, CH_4	-
Hydrosphere	Aquatic plants, ocean,	Photosynthesis, respiration

In the drawing, it was observed that Canan identified eight component and five processes related with the terrestrial part of the carbon cycle. In addition, she defined two components and two processes in the hydrosphere. On the other hand, even though she described two components, any process in relation with the atmosphere could not be identified. It was obtained that, as in the previous levels, she mainly focused on the terrestrial part of the carbon cycle. In addition, it was observed the carbon flow represented as “input” and “output” with arrows over the components without indicating the source of the “input” carbon which demonstrated lack of cyclic understanding of the carbon cycle system based on her drawing. (Sibley et. al., 2007).

Two interview question was asked to investigate whether the participant hold a cyclic perception considering the carbon cycle (Ben-Zvi Assaraf, & Orion, 2005).

> Interviewer: “Is there a starting point for the carbon cycle?”
>
> Canan: “I do not think, there should be a starting point for the carbon cycle. Carbon is released by the plants and then it [carbon] is used by the plants again. Thus, how one can define a starting point in this case.”
>
> Interviewer: “Then, is there an end point for the carbon cycle?”
>
> Canan: “If there is no starting point, then, we cannot talk about the ending point as well.”

It was seemed that Canan was aware that there is no starting or ending point for the carbon cycle. Therefore, she demonstrated the cyclic perception in the carbon cycle (Ben-Zvi Assaraf, & Orion, 2005). On the other hand, a detailed analysis on how she perceived the cyclicality on carbon cycle is required to investigate her understanding the cyclic nature of the carbon cycle system.

The analysis of this level continued with the interview questions that analyzed the exchange of carbon and energy among the four-sub-cycles of the carbon cycle system.

Interviewer: “How carbon reaches to the atmosphere?”

Canan: “I think it reaches through the respiration. Plants and animals perform respiration. I think, after respiration carbon reaches to the atmosphere in the form of CO_2…[Additionally], factories release CO_2 to the atmosphere. Moreover, when volcanoes explode, they [volcanoes] release CO_2 [to the atmosphere] as well”

Interviewer: “How carbon reaches to the plants?”

Canan: “I am not sure, but we always say plants takes CO_2 from atmosphere to perform photosynthesize with using sunlight and water. Hence, I think that is the way of carbon when reaching the plants.”

Interviewer: “How carbon reaches to the animals?”

Canan: “I think they get carbon through foods. I cannot be sure about that. I know food contains carbon. Thus, they [animals] should take carbon in that way”

Interviewer: “How carbon reaches to the soil?”

Canan: “when organism die, they accumulate in the soil. I cannot explain what happens to them [dead organisms] exactly in the soil, but then, I know they [dead organisms] turns into fossil fuels. Then we [humans] use them.”

Interviewer: “How do we [humans] use fossil fuels?”

Canan: “I mean, while driving cars or factories, or food transport etc., we released carbon to the atmosphere.”

Interviewer: “How carbon reaches to the ocean?”

Canan: “I do not know. I think it could be related with the photosynthesis and respiration. However, I cannot explain how.”

Interviewer: “You mentioned about volcanoes. How carbon reaches to the volcano?”

Canan: “I really do not know how volcanoes explode. But, I know when it [volcano] explodes, CO2 is released to the atmosphere.”

Interviewer: “What makes carbon to move in all this action?”

Canan: “I think carbon moves because of chemical reactions. When we said a component releases CO_2 or something related with carbon, we meant the product of a chemical reaction. For example, plants release CO_2 as a product of respiration. That’s all I can say.”

It was observed that she could be able to identify the sub-cycle that covers the exchange of carbon among two-subsystems which are terrestrial system and atmosphere. The cycle was identified as carbon exchange from *atmosphere* to *plants* as in the form of CO_2 via the process of photosynthesis and from *plants* to *atmosphere* as in the form of CO_2 through the process of respiration. In addition, she could be able to discuss the carbon release in the form of CO_2 to the *atmosphere* over the process of respiration in *animals*. On the other hand, how carbon reaches to the animals remained unclear. The processes of food chain that transform carbon through the plants to the animals could not be observed. In addition, she was aware of the exchange of carbon from animals and plants to the soil, however, she could not be able to trace it back into the atmosphere over the process of decomposition. In short, it was seemed that she could be able to perceive of exchange of carbon in the sub-cycle (a) which in between terrestrial carbon pools (plants, animals) and atmosphere (CO_2) over the processes of photosynthesis and respiration. Additionally, the movement of carbon among the reservoirs were related only with the chemical energy occurring as chemical reactions on the various carbon pools (i.e. plants). However, although she could be able to identify sunlight, she could not be able to identify exchange of energy among the atmosphere to terrestrial system over the transformation of solar energy to the chemical energy.

Moreover, considering the sub-cycle (b), she identified the exchange of carbon among the terrestrial system and atmosphere in a degree among the terrestrial reservoirs (dead organisms, soil, fossils and fossil fuels) and the atmosphere via the processes of burial and combustion. She discussed carbon exchange to the atmosphere are caused by human activities (driving cars, factories) that combust fossil fuels. On the other hand, it was seemed that she could not be able to explain how carbon is exchanged among the dead organisms, fossils and fossil fuels via the process of fossilization. As a result, she could not be able to trace the carbon in the soil. Since no process regarding to soil identified concerning the sub-cycle (b) she could not be able to discuss any exchange of energy among the different carbon reservoirs (chemical energy to thermal).

In addition, she could be able to exchange of carbon between hydrosphere and atmosphere in the sub-cycle (c) as in the form of CO_2. She described aquatic plants responsible for the exchange of carbon between ocean and the atmosphere via the process of photosynthesis and respiration. On the other hand, processes of diffusion of carbon in and out ocean could be observed. Therefore, how carbon enters the oceanic water and leaves it remained unexplained. Additionally, she did not mention the energy exchanges occur between the hydrosphere and atmosphere (kinetic energy turns into potential; potential energy turns into kinetic, solar energy turns into chemical).

However, sub-cycle (d) which describes the exchange of carbon and energy among the reservoirs of terrestrial system, the hydrosphere and the atmosphere could not be observed. Since she did not mention the main reservoir of carbon on the Earth (Earth's crust or rocks), she could not be able to trace the exchange of carbon among the rocks (sedimentary), ocean and atmosphere while energy exchanged via dissolution, precipitation, plate tectonics-volcanism (gravitational potential energy (e.g. sediments and water) turns into kinetic; geothermal energy powers plate tectonics which transferred to atmosphere and the space).

In brief, Canan demonstrating an understanding on matter (carbon) exchanges among the carbon reservoirs in a part of the sub-cycle-a which is in between plants and the atmosphere via photosynthesis and respiration. On the other hand, carbon exchanges among the animals, plants and the soil via the processes of food chain and soil respiration (i.e. decomposition) could not be observed. Therefore, other part of the sub-cycle-a which completes the exchanges of matter (carbon) within atmosphere and the terrestrial carbon reservoirs could not be identified. In addition, she was aware that energy is responsible for the movement of carbon among the carbon reservoirs. However, Canan could not be able to relate it to the energy exchanges between the atmosphere and terrestrial system. Moreover, Canan demonstrated a partial understanding of exchanging carbon considering the sub-cycle-b which is in between atmosphere and terrestrial system (dead organisms, soil, fossils and fossil fuels) reservoirs. However, the exchanges of carbon within the soil and the atmosphere was missing in her description of the sub-cycle-b. Additionally, exchanges of energy could not be observed among the atmosphere and terrestrial reservoirs as well for the sub-cycle-b. Moreover, it was obtained that Canan was aware of the exchanges of carbon within atmosphere and hydrosphere. However, she could not be able to show an understanding that how the exchanges occur. In addition, the exchanges of energy within atmosphere and the hydrosphere was missing as well. Lastly, Canan could not be able to identify the sub-cycle-d that covers the carbon and energy exchanges among the terrestrial system, atmosphere and the hydrosphere. Hence, although it was observed that Canan hold a cyclic perception considering the carbon cycle, she could be able to show a partial understanding of exchanges of carbon in the three sub-cycle (-a-b-c) in the carbon cycle. Even if, she was aware that energy should be exchanged among the carbon reservoirs, there were no energy exchanges and transformations observed while the carbon cycles through the carbon cycle. Therefore, she was classified as developing level for understanding the cyclic nature of the carbon cycle.

4.1.2.6. STS-6-The ability to recognize hidden dimensions of the system

In this level, it is expected from participants to recognize the hidden dimensions of the carbon cycle system. This ability means that identifying relationships that are not seen on the surface. In the context of this study, while analyzing the hidden dimensions in the carbon cycle mainly focused on the recognizing interrelationships among the various Earth cycles such as water cycle or nitrogen cycle. This level analyzed via through the interview questions and drawings that investigated the interrelationships among the various Earth cycles from multiple scales. According to the answers, she was classified as pre-aware, emerging, developing or mastery.

> Interviewer: “Is there any relationship among the carbon cycle and the other Earth cycles?”
>
> Canan: “Yes, I mean, there should be… there should be connections among the cycles…Hmm… I am sure that there are connections among the various cycles such as water cycle and carbon cycle…but, I cannot explain them.”

It was observed Canan was aware that the Earth cycles connected with each other. In her drawing, it was obtained ocean as a part of the water cycle as well. However, she could not identify the relationships among the water and carbon cycle. Moreover, even though she was able to consider molecular movement in the terrestrial system and the atmosphere through CO_2 and methane via the processes of photosynthesis, respiration and decomposition (STS-5), she could not be able to consider microscopic scales in the carbon cycle in a way to relate other Earth cycles. Additionally, she was not able to consider carbon movement in carbon cycle at a macro-scale relating all the three sub-systems including terrestrial system, hydrosphere and the atmosphere (STS-5). Hence, she could not be able to identify the interrelationships among the various Earth cycles. Therefore, since she was only aware of connections among the cycles of the Earth but could not be able to recognize them at multiple scales, Canan was classified as emerging level for the sixth system thinking level.

4.1.2.7. STS-7-The ability to make generalizations

In this level, generalization might be expressed within the carbon cycle system by the understanding that this system is dynamic and cyclic. In the context of carbon cycle, that understanding implemented on discussing the how environmental issues (i.e. global warming, climate change) occurred such as the current imbalances among the processes within the carbon cycle's sub-systems including terrestrial system, hydrosphere and atmosphere. This level, it was analyzed the participant's ability to identify current imbalances of the carbon cycle process with referring the feedback mechanisms among the components in three sub-systems of carbon cycle while discussing the global environmental issues. The seventh system thinking skill which is described as the ability to make generalizations was analyzed by the interview questions. A series of interview questions asked to the participant to analyze her understanding of generalizations in the context of carbon cycle. According to the answers, she was classified as pre-aware, emerging, developing or mastery.

> Interviewer: "What can you say when I want you to talk about the climate change?"
>
> Canan: "Climate change is a global environmental problem which causes a shift in the climates results in the extreme weather patterns."
>
> Interviewer: "Is there any relationship between climate change and the carbon cycle?"
>
> Canan: "Yes, there is. For example, because of climate change wildfires among forests are common. There plants who perform photosynthesize and respiration in the forests. Therefore, carbon cycle is affected. I do not know, the exact effect of climate change on the carbon cycle or vice versa. When the temperature rises in the atmosphere because of the climate change effects, glaciers will be melted. Hence, the aquatic plants will be affected. Somehow, I cannot explain how, carbon cycles balance will be disturbed."

It was observed that Canan identified the connection between the climate change and the carbon cycle. She was aware that the balance of the carbon cycle was disturbed with the consequences of the climate change. On the other hand, she could not be able to recognize climate change is caused by the imbalance of the processes in the carbon cycle. Moreover, there were no signs feedback mechanisms among the components rather than one-way cause and effect relationships among rising temperature-melting glaciers and aquatic plants between the hydrosphere and atmosphere without describing how effected aquatic plants in turn effects the system. Therefore, she could not be able to identify the feedback mechanisms among the all three sub-systems of carbon cycle that causes the current imbalance of the carbon cycle processes which then results in climate change. Hence, she was classified as emerging for the making generalizations in the carbon cycle system.

4.1.2.8. STS-8- The ability to think temporally: retrospection and prediction

In the context of the carbon cycle, this level means that Understanding that some of the presented interaction within the system took place in the past, while future events may be a result of present interactions (Ben-Zvi Assaraf, 2003). In the context of carbon cycle, such understandings could be implemented in cases such as industrial revolution effect on the increasing concentration of CO_2 throughout the decades or predict consequences of population growth on the CO_2 concentration in the atmosphere for the upcoming ages (Batzri et al., 2015; Zangori, et al., 2017).

The eighth system thinking skill which is described as the ability to think temporally: retrospection and prediction was analyzed by the interview questions.

A series of interview questions asked to the participant to analyze her ability to think temporally: retrospection and prediction in the context of carbon cycle. According to the answers, she was classified as pre-aware, emerging, developing or mastery.

> Interviewer: “What is the effect of humans on the carbon cycle?”
>
> Canan: “I think, they [humans] effect carbon cycle in a bad way. For example, a thousand years ago, there were no factory on the Earth. The carbon level in the atmosphere was not that much high. After that, we build up factories which released CO_2 to the atmosphere and raised the level of atmospheric temperature. Hence, now glaciers are melted which affected the life on the Earth negatively. Therefore, the effect of humans in the carbon cycle is unfavorable.”

It was observed that Canan could be able to think retrospectively on the carbon cycle which she described the consequences of building factories on increasing level of atmospheric temperature.

Her answer showed that she was recognize the past (absence of factories) of the carbon cycle to explain a current phenomenon (melting glaciers because of excessive CO_2 release caused by factories). Therefore, since she described a relationship on the carbon cycle considering in the two-time spans (past-present) on the today's glaciers meltdown, Canan was classified as developing level for the eighth system thinking level.

4.1.3. Canan's Definition of System

Canan's description of system included the properties interactions of components among the system. She mentioned that a system should be dynamic while explaining the system. The description of a system according the Canan is given in below.

> "When we talk about systems, we are talking about components and their interactions within a framework which includes dynamism as well. Concerning the carbon cycle, we mentioned about the movement of carbon among the components of the carbon cycle which defines both dynamism and interaction"

4.1.4. Canan's Summary of Systems Thinking Skills

Canan could not be classified as mastery level for any system thinking skills. She classified as developing level for the STS-1, STS-2, STS-5, STS-8 concerning the system thinking abilities in the carbon cycle. On the other hand, considering the other system thinking skills (including STS-3, STS-4, STS-6, STS-7), she was classified as emerging level. The description of system definition she gave revealed that she had a system understanding considering the system thinking with referring the interactions and dynamism in the carbon cycle. However, could not be able to implement her understanding of system to the carbon cycle context. Summarization of Canan's system thinking analysis were presented in the Table 4.8.

Table 4.8

Summary of Canan's System Thinking Levels

System thinking skill	Level
STS-1- The ability to identify the components of a system and processes within the system	Developing
STS-2- The ability to identify simple relationships between or among the system's components.	Developing
STS-3- The ability to identify dynamic relationships within the system.	Emerging
STS-4 The ability to organize the systems' components, processes, and their interactions, within a framework of relationships.	Emerging
STS-5 The ability to identify cycles of matter and energy within the system—the cyclic nature of systems.	Developing
STS-6 The ability to recognize hidden dimensions of the system.	Emerging
STS-7 The ability to make generalizations	Emerging
STS-8 The ability to think temporally: retrospection and prediction.	Developing

4.2. Case 2: Melisa

4.2.1. Melisa's Demographic Data

Melisa is 24-year-old senior student from elementary science education department in the one of the well-known universities in the Turkey. She grown up and currently live in one of the major cities of Turkey.

Melisa passed all the courses which are mandatory in the undergraduate curriculum including organic chemistry, analytic chemistry, biology, physiology, physics, geology and environmental education. In addition, she took elective sustainability courses.

4.2.2. Melisa's System Thinking Skills

Melisa's system thinking levels were analyzed according with the three data collection tools which are interviews, drawings and concept map. Results were presented for each system thinking level.

4.2.2.1. STS-1 Identify system components and processes within the system

In this level, it is expected from participants to identify the components and processes within the Carbon Cycle. The investigation of this level was conducted on the data observed throughout the interviews and drawing in terms of three categories that is described in the context of carbon cycle as the atmosphere, the hydrosphere and the terrestrial system. The main intention to perform such categorization is to understand participant's perception of carbon cycle as a complex system through components whether she could define multiple components on the three categories including terrestrial, hydrosphere and atmosphere or not. The drawing that Melisa draw were presented in Figure 4.3.

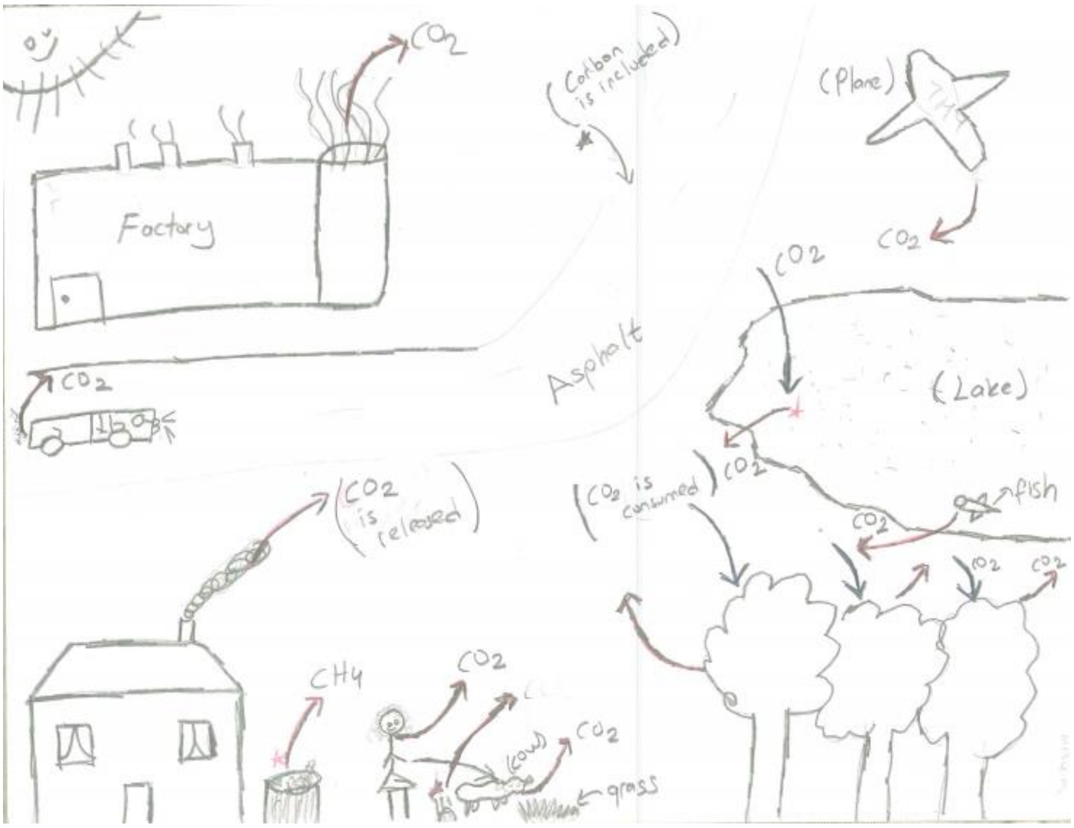

Figure 4.3. Melisa's Drawing of Carbon Cycle

The first level of system thinking model encompasses the ability to identify processes of in a system as well as identifying components in the system. Processes such as photosynthesis, respiration, combustion, decomposition, food webs or formation of carbonate shells etc. were included in the carbon cycle. As is the analysis of the components, the processes of the carbon cycle were investigated on where they identified on the three sub-systems; terrestrial system, hydrosphere or atmosphere. A brief summary of the components that Melisa identified was categorized and listed in the Table 4.9.

Table 4.9

Table 4.9 Identified components by Melisa

Categories	**Components within carbon cycle**	**Number of components**
Terrestrial System	Plant, tree, humans, animals, cow, glucose, garbage, asphalt, food, plane, coal, decomposers, cars, factory, industry, plane, houses, water, animal (human) waste	20
Hydrosphere System	lake, cyano bacteria, fish, seashells	4
Atmosphere	methane, carbon dioxide, carbon mono-oxide, oxygen, greenhouse gases	5

> Interviewer: “What are the components of the carbon cycle?”
>
> Melisa: “The components of the carbon cycle are plants, trees, animals, humans. They are the first components comes into my mind. Moreover, there are also cars and factories present in the carbon cycle. Moreover, we can say decomposers, coal in here as well.”

As it can be seen in the Table 4.9, Melisa mainly focused on the Terrestrial part in the carbon cycle system (twenty components). Moreover, she identified four components in the Hydrosphere and five components in the Atmosphere. Melisa identified multiple components on the three category which shows that she considered all the sub-systems of the carbon cycle system. Therefore, she classified as mastery level for the components of the carbon cycle system.

When it is asked about the processes in the carbon cycle (Question 4), she identified the processes both on interview and drawing. The processes she identified were listed in Table 4.10.

Table 4.10

Identified processes within the carbon cycle by Melisa

Category	**Processes within the Carbon Cycle**
Terrestrial System	Photosynthesis, respiration, decomposition, digestion, food chain, combustion
Hydrosphere system	Photosynthesis, respiration, formation of carbonate shells.
Atmosphere	-

> Interviewer: "Can you identify the processes within the carbon cycle?"
>
> Melisa: "From the very beginning of the Earth, life began respire to produce CO_2 in order to break down organic material [*respiration*]. At the end of the process carbon and hydrogen combined to form CO_2. Moreover, CO_2 used by the plants, trees and cyano-bacteria in *photosynthesis*. In addition, humans burn coal in their houses [*combustion*]. Moreover, decomposers break down organic material in the dead organism but, I cannot remember whether they release CO_2 or not [*decomposition*]. In addition, cow eat plants and we [humans] eat cow which at the end cow and humans produce CO_2 [*food chain*]. Moreover, when we eat, that organic molecule needed to break down into smaller ones in order to move into cells which produce CO_2 during the process[*digestion*]. In addition, some marine organisms have shells and their shells made up of cellulose which is a type of carbohydrate. Thus, in some way they [shells] had to form [*formation of carbonate shells*]. However, I cannot explain how forms.

It was observed that Melisa mainly identified processes related to terrestrial system (six processes). In addition, she defined three processes in the hydrosphere system. On the other hand, no atmospheric processes considering the carbon cycle could be identified.

Thus, Melisa could be able to identify processes on two sub-systems in the carbon cycle including terrestrial and hydrosphere system. Therefore, she classified as developing level for the process within the carbon cycle.

In brief, it was observed that Melisa mainly concentrated on the terrestrial system with identifying twenty components. In addition, she identified components related with all three sub-systems of the carbon cycle referring four components on the hydrosphere and five components on the atmosphere. On the other hand, she only could be able to identify processes related with the two sub-systems of the carbon cycle in relation with terrestrial system (6) and the hydrosphere (4). Therefore, Melisa was classified as developing level for the STS-1. A summary table that include Melisa's ability to identify both processes and components within the system was presented in the Table 4.11.

Table 4.11

Melisa's Ability to Identify Components and Processes within the Carbon Cycle

System Thinking Level	Categories			Level
STS-1- Ability to identify components and processes within the system.	Terrestrial System	Hydrosphere	Atmosphere	Developing level- identified components belonging to all three sub-systems of carbon cycle, however, identified processes only in two sub-systems.

Table 4. 11 (cont'd)

System Thinking Level	Categories			Level
Components of the carbon cycle	Plant, tree, humans, animals, cow, glucose, garbage, asphalt, food, plane, coal, decomposers, cars, factory, industry, plane, houses, water, animal (human) waste	lake, cyano bacteria, fish, seashells	methane, carbon dioxide, carbon mono-oxide, oxygen, greenhouse gases.	Mastery—identify components includes all three sub-systems of carbon cycle.
Processes of the carbon cycle	Photosynthesis, respiration, decomposition, digestion, food chain, combustion	Photosynthesis, respiration formation of carbonate shells.	-	Developing—identified components only in two sub-system except for the atmosphere.

4.2.2.2. STS-2 The ability to identify relationships among the components within the system

In this level, the relationships within the carbon cycle were analyzed. The relationships were investigated on the three sub-systems of the carbon cycle. The analysis of this level was concentrated on the relationships among the components that are belonging to the three sub-systems in the carbon cycle including terrestrial, hydrosphere and atmosphere. In addition, cause and effect relationships were investigated among the components to observe the casuality in the carbon cycle system (Lee,2015). Interview questions were used to analyze the second system thinking skill. According to the answers, she was classified as pre-aware, emerging, developing or mastery. A brief summary of Melisa's ability to identify relationships among the components of the carbon cycle were presented in the Table 4.12.

Detailed analysis of the interviews was presented in the following part. The responses Melisa gave during the interview revealed that she mainly considered the terrestrial part of the carbon cycle while identifying relationships. In addition, relationships considering the other parts of the carbon cycle were observed as well. On the other hand, she could be able to identify one relationship including cause and effect relationship among using fossil fuels in planes and cars as a cause for increasing CO2 level in the atmosphere. The other relationships just identified as a simple linear relationship without referring any causality.

> Interviewer: "What are the relationships among components in the carbon cycle?"
>
> Melisa: "The first thing comes in my mind is photosynthesis. Plants take CO_2 from the atmosphere and produce their [plants'] own food. In addition to plants, cyano-bacteria in the lakes do photosynthesis. I think they [cyano-bacteria] use dissolved CO_2 in the water, but I am not sure. Beside photosynthesis, cow, humans, plants all of them do respiration which is a process give out CO_2 to the atmosphere. I think fish uses dissolved oxygen in the water for respiration and give out CO_2 to the water. Moreover, methane released from the garbage resulted from decomposers activities. Factories released CO_2 to the atmosphere. We burn coal in our homes which releases CO_2. In addition to coal, we use different forms of fossil fuels such as gasoline in (driving) cars that release CO_2 to the atmosphere."

Table 4.12

Melisa's Ability to Identify Relationships Among the Components within the Carbon Cycle

STS Level	Relationships	Level
STS-2 Ability to identify relationships among the components within the system		Developing Level--- Relationships identified among two sub-systems including terrestrial system and the atmosphere referring a cause and effect relationship.
Among the terrestrial system components	-	-
Among the hydrosphere components	- cyano-bacteria-dissolved CO_2	Linear relationships identified over the processes of photosynthesis. Did not include cause and effect relationships among the components.
	- Fish- dissolved O2	Linear relationships identified over the process of respiration. Did not include cause and effect relationships among the components.
Among the atmosphere components	-	-

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Table 4.12 (cont'd)

STS Level	Relationships	Level
Among Terr. System and the atmosphere components	- plants, atmosphere, CO_2, atmosphere, food	Linear relationships identified over the processes of photosynthesis Did not include cause and effect relationships among the components.
	- cow, humans, plants, CO_2.	Linear relationships identified over the processes of respiration. Did not include cause and effect relationships.
	- garbage, decomposers, methane	Linear relationships identified over the process decomposition. Did not include cause and effect relationships.
	- factory, house, coal, CO_2	Linear relationships identified over the process combustion. Did not include cause and effect relationships.

Table 4.12 (cont'd)

STS Level	Relationships	Levels
	- Plane, cars, fossil fuels, CO_2	Linear relationships identified over the processes of anthropogenic combustion.
Among the Terr. System and hydrosphere components	-	
Among the hydrosphere and the atmosphere components	-	
Among Terr. System- the Hydrosphere and the atmosphere components	-	

It was observed that Melisa identified relationship among the terrestrial system components (plants, atmosphere, CO_2, atmosphere, food) via the process of photosynthesis. In addition, she identified a relationship among terrestrial system components (plants, cow, humans) and atmosphere (CO_2) through the process of respiration. Additionally, Melisa identified a relationship between the terrestrial system component (decomposers, garbage) and the atmosphere (methane) via the release of methane gas to the atmosphere via the process of decomposition. Moreover, she identified relationships among the terrestrial system components (house, coal, factory, (driving) cars and the atmosphere (CO_2) through the process of combustion while CO_2 is released to the atmosphere. Additionally, she identified cyano-bacteria in hydrosphere which perform photosynthesis by using the dissolved CO_2 in the water. By this way, she identified a relationship occurring between the hydrosphere components (cyano-bacteria, dissolved CO_2). In addition to the relationship between cyano-bacteria and the dissolved CO_2, Melisa identified a relationship among hydrosphere components fish and dissolved oxygen in the lake over the process of respiration.

Melisa continued to identify relationships with questions in the interview.

> Interviewer: "Do you want to add anything to the relationships in the carbon cycle?"
>
> Melisa: "I can add human activities. We [humans] produce carbon while we are using planes and cars, we use fossil fuels which causes an increase the level of CO_2 in the atmosphere."

It was observed that Melisa identified only one cause and effect relationship among the terrestrial system components (plane, cars, fossil fuels) and the CO_2 in the atmosphere through the combustion of fossil fuels which described as influence the increase on the atmospheric level of CO_2. The cause was identified as the using fossil fuels in planes and cars which effects the level of CO_2 in the atmosphere.

In conclusion, investigation of the second level of system thinking revealed that Melisa identified relationships among the components located in the two-subsystems which are terrestrial system and the atmosphere as well as among the components of the hydrosphere.

The hydrosphere part of the relationships seemed to be perceived as separately with no relation to the terrestrial system and the atmosphere. On the other hand, only one cause and effect relationship could be identified which was among the components of terrestrial system and the atmosphere. Therefore, since Melisa could able to identify relationships among the two-subsystems of the carbon cycle (terrestrial system and the atmosphere) with referring only one cause and effect relationship, she classified as developing level for the STS-2.

4.2.2.3. STS-3 Identifying Dynamic Relationships in the System

In this level, dynamic relationships within the carbon cycle were investigated. In this study, dynamism in the carbon cycle means identifying carbon fluxes among the carbon pools which includes transportation and transformation of carbon. In this level, dynamic relationships analyzed over the transportation and transformation carbon among the carbon pools that are classified into sub-systems of the carbon cycle including the terrestrial system, the hydrosphere and the atmosphere. The third system thinking skill were analyzed over the interview questions. According to the answers, she was classified as pre-aware, emerging, developing or mastery.

The analysis demonstrated that Melisa identified dynamic relationships on the among the terrestrial carbon pools (animals, plants, decomposers) and the atmosphere mainly. In addition, she identified dynamic relationships among the hydrosphere as well. On the other hand, she could not be able to identify any dynamic relationships related with the atmosphere.A brief summary of Melisa’s ability to identify relationships among the components of the carbon cycle were presented in the Table 4.13.

Table 4.13

Melisa's Ability to Identify Dynamic Relationships Among the Components of the Carbon Cycle

STS Level	Relationships	Level
STS-3 Ability to identify dynamic relationships among the components within the system		- Developing Level--- Relationships identified among two sub-systems including terrestrial system pools and the atmosphere with referring on transportation and transformation of carbon.
Among the terrestrial system components	-	-
Among the hydrosphere components	- Cyano-bacteria-Dissolved CO_2 in the water	Identified over the process of photosynthesis, referring only transformation of carbon partially.
	- Fish-dissolved oxygen in the water	Identified over the process of respiration, only referring the transformation of carbon partially.
Among the atmosphere components	-	-

Table 4.13 (cont'd)

STS Level	-	Relationships	Level
Among Terr. System and the atmosphere components	-	CO_2 in the atmosphere-Plants	Identified over the process of photosynthesis, referring the transportation of carbon from air to plants, and transformation of carbon from carbon in the CO_2 into carbon in the food.
	-	Animals-CO_2 in the atmosphere	Identified over the process of respiration, referring the transportation of carbon from animals to air, and transformation of carbon from carbon in the food into carbon in the CO_2.
	-	Decomposers- methane in the atmosphere	Identified over the process of decomposition, referring only the transportation of carbon from decomposers to air,
Among the Terr. System and hydrosphere components	-		-
Among the hydrosphere and the atmosphere components	-		-
Among Terr. System- the Hydrosphere and the atmosphere components	-		

The table demonstrated that Melisa could be able to identify dynamic relationships in between terrestrial system carbon pools (plants, animals, decomposers) and atmosphere through the processes of photosynthesis and respiration. The dynamism she identified among the terrestrial system and atmosphere pools included transportation and transformation except for decomposers. She only could be able to identify the transportation of carbon concerning the dynamism related with decomposers and atmosphere. In addition, she was able to identify dynamic relationships concerning the hydrosphere pools (cyano-bacteria-dissolved CO_2 and fish- dissolved oxygen). However, she struggled to refer transportation of carbon in the hydrosphere. Dynamic relationships considering atmosphere, she was not able to define any. The analysis continued with the interview questions investigating the relationship among the carbon pools that Melisa defined in the STS-1.

> Interviewer: "What happens to carbon in the plants?"
>
> Melisa: "Plants take CO_2 form air to do photosynthesize. During this process, food is produced. I think, plant converts carbon in the CO_2 to the carbon in the food."
>
> Interviewer: "What happens to carbon in animals?"
>
> Melisa: "Animals do respiration. They [animals] release CO_2 during the respiration process. I think, during the respiration process, the carbon in the food transform into carbon in the CO_2. Then, CO_2 released to the air."
>
> Interviewer: "What happens to carbon in the decomposers?"
>
> Melisa: "They [decomposers] *somehow* releases CO_2 to the air resulting from their [decomposers'] activity in such as garbage. Decomposers break down wastes such as human waste and released CO_2 to the air as well. They break down organic material to its' constituents, but I cannot explain how they decompose the material."
>
> Interviewer: "What happens to carbon in the water (lake)?"
>
> Melisa: "There are cyano-bacteria in the lake which do photosynthesis using dissolved CO2 in the water. In addition, If I am not wrong, I think there are seashells in the water. I remember that their [seashells'] shell made up of cellulose which includes carbon."
>
> Interviewer: "What happens to carbon in the atmosphere?
>
> Melisa: "I do not know. It [CO_2] stays in the atmosphere. Why CO_2 should return to the below [terrestrial part and ocean]. I think, it [CO_2] stays in the atmosphere."

Overall, it was observed that Melisa could be able to identify dynamic relationships among the terrestrial system and atmosphere carbon pools (plants-atmosphere, and animals-atmosphere) through the processes of photosynthesis and respiration with referring the transportation and transformation of the carbon. In addition, she could be able to identify dynamic relationship among the terrestrial system (decomposers) and atmosphere with only referring the transportation of carbon. Moreover, dynamic relationships among the hydrosphere (cyano-bacteria, dissolved CO2 and fish and dissolved oxygen) were identified over the processes of photosynthesis and respiration in the water referring partially transformation of carbon. On the other hand, no dynamic relationship was identified in the atmosphere part. Moreover, it was observed that she perceived the atmosphere part of the carbon cycle separately as static, not a dynamic part. Therefore, since Melisa could be able to identify dynamic relationships between two-subsystems including terrestrial pools and the atmosphere with referring the transportation and transformation of carbon, she was classified as developing level for the STS-3 (See Table 4.13).

4.2.2.4. STS-4 Organizing the systems' components, processes, and their interactions, within a framework of relationships

In this level, organizing the components and processes of carbon cycle within a framework of relationships were intended to analyze. Therefore, it is important to underlie the connections among more than two components for organizing the components and processes and their interactions within a framework which describe a carbon cycle system. Hence, this level was analyzed through the concept maps which seeks for the interactions among the carbon cycle parts. In this level, it was asked participant to write the 12-words concerning carbon and to draw a concept map that relates those concepts to each other.

> Interviewer: "What comes in your mind when I say carbon?"
>
> Melisa: "I can say CO_2, CO, and green-house gases since they include carbon. In addition, I can say plants produce carbo-hydrates such as glucose through the processes of photosynthesis which also produce oxygen. Moreover, plants also perform respiration. In addition, we can say organic chemistry which interested in organic compounds such as methane and methyl."

Interviewer: “Can you draw a concept map that relates those concepts to each other?”

The concept map she had drew was presented in the Figure 4.4.

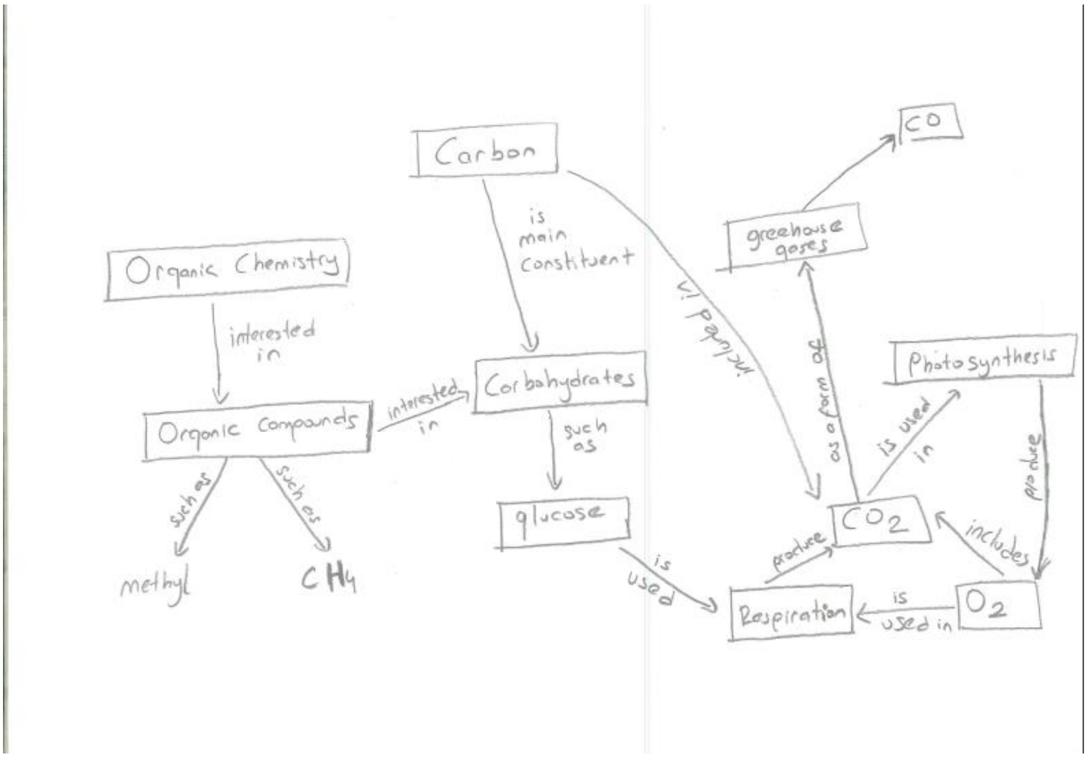

Figure 4.4. Melisa’s Concept Map

It was observed that Melisa could be able to identify connections among concepts with more than two concepts (seven concepts). Moreover, it seemed that she described her drawing included two processes. The interactions among the concepts that are related with more than two concepts were mainly described through the photosynthesis and respiration. The concepts that she discussed in the concept map was summarized in the Table 4.14. It was obtained that the interactions among the concepts (components and processes) observed in the terrestrial and atmosphere part of the carbon cycle system.

Table 4.14

Melisa's Ability to the Systems' Components, Processes, and Their Interactions, Within a Framework of Relationships

Dimensions within the concept map	Examples	Number of the concepts
Terrestrial system	Carbon-hydrate glucose,	2
Atmosphere	CO_2, O_2, green-house-gas, CO	4
Hydrosphere	-	-
Miscellaneous	Carbon, Organic chemistry, Organic compounds, CH_4, methyl,	5
Processes	Photosynthesis, respiration,	2
Concepts related more than two concepts	CO_2, Carbon, organic compounds, glucose, respiration, O_2, Photosynthesis	7

On the other hand, even though she could be able to identify hydrosphere part in the carbon cycle in STS-1, and STS-2, no concepts were observed related to hydrosphere part of the system. Therefore, hydrosphere part was absent in her framework. Moreover, as in the STS-1 and STS-2, no atmospheric processes were identified. Hence, her concept map was lack of consideration interactions among the atmosphere-terrestrial system with hydrosphere in a framework of relationships. Therefore, since she only described a framework relating terrestrial system and atmosphere, but failed to connect hydrosphere to this framework, she classified as developing level for the STS-4 (See Rubric in Table 3.2).

4.2.2.5. STS-5 Understanding the cyclic nature of the systems

In this level, participant's understandings of cyclic nature of the carbon cycle system were analyzed. Therefore, in this context, participant's understanding of exchanges matter and energy via transformation of carbon and energy among the four-sub-cycles located in the sub-systems of the carbon cycle was examined. The fifth system thinking skill which is described as understanding the cyclic nature of the carbon cycle system were analyzed by the interview questions and the drawings. According to the answers, she was classified as pre-aware, emerging, developing or mastery.The drawing that Melisa drew was presented in the Figure 4.3 (See p. 76). The components and the processes in the drawing was summarized in the Table 4.15.

In her drawing, it was observed that Melisa mainly identified terrestrial system components with eleven components. Moreover, she identified three components related with hydrosphere and two components with the atmosphere. In addition, she identified the Sun as a component in her drawing. The exchange of carbon among the considering the carbon pools were observed only atmosphere and plants which encompassed the terrestrial system and the atmosphere. Apart from that exchange of carbon between plants and atmosphere, the carbon exchange among the other carbon pools were described as “inputs” or “outputs” without referring the source of the input.

Table 4.15

Components and Processes identified by Melisa in her drawing

Sub-systems of Carbon cycle	Components	Processes
Terrestrial system	Cow, human, tree, factory, garbage, grass, human waste, house, plane, car, asphalt	Photosynthesis, respiration, combustion, decomposition
Atmosphere	CO_2, CH_4	-
Hydrosphere	lake, fish, cyano-bacteria	Photosynthesis, respiration
Miscellaneous	The Sun	

Therefore, her drawing revealed lack of cyclic understanding considering the flow of carbon among the three-sub-system of the carbon cycle apart from exchanging carbon between plants and the atmosphere. Two interview question was asked to investigate whether the participant hold a cyclic perception considering the carbon cycle.

> Interviewer: “Is there a starting point for the carbon cycle?”
>
> Melisa: “No, there is no starting point or end points for the carbon cycle. However, if we back to millions of years ago, I think carbon cycle begins with the photosynthesis. The CO2 is taken from the air and food is produced. Then, respiration takes place. Carbon in the food go back into atmosphere. By cycling the carbon, life evolved and became diversified. Thus, the starting point of the carbon cycle is where the time that photosynthetic organisms were formed.”

Interviewer: "Is there an end point for the carbon cycle?"

Melisa: "No, I there are no end points for the carbon cycle."

It was observed that Melisa tried to describe a starting point for the carbon cycle by referring the evolution of life on the Earth. She defined formation of photosynthetic organism as a starting point for the carbon cycle through the first process of photosynthesis and then respiration. According to the experts, emphasizing on there are no starting or end points for the carbon cycle except for considering the first processes that describe early stages of carbon cycle via evolution of life on Earth such as "*carbon cycle begins with the photosynthesis..., after respiration takes place*" considered as an indicator for cyclic perception concerning the carbon cycle (Batzri et al., 2015).

The analysis of this level continued with the interview questions that analyzed the exchange of carbon and energy among the four-sub-cycles of the carbon cycle system.

Interviewer: "How carbon reaches to the air?"

Melisa: "I am not sure, but I think maybe through respiration. Plants and animals do respiration which released CO2 to the air. There is decomposition process [in the carbon cycle] which release methane to the air as well. Moreover, CO2 is released by the factories, cars and plane too."

Interviewer: "How carbon reaches to the plants?"

Melisa: "They [plants] take carbon from the air in the form of CO2. Then, through the photosynthesis, it [CO2] turns into carbon in the food. Then, plants perform respiration which CO2 is released to the atmosphere."

Interviewer: "How carbon reaches to the animals?"

Melisa: "Animals take carbon through foods when they [animals] eat plants. Carbon in the food goes to animals, and throughout the respiration, CO2 is released to the air."

Interviewer: "How carbon reaches to the decomposers?"

Melisa: "I do not know, how it reaches. I cannot explain. However, through decomposition methane is released to the air."

Interviewer: "How carbon reaches to the lake?"

Melisa: "We mentioned about seashells in the water which include cellulose a type of carbon…hmm… However, I cannot explain how they formed. I do

> not know, but carbon should be reach to the water since there are cyano-bacteria in the lake perform photosynthesis which require CO_2. Thus, carbon is present in the water. Maybe, during respiration fish releases CO_2 and cyano-bacteria use that CO_2, but I am not sure."
>
> Interviewer: "How humans use carbon?"
>
> Melisa: "We burn fossil fuels, when we burn fossil fuels while using cars and planes which releases CO_2 to the air. Moreover, we use fossil fuels factories and our houses as well. All these actions release CO_2 to the air.
>
> Interviewer: "What makes carbon to move in all this action?"
>
> Melisa: "I think it is about carbon's tendency to make bonds with other elements. For example, In the water, carbon reacts with the water, I cannot explain what happens when they react. On the other hand, this tendency of making bond with other elements make carbon move."

It was observed that Melisa could be able to identify the sub cycle (a) which describe exchange of carbon among the terrestrial system pool and the atmosphere. She recognized the exchange of carbon from *air [atmosphere*] to *plants* through the process of photosynthesis as in the form of CO_2 and from *plants* to *air* as in the form of CO_2. Moreover, she could be able to identify exchange of carbon through *decomposer* to *air* via the process of decomposition as in the form of methane gas. In addition, she could be able to describe the way that carbon reaches to the animals from plants through the food chain which transform carbon among the two terrestrial pools (plants-animals). On the other hand, Melisa could not be able to recognize how carbon reaches to the decomposers. Even if, she could trace carbon from decomposers to air, she had no clue concerning the way carbon reach the decomposers. In short, she could be able to identify the exchange of carbon among the sub-cycle-a which is in the terrestrial system (animals-plants) and atmosphere (CO_2) through the processes of photosynthesis, respiration and food chain. In addition, she partially identified the exchange of carbon among the decomposers and the atmosphere through the process of decomposition without referring how carbon reached to the decomposers. On the other hand, even though she added the Sun in her drawing, no energy transformation was included in her description of sub-cycle-a such as transformation of solar energy into chemical energy during photosynthesis.

Moreover, in the context of sub-cycle-b which described the exchange of carbon among the terrestrial system and the atmosphere reservoirs, Melisa could only be able to identify the partial exchange of carbon from usage of fossil fuels (in factory, plane, cars, houses) to atmosphere through the process of combustion. On the other hand, there were no exchange of carbon among the dead organisms to fossil fuels in the soil was observed. Her description included only the usage of fossil fuels and releasing of CO2 to the atmosphere without referring how carbon exchanged in the soil. Thus, she only could be able to partially describe the sub-cycle-b with no energy exchanges among the different carbon reservoirs such as chemical energy to thermal.

In addition, she was aware that carbon should be exchanged among the atmosphere and the hydrosphere (lake) in the sub-cycle-c. However, she could not be able to describe the way of carbon through atmosphere to the lake and vice versa referring to the process of diffusion. Although she identified the processes such as photosynthesis and respiration in the lake, it seemed that she could only be able to describe the exchange of carbon in hydrosphere as a separate cycle, with no interaction with the atmosphere. In addition to exchange of carbon among the carbon reservoirs, Melisa could not describe any energy exchanges among the hydrosphere and atmosphere including solar energy turns into chemical and kinetic energy turns into potential; potential energy turns into kinetic.

Moreover, sub-cycle-d which considers the exchange of carbon and energy among the different reservoirs of terrestrial system, hydrosphere and the atmosphere could not be observed. Even if she identified the seashells as a component in the hydrosphere which the shells made up of cellulose, Melisa could not be able to track it [carbon in the cellulose] in the water referring to the process such as dissolution of CO2 in the atmosphere and formation of seashells which then go deep in the water to form surface layer consisting of sediments (organic materials). In addition, she could not be able to describe any energy exchanges among the various reservoirs of the sub-systems carbon cycle such as gravitational potential energy (e.g. sediments and water) turns into kinetic; geothermal energy powers plate tectonics which transferred to atmosphere and the space.

In brief, Melisa could be able to identify the sub-cycle-a which describes the exchange of carbon among the terrestrial system (plant-animal, decomposers) and the atmosphere (CO2, methane) with referring the processes of photosynthesis, respiration, food chain, and decomposition. On the other hand, she could not describe how carbon reaches to the decomposers. Since the processes in the soil was absent, she could not be able to define any exchanges of carbon including the soil. In addition, there were no energy exchange described in her interview concerning the sub-cycle-a. Moreover, she could be able to partially describe how carbon exchanged among the reservoirs of the considering the sub-cycle-b by identifying the exchange of carbon from the fossil fuels to the air as in the form of CO2. However, there were no energy exchange described in the sub-cycle-b. Additionally, it was observed that she was aware that carbon should be exchanged among sub-cycle-c located in the hydrosphere and atmosphere, but failed to describe how carbon exchanged occurred with referring the process of diffusion. Although she could be able to identify processes such as photosynthesis and respiration, she could not be able to define how carbon exchanged among atmosphere and the hydrosphere. In addition, no energy exchange among the atmosphere and hydrosphere was obtained. Moreover, it was seemed that she could not be able to describe the sub-cycle-d which describes the carbon and energy exchange among the terrestrial system, hydrosphere and the atmosphere. Therefore, since she could be able to partially describe exchange of carbon in the sub-cycle-a-b-c without referring any energy exchanges, she classified as developing level for the STS-5 (See rubric in Table 3.2).

4.2.2.6. STS-6-The ability to recognize hidden dimensions of the system

In this level, recognizing the hidden dimensions of the carbon cycle system were analyzed. In the context of this study, hidden dimensions in the carbon cycle were considering as the recognizing connections among the different Earth cycles at multiple scales including macroscopic and microscopic. Therefore, in this level, interrelationships among the Earth cycles were analyzed through the interview questions and drawings.

Interviewer: “Is there any relationship among the carbon cycle and the other Earth cycles?”

Melisa: “I think carbon cycle is related with the water cycle. I am not sure, but in photosynthesis, plants use water as well as CO2. However, I cannot explain what happens after. On the other hand, I can say there is a relationship between carbon cycle and water cycle.”

Interviewer: “Do you want add anything to the question?”

Melisa: “All the cycles are related. Carbon cycle-water-cycle-nitrogen cycle, they are all related. However, I have not considered how they related until now.”

It was observed that Melisa was tried to describe the relationship among carbon cycle and water cycle at microscopic scale with referring the molecule movements in the carbon cycle. However, she struggled recognize the water and carbon movement across the carbon cycle although she identified lake as a component in the water cycle. In addition, any relationship concerning the macroscopic scale which includes carbon across terrestrial system, hydrosphere and atmosphere could not be identified. In addition, although she was aware that all the Earth cycles related to each other, she was not able to describe any apart from the relation between carbon cycle and water cycle. Hence, she was only aware of connections among the cycles of the Earth but could not be able to recognize them at multiple scales. Therefore, Melisa was classified as emerging level for the STS-6 (See Rubric in Table 3.2).

4.2.2.7. STS-7-The ability to make generalizations

In this level, ability to make generalization within the carbon cycle system were analyzed. In the context of carbon cycle, this ability implemented on discussing the how today’s environmental problems emerged referring to the current imbalances among the processes within the carbon cycle’s sub-systems including terrestrial system, hydrosphere and atmosphere. In this level, participant’s ability to identify feedback mechanisms on explaining the current imbalances among the carbon cycle when discussing environmental issues were investigated. According to the her answers, she was classified as pre-aware, emerging, developing or mastery.

> Interviewer: "What can you say when I want you to talk about the climate change?"
>
> Melisa: "Climate change is caused by the greenhouse gases. When green house gases accumulated in the atmosphere, the atmospheric temperature rises. After that, shifts in climate will be observed."
>
> Interviewer: "Is there any relationship between climate change and the carbon cycle?"
>
> Melisa: "Of course, there is. The component of climate change is the components of carbon cycle as well. For example, trees do photosynthesis which removes CO2 from the air. In that way, they slow down the global warming, which helps to deal with climate change."

It was seemed that Melisa could be able to identify climate change over the two-subsystems of the carbon cycle including terrestrial system (plants) and atmosphere (CO_2) via the process of photosynthesis. On the other hand, the climate change and global warming were not discussed through the imbalances of processes in the carbon cycle. Moreover, she was only able to define one-way-cause and effect relations instead of feedback mechanisms such as greenhouse gases *causes* rise in *atmospheric temperature* which results in *climate change* and removing CO2 from the air by photosynthesis *causes* slowing down global warming which *leads to* deal with climate change. The one-way casual relationships did not include how climate change in turn effects the system components. Therefore, Melisa could not be able to identify the feedback mechanisms among the all three sub-systems of carbon cycle that leads to the current imbalance of the carbon cycle processes which then results to climate change. Hence, she was classified as emerging for the STS-7.

4.2.2.8. STS-8- The ability to think temporally: retrospection and prediction

In the context of the carbon cycle, this level means that understanding that past is the key to explain the present state of the system while the present is to key to understand the future. Such understandings could be implemented in cases such as industrial revolution effect on the increasing concentration of CO_2 throughout the decades or predict consequences of population growth on the CO_2 concentration in the atmosphere for the upcoming ages.

This level was analyzed by the interview questions. According to the answers, she was classified as pre-aware, emerging, developing or mastery.

> Interviewer: "What is the effect of humans on the carbon cycle?"
>
> Melisa: "We [humans] affect the carbon cycle negatively. For example, global warming always warmed the Earth. However, especially with the industrial revolution, humans released carbon included gases such as CO2 to the air which increases the rate of global warming. In addition, with the increasing demands and reliance of humans on technology and industrial products, in the future, I think we [human] will face more dangerous consequences of global warming and hence climate change."

It was observed that Melisa could be able to describe global warming by referring all time spans- including past-present and future. She could be able to explain the present situation of the global warming is caused by the industrial revolution consequences such as releasing excessive amount of CO2 to the air in the past. In addition, she predicted the future of the system by describing the more severe consequences of global warming based on today's increasing demand to the industrial products. Therefore, since she was able to identify the all three-time spans (past, present and future), she was classified as mastery level for the STS-8.

4.2.3. Melisa's Definition of System

Melisa's description of system included the properties interactions of components among the system. She mentioned that a system should be dynamic and cyclic while explaining the carbon cycle as a system. The description of a system according the Melisa is given in below.

> "Systems includes web of interactions among its components. For example, considering the carbon cycle, the components of the cycle are in interaction. Moreover, a system like carbon cycle should define a cycle with no end or starting point [*cyclic*] as well as the movement of material among its components [*dynamism*]"

4.2.4. Melisa's Summary of Systems Thinking Skills

Melisa was the only participant who classified as mastery level for a system thinking skills (STS-8). She classified as developing level for the STS-1, STS-2, STS-3, STS-4, STS-5 concerning the system thinking abilities in the carbon cycle. On the other hand, considering the other system thinking skills (including STS-6, STS-7), she was classified as emerging level. The description of system definition she gave revealed that she had a system understanding considering the system thinking with referring the interactions, dynamism and cyclicality in the carbon cycle. She could be able to implement her understanding of system to the carbon cycle context in a degree. Summarization of Melisa's system thinking analysis were presented in the Table 4.16.

Table 4.16

Summary of Melisa's System Thinking Levels

System Thinking Skills	Level
STS-1- The ability to identify the components of a system and processes within the system	Developing
STS-2- The ability to identify simple relationships between or among the system's components.	Developing
STS-3- The ability to identify dynamic relationships within the system.	Developing
STS-4 The ability to organize the systems' components, processes, and their interactions, within a framework of relationships.	Developing
STS-5 The ability to identify cycles of matter and energy within the system—the cyclic nature of systems.	Developing

Table 4.16 (cont'd)

System Thinking Skills	Level
STS-6 The ability to recognize hidden dimensions of the system.	Emerging
STS-7 The ability to make generalizations	Emerging
STS-8 The ability to think temporally: retrospection and prediction.	Mastery

4.3. Case 3: Mehtap

4.3.1. Mehtap's Demographic Data

Mehtap is 25-year-old senior student from elementary science education department in the one of the well-known universities in the Turkey. She grown up and currently live in one of the major cities of Turkey.

Mehtap passed all the courses which are mandatory in the undergraduate curriculum including organic chemistry, analytic chemistry, biology, physiology, physics, geology and environmental education. In addition, she took one elective course related to sustainability.

4.3.2. Mehtap's System Thinking Skills

Mehtap's system thinking levels were analyzed according to answers given to the three data collection tools which are interviews, drawings and concept map. Results were presented for each system thinking level.

4.3.2.1. STS-1 Identify system components and processes within the system

In this level, it is expected from participants to identify the components and processes within the Carbon Cycle. This level is analyzed accordingly with the data obtained from the interviews and drawing in terms of three categories that is described in the context of carbon cycle as the atmosphere, the hydrosphere and the terrestrial system. The drawing that Mehtap draw were presented in the Figure 4.5.

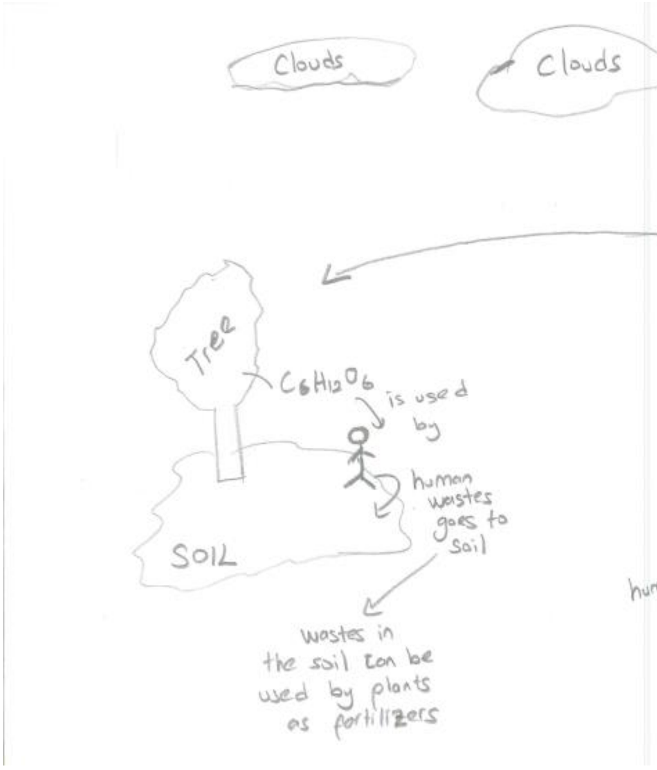

Figure 4.5. Mehtap's Drawing of Carbon Cycle

It was observed that Mehtap was able to identify nine components related with the terrestrial system. In addition, she identified one component related with the atmosphere. On the other hand, she could not be able to any components related with the hydrosphere. Therefore, since she could be able to identify multiple components only on the terrestrial system, she classified as emerging level for the identifying components within the carbon cycle. A brief summary of the components that Mehtap identified was categorized and listed in the Table 4.3.2.1.1.

Table 4.16

Identified components within the carbon cycle by Mehtap

Categories	Components within carbon cycle		Number of components
Terrestrial System	Plant, soil, fertilizers, decomposers tree, glucose [food],	fossil fuels, humans, animals, animal waste,	9
Hydrosphere System	-		-
Atmosphere	carbon dioxide		1

> Interviewer: "What are the components of the carbon cycle?"
> Mehtap: "In the carbon cycle, we can say plants, humans, animals, decomposers and CO_2 as components. Other than that, we can talk about fertilizers and fossil fuels in the soil."

The first level of system thinking model encompasses the ability to identify processes of carbon cycle as well as its components. The processes were analyzed on where they were identified on including terrestrial system, hydrosphere or atmosphere, which are the sub-systems of carbon cycle.

When it is asked about the processes in the carbon cycle, she identified the processes both on interview and drawing. The processes she identified were listed in Table 4.17.

Table 4.17

Identified processes within the carbon cycle by Mehtap

Category	Processes within the Carbon Cycle
Terrestrial System	Photosynthesis, respiration, decomposition, food chain, digestion, combustion
Hydrosphere system	-
Atmosphere	-

> Interviewer: "Can you identify the processes within the carbon cycle?"
>
> Mehtap: "plants produce food during photosynthesis. Moreover, animals use that food and do respiration which [animal] waste is produced… [In addition,] when they [animals] die, animals are consumed by the decomposers. I think, that is all I can define for now."

It was obtained that Mehtap identified six processes concerning the terrestrial system. However, she could not be able to identify any processes related with the hydrosphere and the atmosphere. Because she was able to identify processes only on terrestrial system, she was classified as emerging level for ability to identify processes in the carbon cycle.

In conclusion, it was observed that Mehtap was only concentrated on the terrestrial system with identifying nine components and six processes. However, she could not be able to identify any components and processes related with hydrosphere and atmosphere parts of the carbon cycle. Therefore, Mehtap was classified as emerging level for the STS-1. A summary table that include Mehtap's ability to identify both processes and components within the system was presented in the Table 4.18.

Table 4.18.

Mehtap's ability to identify components and processes within the Carbon Cycle

System Thinking Level	Categories			Level
STS-1- Ability to identify components and processes within the system.	Terrestrial System	Hydrosphere	Atmosphere	Emerging level-identified components and processes includes only on one sub-system of the carbon cycle.
Components of the carbon cycle	Plant, tree, glucose [food], humans, animals, animal waste, fossil fuels, soil, fertilizers, decomposers	-	carbon dioxide,	emerging—identified multiple components includes only on one sub-system of the carbon cycle.

Table 4. 18 (cont'd)

Processes of the carbon cycle	Photosynthesis, respiration, decomposition, food - chain, digestion, combustion	emerging—identified processes includes only on one sub-system of the carbon cycle.

4.3.2.2. STS-2 The ability to identify relationships among the components within the system

In this level, it is expected from participants to identify the relationships among the components within the carbon cycle. The relationships analyzed on three categories such that include interactions of terrestrial, hydrosphere and atmosphere systems of the carbon cycle with investigating casual relationship among the components which is a system characteristic. Interview questions were used to analyze the second system thinking skill. According to the answers, she was classified as pre-aware, emerging, developing or mastery. A brief summary of Mehtap's ability to identify relationships among the components of the carbon cycle were presented in the Table 4.19.

Detailed analysis of the interviews was presented in the following part. The responses Mehtap gave during the interview revealed that she considered the terrestrial part of the carbon cycle while identifying two relationships. In addition, relationships considering the in between terrestrial system and atmosphere (3) was observed which including one causal relationship among the human, fossil fuels, CO_2. On the other hand, she could not be able to any relationships including hydrosphere system.

> Interviewer: "What are the relationships among components in the carbon cycle?"
>
> Mehtap: "All the components of the carbon cycle are related with each other. For example, plants take CO_2 from do atmosphere and do photosynthesize. In addition, animals take food [glucose] from the plants and do respiration. In addition, animals produce waste when they digest food. Moreover, when animals die, decomposers consume them [animals]. I cannot remember what happens after. However, I remember that when they die, the become fertilizers for other plants. In addition, we [humans] uses fossil fuels which causes the increase in CO_2 level [in the atmosphere]"

It was obtained that Mehtap could be able to identify only one cause and effect relationship among the terrestrial system components (humans) and atmosphere over the process of combustion of fossil fuels as a cause to increase in the level of CO2 in the atmosphere.

Table 4.19

Mehtap's Ability to Identify Relationships Among the Components within the Carbon Cycle

STS Level	Relationships	Level
STS-2 Ability to identify relationships among the components within the system		Developing Level--- Relationships identified among two sub-systems including terrestrial system and the atmosphere referring a cause and effect relationship.
Among the terrestrial system components	plants, animals, glucose (food)	Linear relationships identified over the process food chain.
		Did not include cause and effect relationships.
	animals, animal waste, soil, decomposers	Linear relationships identified over the processes of digestion, burial, decomposition.
		Did not include cause and effect relationships.

Table 4.19 (cont'd)

Among the hydrosphere components	-	-
Among the atmosphere components	-	-
Among Terr. System and the atmosphere components	- plants, atmosphere, CO_2, atmosphere, glucose (food)	Linear relationships identified over the processes of photosynthesis Did not include cause and effect relationships among the components.
	- animals, humans, CO_2.	Linear relationships identified over the processes of respiration. Did not include cause and effect relationships.
	- human, fossil fuels, CO_2	Linear relationships identified over the processes of anthropogenic combustion (cars, factory) referring a cause and effect relationship which anthropogenic use causes an increase level of CO_2 in the atmosphere.
Among the Terr. System and hydrosphere components	-	

Table 4.19 (cont'd)

Among the hydrosphere and the atmosphere components	-
Among Terr. System- the Hydrosphere and the atmosphere components	-

In addition, it was observed that Mehtap only concentrated on the relationships among the terrestrial system and the atmosphere. She was identified a relationship among terrestrial system (plants, animals) and the atmosphere (CO_2) through the process of photosynthesis and respiration. In addition, she identified relationship among terrestrial system components (plants, animals, glucose (food)) through the process of food chain. In addition, she related terrestrial system components (animals, animal waste, soil, decomposers) over the processes of digestion, burial and decomposition. On the other hand, she could not be able to identify any relationships considering the relationships among hydrosphere and atmosphere as well as the relationships among the all three-sub-systems. Therefore, since she could be able to identify relationships considering among the terrestrial system components and between terrestrial system and atmosphere encompassing one casual relationship, she classified as developing level for the STS-2 (See Table 4. 19).

4.3.2.3. STS-3 Identifying Dynamic Relationships in the System

In this level, dynamic relationships within the carbon cycle were investigated. In the context of the study, dynamism interpreted as identifying carbon fluxes among the carbon pools which includes transportation and transformation of carbon through the sub-systems of the carbon cycle. Therefore, this level analyzed via the transportation and transformation carbon among the carbon pools that are classified into sub-systems of the carbon cycle including the terrestrial system, the hydrosphere and the atmosphere. The third system thinking which is identifying dynamic relationship in the system were analyzed over the interview questions. According to the answers, she was classified as pre-aware, emerging, developing or mastery.

The analysis demonstrated that Mehtap identified dynamic relationships on the among the terrestrial carbon pools (animals, plants) and the atmosphere. In addition, she identified dynamic relationships among the terrestrial system pools as well. On the other hand, she could not be able to identify any dynamic relationships related with the atmosphere and hydrosphere pools. A brief summary of Mehtap's ability to identify relationships among the components of the carbon cycle were presented in the Table 4.20.

Table 4.20

Mehtap's Ability to Identify Dynamic Relationships Among the Components of the Carbon Cycle

STS Level	Relationships	Level
STS-3 Ability to identify dynamic relationships among the components within the system		- Emerging Level--- Relationships identified among two sub-systems including terrestrial system pools and the atmosphere focusing mainly on transportation of carbon without referring transformation of carbon explicitly.
Among the terrestrial system components	- Plants-animals	- Identified over the process of food chain, referring the transportation of carbon from plants to animals.
	- Animals-soil-decomposers	- Identified over the process of digestion, burial and decomposition referring only the transportation of carbon from animals to soil.
Among the hydrosphere components	-	-

Table 4.20 (cont'd)

Among the atmosphere components	-	-
Among Terr. System and the atmosphere components	- CO_2 in the atmosphere-Plants	Identified over the process of photosynthesis, referring the transportation of carbon from atmosphere to plants
	- Animals-CO_2 in the atmosphere	Identified over the process of respiration, referring the transportation of carbon from animals to atmosphere.
Among the Terr. System and hydrosphere components	-	-
Among the hydrosphere and the atmosphere components	-	-
Among Terr. System- the Hydrosphere and the atmosphere components	-	-

The table demonstrated that Melisa could be able to identify dynamic relationships in between terrestrial system carbon pools (plants, animals) and atmosphere through the processes of photosynthesis and respiration. The dynamism she identified among the terrestrial system and atmosphere pools was only included transportation of carbon. Moreover, she was able to identify dynamic relationships concerning the terrestrial system pools (plants, animals, soil and decomposers). In addition, she referred transportation of carbon in the terrestrial system among plants and animals and, animals and soil except for transportation in the soil including decomposers. On the other hand, she was not able to identify transformation of carbon in the terrestrial system carbon pools. In addition, she was not able to define any dynamic relationships considering atmosphere and hydrosphere pools. The analysis continued with the interview questions investigating the dynamic relationships among the carbon pools that Mehtap defined in the STS-1.

> Interviewer: "What happens to carbon in the atmosphere?"
>
> Mehtap: "I do not know. I think it can be used by the plants in the photosynthesis as in the form of CO_2. That's all I can say."
>
> Interviewer: "What happens to carbon in the plants?"
>
> Mehtap: "Plants do photosynthesize with using CO_2 in the air. However, I do not know what happens to carbon in plants."
>
> Interviewer: "What happens to carbon in animals?"
>
> Mehtap: "Animals perform respiration which releases CO2 to the atmosphere. Moreover, they [animals] digest the food obtained from the plants and produce wastes which goes to here [soil]."
>
> Interview: "What happens carbon in soil?"
>
> Mehtap: "There are decomposers in the soil. They take the carbon to decompose the materials in the soil."
>
> Interview: "Then, what happens to carbon in decomposers?"
>
> Mehtap: "When animals die, decomposers consume them [animals] in the soil. I think they transform carbon into something else which can participate the cycle again. However, I cannot explain how or what happens."

It was observed that Mehtap could be able to identify the dynamic relationship in between terrestrial system and the atmosphere with referring transportation of carbon during respiration.

On the other hand, she could not be able to identify transformation of carbon in animals through carbon in the glucose to carbon in the CO_2. Moreover, it was observed that Melisa was able to identify dynamic relationships referring transportation of carbon among the terrestrial carbon pools plants and animal via the process of food chain In addition, she could be able to identify dynamism in the animals and soil through the process of digestion which produce wastes referring transfer of carbon in the terrestrial system. Therefore, she identified dynamic relationship among the terrestrial system (animals) and atmosphere pools through the process of respiration with referring transportation of carbon. In addition, dynamism among the terrestrial system pools; plants and animals via food chain and animals and soil via the processes of digestion which she only referred the transportation of carbon.

It was observed that Mehtap was able to identify the dynamic relationship between the terrestrial pools, animals and soil via the process of burial with referring the transportation of carbon. Moreover, she identified dynamism between decomposers soil via the process of decomposition in the soil. On the other hand, even if she was aware that carbon should be transformed and transferred in the soil, she was not able to explain how it occurred. Therefore, she was able to identify the dynamism among animal, soil and decomposers via the processes of burial and decomposition with referring only the transportation of carbon through animals to soil in the terrestrial system.

In brief, it was observed that Mehtap could be able to identify dynamic relationships between the carbon pools including two-sub-systems, terrestrial system and the atmosphere. She identified dynamism between plants and atmosphere over the process of photosynthesis. In addition, she defined dynamism between animals and atmosphere via the process of respiration. On the other hand, while she identified the dynamism among the terrestrial system pools and the atmosphere, she was only able to identify the transportation of carbon without noticing transformation of carbon among these pools. Moreover, she could be able to identify dynamic relationships among terrestrial pools. She identified dynamism among the plants and animals via the process of food chain with referring transportation of carbon. In addition, she defined dynamism among animal-soil and decomposers via the processes of burial and decomposition with referring only the transportation of carbon in the soil. On the other hand, she could not be able to identify the transformation of carbon among the animals-decomposers and soil. Therefore, since she was able to identify dynamic relationships between the terrestrial system and atmosphere pools with referring only transportation of carbon, she was classified as emerging level for the STS-3.

4.3.2.4. STS-4 Organizing the systems' components, processes, and their interactions, within a framework of relationships

In this level, organizing the components and processes of carbon cycle within a framework of relationships were intended to analyze. Therefore, it is important to underlie the connections among more than two components for organizing the components and processes and their interactions within a framework which describe a carbon cycle system. Therefore, this level was analyzed through the concept maps which investigates the interactions among the carbon cycle parts. In this level, it was asked participant to write the 12-words concerning carbon and to draw a concept map that relates the concepts to each other.

> Interviewer: "What comes in your mind when I say carbon?"
>
> Mehtap: "I can say when we talked about carbon, we should say coal which causes CO poisoning in people. Moreover, when we burn coal, CO_2 released to the atmosphere. Moreover, we can say carbon cycle. In addition, organic chemistry interested in the carbon which the life we know based on the carbon."
>
> Interviewer: "Can you draw a concept map that relates those concepts to each other?"

The concept map she had drew was presented in the Figure 4.6.

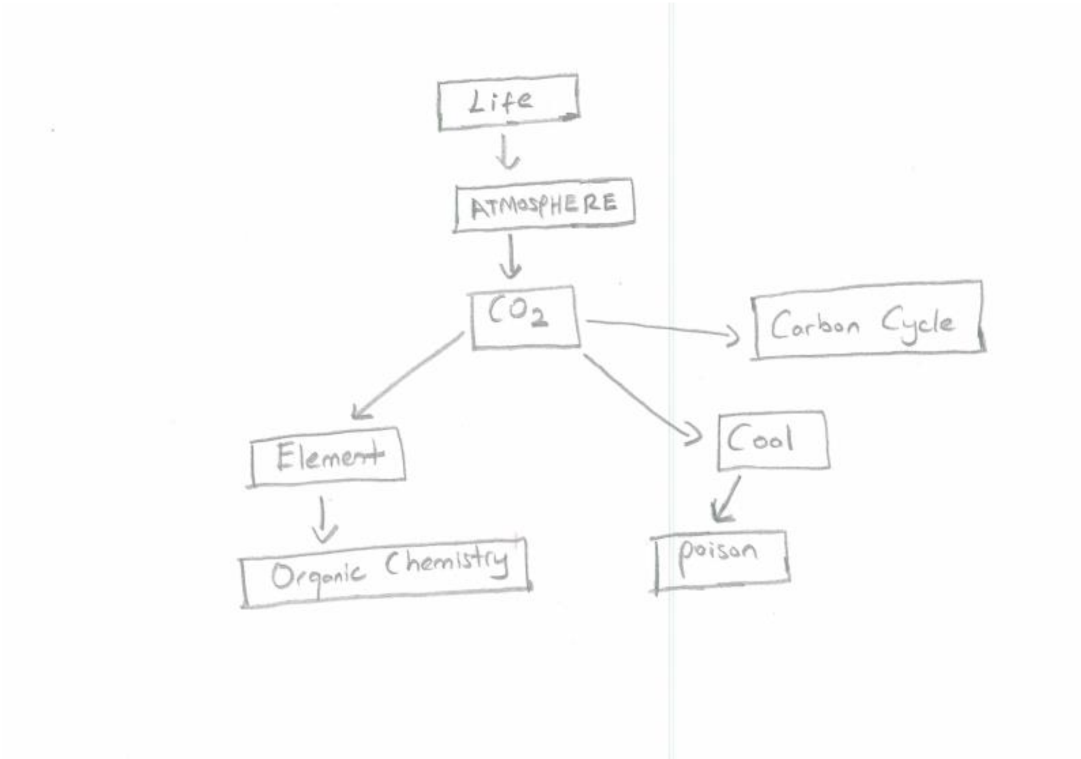

Figure 4.6. Mehtap's Concept Map

It was observed that Mehtap identified only one concepts (CO_2) were related to more than two concepts in the concept map. She related CO_2 with the carbon cycle but could not be able to describe the relationship. It was observed that she identified two concepts related with the atmosphere as well as two components in the terrestrial system. On the other hand, no concepts related with the hydrosphere could be identified. Moreover, her map mainly based on relating pairs of concepts (2-concepts) which was inadequate to form a framework with missing any cross-sectional arrows. The concepts that she discussed in the concept map was summarized in the Table 4.21.

Table 4.21

Mehtap's ability to the systems' components, processes, and their interactions, within a framework of relationships

Dimensions within the concept map	Examples	Number of the concepts
Terrestrial system	Coal, CO Poisoning (caused by coal),	2
Atmosphere	CO_2, atmosphere	2
Hydrosphere	-	-
Miscellaneous	elements, organic chemistry, carbon cycle, life	5
Processes	-	-
Concepts related more than two concepts	CO_2	1

The interactions among the concepts were limited only with the atmosphere and terrestrial system without describing any processes or relationship. Therefore, since there were no indication of processes and relationships among the concepts, she was classified as pre-aware in organizing carbon cycle' components, processes, and their interactions, within a framework of relationships (See the Rubric in Table 3.8.1).

4.3.2.5. STS-5 Understanding the cyclic nature of the systems

In this level, participant's understandings of cyclic nature of the carbon cycle system were analyzed. Therefore, in this context, participant's understanding of matter and energy exchanges via transformation of carbon and energy among the four-sub-cycles located in the sub-systems of the carbon cycle was examined. This level was analyzed by the interview questions and the drawings. According to the answers, she was classified as pre-aware, emerging, developing or mastery.

The drawing that Mehtap drew was presented in the Figure 4.5 (See p. 107).

The components and the processes in the drawing was summarized in the Table 4.22.

Table 4.22

Components and Processes Identified by Mehtap in Her Drawing

Sub-systems of Carbon cycle	Components	Processes
Terrestrial system	Animal, human, tree, $C_6H_{12}O_6$ (glucose), soil, human waste, decomposers, fertilizers	Photosynthesis, respiration, decomposition, digestion
Atmosphere	CO_2, clouds (to represent atmosphere)	-
Hydrosphere	-	-

In the drawings, it was observed that Mehtap mainly identified terrestrial system components with eight components. Moreover, she identified two components with the atmosphere.

The exchange of carbon among the carbon pools were observed encompassed the terrestrial system and the atmosphere. Apart from that exchange of carbon between plants and atmosphere, the carbon exchange among the other carbon pools were described a complete flow which carbon was tracked through identified components in terrestrial system and atmosphere. On the other hand, she could not be able to identify any components related with the hydrosphere part of the carbon cycle. Moreover, apart from CO_2 and clouds, she could not be able to identify any atmosphere components as well. Therefore, her drawing revealed lack of cyclic understanding considering the exchange of carbon among the three-sub-system of the carbon cycle by ignoring hydrosphere part.

Two interview question was asked to investigate whether the participant hold a cyclic perception considering the carbon cycle.

> Interviewer: "Is there a starting point for the carbon cycle?"
>
> Mehtap: "I think there should be no starting point for the carbon cycle. If we consider the evolution, first there were bacteria on the Earth, then animals and plants were evolved. Thus, maybe starting point is the formation of bacteria who perform photosynthesis. Then, other processes take place such as respiration, decomposition etc."
>
> Interviewer: "Is there an end point for the carbon cycle?"
>
> Mehtap: "I think, there is not [an end point for the carbon cycle]. For example, when people die, their carbon goes to the soil. After, the carbon goes to other components as well. That describe a cycle with no end points, carbon always move one component to another."

It was observed that Mehtap tried to identify starting point for the carbon cycle by underlying the early stages of carbon cycle with photosynthesis and following processes such as respiration and decomposition. In addition, she was aware that carbon was always a dynamic state in the carbon cycle among the components which defines a cycle with no end points. Therefore, she demonstrated a cyclic perception concerning the carbon cycle with referring early stages of the carbon cycle (Batzri et al., 2015).

The analysis of this level continued with the interview questions that analyzed the exchange of carbon and energy among the four-sub-cycles of the carbon cycle system.

> Interviewer: "How carbon reaches to the atmosphere?"
>
> Mehtap: "Carbon reaches to the atmosphere in the form of CO_2 as a product to the process of respiration. Other than that, we [humans] release CO_2 to the atmosphere while driving cars."
>
> Interviewer: "How carbon reaches to the plants?"
>
> Mehtap: "plants take carbon from the atmosphere in the form of CO_2. Then, they [plants] perform photosynthesis."
>
> Interviewer: "How carbon reaches to the animals?"
>
> Mehtap: "They [animals] take food through the plants and digest it [food].
>
> Interviewer: "How carbon reaches to soil?"
>
> Mehtap: "When animals die, they [(dead) animals] accumulate in the soil. Then, decomposers break down the (dead) animals which then, maybe, fertilizers formed and helps other plants to grow. After that, animals and humans eat those plants, and the cycle continues. However, I cannot describe what happens in the soil excepting for decomposition."
>
> Interviewer: "What makes carbon to move in all this action?"
>
> Mehtap: "I do not know. However, I have not thought about it."

It was observed that Mehtap was able to consider the sub-cycle-a which describes the exchange of carbon and energy between the terrestrial system and the atmosphere. She identified exchange of carbon between plants, animals, soil, decomposers and the atmosphere, over the processes of food chain and respiration, which describes the flow of carbon among the plants to animals as in the form of glucose, and then, identified CO_2 release by respiration in animals. Besides, she identified digestion of glucose which produces waste and carbon movement into the soil. On the other hand, release of carbon by decomposition process could not be described. In addition, even though she identified the carbon exchange between plants and atmosphere over the processes of photosynthesis partially which CO_2 up taking through photosynthesis, carbon release from plants to atmosphere via respiration in plants was missing in her drawing.

In addition, energy transformation was not included in her description of sub-cycle-a such as transformation of solar energy into chemical energy during photosynthesis.

In addition, considering the sub-cycle-b, she was only able to identify dead animals (organism), decomposers in soil. On the other hand, although she was aware decomposition process and accumulation of carbon in the soil, she was not able to describe how carbon exchanged among reservoirs the in the soil. Therefore, even if she was aware that there is a carbon movement in the soil, she could not be able to describe how carbon movement occurs. In addition, she did not mention any energy exchanges among the reservoirs of the sub-cycle-b.

Additionally, she was not able to identify any reservoir related with sub-cycle-c that describes energy and carbon exchange among the atmosphere and the hydrosphere. In addition, she did not identify sub-cycle-d which describes the energy and carbon exchange among terrestrial system, atmosphere and the hydrosphere. Therefore, since she was only able to partially identify the sub-cycle-a with no referring the energy transformations, she was classified as emerging level for the STS-5 (See Rubric in Table 3.2.).

4.3.2.6. STS-6-The ability to recognize hidden dimensions of the system

In this level, recognizing the hidden dimensions of the carbon cycle system were analyzed. In the context of this study, hidden dimensions in the carbon cycle were considering as the recognizing connections among the different Earth cycles at multiple scales including macroscopic and microscopic. Therefore, in this level, interrelationships among the Earth cycles were analyzed through the interview questions and drawing.

> Interviewer “Is there any relationship among the carbon cycle and the other Earth cycles?”
>
> Mehtap: “I think, all the Earth cycles should be related…hmm…but I cannot explain, how they are related.”
>
> Interviewer: “Can you give an example?”
>
> Mehtap: “I do not know. I think I cannot explain.”

It was observed that Melisa was aware connections among the Earth cycles. However, no Earth cycles rather than carbon cycle was identified. In addition, no indication related with the other Earth cycles were found in her drawing. Moreover, she could not be able to identify any relationship among the various Earth cycles at the multiple levels at microscopic and macroscopic levels. Therefore, she was classified as emerging level for the STS-6.

4.3.2.7. STS-7-The ability to make generalizations

Ability to make generalization within the carbon cycle system were analyzed in this level. In the context of carbon cycle. This level means discussing the how today's environmental problems emerged referring to the current imbalances among the processes via feedback mechanisms within the carbon cycle's sub-systems including terrestrial system, hydrosphere and atmosphere. Thus, participant's ability to identify feedback mechanisms on explaining the current imbalances among the carbon cycle when discussing environmental issues were investigated. According to the answers, she was classified as pre-aware, emerging, developing or mastery.

> Interviewer: "What can you say when I want you to talk about the climate change?"
>
> Mehtap: "It [climate change] is a shift in the climates on the Earth. For example, excessive release to CO_2 to the atmosphere rises the temperature of the atmosphere which causes glacier meltdown. When glaciers meltdown, climate is shifted"
>
> Interviewer: "How glacier meltdown causes climate change?"
>
> Mehtap: "hmm…somehow it [glacier meltdown] causes climate change. No, I cannot explain how."
>
> Interviewer: "Is there any relationship between climate change and the carbon cycle?"
>
> Mehtap: "Yes, there is. On the other hand, I cannot be sure on how they are related."

It was observed that Mehtap was aware the relationship between the climate change and the carbon cycle. On the other hand, she was not able to describe any relationship concerning climate change and the carbon cycle.

Moreover, the climate change could not been discussed by referring the current imbalances of the carbon cycle via referring the feedback mechanism. It was observed that she was only able to identify one-way-cause and effect relationship among terrestrial system and the atmosphere by emphasizing the excessive release of CO_2 to the atmosphere as a cause for the atmospheric CO_2 level rise which causes the glacier meltdown which causes the climate change. On the other hand, she was not able to explain how glacier meltdown causes the climate change. Moreover, how the components or the processes in the carbon cycle effects in turn was missing in her answer. Therefore, Mehtap could not be able to identify the feedback mechanisms among the all three sub-systems of carbon cycle that leads to the current imbalance of the carbon cycle processes which then results to climate change. Hence, she was classified as emerging for the STS-7 (See Rubric in Table 3.8.1).

4.3.2.8. STS-8- The ability to think temporally: retrospection and prediction

This level means that understanding that past is the key to explain the present state of the system while the present is to key to understand the future. Such understandings could be implemented in cases such as industrial revolution effect on the increasing concentration of CO_2 throughout the decades or predict consequences of population growth on the CO_2 concentration in the atmosphere for the upcoming ages. In the context of carbon cycle, this level was analyzed by the interview questions. According to the answers, she was classified as pre-aware, emerging, developing or mastery.

> Interviewer: "What is the effect of humans on the carbon cycle?"
>
> Mehtap: "Since the industrial revolution, we [humans] effect carbon cycle in a negative way. We [humans] released too much carbon since the beginning of industrial revolution by industrial activity. They [humans] released large amounts of CO2 to the atmosphere which causes the rise in the atmospheric CO2 levels and hence, [results in] climate change."

It was observed that Mehtap could be able to think retrospectively on the carbon cycle which she described the consequences of industrial revolution on increasing CO2 level in atmosphere.

It was obtained that she explained the current phenomena (climate change) is caused by a past event (excessive CO2 release since the industrial revolution). Therefore, since she was able to identify two-time spans (past-present) in the carbon cycle while explaining the climate change, Mehtap was classified as developing level for the STS-8.

4.3.3. Mehtap's Definition of System

Mehtap's description of system included the properties interactions of components among the system. The description of a system according the Mehtap is given in below.

> "A system is formed by components and their interactions. Therefore, you need to understand the whole if one wants to understand a system completely. Considering the carbon cycle, the same is valid."

4.3.4. Mehtap's Summary of Systems Thinking Skills

Mehtap could not be classified as mastery level for any system thinking skills. She classified as developing level for the second system thinking level (STS-2) and STS-8 in the carbon cycle. On the other hand, considering the other system thinking skills (including STS-1, STS-3, STS-5, STS-6-STS-7), she was classified as emerging level. In addition, she was classified as pre- aware for the STS-4. The description of system definition she gave revealed that she had a system understanding considering the system thinking with referring the interactions in the carbon cycle. However, could not be able to implement her understanding of system to the carbon cycle context. Summarization of Mehtap's system thinking analysis were presented in the Table 4.23.

Table 4.23

Summary of Mehtap's System Thinking Levels

System Thinking Skill	Level
STS-1- The ability to identify the components of a system and processes within the system	Emerging
STS-2- The ability to identify simple relationships between or among the system's components.	Developing
STS-3- The ability to identify dynamic relationships within the system.	Emerging
STS-4 The ability to organize the systems' components, processes, and their interactions, within a framework of relationships.	Emerging
STS-5 The ability to identify cycles of matter and energy within the system—the cyclic nature of systems.	Emerging
STS-6 The ability to recognize hidden dimensions of the system.	Emerging
STS-7 The ability to make generalizations	Emerging
STS-8 The ability to think temporally: retrospection and prediction	Developing

4.4. CASE 4: BERFIN

4.4.1. BERFIN's Demographic Data

Berfin is 24 year-old senior student from elementary science education department in the one of the well-known universities in the Turkey. She currently lives in one of the major cities of Turkey.

Berfin passed all the courses which are mandatory in the undergraduate curriculum including organic chemistry, analytic chemistry, biology, physiology, physics, geology and environmental education. In addition, she took one elective course related to sustainability.

4.4.2. Berfin's System Thinking Skills

Berfin's system thinking levels were analyzed according to answers given to the three data collection tools which are interviews, drawings and concept map. Results were presented for each system thinking level

4.4.2.1. STS-1 Identify system components and processes within the system

In this level, it is expected from participants to identify the components and processes within the Carbon Cycle. The investigation of this level was conducted on the data observed throughout the interviews and drawing in terms of three categories that is described in the context of carbon cycle as the atmosphere, the hydrosphere and the terrestrial system. The main intention to perform such categorization is to understand participant's perception of carbon cycle as a complex system through components whether she could define multiple components on the three categories including terrestrial, hydrosphere and atmosphere or not. The drawing that Berfin draw was presented in Figure 4.7.

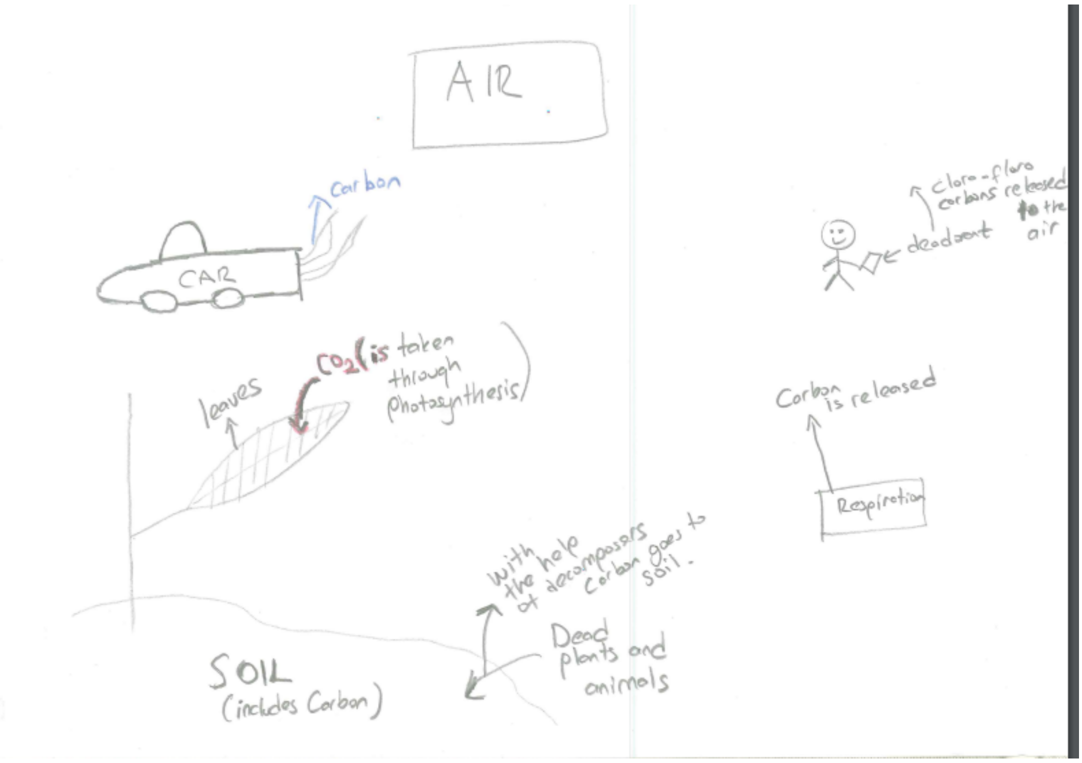

Figure 4.7. Berfin's drawing of the Carbon Cycle

A brief summary of the components that Berfin identified was categorized and listed in the Table 4.24.

It was observed that Berfin mainly focused on the Terrestrial part in the carbon cycle system (ten components). Moreover, she identified three components in the Atmosphere. On the other hand, she could not be able to identify any components related to hydrosphere. Therefore, since Berfin identified multiple components on the two sub-systems of the carbon cycle (terrestrial and atmosphere), she considered, she classified as developing level for the components of the carbon cycle system. The first level of system thinking model includes the ability to identify processes of in a system additional to its components.

Table 4.24

Identified Components within the Carbon Cycle by Berfin

Categories	Components within carbon cycle	Number of components
Terrestrial System	Plant, animals, humans, animal wastes, decomposers, soil, dead plants' and animals' wastes (dead organisms), carbon footprint, cars Deodorants (perfume)	10
Hydrosphere System	-	-
Atmosphere	carbon dioxide, cloro-floro carbons, air	3

> Interviewer: "What are the components of the carbon cycle?"
> Berfin: "When we say components, we can talk about plants, animals, decomposers as well as cars in here. Moreover, we can talk about the CO_2 and cloro-floro carbon in the air."

When it is asked about the processes in the carbon cycle, she identified the processes both on interview and drawing. The processes she identified were listed in Table 4.25.

Table 4.25

Identified Processes within the Carbon Cycle by Berfin

Category	Processes within the Carbon Cycle
Terrestrial System	Photosynthesis, respiration, combustion, decomposition
Hydrosphere system	-
Atmosphere	-

> Interviewer: "Can you identify the processes within the carbon cycle?"
>
> Berfin: "there is photosynthesis in the carbon cycle as well as respiration. These two processes are vice versa such that plants take CO2 in the photosynthesis and give out CO2 in the respiration. In addition, when we [humans] use cars, CO2 is released to the atmosphere [*combustion*]. Moreover, decomposers consume plants' and animals' wastes [*decomposition*]. These are the processes in the carbon cycle."

It was observed that Berfin identified four processes which all of them located in the terrestrial system. She was not able to identify processes related with hydrosphere system and the atmosphere. Therefore, since she could be able identify processes related with only one sub-system in the carbon cycle, she classified as emerging level for the processes.

All in all, it was observed that Berfin mainly considered the terrestrial part of the carbon cycle system with identifying nine components and four processes. In addition, she was able to identify three components related with the atmosphere. On the other hand, no processes was identified related with that sub-system. In addition, she could be able to identify neither components nor processes concerning the hydrosphere part of the carbon cycle system. Therefore, since she was only able to identify multiple components and processes covering one-sub-system (terrestrial) of the carbon cycle, she classified as emerging level for the STS-1. A summary table that include Berfin's ability to identify both processes and components within the system was presented in the Table 4.26.

Table 4.26

Berfin's Ability to Identify Components and Processes within the Carbon Cycle

System Thinking Level	Categories			Level
STS-1- Ability to identify components and processes within the system.	Terrestrial System	Hydrosphere	Atmosphere	Emerging level- identified components belonging to two-sub-systems of carbon cycle, however, identified processes only in one sub-system.
Components of the carbon cycle	Plant, animals, humans, decomposers, soil, dead plants' and animals' wastes (dead organisms), carbon footprint, cars Deodorant (perfume)	-	carbon dioxide, cloro-floro carbons, air	developing—identify components includes only in two sub-systems of carbon cycle.

Table 4.20 (cont'd)

Processes of the carbon cycle	Photosynthesis, respiration, combustion, decomposition,	-	-	emerging—identified components only in one sub-system except for the atmosphere.

4.4.2.2. STS-2 The ability to identify relationships among the components within the system

In this level, the relationships within the carbon cycle were analyzed. The relationships were investigated on the three sub-systems of the carbon cycle. The analysis of this level was concentrated on the relationships among the components that are belonging to the three sub-systems in the carbon cycle including terrestrial, hydrosphere and atmosphere with causality in the carbon cycle system. Interview questions were used to analyze the second system thinking skill. According to the answers, she was classified as pre-aware, emerging, developing or mastery. Detailed analysis of the interviews was presented in the following part. The responses Berfin gave during the interview revealed that she mainly considered the terrestrial part of the carbon cycle while identifying relationships. On the other hand, relationships considering the other parts of the carbon cycle could not be observed such as hydrosphere. In addition, she could not be able to identify any relationship including cause and effect relationship. A brief summary of Berfin's ability to identify relationships among the components of the carbon cycle were presented in the Table 4.27.

> Interviewer: "What are the relationships among components in the carbon cycle?"
>
> Berfin: "Firstly, there is a relationship between photosynthesis and respiration. Plants perform photosynthesize by taking CO_2 from the air. In addition, animals and plants do respiration which released CO_2 to the air. Moreover, while we [humans] drive cars, CO_2 is released to the air. In addition, animals' and plants' wastes are consumed by decomposers in the soil.
>
> Interviewer: "Do you want to add anything about the relationships among the components of carbon cycle?"
>
> Berfin: "No, I think that is all."

It was observed that Berfin identified relationship between the terrestrial system (plants) and the atmosphere (air, $CO_{2,}$) over taking up CO_2 form the air through the process of photosynthesis.

Table 4.27

Berfin's Ability to Identify Relationships Among the Components within the Carbon Cycle

STS Level	Relationships	Level
STS-2 Ability to identify relationships among the components within the system		Emerging Level--- Relationships identified among two sub-systems including terrestrial system and the atmosphere without referring cause and effect relationship.
Among the terrestrial system components	- soil, decomposers, dead animal and plant wastes	- Linear relationships identified over the processes of photosynthesis Did not include cause and effect relationships among the components.
Among the hydrosphere components	-	-
Among the atmosphere components	-	-
Among Terr. System and the atmosphere components	- plants, CO_2, air	Linear relationships identified over the processes of photosynthesis Did not include cause and effect relationships among the components.

	-	animals, plants, air, CO_2.	Linear relationships identified over the processes of respiration. Did not include cause and effect relationships.
	-	cars, humans, air, CO_2	Linear relationships identified over the process combustion. Did not include cause and effect relationships.
Among the Terr. System and hydrosphere components	-		
Among the hydrosphere and the atmosphere components	-		
Among Terr. System- the Hydrosphere and the atmosphere components	-		

Additionally, she identified a relationship between animals (terrestrial system) and atmosphere via releasing of CO_2 to the air through the process of respiration. Moreover, she identified relationship among human activity, driving cars, (terrestrial system) and the atmosphere via the releasing of CO_2 to the air over the process of combustion. In addition, she identified relationships among the terrestrial components (soil, decomposers, dead animal and plant wastes) via the removal of dead animals and plants in the soil by decomposers through the process of decomposition. On the other hand, she could not be able to identify any relationship considering the hydrosphere part of the carbon cycle. Moreover, no causal relationship was identified among the components of the three-sub-systems. Therefore, since Berfin was able to identify relationships among terrestrial system, and between terrestrial system and atmosphere components without referring any causality, she classified as emerging level for the STS-2 (See the Table 4.27.).

4.4.2.3. STS-3 Identifying Dynamic Relationships in the System

In this study, dynamism in the carbon cycle was interpreted as identifying carbon fluxes among the carbon pools which includes transportation and transformation of carbon. In this level, dynamic relationships analyzed over the transportation and transformation carbon among the carbon pools that are classified into sub-systems of the carbon cycle including the terrestrial system, the hydrosphere and the atmosphere. The third system thinking skill were analyzed over the interview questions. According to the answers, she was classified as pre-aware, emerging, developing or mastery.

The analysis revealed that Berfin identified dynamic relationships on the among the terrestrial carbon pools (animals, plants) and the atmosphere and among the terrestrial pools (dead plants' and animals' wastes, decomposers, soil). On the other hand, she could not be able to identify any dynamic relationships related with the hydrosphere. A brief summary of Berfin's ability to identify relationships among the components of the carbon cycle were presented in the Table 4.28.

Table 4.28

Berfin's Ability to Identify Dynamic Relationships Among the Components of the Carbon Cycle

STS Level	Relationships	Level
STS-3 Ability to identify dynamic relationships among the components within the system		- Emerging Level--- Relationships identified among two sub-systems including terrestrial system pools and the atmosphere focusing mainly on transportation of carbon without referring transformation of carbon explicitly.
Among the terrestrial system components	- dead plants' and animals' wastes-decomposers-soil.	- Identified over process of decomposition. Only transportation of carbon could be identified
Among the hydrosphere components	-	-
Among the atmosphere components	-	-

Table 4.28 (cont'd)

Among Terr. System and the atmosphere components	-	CO_2 in the atmosphere-Plants	Identified over the process of photosynthesis, however, only referring the transportation of carbon from atmosphere to plants.
	-	Animals-CO_2 in the atmosphere	Identified over the process of respiration, only referring the transportation of carbon from animals to atmosphere.
Among the Terr. System and hydrosphere components	-		
Among the hydrosphere and the atmosphere components	-		
Among Terr. System- the Hydrosphere and the atmosphere components	-		

The table demonstrated that Berfin could be able to identify dynamic relationships in between terrestrial system carbon pools (plants, animals) and atmosphere through the processes of photosynthesis and respiration. In addition, she defined dynamism among the terrestrial carbon pools which are dead plants' and animals' wastes, decomposers, and soil. On the other hand, the dynamism she defined was lack of considering the transformation of carbon among the pools explicitly. Additionally, she was not able to define any dynamism related with the hydrosphere. The analysis continued with the interview questions investigating the relationship among the carbon pools that Berfin defined in the STS-1.

> Interviewer: "What happens to carbon in the plants?"
>
> Berfin: "Plants take CO_2 form the air to perform photosynthesis. However, I do not know what happens to carbon in plants."
>
> Interviewer: "What happens to carbon in animals?"
>
> Berfin: "Animals do respiration which CO_2 is released to the air. That's all I can say. "
>
> Interviewer: "What happens to carbon in the soil?"
>
> Berfin: "There are dead plants' and animals' wastes in the soil which are consumed by decomposers."
>
> Interviewer: "Then, what happens to carbon in the decomposers?"
>
> Berfin: "I do not know the processes. May be, they eat them [dead plants' and animals' wastes] …hmm…no I cannot explain."
>
> Interviewer: "What happens to carbon in the atmosphere?"
>
> Berfin: "I think carbon stays there [in the atmosphere], but I am not sure."

It was obtained that Berfin could be able to identify the transportation of carbon from animals to atmosphere as in the form of CO_2. On the other hand, she could not be able to identify the transformation of carbon in the animals such as carbon in the food transform into carbon in the CO_2. Therefore, she could be able to identify dynamism between terrestrial system pool (animal) and the atmosphere with only referring to the transportation of carbon.

It was obtained that Berfin could be able to identify the transportation of carbon from dead plants' and animals' wastes to decomposers through the decomposition process in the soil. However, she could not be able to identify the transformation of carbon in the decomposers such as carbon in the glucose transform into CO_2 in the atmosphere. Therefore, she could be able to identify dynamism considering only transportation of carbon to the decomposers in the soil.

To be brief, Berfin was able to identify dynamic relationships between the terrestrial system pools (plants) and the atmosphere with referring only transportation of carbon through the process of photosynthesis. In addition, she identified dynamism between the terrestrial system pools (animals) and the atmosphere with referring only transportation of carbon through the process of respiration. Moreover, she was able to identify dynamic relationship considering terrestrial reservoirs of dead plants' and animals' wastes to decomposers through the process of decomposition in the soil. On the other hand, she did not refer to any transformation of carbon during the decomposition process. In addition, it was observed that she held a static, not dynamic, view considering the atmosphere part in the carbon cycle. In addition, since she could not be able to identify any components in the hydrosphere, she did not identify any dynamism related with the hydrosphere. Therefore, since Berfin was able to identify dynamic relationship considering the carbon pools between the two-sub systems of carbon cycle with referring only transportation of carbon, she was classified as emerging level for the STS-3 (see in the Table 4.28).

4.4.2.4. STS-4 Organizing the systems' components, processes, and their interactions, within a framework of relationships

In this level, organizing the components and processes of carbon cycle within a framework of relationships were intended to analyze. Therefore, it is important to see the connections among more than two components for organizing the components and processes and their interactions within a framework which describe a carbon cycle system. Therefore, this level was analyzed through the concept maps which investigates the interactions among the carbon cycle parts. In this level, it was asked participant to write the 12-words concerning carbon and to draw a concept map that relates the concepts to each other. The concept map she had drew was presented in the Figure 4.8.

> Interviewer: "What comes in your mind when I say carbon?"
>
> Berfin: "I can say as humans we use cars which releases CO_2 to the air. In addition, as human we use deodorants and perfumes. Moreover, carbon present in the soil as in the form of diamond or graphite."
>
> Interviewer: "Can you draw a concept map that relates those concepts to each other?"

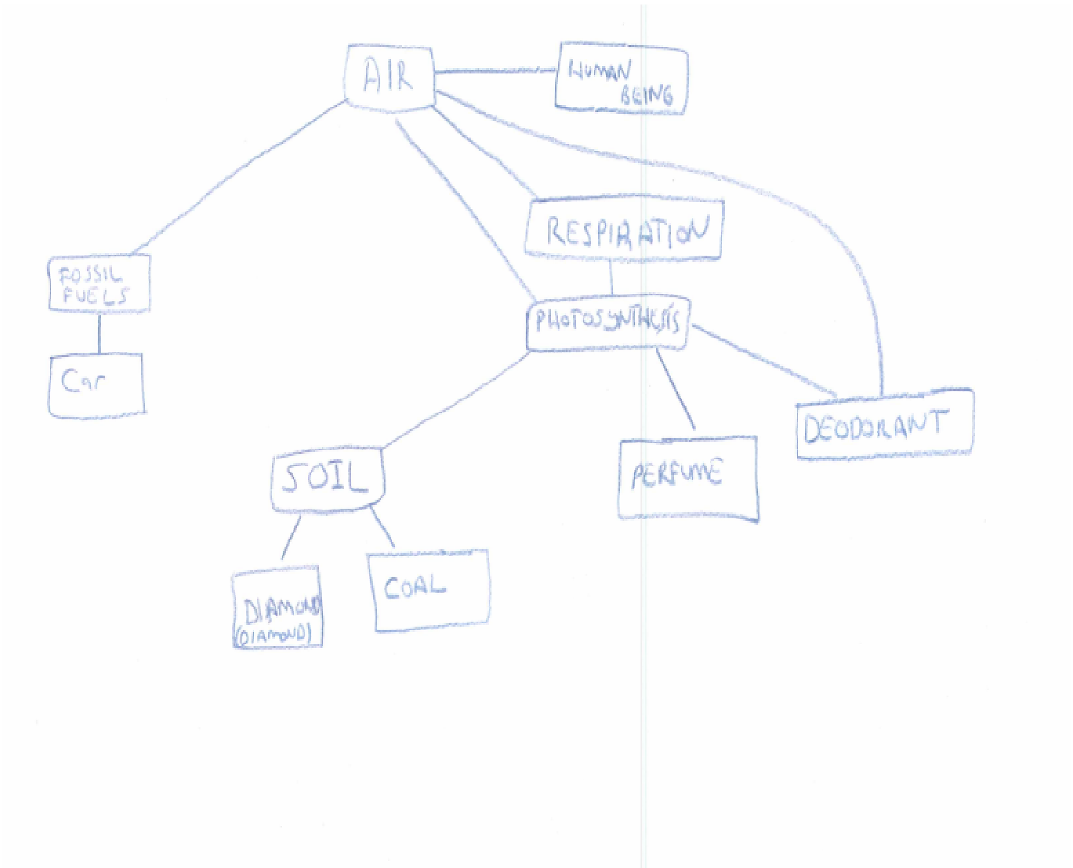

Figure 4.8. Berfin's Concept Map

It was observed that Berfin could be able to identify connections among concepts with more than two concepts (eight concepts). Moreover, it seemed that she described her drawing included two processes. The concepts that she discussed in the concept map was summarized in the Table 4.29.

Table 4.29

Berfin's Ability to the Systems' Components, Processes, and Their interactions, within a Framework of Relationships

Dimensions within the concept map	Examples	Number of the concepts
Terrestrial system	Fossil fuels, cars, soil, coal, diamond, humans, perfume, deodorant	8
Atmosphere	Air,	1
Hydrosphere	-	-
Processes	Photosynthesis, Respiration	2
Concepts related more than two concepts	Air, photosynthesis, respiration, soil	4

The interactions among the concepts that are related with more than two concepts were mainly described through the photosynthesis and respiration. It was obtained that the interactions among the concepts (components and processes) observed in the terrestrial and atmosphere part of the carbon cycle system. On the other hand, even if she mentioned fossil fuels and car in her map, she did not mention the process of combustion. Moreover, although she identified the process of decomposition in the soil in STS-1, she did not mention that process in her drawing as well. Additionally, she was able to discuss only air in the atmosphere without mentioning the CO2 or which she defined in the STS-1 as well. In addition, she was not able to identify any concepts related with the hydrosphere. The interactions among the concepts were limited only with the atmosphere and terrestrial system without describing any processes or relationship except from the photosynthesis and respiration which is insufficient to create an organized framework. In conclusion, since the interaction of the concepts she discussed only cover the terrestrial and atmosphere without the hydrosphere part of the carbon cycle, she classified as developing level for the STS-4 (See Rubric in the Table 3.2).

4.4.2.5. STS-5 Understanding the cyclic nature of the systems

In this level, participant's understandings of cyclic nature of the carbon cycle system were analyzed. Therefore, in this context, participant's understanding of matter and energy exchanges via transformation of carbon and energy among the four-sub-cycles located in the sub-systems of the carbon cycle was examined. This level was analyzed by the interview questions and the drawings. According to the answers, she was classified as pre-aware, emerging, developing or mastery.

The drawing that Berfin drew was presented in the Figure 4.7 (See p. 133).

The components and the processes in the drawing was summarized in the Table 4.30.

Table 4.30. Components and Processes identified by Berfin in her drawing

Sub-systems of Carbon cycle	Components	Processes
Terrestrial system	Cars, leaves, decomposers, soil, plants' and animals' wastes	Photosynthesis, respiration, decomposition, combustion.
Atmosphere	CO_2, air, cloro-floro-carbons,	-
Hydrosphere	-	-

In her drawing, it was obtained that Berfin identified five component and four processes related with the terrestrial part of the carbon cycle. In addition, she defined three components in the atmosphere. On the other hand, even though she described three components, any process in relation with the atmosphere could not be identified. Moreover, there were no concepts observed in relation with the hydrosphere part. It was obtained that, as in the previous levels, she mainly focused on the terrestrial part of the carbon cycle. In addition, carbon flow that represented as “input” and “output” with arrows over the components without indicating the source of the “input” carbon demonstrated lack of cyclic understanding of the carbon cycle system based on her drawing.

Two interview question was asked to investigate whether the participant hold a cyclic perception considering the carbon cycle.

Interviewer: “Is there a starting point for the carbon cycle?”

Berfin: “No. There are no end point for the carbon cycle as well. For example, considering the evolution, first photosynthetic organism formed, and then other organisms. Since then, it [carbon] produced and consumed that is in cycle among the organisms.”

It was observed that Berfin described a starting point for the carbon cycle by referring the evolution of life on the Earth. She defined formation of photosynthetic organisms as a starting point for the carbon cycle through the first process of photosynthesis. Moreover, she described no end points for the carbon cycle because carbon is continuously produced and consumed. Therefore, since she was able to describe no starting and end points by referring the evolution of photosynthetic organisms, she was held a cyclic perception (Batzri et al., 2015). The analysis of this level continued with the interview questions that analyzed the exchange of carbon and energy among the four-sub-cycles of the carbon cycle system.

Interviewer: “How carbon reaches to the air?”

Berfin: “Carbon reaches to atmosphere…hmm…For example, animals and plants do respiration which releases CO_2 to the air. Moreover, Humans use cars that causes release of CO_2 to the air. In addition, we use perfumes or deodorants which releases cloro-floro-carbon to the air.”

Interviewer: “How carbon reaches to the plants?”

Berfin: “Plants perform photosynthesize which take CO_2 from the air.”

Interviewer: “How carbon reaches to the animals?”

Berfin: “I have not thought about until now. I should study more on the cycle”

Interviewer: “How carbon reaches to the soil?”

Berfin: “I think carbon is already present in the soil. I do not know how, but it [carbon] is present. Moreover, plants’ and animals’ wastes accumulated carbon in the soil. Then, decomposers consume them [plants and animals’ wastes].

Interviewer: “What makes carbon to move in all this action?”

Berfin: “I do not know. However, I know carbon should be in move because that is a cycle”

It was observed that Berfin was able to consider the sub-cycle-a which describes the exchange of carbon and energy between the terrestrial system and the atmosphere. She identified the carbon exchange between plants, animals through the processes of photosynthesis and respiration in the form of CO_2. On the other hand, even if she identified the movement of carbon to decomposers in the soil via plants’ and animals’ wastes, she could not be able to track it back to atmosphere through the process of decomposition. In addition, energy transformation was not included in her description of sub-cycle-a such as transformation of solar energy into chemical energy during photosynthesis.

Additionally, considering the sub-cycle-b that described the exchange of carbon among the terrestrial system and the atmosphere reservoirs, Berfin could only be able to identify the partial exchange of carbon from usage of cars by release CO_2 to atmosphere through the process of combustion. On the other hand, there were no exchange of carbon among the dead organisms to fossil fuels in the soil was observed.

Her description included only the usage of cars and releasing of CO_2 to the atmosphere without referring how carbon exchanged in the soil. Thus, she only could be able to partially describe the sub-cycle-b with no energy exchanges among the different carbon reservoirs such as chemical energy to thermal.

Moreover, she was not able to identify any reservoir related with sub-cycle-c that describes energy and carbon exchange among the atmosphere and the hydrosphere. In addition, she did not identify sub-cycle-d which describes the energy and carbon exchange among terrestrial system, atmosphere and the hydrosphere. Therefore, as she was only able to partially identify the sub-cycle-a with no reference to the energy transformations, she was classified as emerging level for the STS-5 (See Rubric in Table 3.2).

4.3.2.6. STS-6-The ability to recognize hidden dimensions of the system

In this level, recognizing the hidden dimensions of the carbon cycle system were analyzed. In the context of this study, hidden dimensions in the carbon cycle were considering as the recognizing connections among the different Earth cycles at multiple scales including macroscopic and microscopic. Therefore, in this level, interrelationships among the Earth cycles were analyzed through the interview questions and drawing.

> Interviewer "Is there any relationship among the carbon cycle and the other Earth cycles?"
>
> Berfin: "I think all the Earth cycles should be related."
>
> Interviewer: "Can you give me an example?"
>
> Berfin: "For example, water cycle and carbon cycle…hmm…I cannot be sure that water reacts with the carbon…No…I cannot be able to describe [relationships among the water and carbon cycles]."

It was observed that Berfin was aware connections among the Earth cycles. On the other hand, when it was asked, she could not be able to describe such relationships at any micro-and macroscopic level. Moreover, in her drawing, there is no indication of relationships with other cycles. Therefore, she was classified as emerging level for the STS-6 (See Rubric in Table 3.2).

4.4.2.7. STS-7-The ability to make generalizations

Ability to make generalization within the carbon cycle system were analyzed in this level. In the context of carbon cycle. This level means discussing the how today's environmental problems emerged referring to the current imbalances among the processes via feedback mechanisms within the carbon cycle's sub-systems including terrestrial system, hydrosphere and atmosphere. Thus, participant's ability to identify feedback mechanisms on explaining the current imbalances among the carbon cycle when discussing environmental issues were investigated. According to the answers, she was classified as pre-aware, emerging, developing or mastery.

> Interviewer: "What can you say when I want you to talk about the climate change?"
>
> Berfin: "climate change is the extreme weather conditions caused by the shift in climates."
>
> Interviewer: "Is there any relationship between climate change and the carbon cycle?"
>
> Berfin: "I think, yes, there is. For example, let us consider the human effects. When human activities such as driving cars, or using perfumes release too much carbon to the atmosphere, we [humans] causes global warming which results in climate change. Thus, there is a relationship between carbon cycle and climate change."

It was observed that Berfin was aware the relationship between the climate change and the carbon cycle. It was observed that she was only able to identify one-way-cause and effect relationship among terrestrial system and the atmosphere by emphasizing the excessive anthropogenic combustion to the atmosphere as a cause for the global warming and hence, climate change. On the other hand, the climate change could not be discussed by referring the current imbalances of the carbon cycle via referring the feedback mechanisms. Therefore, Berfin could not be able to identify the feedback mechanisms among the all three sub-systems of carbon cycle that leads to the current imbalance of the carbon cycle processes which then results to climate change. Hence, she was classified as emerging for the STS-7 (See Rubric in Table 3.2).

4.4.2.8. STS-8- The ability to think temporally: retrospection and prediction

This level means that understanding that past is the key to explain the present state of the system while the present is to key to understand the future. Such understandings could be implemented in cases such as industrial revolution effect on the increasing concentration of CO_2 throughout the decades or predict consequences of population growth on the CO_2 concentration in the atmosphere for the upcoming ages. In the context of carbon cycle, this level was analyzed by the interview questions. According to the answers, she was classified as pre-aware, emerging, developing or mastery.

> Interviewer: "What is the effect of humans on the carbon cycle?"
>
> Berfin: "I can remember that one of the classes, we talked about how industry affects the carbon cycle. With the industrial revolution, our rate of releasing CO_2 is increased. Therefore, today's high carbon measurements related with the industrial revolution. Hence, it [industrial revolution] contributes global warming."

It was observed that Berfin could be able to think retrospectively on the carbon cycle which she described the consequences of industrial revolution on increasing CO_2 concentrations in atmosphere. It was obtained that she explained the current phenomena (global warming) is caused by a past event (increasing CO_2 release since the industrial revolution). Therefore, since she was able to identify two-time spans (past-present) in the carbon cycle while explaining the climate change, Berfin was classified as developing level for the STS-8 (See Table 3.2).

4.4.3. Berfin's Definition of System

Berfin's description of system included the properties interactions of components among the system. She mentioned that a system should be dynamic while explaining why carbon cycle is a system. The description of a system according the Berfin is given in below.

> "When we talk about systems, I directly thinking of components and their relationships with each other. For example, in the carbon cycle, the components of plants and animals are in a relationship since CO2 is cycled among them through photosynthesis and respiration which also shows carbon is not stable, always in a movement."

4.4.4. Berfin's Summary of Systems Thinking Skills

Berfin could not be classified as mastery level for any system thinking skills. She classified as developing level for the STS-4 and STS-8 concerning the system thinking abilities in the carbon cycle. On the other hand, considering the other system thinking skills (including STS-1, STS-2, STS-3, STS-5, STS-6-STS-7), she was classified as emerging level. The description of system definition she gave revealed that she had a system understanding considering the system thinking with referring the interactions and dynamism in the carbon cycle. However, could not be able to implement her understanding of system to the carbon cycle context. Summarization of Berfin's system thinking analysis were presented in the Table 4.31.

Table 4.31

Summary of Berfin's System Thinking Levels

System Thinking Skill	Level
STS-1- The ability to identify the components of a system and processes within the system	Emerging
STS-2- The ability to identify simple relationships between or among the system's components.	Emerging
STS-3- The ability to identify dynamic relationships within the system.	Emerging
STS-4 The ability to organize the systems' components, processes, and their interactions, within a framework of relationships.	Developing
STS-5 The ability to identify cycles of matter and energy within the system—the cyclic nature of systems.	Emerging
STS-6 The ability to recognize hidden dimensions of the system.	Emerging

Table 4.31 (cont'd)

STS-7 The ability to make generalizations	Emerging
STS-8 The ability to think temporally: retrospection and prediction.	Developing

CHAPTER 5

DISCUSSION, CONCLUSION AND IMPLICATIONS

Firstly, findings regarding the participants answers were discussed. Then, discussion part followed by the conclusion part. Lastly, implications of this study discussed.

5.1. Systems Thinking Levels of Pre-Service Science Teachers in the context of the Carbon Cycle

This study examined the systems thinking skills of the pre-service science teachers in the context of the carbon cycle by using the System Thinking Hierarchical (STH) Model (2005) that is proposed by Ben-Zvi Assaraf and Orion by taking three-subsystems of carbon cycle which are terrestrial system, hydrosphere and the atmosphere into consideration.

The first systems thinking skill which is described as ability to identify components and processes within the system. The first skill formed the basis of the other seven following skills in the STH Model. In the context of this study, only two participants (Canan and Melisa) were able to identify components at mastery level which includes all three-sub-systems of the carbon cycle. On the other hand, they failed to identify processes related with the atmosphere which they classified as developing level for the STS-1. Moreover, one of the participants (Berfin) was able to identify components at developing level without referring the hydrosphere components. She could only be able to identify processes on the terrestrial system. Therefore, she classified as emerging level for the STS-1. In addition, the other participant (Mehtap) could only be able to identify components and processes related with terrestrial system. Thus, she classified as emerging level for the STS-1. It was observed that all the participants mainly focus on the terrestrial part of the carbon cycle with referring components such as plants, animals, decomposers and processes such as photosynthesis and respiration.

Similar with the study conducted by Zangori et al. (2017), participants were struggled to identify the components and processes related with hydrosphere and atmosphere. Participants tended to perceive carbon cycle based on terrestrial system (Mohan et al., 2009). As cited in the study of Sibley (2007), the participants mainly focused on the visible components and processes related with terrestrial system that they were already familiar with during their undergraduate courses. On the other hand, since hydrosphere and atmosphere parts were only included in the last semester on their undergraduate courses, it seemed that their disciplinary knowledge concerning these two sub-system (atmosphere and hydrosphere) of carbon cycle were inadequate to identify components and processes related with the carbon cycle system.

The second systems thinking skill which proposed as ability to identify relationships among the components within the system. In the context of this study, there were no participants classified as mastery level for the STS-2. The highest level was found to be as developing for three participants (Canan, Melisa, Mehtap). These participants were able to identify relationships among the components of terrestrial system and the atmosphere with referring a linear cause and effect relationship. The casual relationship was identified only on the terrestrial system (human, factory, cars) and the atmosphere over the excessive release of CO2 as cause for the global warming. In addition, two of the participants (Canan and Melisa) could be able to identify relationship concerning the hydrosphere with no referring to the causal relations. On the other hand, one participant (Berfin) were classified as emerging level with only identify relationship between components of terrestrial system and the atmosphere. The most common relationship was found on the terrestrial system and atmosphere through animals, plants and CO_2 via the processes of photosynthesis and respiration for all the participants. The reason behind it may emerged from their perception of terrestrial systems based carbon cycle that was found in the STS-1. Similar with Cox et al. (2017) and Lee (2015), although participants were able to identify components of the carbon cycle, they were unable to find interrelationship among the components. This result might arise from their inadequate knowledge concerning the processes of carbon cycle (Mohan et al., 2009).

As Grötzer et al. (2000) and Sibley et al. (2007) suggested, participants lack of knowledge considering the explanations of processes in terms of their locations and roles in the carbon cycle led them to consider only relationships terrestrial part of the carbon cycle without referring the casual relationships in the all-three-sub-systems.

The third systems thinking was described as ability to identify the dynamic relationships within the carbon cycle. In the history of research in the systems thinking, researchers pointed out that dynamic relationships were difficult to identify since they include transportation and transformation of matter which requires considerable level of disciplinary knowledge (Mohan et al., 2009). In the case of the carbon cycle, identifying such dynamic relationships includes disciplinary knowledge on the topics such as organic chemistry, geology, or biology (You et al., 2017). Although all participants passed their courses related with their knowledge concerning the carbon and carbon cycle properties, only one participant was classified as the developing level which could be able to identify transformation and transportation of the carbon among two-sub-systems of the carbon cycle (terrestrial system and atmosphere). In addition, as in the STS-1 and STS-2, most of the participants in this study, mainly focused on the dynamism between terrestrial system and the atmosphere, ignoring the hydrosphere part. As it was cited by Zangori et al (2017), it seemed that lack of systems perception in the previous skills (STS-1 and STS-2) led to lack of dynamism considering all three-sub systems of the carbon cycle. Moreover, while identifying dynamic relationships in the terrestrial system and atmosphere, they mainly referred to transportation of carbon rather than considering both transportation and transformation of carbon in the cycle. As pointed out in studies of Sibley et al (2007) and Zangori et al. (2017), it was mainly caused by the lack of knowledge considering chemical expressions the processes of the carbon cycle since the flux of the carbon is managed by the processes such as photosynthesis or decomposition among the carbon pools related with sub-systems of the carbon cycle. Since participants did not know what happens to carbon in the, for example, soil or decomposers, they could not trace the flux of carbon through the carbon pools.

Therefore, since most of the participants were failed to trace the carbon flux among the carbon pools, they showed poor systems understandings concerning the carbon cycle.

The fourth systems thinking skill which is described as ability to organize carbon cycle's components, processes, and its interactions, within a framework of relationships. It was stated that even though students could identify the components and processes in a system, they could not be able to relate them in a framework (Orion, 2002; Ben-Zvi Assaraf, 2003). In this thesis, the fourth systems thinking skill was investigated through concept maps concerning the carbon. On the other hand, it was observed that only one participant could be able to draw a concept map using meaningful linkage words. As it was stated by Ben-Zvi Assaraf (2003), concepts that are related with more than two concepts give Earth cycle system characteristic. In this study, it was observed that even though most of the students was able to relate concepts more than two concepts, they failed to find meaningful linkage words to connect them. This might be caused by their lack of disciplinary knowledge considering the carbon cycle components and processes (Batzri et al., 2015; Sibley et al., 2007). Moreover, participants' concepts maps were mainly focused on the terrestrial system and atmosphere via biological processes with ignoring hydrosphere as in the previous systems thinking abilities (STS-1, STS-2, STS-3). As it was pointed out, students' inability to identify the locations of the processes in the carbon cycle prevented them to organize carbon cycle's components, processes and interactions in a framework of relationships (Mohan et al., 2009; Zangori et al., 2017). Therefore, participants demonstrated lack of systems thinking levels considering the carbon cycle.

The fifth systems thinking level was described as understanding the cyclic nature of the carbon cycle. It was observed that all the participants perceived carbon cycle as a cycle which means there is no starting or ending point in the cycle (Batzri et al., 2015). On the other hand, in the drawings, it was observed that most of the participants could be able to identify sub-cycle -a which mainly identified on terrestrial part and atmosphere as in the previous levels in the model which indicated fragmented perception considering the carbon cycle. Only one participant could be able to discuss the exchange of carbon in the hydrosphere through only the biological processes including photosynthesis and respiration without identifying diffusion of carbon. Similar with the study conducted by Ben-Zvi Assaraf et al (2005), participants lack of consideration interactions among the different sub-systems of carbon cycle in the previous levels of the STH model (STS-1, STS-2, STS-3-STS-4), they mainly concentrated on the terrestrial part (with only biological processes) and the atmosphere with ignoring hydrosphere part. Moreover, it was indicated that students' dynamic perceptions and cyclic perceptions considering an Earth cycle are developed together which means they are coherent structures (Ben-Zvi Assaraf, 2003; Batzri et al. 2015). Accordingly, since participants' dynamic perception concerning the carbon cycle was poor, their cyclic understanding in the carbon cycle was considerably low. In addition, most of the participants could not be able to refer the energy transformations among the carbon pools in the sub-cycles of the carbon cycle. They identify energy as a factor that enables carbon to move, their explanation could not go beyond identifying chemical energy. Only one participant explicitly identified energy transformation in sub-cycle-a through the processes of photosynthesis as from solar energy to chemical energy. One of the reasons why energy transformations could not be identified in the carbon cycle may be caused by the lack of knowledge considering the energy concept in general. As study conducted by Finley et al (2011), since energy was not the core idea of the disciplinary curriculums, even though participants were trained in the different forms of energy in various courses, they were struggled to identify energy transformations in the carbon cycle. Second reason of not identifying energy transformations in the carbon cycle may resulted from the concept of energy is too abstract to consider it in relation with the processes of the carbon cycle on the surface. As Finley (2011) stated that, if energy concept in the Earth cycles could not be handled in more concrete ways to students to observe, they would have no chance to identify energy transformations on the Earth cycles. Accordingly with Finley (2011), energy concept may too abstract to participants to consider in the context of this study. That is why participants could not identify the energy transformations as carbon cycles through the carbon cycle.

The sixth systems thinking skill was described as identifying hidden dimensions. In the context of carbon cycle seeing the relationships among the various Earth cycles required to examine systems at multiple levels from macroscopic (carbon cycle movement of carbon across terrestrial system, hydrosphere and atmosphere) to microscopic (molecule movements across the carbon cycle) levels in the system (Lee, 2015). It was observed that although most of the participants were able to identify carbon movements at macroscopic scale such as carbon transfer among the carbon pools, they were failed to trace carbon in microscopic levels which trace the transformation of carbon within and among the carbon pools. As Ben-Zvi Assaraf et al (2009) stated that, lack of dynamic (STS-3) and cyclic (STS-5) understandings in the system make it difficult to identify the hidden mechanism in the carbon cycle system which none of the participants could be able to identify the relationships among the various Earth cycles. Additionally, as Lee (2015) pointed out, identifying relationships only focusing on the only terrestrial system and the atmosphere part of the carbon cycle (STS-2), made participants to perceive carbon cycle as separated from other Earth cycle such as water cycle. In addition, as cited in the study conducted by Ben-Zvi Assaraf et al. (2005) in the context of water cycle, similarly in the carbon cycle, lack of identifying relationships among the components of carbon cycle at multiple scales led participants to demonstrated poor abilities to identify relationships among the various Earth cycles.

The seventh systems thinking skill was described as ability to make generalizations. In the context of this study, this ability includes discussing environmental issues referring the imbalances among the processes in the carbon cycle which caused by the feedback relationships in the sub-systems in the system. It was observed that all of the participants have solid ideas concerning the climate change. However, no participants were classified as mastery or developing level for the STS-7. Most the participants, tried to explain occurance of this global issue as mono-causal relations (as in the case of STS-2) among the two-sub-systems of the carbon cycle including terrestrial system and atmosphere. The main process mentioned while explaining the carbon cycle was combustion (driving cars, factorial release), which did not include any feedback relations among the systems’ components.

It was observed that although all the participants were aware that carbon cycle is related with climate change and affect each other, they failed to create links between these two phenomena. The difficulty in explaining the relationship between climate change and carbon cycle may cause from the participants' lack of knowledge in terms of dynamism and cyclic perception in the carbon cycle. As cited in the Ben-Zvi Assaraf (2003), Batzri et al. (2015) and Mohan et al. (2009), since participants were demonstrated poor understandings in the context of dynamism of the carbon cycle (STS-3) alongside with the cyclic perception (STS-5), they could not be able to generalize the imbalances of the processes of carbon cycle to complex global issues such as climate change. In addition, lack of identifying feedback relations may resulted from lack of cyclic relations among the carbon cycle (Sweeney et al., 2007). Since the participants mainly considered the mono-causal-relations (STS-2) only on two-sub-system of the carbon cycle which are terrestrial system and the atmosphere, they could not be able to identify cyclic feedback relations which caused by multiple causes. Therefore, they could not be able to observe global issues as complex systems since they could not be able to identify current imbalances caused by feedback relationships of the components of the carbon cycle.

The eight systems skill was described as ability to think temporally: retrospection and prediction. In the context of this study, this means that understanding that some of the presented interaction within the system took place in the past, while future events may be a result of present interactions (Ben-Zvi Assaraf et al., 2005). It was observed that only one participant classified as mastery level which she integrated the three-time spans (past-present-future) in terms of industrial revolution and population growth. Remaining participants could only able to identify in two-time spans (present-past) referring the industrial revolution. It was pointed out that thinking in time dimensions were difficult to identify in the context of Earth systems since it requires considerable knowledge of socio-biogeochemical-processes (Mohan et al., 2009; Zangori et al., 2017). On the other hand, in this thesis, it was observed that even though participants demonstrated low systems thinking levels considering the carbon cycle, they were able to think at least two-time span while examining the interactions among the system (human-carbon cycle).

One of the main reason of this result might arise from their environmental science course and sustainability courses. Since retrospection and prediction in the context of Earth systems were a part of these courses, participants who had passed those courses, had considerable understandings to consider the Earth systems at least two-time-span.

To sum up, the findings of this study suggested that a non-hierarchical model for the systems thinking in the context of carbon cycle. As Sibley et al (2007) suggested second systems thinking level is unnecessary in the STH model since the relationships already defined over the processes and components in advance. In addition, accordingly with Sibley (2007), it was obtained that identifying dynamic relationships is an excessive level in the STH model, since it is the processes that transport and transform the matter (carbon) in a cycle. Therefore, in this thesis, it was observed that the third systems thinking skill is redundant of the first and second systems thinking skills. Moreover, for participants dynamic and cyclic relations alongside with the hidden dimensions were found to be challenging as it was cited in the previous studies (i.e. Batzri et al., 2015; Sibley et al., 2007; Lee, 2015). It was found that basic disciplinary knowledge concerning the carbon cycle processes were inadequate to form a complex system perspective in the context of carbon cycle as cited in the literature (Raia, 2005). Therefore, this study points out a significant link between the knowledge of systems and the systems understanding of the system. Therefore, with implementation, systems thinking skills of the participants can be developed.

5.2 Conclusion and Implications

There are several conclusions that can be obtained from this study. As indicated by the Ben-Zvi Assaraf et al. (2005), analyzing systems thinking through word association test, concept maps and drawings alongside with the interviews give researchers deeper understanding of participants systems thinking in the context of natural systems. Secondly, there are eight systems thinking skills in the system thinking hierarchical (STH) model which is proposed as hierarchical in the context of Earth systems (Ben-Zvi Assaraf et al., 2005). On the other hand, the researchers who developed this model were studied in the context of water cycle which is considerably a less complex cycle comparing the carbon cycle. Therefore, based on the results of system thinking analysis in the context of carbon cycle, in more complex systems than water cycle, the STH model loses its hierarchical ability. Thirdly, it was observed that the participants of this study hold common systems understandings. On the other hand, weak conceptions related with the processes in the carbon cycle led them to inadequate considerations of multiple interactions among the sub-systems (terrestrial system, atmosphere and hydrosphere) of the carbon cycle. Such weak considerations may create a challenge during their professional years as teachers while implementing systems thinking in their classrooms. Moreover, the barriers defined in the literature were observed during the research as identify processes in the system, identifying multiple interactions within subsystems and struggling to identify hidden dimensions within the system (Lee, 2015; Ben-Zvi Assaraf et al., 2005; Covitt et al., 2009). The participants mainly focused on the linear-mono-causal relationships among terrestrial system and the atmosphere. Lastly, this study did not include any implementation. It was aimed to present the current systems understandings of the participants in the context of the carbon cycle. As it was pointed out previous researches (Finley et al., 2017), it was seemed that lack of disciplinary knowledge in relation with the carbon cycle impacts the systems understandings of the participants in that context.

The findings of this study had implications for the systems thinking in the context of Earth systems for researchers and teachers as well. This study suggested that systems thinking can be studied in the context of various Earth cycles including carbon cycle by using the assessment tools which were used in the context of this study that can be adapted to different contexts. In addition, teachers can use the results of this thesis to improve systems thinking abilities of their students in the context of Earth systems. Approaching Earth systems from systems thinking perspective give a chance for seeing the Earth as a whole, singular unit with interconnected parts. That knowledge might later be implemented on the understanding and solving the complex global issues such as climate change.

5.3. Recommendations

This study suggests some recommendations for the research in the future. First of all, the framework of this thesis was constructed based on the studies conducted by Ben-Zvi Assaraf et al (2005) and Lee (2015) which using system thinking hierarchical model in the context of carbon cycle. On the other hand, there are various models in the context of systems thinking research area. Carbon cycle as a complex system should be investigated through these models (i.e. SBF) as well. In addition, in the future researches, if STH model will be used, the revised version of this model that is proposed by Sibley et al. (2007) should be used in relation with more complex cycles such as carbon cycle.

In addition, this study assumed that participants had basic knowledge considering the carbon cycle processes relied on their undergraduate courses. On the other hand, keeping in mind that a significant relation between disciplinary knowledge and the systems thinking on the Earth systems science (Raia, 2005; Batzri et al., 2015), first, participants disciplinary knowledge considering the related Earth systems should be analyzed in order to present a more detailed systems perceptions of the participants.

Moreover, because of the convenience sampling, only female participants were participated in the study. Therefore, as it was suggested a repeating of this study including the male participants were recommended in order to see any impact of gender differences in the context of carbon cycle system (Cox et al., 2017).

As a last suggestion, it was recommended to examine in-service science teachers' systems thinking abilities in the context of carbon cycle in order to investigate the effect of experience on the implementation of systems thinking in the context of Earth systems. Moreover, it should be examined weather they feel any responsibility to teach Earth systems to their students in terms of systems thinking. In this context, teachers' feelings and attitudes towards the systems thinking should be analyzed.

As a conclusion, this thesis presented a picture of pre-service science teachers in one of the universities in Turkey. This study might help researchers who wanted to examine the systems thinking in the context of education especially for the context of Turkey. As the world around us getting more complex with the increasing usage of technologies and related developments, we needed to understand the complex systems which we confronted our everyday lives. As the global problems such as water scarcity, climate change, hunger, poverty becoming more complex, we need citizens who can understand and solve them by systems thinking since thinking in systems were presented as key point to achieve those complex issues (Richmond, 1993; Arnold & Wade, 2015). On the other hand, clearly as this study and the other previous researches pointed out, there is still much to do in the area of systems thinking in science education to raise such citizens.

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APPENDICES

APPENDIX A: Interview Questions in English

1. Can you define what is a system?
2. Is carbon cycle a system or not? Why?
3. Which courses did you take until this your senior year?
4. How old are you?
5. Can you write down the 12-concepts when I say carbon?
6. Where in carbon present on the Earth? Can you draw a carbon cycle based on this knowledge?
7. What are the components of the carbon cycle?
8. What are the processes in the carbon cycle?
9. What is the main reservoir of carbon on the Earth?
10. What is the relationship among the components in the carbon cycle?
11. Which components affects each other. Can you explain?
12. What happens to carbon in the atmosphere?
13. What happens to carbon in the soil?
14. What happens to carbon in the organism when it died?
15. What happens to carbon in the decomposers?
16. What happens to carbon in the plants?
17. What happens to carbon in the animals?
18. What happens to carbon in the water?
19. Can you relate the concepts you identified in the WAT in a concept map?
20. Is there any starting point in the carbon cycle?
21. Is there any ending point for the carbon cycle?

22. What makes carbon move in the carbon cycle?
23. How carbon reaches to the atmosphere?
24. How carbon reaches to the soil?
25. How carbon reaches to the plants?
26. How carbon reaches to the animals?
27. How carbon reaches to the water?
28. How carbon reaches to the rocks?

29. Have you ever heard of the climate change? If so, what is climate change?
30. Is climate change related with carbon cycle? If so, how?

31. Is there a relationship among the different Earth cycles with carbon cycle?

32. What is the effect of humans on the carbon cycle?

APPENDIX B: Analysis of Rubric

STS Level	Mastery	Developing	Emerging	Pre-aware
1.Identify the components of a system and processes within the system.	Multiple components and processes are identified on all three sub-systems of carbon cycle including terrestrial system, hydrosphere and the atmosphere.	Multiple components and processes are identified on at least two sub-systems (i.e. terrestrial system and hydrosphere)	Multiple Components and processes are identified but only in one sub-system (i.e. terrestrial system)	No components are identified. Identifying no processes.

2. Identify relationships between or among the system.	Relationships are identified among all three sub-systems. Includes cause and effect relationships among all three.	Relationships identified among at least two sub-systems. Includes cause and effect rel.	Relationships identified among just two sub-systems. No casual relations.	No relationship is identified.
3. Identify dynamic relationships within the system.	Transportation and Transformation of carbon among all three sub-systems explicitly. The fluxes kept limited with the carbon pools	Transformation of carbon among at least two sub-systems with both referring transportation and transformation of carbon.	Transformation of carbon covers at least two sub-systems with only referring transportation of carbon.	Non-dynamic, stable perspective of carbon cycle.

4. Organizing systems' components, processes, and their interactions, within a framework of relationships.	Includes interaction among the concepts to an organized framework that covers all three sub-systems of the carbon cycle.	Connecting concepts related more than two concepts which describes an organized framework on at least two sub-systems of the carbon cycle.	Connecting pairs of concepts but could not be able to connect an organized framework.	No indication of web of processes and relationships are identified in the carbon cycle.
5. Understanding the cyclic nature of the systems.	Understanding all sub-cycles of the carbon cycle with referring energy and matter exchanges within them.	Partially Understanding at least two sub-cycles of the carbon cycle, having an awareness and matter exchange without referring the energy.	Partially understanding only one sub-cycle sub-cycles of the carbon cycle, having an awareness and matter exchange without referring the energy.	No explanation about cyclic nature of the system.

6. Making generalization	While discussing environmental threats concerning carbon cycle, showing the understanding that the threats occurred such as the current imbalances among the processes within all the carbon cycle sub-systems (terrestrial, hydrosphere and atmosphere systems)	Showing the understanding the environmental threats occurred such as the current imbalances among the processes within at least two sub-systems of the carbon cycle with referring feedback mechanisms among components.	Showing the understanding environmental threats occurred such as the current imbalances among the processes in at least sub-systems without referring feedback mechanisms among components.	(Showing) no understanding concerning the Carbon cycle is dynamic and cyclic.
7.Understanding the hidden dimensions	Identifying inter-relationships among all Earth cycles at multiple scales (microscopic and macroscopic)	Recognizing inter-relationships among at least two Earth cycles referring at least one multiple scale (microscopic or macroscopic)	Aware of the inter-relationships among Earth cycles but could be able to explain.	No hidden dimension is identified.

8. Thinking temporarily; retrospection and prediction	Making relationship between past, present and future referring the cases such as industrial growth or glaciers meltdown.	Trying to make relationship between past, present and future; mostly consider two time spans (e.g., past and present).	Struggling to make relationship between past, present and future.	No relationship is identified connecting the past, present and future.

APPENDIX C

Human Subjects Ethics Comitee Permission

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Gönderen: ODTÜ İnsan Araştırmaları Etik Kurulu (İAEK)

İlgi: İnsan Araştırmaları Etik Kurulu Başvurusu

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Danışmanlığını yaptığınız yüksek lisans öğrencisi Deniz TURAN'ın **"Fen Bilimleri Öğretmenlerinin Karbon Döngüsü Konusundaki Sistemsel Düşünme Becerilerinin İncelenmesi"** başlıklı araştırması İnsan Araştırmaları Etik Kurulu tarafından uygun görülerek gerekli onay **2018-EGT-059** protokol numarası ile **21.05.2018 - 30.08.2018** tarihleri arasında geçerli olmak üzere verilmiştir.

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APPENDIX D.

EXTENDED TURKISH SUMMARY/TÜRKÇE ÖZET

Fen Bilimleri Öğretmen Adaylarının Karbon Döngüsü Konusundaki Sistemsel Düşünme Becerilerinin Analizi

GİRİŞ

İçinde yaşadığımız dünya bünyesinde bir çok karmaşık ve birbirleri ile ilişkili sistemler barındırır. Ekosistemlerden, madde döngülerine kadar çeşitli yerel ve global sistemler yeryüzündeki canlılar tarafından paylaşılır (Lee, 2015). Hayatlarımızda bu kadar önemli olan bu sistemleri bilmek ve tanımak, onların önemini anlamak yaşadığımız Dünya'yı anlamak açısından büyük önem arz etmektedir. Fakat karmaşık sistemleri basitçe ele almak çoğu zaman mümkün olmamaktadır (Raia, 2005). Çünkü, bu sistemler birden fazla elamanın neden-sonuç ilişkileri şeklinde birbirlerine bağlanması ile oluşur (Ben-Zvi Assaraf, 2003). Bu tür ilişkiler ancak bu tip karmaşık sistemlere bir bütün olarak, birden fazla bakış açısıyla çözümlenebilir (Mohan, Chen, & Anderson, 2009).

Moxnes (2004) yaptığı çalışmada bugünün çocuk nüfusunun gelecekte şu an deneyimlediğimiz karmaşık global problemler ile uğraşacağını, ayrıca, zamanla yeni karmaşık problemlerin de gelecekte ortaya çıkacağını iddaa etmektedir (iklim değişikliği, sera etkisi). Sonuç olarak, Moxnes eğitim de yeni bir yaklaşım ile bugünün çocuklarında karmaşık sistemlere ve ya problemlere karşı bir farkındalık kazandırmayı amaçlayan farklı yöntemler bulunması gerektiğini ifade etmiştir. Bu bakış açısı ile Barry Richmond (1993) eğitimcileri global ve karmaşık sistemleri inclemek ve öğrencilerine Dünya'nın farklı karmaşık sistemlerden biraraya gelen bir bütün olduğunu gösterecek "sistemsel düşünce" yaklaşımını tanımlamıştır. Buna bağlı olarak, eğitimciler arasında sistemsel düşünce farklı konu başlıkları altında çalışılmıştır. Bu konular arasında tıp (Faughman & Elson, 1998), sosyal bilimler (Senge, 1990) ve fen eğitimi yer almaktadır (Jacobson & Wilensky, 2006; Kali et al., 2003; Sabelli, 2006; Ben-Zvi Assaraf & Orion, 2005; Hmelo- Silver & Azevedo, 2006; Ben-Zvi Assaraf & Orion, 2005; Zangori et al., 2017).

Fen eğitimi alanında yayımlanan sayısız makaleleri inceleyen Hmelo-Silver (2000) fen eğitimindeki karmaşık sistemleri belirli ana karakterler gösterdiğini belirlemiştir. Bu karakterler karmaşık sistemlerin bir den fazla hiyerarşik alt-sistemden oluştuğunu göstermektedir. İkincil olarak, karmaşık sistemlerin elemanları arasında bir nedensellik ilişkisi bulunmalıdır. Son olarak, herhangi bir karmaşık sistemin elamanları arasındaki nedensellik ilişkisi zaman faktöründen (geçmiş, şimdi, gelecek) etkilenmektedir. Bu karakterlerden yola çıkarak Ben-Zvi Assaraf and Orion (2005) özellikle Madde Döngüleri gibi konular için önerdikleri "hiyerarşik sistemsel düşünce modeli" adı altında bir model geliştirdiler. Geliştirmiş oldukları bu model de Dünya üzerinde ki karmaşık sistemlerin dinamik ve döngüsel doğasına odaklandılar. Bu model içerisinde temel olarak üç ayrı seviye ve seviyeler arasında da belirli sistemsel düşünce becerileri tanımlandı. Birinci seviye analiz seviyesi, ikinci seviye sentez seviyesi ve üçüncü seviye uygulama seviyesi olarak tanımlandı. Modelin daha detaylı görünümü aşağıda ki tablo da özetlenmiştir. Tabloda da görüldüğü üzere hiyerarşik sistemsel düşünce modeli içersinde analiz level, sistem içerisinde ki elamanları ve süreçleri tanımlayabilmek, sentez level, sistemdeki elamanlar ve süreçler arasındaki ilişkileri tanımlayabilmek, sistem içerisinde ki dinamik ilişkileri tanımlayabilmek, sistem içerisinde ki elamanları ve süreçleri belirli bir çerçeve içersinde organize edebilmek, sistemin döngüsel doğasını tanımlayabilmek ve son olarak ta analiz level; sistem içerisindeki gizli (hidden) mekanizmaları tanımlayabilmek, belirli bir sistem içerisinde kullandığı bilgiyi farklı sistemlere de uygulamak ve sistem içerisinde yer alan bir takım olayların geçmişte yaşanan olayların sonucu oluğunu ve gelecekte yaşanacak olayların da şu an yaşanan olaylardan meydana geldiğini tanımlayabilmek becerilerini içerir.

Table 33

Hiyeraşik Sistemsel Düşünce Modeli (*Ben-Zvi Assaraf & Orion*, *2005, p.523)*

Tanımlar	Sistemsel düşünce becerileri	Seviyeler
Sistem içerisinde ki elamanları ve süreçleri tanımlayabilmek	SDB-1	Analysis
Sistemdeki elamanlar ve süreçler arasındaki ilişkileri tanımlayabilmek	SDB-2	Synthesis
Sistem içerisinde ki dinamik ilişkileri tanımlayabilmek	SDB-3	
Sistem içerisinde ki elamanları ve süreçleri belirli bir çerçeve içersinde organize edebilmek	SDB-4	
Sistemin döngüsel doğasını tanımlayabilmek	SDB-5	
Sistem içerisindeki gizli (hidden) mekanizmaları tanımlayabilmek	SDB-6	Implementation
Belirli bir sistem içerisinde kullandığı bilgiyi farklı sistemlere de uygulamak.	SDB-7	

Table 33. (cont'd)

Sistem içerisinde yer alan bir takım olayların geçmişte yaşanan olayların sonucu oluğunu ve gelecekte yaşanacak olayların da şu an yaşanan olaylardan meydana geldiğini tanımlayabilmek	SDB-8

Genel olarak Dünya sistemleri (i.e. madde döngüleri) fen eğitimi kapsamında bu model kullanılarak incelenmiştir (su döngüsü konusunda; Ben-Zvi Assaraf, 2003); su ve karbon döngüsü konusunda; Sibley, 2007). Fakat Mohan ve Chen (2009) belirttiği üzere karbon döngüsü konusuna sistemsel düşünce yaklaşımı literatürde öok az yer kaplar. Bu bilgi doğrultusunda araştımacılar (i.e. Mohan, & Chen, 2009; Zangori et al., 2017) karbon döngüsü konusunun daha fazla incelenmesi gerekililiğinin önemine vurgu yapmıştır.

Karbonun doğada bulunan en yaygın element olduğu ve hemen hemen her element ile kimyasal reaksiyona girdiği düşünülünce karbon döngüsünün de bir çok farklı ve birbiri ile ilişkili sistemden meydana geldiğini anlamak mümkündür (Kump, Kasting, & Crane, 2004). Karbonun Dünya üzerinde bol bulunduğu yerler karbon rezervuarı olarak adlandırılır. Bu rezervuarlar arasındaki karbon akımları karbon döngüsünün temelini oluşutur. Örnek vermek gerekirse, bitkiler, Dünya üzerinde bulunan en önemli karbon rezervuarlarından biridir. Aynı zamanda atmosferde de göz önüne alınması gereken miktar da karbon bulunur. Fotosentez olayı sürecinde bitki havadan aldığı karbondioksiti, besin içerisinde ki glikoza dönüştürür. Aynı zamanda solunum olayı neticesinde glikoz içersindeki karbon atmosphere verilir. Bu iki olay (solunum ve fotosentez) kendi içerisinde ufak bir döngü yaratır. Bunun gibi bir çok döngünün global boyutta bir araya gelmesi ise karbon döngüsünü oluşturur. Karbon döngüsü içerisinde birden fazla reservuar dolayısı ile birden fazla sistem barındırır. Bu sebeple sistemsel düşünce yaklaşımı olmaksızın bu döngünün dinamiklerini anlamak tam anlamı ile mümkün olamaktadır (Kump et. al., 2004).

Karbon döngüsü kendi haline bırakıldığında denge durumunda olan bir döngü olarak tanımlanmıştır. Denge durumu, Karbon Döngüsü'ndeki reservuarlar arasındaki karbon akımlarının bir biri ile aynı olduğu durumu tanımlamaktadır. Ancak bu denge durumu günümüz şartları altında, örneğin aşırı miktarda karbon içeren gazın atmosfere salınması, bozulmaktadır (Mohan, & Chen, 2009). İklim değişikliği olarak tanımlanan günümüzün en önemli problemlerinden birinin ana kaynağı Karbon

Döngüsü'ndeki reservuarlar arasında karbon akım dengesinin bozulması olarak öne sürülmektedir. (Mohan et.al., 2009; Zangori et al., 2017). Doğal olarak, son zamanlarda araştırmacılar iklim değişikiliğini Karbon Döngüsü'nün üzerinden incelemeye başladılar (IPCC, 2014). IPCC (2014) yılında yayınlamış olduğu raporda iklim değişikliğinin ve etkilerinin anlaşılabilmesi için iklim değişikliği kavramının doğa sistemleri içerisinde sistematik bir bakış açısı ile incelenmesi gerekliliğini vurgulamıştır. Zangori et al. (2017) yılında yaptığı çalışmada karbon döngüsü sistemsel bir şekilde iklim değişikliği ile sentezleyerek tanımlamıştır. Bu çalışmadaki araştırmacılara göre karbon döngüsü sistematik bir biçimde tanımlanabilir. Bu tanım aşağıdaki gibidir;

> Karbon döngüsü, karbonun üretildiği, oksitlendiği, ve dönüştüğü bir seri doğal süreçten oluşur. Bu süreçler fotosentez, solunum, sindirimdir. Ayrıca, insan kaynaklı süreçlerde bulunur. Bu süreç yanma olarak tanımlanabilir. Eğer bir reservuara giren karbon miktarı, rezervuardan çıkan karbon miktarından fazla ise, Karbon Döngüsü sistemi denge durumunu kaybetmektedir (Zangori et al., 2017, p. 1256).

Karbon döngüsünün anlaşılabilmesi için bu döngü içerisindeki elamanlar, süreçler ve aralarındaki ilişkileri net bir şekilde anlaşılmalıdır (McNeill & Vaughn, 2012). Ancak bu şekilde karbon döngüsüne sistemsel bir bakış açısı ile bir çok farklı perspektiften yaklaşılabilir ve iklim değişikliği ve benzer global karmaşık sorunlar ile daha rahat başa çıkılabilir (IPCC, 2014; Melillo, Richmond, & Yohe, 2014). Bununla birlikte Dünya sistemlerini sistemsel bir bakış açısı ile ele alan onlarca çalışma yapılmıştır. Bu çailşmalar genel olarak farklı modeller kullanarak Dünya sistemlerini, su döngüsü ya da karbon döngüsü, sistemsel bir şekilde ele almaya çalışır. Tüm bu modellerin içerisinde ise "hiyerarşik sistemsel düşünce modeli" Dünya sistemleri üzerinde çalışan araştrmacılara en çok önerilendir (Scherer et al., 2017). Bu araştırmanın ışığı altında, bu araştırma da "hiyerarşik sistemsel düşünce modeli" son sınıf fen bilgisi öğretmen adaylarının Karbon Döngüsü'ndeki sistemsel düşünce becerilerini analiz etmek için kullanılmıştır.

Çalışmanın Amacı ve Araştırma Soruları

Bu çalışma fen bilimleri öğretmen adaylarının karbon döngüsü konusundaki sistemsel düşünme becerilerinin düzeylerini belirlemeyi amaçlamaktadır. Bu çerçevede, bu tezde fen bilimleri öğretmen adaylarının Karbon Döngüsü'nün karasal, hidrosfer ve atmosfer bileşenleri arasındaki ilişkileri sistemsel bir yaklaşımla ele alıp almadığı incelenmiştir. Çalışmada tartışılan araştırma soruları aşağıdaki gibidir:

1- Fen bilimleri öğretmen adaylarının karbon döngüsü konusundaki sistemsel düşünme becerileri nedir?

YÖNTEM

Bu çalışma fen bilimleri öğretmen adaylarının sistemsel düşünme becerilerini Karbon Döngüsü konusunda değerlendirmeyi hedeflemiştir. Cox (2014) yılında belirttiği üzere kişilerin kişisel geçmişleri ve alan bilgileri sistemsel düşünme becerilerini etkileyen faktörlerden olabilir. Buradan yola çıkarak bu çalışmada bir nitel çalışma yöntemi olan çoklu durum çalışması kullanılmıştır. Çoklu durum çalışması üzerinde çalışılan konun daha ayrıntılı bir şeklide incelenmesine fırsat tanımaktadır. Ayrıca, Durumlar, bir bütün olarak araştırmacı tarafından tartışılabilinir (Stake, 2005).

Katılımcılar

Bu çalışmaya Türkiye'de bir devlet üniversitesinde son sınıf öğrencisi olan dört fen bilimleri öğretmen adayı katılmıştır. Katılımcılara sırasıyla Canan, Melisa, Mehtap, ve Berfin olmak üzere rumuz isimler verilmiştir. Örneklem grubu oluşturulurken üç adet koşul belirlenerek amaçlı örneklem yöntemi kullanılmıştır. Bütün katılımcıların aynı üniversitede öğrenci olmasına, son sınıf öğrencisi olmalarına ve üniversitede aynı öğrenim programından geçmiş olmalarına dikkat edilmiştir.

Veri toplama araçları

Bu çalışmada fen bilgisi öğretmen adaylarının sistemsel düşünme becerilerini değerlendirmek amacıyla sırasıyla kelime çağırışım testi, kavram haritası ve karbon döngüsü çiziminin yanında görüşme soruları sorulmuştur.

Bu çalışmada katılımcıların yaşadıkları yerler ve akademik başarıları da göz önüne alınarak ikisi demografik olmak üzere 32 görüşme sorusu sorulmuştur. Görüşme soruları, katılımcıların cevaplarını daha detaylı analiz etme ve onların duygu ve düşüncelerini daha ayrıntılı analiz etme olanağı sağlamaktadır (Patton, 1990). Bu çalışmada yarı-yapılandırılmış görüşme soruları kullanılmıştır. Görüşme sorularının yönledirici olmamasına dikkat edimiş ve sorular cevaplanırken katılımcıların kendilerini rahat hissetmeleri açısından olabildiğince açık uçlu sorular sorulmuştur.

Veri Analizi

Görüşmeler Ben-Zvi Asssaraf ve Orion (2005) tarafından tanımlanan sistemsel düşünce becerilerine göre analiz edilmiştir. Çalışma sırasında elde edilen verilerin analizi için bu çalışmaya özel olarak bir rubrik geliştirilmiştir. Rubrik geliştirilmesi sırasında çeşitli çalışmalardan faydalanılmıştır (Tablo 3.3.). Her bir sistemsel düşünce becerisi karbon döngüsünün alt-sistemeleri olan karasal system, hidrosfer ve atmosfer olmak üzere üç kategoride incelenmiştir.

TARTIŞMA VE SONUÇ

Bu çalışmada fen bilimleri öğretmen adaylarının karbon döngüsü konusundaki sistemsel düşünme becerileri incelenmiştir.

Fen bilimleri öğretmen adaylarının sistemsel düşünce becerilerinin değerlendirilmesi

Değerlendirme sonucunda katılımcıların sistemsel düşünme becerilerinin gelişimlerinin farklılık gösterdiği ve hiyerarşik olmayan bir düzlemde ilerlediği gözlemlenmiştir.

Bu çalışmada ele alınan ilk sistemsel düşünme becerisi “sistem içerisindeki bileşenleri ve işlemleri tanımlamak” (SDB 1)’tır. Sistemin bileşenlerini tanımlamak sistemsel düşünmenin ilk ve en önemli basamaklarından biridir (Ben-Zvi Assaraf & Orion, 2005). Bu beceri kapsamında katılımcılardan beklenen Karbon Döngüsü’nün elamanlarını ve süreçlerini tanımlamalarıdır. Biri hariç bütün katılımcılar Karbon Döngüsü’nün elemanları tanımlayabilme de en üst düzeye ulaşmışlardır. Ancak Karbon Döngüsü’nün süreçlerini en üst düzeyde tanımlayabilen sadece tek bir katılımcı olduğu gözlemlenmiştir. Veriler daha yakından incelendiğinde katılımcıların genel olarak Karbon Döngüsü içerisindeki karasal sistemlere odaklandığı görülmektedir. Sibley (2007) yaptığı çalışmasında katılımcıların genel olarak görebildikleri ya da zaten aşina oldukları elemanları tanımlama eğiliminde olduğunu söylemektedir. Bu kapsam da bu çalışmada ki katılımcıların da bu eğilimi gösterdiklerini söylenebilir. Aynı zamanda hidrosfer ve atmosfer alt-sistemlerinin genel olarak göz ardı edilmesi katılımcıların alan bilgileri ile de açıklanabilir. Cox et al. (2014) yılında yaptığı çalışmada alan bilgisinin sistemsel düşünce becerisini etkileyen öenmli bir faktör olduğunu vurgulamıştır. Aynı şekilde bu çalışmada yer alan katılımcıların sadece son sınıfta hidrosfer ve atmosferi detaylı bir şeklide irdeleme fırsatı olduğu düşünüldüğünde, karasal sistemlere odaklanmaları anlaşılabilir.

Bu çalışmada ki katılımcılar genel olarak Karbon Döngüsü’ndeki elamanlar arasındaki ilişkileri üst düzeylerde tanımlayabilmişlerdir (SDB-2). Bu tanımlamalar linear bir şekilde tanımlansa dahi genel olarak karasal sistemler, hidrosfer ve atmosfer elemanları arasında bir ilişki göz önüne serdiği gözlemlenmiştir. Fakat, katılımcıların ilk sistemsel düşünce becerisi olan elemanları ve süreçleri tanımlarken odaklandıkları karasal sistemler, katılımcılar elemanlar arasındaki ilişkileri tanımlarken ortaya çıktığı gözlemlenmiştir. Bunun önemli sebeplerinden biri olarak ilk sistemsel düşünce becerisinin (SDB-1), katılımcılar tarafından bu beceriyi tanımlamak için kullanıldığı gerçeği olduğu gözlemlenmiştir. Katılımcıların elemanlar arasndaki ilişkileri tanımlarken neden-sonuç ilişkilerine odaklanmadıkları görülmüştür. Bunun en önemli nedeni, katılımcıların Karbon Döngüsündeki elemanların roller ve süreçleri tam olarak ifade edememeleri ile bağlantılı olduğu gözlemlenmiştir (Mohan et al., 2009; Sibley et al., 2007).

Ayrıca katılımcıların genel olarak karasal sistemlere odaklanıp, hidrosfer ve atmosfer sistemlerine daha az önem vermeleri onların, Karbon Döngüsü'ndeki elemanları belirli bir çerçeve içersinde organize etmelerini engellediği gözlemlenmiştir. Bu olay genel olarak Ben-Zvi Assaraf (2003) tarafından madde döngülerine "eksik ve ya parçalı" bir algı olarak yaklaşıldığı savını doğrular niteliktedir. Katılımcıların Karbon Döngüsü'nde yer alan elemanların ve süreçlerin yerlerini ve görevlerini tanımlayamamaları onların Karbon Döngüsü'nü parçalı, bütüncül olmayan bir şekilde ele almaya ittiği gözlemlenmiştir.

Katılımcıların genellikle düşük seviyelerde olduğu sistemsel düşünce becerileri is dinamik düşünce (SDB-3) ve döngüsel düşünce (SDB-5) olduğu gözlemlenmiştir. Dinamik düşüncenin gelişmesinin düşük seviyelerde olmasının başlıca nedenlerinden biri daha önceki çalışmalarda gösterildiği gibi (Ben-Zvi Assaraf, & Orion, 2005; Sibley et al., 2007) sistem içersindeki elemanların ve süreçlerin (SDB-1) eksik tanımlanmasına bağlanabilir. Ayrıca, Grözter (2000) ve Sibley (2007) yaptıkları çalışmalar da bir karbon döngüsüne ait elemanların ve süreçlerin döngü içerisindeki yerlerinin bilinmemesi, dinamik düşünceyi etkilemektedir. Bu çalışmada da katılımcıların Karbon Döngüsü'nün elemanları ve yerlerini (locations) tam olarak tanımlayamamaları reservuarlar arasındaki dinamiksel karbon akımlarını tanımlayabilmelerinin önüne geçmiş olduğu gözlemlenmiştir. Ek olarak, Karbon döngüsü konusunda ki sistemsel bir düşünce yapısı için gerekli alan bilgisinin katılımcılar bazında yetersiz olduğu gözlemlenmiştir. Özellikle karbonun reservuarlar arasında nasıl ilerlediğini ve dönüştüğünü, katılımcıların hiç biri üst düzeyde tanımlayamamışlardır (You et al., 2017). Bunun gerekçelerinden biri olarak katılımcıların karbon ve Karbon Döngüsü konularında ki kimyasal değişimleri eksik olarak tanımlamaları görülmüştür (Zangori et al., 2017).

Katılımcılar karbona rezervuarlar arasında ne olduğunu tanımlayamadıkları için, karbon akımlarını tam olarak açıklayamamış oldukları ve bu yüzden de dinamiksel düşüncelerinin düşük seviyelerde olduğu gözlemlenmiştir.

Diğer bir düşük seviyeler de gözlemlenen beceri ise Karbon Döngüsü konusundaki döngüsel düşüncedir (SDB-5). Ben-Zvi Assaraf (2003) yılında su döngüsü konusundaki sistemsel düşünce analizi yaptığı çalışmasında dinamiksel düşüncenin, döngüsel düşünce ile birlikte geliştiğini, birinin düşük seviyelerde oluşunun, diğeri içinde düşük bir seviye belirteceğini vurgulamıştır. Aynı şekilde, bu çalışmada katılımcıların döngüsel düşüncelerinin (SDB-5), tıpkı dinamik düşünceleri (SDB-3) gibi düşük seviyelerde olduğu gözlemlenmiştir. Bu veriden yola çıkılarak, Ben-Zvi Assaraf'ın (2003) altını çizdiği noktaya bu çalışma tarafından da desteklendiği görülmüştür. Katılımcıların Karbon Döngüsü konusunda düşük seviyedeki dinamik ilişkileri tanımlayabilme becerileri (dinamik düşünce, SDB-3), Karbon Döngüsü'nün döngüsel doğasını tanımlayabilmelerini etkilemiştir. Ayrıca, genel olarak katılımcıların tanımlayabildikleri elemanlar ve süreçler üzerinden karbon döngüsündeki mini-döngüleri tanımlayama çalıştıkları gözlemlenmiştir (SDB-1). Bu şekilde, katılımcıların çoğunluk ile karasal sistemler (örn; bitki) ve atmosfer arasında bu çalışma kapsamında tanımlanan (a) mini-döngüsünü tanımladıkları gözlemlenmiştir. Diğer bir mini-döngü olan ve atmosfer ve hidrosfer arasında karbon değişimlerini tanımlayan (c) mini-döngüsü ise sadece tek bir katılımcı tarafından tanımlanabildiği gözlemlenmiştir. Atmosfer, hidrosfer ve karasal sistemlerin tümü arasındaki karbon değişimlerini tanımlayan (d) mini-döngüsü ise hiçbir katılımcı tarafından tanımlandığı gözlemlenmemiştir. Bu karbon döngüsünü bir bütün olarak küçük (mini) döngülerden bir araya gelen bir Dünya sistemi olarak tanımlamalarının önüne geçtiği gözlemlenmiştir (Batzri et al., 2015; Raia, 2005). Ek olarak, karbon döngüsünün döngüsel doğası içerisinde enerji, karbonun rezervuarlar arasında akışının en önemli faktörü olarak kabul edilir (Ben-Zvi Assaraf et al., 2005). Bu çalışmada katılımcıların Karbon Döngüsü'ndeki enerji dönüşümlerine bir katılımcı dışında değinmedikleri gözlemlenmiştir.

Bu konuda litaratürde öne sürülen sebeblerden biri katılımcıların enerji konusundaki eksik bilgileri, onların sistemler arasında karbon haraket ederken, enerji dönüşümlerini tanımlayabilmelerine engel olduğu gözlemlenmiştir (Cox et al., 2017). Ayrıca, enerji konseptinin genel olarak öğrenim programlarının çekirdek fikri olarak benimsenmemesi, enerji konusundaki eksik ve yetersiz bilgileri açıklayabilir. Finley et al. (2011) yılında yaptığı çalışmasında, enerjinin bir çekirdek fikir olarak öğrenim programlarının temelini oluşturmamasının ve enerji konseptinin farklı dersler içerisinde birbirinden ayrı ve ilişkisiz bir konsept olarak anlatılmasının, öğrencilerin karbon döngüsü konusundaki enerji dönüşümlerini açıklayamamalarını sebep olduğunu ileri sürmüştür. Bu bilgiye dayanarak, bu çalışmada ki katılımcılarda sadece birinin enerji dönüşümlerinden bahsetmesi ve bu enerji dönüşümünün de sadece kimyasal enerji ile igili olması, Finley et al. (2011) 'in yaptığı çalışmayı desteklediği görülmektedir. Buna ek olarak, Karbon Döngüsü'ndeki enerji dönüşümlerinin bu çalışmadaki katılımcılar tarafından tanımlanamaması, enerjinin soyut ve zor anlaşılan bir kavram olduğu gerçeğinden de kaynaklanabilir. Finley et al. (2011) yılında yaptığı çalışmasında enerji konseptinin daha somut bir hale getirilip anlatılmaz ise, öğrencilerin madde döngülerindeki enerji dönüşmlerini tanımlayamayacaklarnı öne sürmüştür.

Karbon döngüsü konusundaki dinamik düşünce becerisi (SDB-3) ve döngüsel düşünce becerisinin (SDB-5) düşük seviyelerde tanımlanmasının yanı sıra, Karbon Döngüsü içerisindeki gizli (hidden) mekanizmalarında katılımcılar tarafından düşük seviyelerde tanımlanabildiği gözlemlenmiştir. Karbon Döngüsü'nde bu beceri kapsamında katılımcılarda diğer madde döngüleri ile mikroskopik (Karbon Döngüsü boyunca meydana geken molekül hareketleri)ve makroskopik (Karbon Döngüsü, karasal sistemler, hidrosfer ve atmosfer boyunca meydana gelen karbon hareketlenmeleri) düzeyde ilişiki kurmaları beklenilmiştir (Lee, 2015; Mohan et al., 2009).

Bu çalışmada katılımcıların karbon rezervuarları arasındaki karbon hareketlenmelerini tanımlayabildikleri halde (makroskopik), Karbon Döngüsü'ndeki carbon dönüşümlerini (molekül hareketleri, mikroskopik) tanımlayamadıkları görülmüştür. Ben-Zvi Assaraf et al. (2009) ve Lee (2015) yılında yaptıkları çalışmalarda vurguladıkları madde döngülerinde ki dinamiksel ve döngüsel düşünce becerisi, bir madde döngüsü sistemini farklı seviyelerde tanımlamayı etkileyen en önemli faktörlerden biri olarak araştırmacıların karşısına sunulmuştur. Bu bilgiyi göz önünene alarak katılımcıların bu çalışmadaki Karbon Döngüsü'ndeki dinamik (SDB-3) ve döngüsel (SDB-5) düşünce becerilerinin düşük seviyede olması, onların Karbon Döngüsü konusundaki gizli (hidden) mekanizmaları ve dolayısı ile diğer madde döngüleri ile Karbon Döngüsü arasındaki ilişkinin tanımlanamamasına sebep olduğu gözlemlenmiştir. Ayrıca Lee (2015) yılında vurguladığı gibi Karbon Döngüsünü sadece karasal sistemler ve atmosfer arasında gerçekleşen bir döngü olarak tanımlamak ve hidrosferi bu ilişkinin dışında tutmak diğer madde döngüleri ile olan ilişkilerin (örn; su döngüsü) tanımlanabilmesini engellediği görülmüştür.

Genel olarak katılımcıların çevresel sorunları tartışırken, bu sorunların karbon döngüsü'ndeki süreçlerin dengesizliğinden kaynaklandığını açıklamada (SDB-7) düşük seviyelerde kaldıkları gözlemlenmiştir. Bu çalışmadaki katılımcılar çevresel sorunları (örn; iklim değişikliğini) anlatırken genel olarak linear (düz) ve her hangi bir geri dönüt içermeyen ilişkilere odaklanıldığı gözlemlenmiştir. Bunun temel sebeplerinden bir olarak, Karbon Döngüsü'ndeki döngüsel (SDB-5) ve dinamiksel (SDB-3) düşüncenin düşük seviyede oluşunun, karbon döngüsü ve iklim değişikliği arasında geri dönütsel ilişkiler kurlumasını engellediği gözlemlenmiştir.

Ayrıca, Katılımcıların genel olarak son sistemsel düşünce becerisi olan Karbon Döngüsü'ndeki zaman boyutunu üst seviyelerde en az iki zaman açısından (geçmiş ve bugün) değerlendirdikleri gözlemlenmiştir. Diğer sistemsel düşünce becerileri ile kıyaslandığında katılımcılar tarafından oldukça yüksek çıkan bu beceri, üniversite son sınıfta verilen çevre ve sürdürülebilirlik dersleri ile ilgili olabileceği saptanmıştır.

Bu derslerin ana konularında birisinin zaman boyutu olduğu için, bu dersleri alan ve geçen katılımcıların, bu beceri (SDB-8) düşünüldüğünde yüksek seviyelerde yer alması açıklanabilir.

Genel olarak, bu çalışmada ki veriler sistemsel düşünce modelinin Ben-Zvi Assaraf ve Orion (2005) tarafından iddaa edildiği üzere hiyerarşik olmadığı gözlemlenmiştir. Aynı zamanda, modelde üçüncü sistemsel becerisi olan dinamik düşünce becerisinin ilk iki düşünce becersini de kapsadığı, bu yüzden, ilk iki sistemsel düşünce becerisine gerek olmadığı gözlemlenmiştir. Ek olarak, bu çalışmada sistemsel düşünce bilgisi ile alan bilgisi arasında da güçlü bir bağ olduğuna yönelik kanıtlar gözlemlenmiştir. Genel olarak katılımcıların, temel sistemsel düşünce becerisine sahip oldukları gözlemlenip, bu yönde bir çalışma ile sistemsel düşüncelerinin de geliştirilebileceği ön görülmüştür.

ÖNERİLER

Bu çalışma sistemsel düşünme becerilerini fen eğitimi alanında kullanmak isteyen araştırmacılar için bir fikir oluşturması amacı ile yapılmıştır. Bu çalışmada fen bilgisi öğretmen adaylarının Karbon Döngüsü konusundaki sistemsel düşünce becerileri analiz edilmiştir. Dünya sistemleri söz konusu olduğunda kullanılabilecek bir çok modelden biri olan "hiyerarşik sistemsel düşünce" modelinin, Karbon Döngüsü söz konusu olduğunda hiyerarşini yitirdiği ve özellikle, modeled tanımlanan ilk iki becerinin anlamının kaybettiği gözlemlenmiştir. Bu konuda ileride yapılacak çalışmalarda Ben-Zvi Assaraf ve Orion'un (2005) hazırladığı bu modelin bir versiyonu olan ve Sibley et al. (2007) tarafından geliştirilen model kullanılabilir.
Ayrıca bu çalışma alan bilgisi ile sistemsel düşünce becerisi arasında güçlü bir bağ olduğunu ortaya koymaktadır. Bu bağdan yola çıkarak katılımcıların öncelikle çalışılan konu hakkındaki alan bilgilerinin de kontrol edilmesi önem arz etmektedir.

Ek olarak bu çalışma erkek öğretmen adayları bulunamadığı için, sadece bayan öğretmen adayları ile yapılmıştır. Cinsiyetin sistemsel düşünce becerisi üstünde olan etkisini tartışan çalışmalar göz önüne alındığında (Cox et al., 2017), bu çalışmanın hem erkek hem de kadınları içeren bir çalışma düzeninde tekrarlanması önemli olabilir.

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