ABSTRACT

LEE, TAMMY DUTTON. Science Teachers’ Representational Competence and Systems Thinking. (Under the direction of Dr. Gail Jones).

The study of systems has long been a part of elementary science standards and recently a new emphasis on teaching with a “systems thinking” approach has grown in importance. Implementing a systems thinking approach involves students understanding the complexity of systems in particular the interactions that occur within and outside of the system. The use of models and representations has been shown as an effective pedagogical approach for teaching systems thinking. The appropriate selection and use of these representations is vital to developing systems thinking and representational competence. This dissertation explored elementary teachers’ application of systems thinking during the planning process of teaching about a complex system. The first study investigated sixty-seven elementary in-service teachers’ and sixty-nine pre-service teachers’ knowledge of the water cycle and their knowledge of systems thinking. Results from this study identified elementary in-service and pre-service teachers’ levels of systems thinking from novice to intermediate. The second study investigated elementary in-service and pre-service teachers’ selection and use of representations for a proposed lesson on the water cycle. Results from this study showed that experienced in-service teachers and novice pre-service teachers selected similar representations and provided similar rationales for their selection. Pedagogical approaches proposed by in-service and pre-service teachers were classified as more teacher centered than student centered. The final section of this dissertation examined representational competence in the context of lessons that teach systems thinking.
Science Teachers’ Representational Competence and Systems Thinking

by
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DEDICATION

To my husband who graciously endured each step of this journey with me, giving me the strength, confidence, and courage to continue and to never give up. Slow and steady always wins the race.

To my daughter, Morgandy Taylor Lee: always face each challenge with perseverance and endurance.

To my Mom and Dad: thank you for always believing in me.

To my brother, sister-in-law, nieces and nephew: Go WOLFPACK!

To all my friends (you know who you are): thank you for reminding me to laugh.

To my colleagues at East Carolina University: thank you for supporting me in every way.

To my friend and colleague Bonnie Glass: thank you for always listening and offering your support in every way possible. I could not have made this journey without you.

To my students at East Carolina University: thank you for your encouragement and being my cheerleaders.

To my colleagues and friends at the Museum of Natural Sciences: thank you for first inspiring me to love science and for sharing your love of nature.

To my grandmothers (Virginia Elliott and Cebah Dutton): thank you for showing me the strength of women.

But with every little bang, every little push

Every little step I take, I get closer....
BIOGRAPHY

Tammy Dutton Lee was born in Raleigh, North Carolina in June of 1972. As a child she always loved being outside and finding her way through the woods. She began her education at East Carolina University obtaining her BS in Elementary Education in 1994. Her teaching career began at Belvoir Elementary teaching kindergarten. She then took a second grade teaching position at G.R. Whitfield Elementary, which lasted ten years. During her second year of teaching she participated in a program called UTOTES (Utilizing The Outdoors to Teach Experiential Science), a yearlong professional development conducted by the Museum of Natural Sciences in Raleigh. It was this experience and many more provided by the museum that inspired her to be a science educator. She began this pursuit of becoming a science educator by obtaining MA in Education with a concentration in Science Education in 2003 from East Carolina University. Upon graduation she left the classroom and worked as a Science Facilitator creating and administering science professional development for elementary teachers for a grant entitled, “Partnerships for Improving Mathematics and Science.” In the summer of 2005, she became a fixed term faculty member at East Carolina University teaching elementary science methods courses and creating a science concentration for elementary majors for the Department of Mathematics, Science, and Instructional Technology Education. During this time, colleagues at ECU encouraged her to pursue her PhD at NC State University in Science Education. In 2009, she began the PhD journey at NC State University. She is forever grateful to the faculty of NC State University and especially Dr. Gail Jones for making the experience most memorable.
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INTRODUCTION

This dissertation focused on the knowledge and application of systems thinking by elementary teachers and pre-service teachers when planning a lesson about a complex system (e.g., water cycle). The first study describes elementary in-service and pre-service teachers’ knowledge of the complex system (e.g., water cycle) and their knowledge of systems thinking. The second study documented how these same teachers selected and used visual representations when planning a lesson on the water cycle. The final section of this dissertation is a chapter that examined representational competence in the context of lessons that teach systems thinking. In the paragraphs that follow, each article and the chapter is identified by its title and a brief abstract.

Teaching Systems Thinking in the Context of the Water Cycle

Complex systems surround us in every aspect of our lives from the ecosystems that we inhabit and share with other living organisms to the systems that supply our water (i.e., water cycle). Developing an understanding of complex systems consists of evaluating events, entities, problems, and systems from multiple perspectives; this approach is known as “systems thinking.” New curricular standards have made explicit the call for teaching with a “systems thinking” approach in our science classrooms. However, little is known about how elementary in-service or pre-service teachers understand complex systems especially in terms of systems thinking. This mixed methods study investigated sixty-seven elementary in-service teachers’ and sixty-nine pre-service teachers’ knowledge of a complex system (e.g., water cycle) and their knowledge of systems thinking. Quantitative and qualitative analyses
of content assessment data, and questionnaires were conducted. Semi-structured interviews were conducted with a subsample of participants. Results from this study showed elementary in-service and pre-service teachers had different levels of systems thinking from novice to intermediate. Common barriers are identified with both in-service and pre-service teachers for identifying components and processes, recognizing multiple interactions and relationships between subsystems and hidden dimensions, and finally, difficulty understanding the human impact on the water cycle system.

**Science Teachers Selection and Use of Visual Representations**

As science grows in complexity, science teachers must translate and communicate these complex models, ideas, and phenomena with representations in their instruction. What is not known is how teachers make choices about pictorial representations in planning lessons. This mixed methods study investigated the pedagogical approaches proposed by elementary in-service and pre-service teachers and the proposed uses of visual representations for a science lesson about the water cycle. Quantitative and qualitative analyses of a card-sort assessment of visual representations was conducted with sixty-seven elementary in-service and sixty-nine elementary pre-service teachers. Semi-structured interviews were conducted with a subsample of teachers. Results from this study showed that both experienced in-service teachers and novice pre-service teachers tended to select similar representations and their rationales for their choices were also similar. Teachers tended to select representations that were aesthetically pleasing, simple in design, and illustrated specific elements of the water cycle. The results also showed that teachers were
not likely to select images that represented the less obvious dimensions of the water cycle. Proposed pedagogical approaches for using representations were classified as more teacher centered than student centered.

**Instructional Representations As Tools To Teach Systems Thinking**

Emphasis on learning about systems in science education has long been part of national and state curricula, but the focus on implementing a “systems thinking” approach in science classrooms has grown in importance. Systems thinking involves helping students to understand the complexity of systems by recognizing the interactions and interrelationships between system components and processes. Evidence from research has shown that effective systems thinking instruction requires teachers to explicitly use models and representations. The selection, interpretation, explanation and use of effective representations is dependent on classroom teachers for developing systems thinking and representational competence. This chapter examines representational competence in the context of lessons that teach systems thinking. Drawing on prior research, theoretical perspectives about systems thinking and the use of representations as instructional tools are discussed. A developed rubric is presented for examining teachers’ pedagogical perspectives when selecting representations for teaching about a complex system.
TEACHING SYSTEMS THINKING IN THE CONTEXT OF THE WATER CYCLE

There are many challenges that face us today, such as enduring water shortages, moving to alternative energy sources, and experiencing global climate change that requires citizens to think about these issues from multiple perspectives. For example, major policy debates around such topics as the effects of cloning or the potential for alternative fuels and their impact necessitate a scientifically informed citizenry (National Research Council, 2007). These complex issues have prompted a call for a “systems thinking” approach by educators, engineers, environmentalists, economists, and scholars (Forrester, 2007). A systems thinking approach requires individuals to view the whole (whether problem, system, event or entity) from multiple perspectives, recognizing the interactions, patterns, and interrelationships between the components, and considering the cause and effect relationships of the components in terms of temporal and spatial dimensions. Systems thinking is essential for increasing our ability to understand the challenges facing our society today, to develop solutions, and more importantly, to take action as global citizens (Booth Sweeney & Sterman, 2007).

To understand complex systems requires an individual to have an understanding and recognition of concepts and principles about a particular domain, which represents key (often dynamic) phenomena and their interrelationships (Hmelo-Silver & Pfeffer, 2004). The study of systems thinking has been examined in many domains, such as social sciences (e.g., Senge, 1990), medicine (e.g., Faughman & Elson, 1998), psychology (e.g., Emery, 1992), curriculum development (e.g., Ben-Zvi Assaraf & Orion, 2004), decision making (e.g.,
Graczyk, 1993), project management (e.g., Lewis, 1998), engineering (e.g., Fordyce, 1988) and mathematics (e.g., Ossimitz, 2000). Research has shown that the ability to think in terms of systems is considered a higher-order thinking skill (Frank, 2000), which is imperative to understanding concepts and principles within science. Although it is currently acknowledged that all areas of science require systems thinking to reason critically, the research of systems thinking in the context of science education has a limited history (Kali, Orion, & Eylon, 2003).

**Systems Thinking Skills Development**

The development of systems thinking skills in education has been examined across a number of contexts and ages of students including elementary (Ben-Zvi Assaraf & Orion, 2010), middle and high school (Penner, 2000; Frank, 2000; Ben-Zvi Assaraf & Orion, 2005; Booth Sweeney & Sterman, 2007), and college students (Booth Sweeney & Sterman, 2007). The development of a systems thinking approach requires skills such as examining, evaluating, and inventing, which include more than just a recall of facts (Frank, 2000). Systems thinking, like higher-order thinking skills, have been defined as complex, capable of providing multiple explanations, involving various amounts of judgment and uncertainty, employing self-regulation, finding structure in disorder, and being productive (Resnick, 1987).

Researchers have questioned the age and grade level that is appropriate for teaching systems thinking since these skills have been characterized as higher order thinking skills. It has been suggested that teachers of all academic levels should engage students in tasks that
involve these higher-order thinking skills (Zohar & Dori, 2003). Other researchers have stated that the foundation of systems thinking skills should begin in elementary school (Ben-Zvi Assaraf & Orion, 2010). Forrester (2007) argued that this development of a systems perspective would take less time if started in elementary school since children at this age have an inquisitive open mind that has not been taught to think in terms of unidirectional cause and effect.

Research has shown a link between the development of systems thinking and conceptual understanding of science (Grotzer & Bell-Basca, 2003). With this in mind, elementary teachers and elementary pre-service teachers are often reported as having a lack of conceptual knowledge in science (Garet, Porter, Desimone, Birman, & Yoon, 2001; Kennedy, 1998; Lee, Lewis, Adamson, Maerten-Rivera & Secada, 2007), which may also indicate a lack of systems thinking. The educational implications of restructuring our classrooms to reflect the ideas of systems thinking has come to the attention of educators and is viewed as a viable teaching strategy (Hmelo, Holton, & Kolodner, 2000). In terms of pedagogy, a systems thinking approach provides learners with a more holistic view of systems, problems, events, or entities than traditional ways of teaching. We need to know more about how teachers think about complex systems in science contexts and how they use systems thinking in instructional planning if we are to realize the goal of promoting systems thinking in science education. The purpose of this research study is to investigate elementary teachers’ and elementary pre-service teachers’ knowledge of the water cycle and the application of systems thinking toward this complex system.
Importance of Systems Thinking

Teaching system thinking skills is a fundamental component of science education since the natural world is composed of many complex phenomena (e.g., ecosystems, moon phase formation, water cycle, carbon cycle, and energy transfer), and developing an understanding of the function and behaviors of complex systems requires thinking in terms of systems (Evagorou, Korfiatis, Nicolaou & Constantinou, 2009). Furthermore, the connection between the development of systems thinking and conceptual understanding in science education has been established (Grotzer & Bell-Basca, 2003). For this reason, researchers and educators have advocated the importance of emphasizing systems thinking skills while teaching standard science topics within areas of ecology and earth science as a prerequisite for conceptual understanding (Hogan & Thomas, 2001; Klopfer & Resnick, 2003; Stieff & Wilensky, 2003; Wilensky & Reisman, 2006). Although there is a call for reforming the teaching of complex systems, relatively few studies explore how students learn complex systems (Jacobson & Wilensky, 2006), and even more limited are studies of teachers’ knowledge of complex systems and systems thinking.

In the past ten years, researchers of social, technological, and natural systems have focused on the importance of understanding complex systems, students’ abilities to learn about complex systems, and instructional methods and tools being used to teach or examine complex systems that support technology (Sabelli, 2006), social systems (e.g., Booth Sweeney, 2000; Booth Sweeney & Sterman, 2007; Kim, 1999; Mandinach, 1989; Steed, 1992; Ullmer, 1986), technological systems (e.g., Frank, 2000), biological systems (e.g., Verhoeff,
Waarlo, & Boersma, 2008), and natural systems (e.g., Ben-Zvi Assaraf & Orion, 2005; Hmelo-Silver, Marathe, & Liu, 2007; Hmelo-Silver & Pfeffer, 2004; Ossimitz, 2000; Wilensky & Resnick, 1999). Investigating how systems work is not a new phenomenon for scientists or engineers, but with advances in technology and the use of modeling, our perspectives of science and the systems within science have been transformed. Areas of science have changed tremendously over the past two decades due to these scientific and technological advances, resulting in a blurring of lines between the traditional disciplines (National Research Council 2007). The emerging fields of science such as biochemistry, bioinformatics, computational biology, and nanoscience represent a blending of traditional fields of science. The study of systems provides a context for cross-disciplinary inquiry between multiple areas of science (Goldstone & Wilensky, 2008). Even though all areas of science require a systems thinking approach, research of systems thinking within science education is limited (Kali et al., 2003).

Call for Systems Thinking: National Science Standards

The emphasis of teaching systems has been a part of our national science standards since the National Science Education Standards (National Research Council, 1996). More recently, the National Research Council’s A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas (National Research Council, 2012) and the newly published Next Generation of Science Standards (NGSS) provide a more explicit call for teaching from a systems thinking approach. The NGSS restates the NSES definition of a system (Achieve, 2013):
The natural and designed world is complex; it is too large and complicated to investigate and comprehend all at once. Scientists and students learn to define small portions for the convenience of investigation. The units of investigations can be referred to as “systems.” A system is an organized group of related objects or components that form a whole. Systems can consist, for example, of organisms, machines, fundamental particles, galaxies, ideas, and numbers. Systems have boundaries, components, resources, flow, and feedback. (NRC, 2012 pg. 91-92)

The explicit call for systems thinking was established with the addition of Dimension 2- Crosscutting Concepts in the Framework and NGSS. The intention of these seven crosscutting concepts was to give students the resources to form a more advanced understanding of the disciplinary core ideas through developing a coherent and scientifically based view of the world. The seven crosscutting concepts identified in the Framework and NGSS are stated as follows: 1) patterns; 2) cause and effect relationships; 3) scale, proportion and quantity; 4) systems and system models; 5) energy and matter — flows, cycles, and conservation; 6) structure and function; and 7) stability and change. The National Research Council (2007) clearly states the crosscutting concepts as key to identifying components of a system, the interactions of the components of a system, and the systems’ behavior as a whole regarding the interrelationships between the components.

**The Water Cycle as a Complex System**

Developing an understanding of the structures, processes, and behaviors of the subsystems of biosphere, atmosphere, hydrosphere, and biosphere leads to environmental
literacy. Covitt, Gunckel, and Anderson (2009) defined two principles (cyclic thinking and human impact) needed when using a systems approach to studying subsystems of earth science. Cyclic thinking requires an individual to understand the cycling processes of the exchange of energy and materials through the subsystems (atmosphere, hydrosphere, geosphere, and biosphere). In addition, part of cyclic thinking includes awareness that humans are a part of these environmental subsystems, and impact the systems’ functions and behaviors (Orion & Ault, 2007). Studying earth science provides the context for developing the knowledge and ability to draw conclusions on environmental issues such as conservation of energy and water, as well as proper utilization of global resources to use as evidence to formulate decisions (Orion, 2002). Researchers claim that earth science programs should be developed within a systems framework (rock, water, and carbon cycles) with the inclusion of human impact among these systems in order to develop environmental literacy (Orion & Ault, 2007). The hydro cycle (e.g., water cycle) is one subsystem of the earth system that can include these components within science classrooms to promote and develop environmental literacy.

The water cycle was chosen as the complex system to investigate for this study because of the emphasis placed on this complex system within the Framework and the NGSS as a major earth science topic to be addressed in the elementary grade band. The study of this complex system (the water cycle) is not just about defining evaporation, condensation, and precipitation, but also about articulating how water changes states and moves from one part of the system to another (Schwartz, Thomas-Hilburn, & Haverland, 2011). Both
documents (Framework and NGSS) state that by the end of fifth grade, students should understand the interactions of Earth’s major systems: the geosphere (solid and molten rock, soil, and sediments), the hydrosphere (water and ice), the atmosphere (air), and the biosphere (living things, including humans). Students need to develop an understanding that all of these systems interact in multiple ways to affect Earth’s surface materials and processes. Even though the importance of hydrology concepts is apparent in the development of environmental science literacy, few studies focus on elementary in-service and pre-service teachers’ knowledge of this complex system (Dickerson, Callahan & Van Sickel, 2007). If elementary teachers are to teach the water cycle as a system and promote systems thinking in students, as called for in these reform documents, more research is needed on their knowledge of this system and their instructional ideas for teaching the water cycle.

**Water Cycle System Framework for Systems Thinking**

This research study used the NGSS disciplinary core idea of earth’s materials and systems, selected crosscutting concepts (Achieve, 2013), and the Systems Thinking Hierarchal Model (STH Model) (Ben-Zvi Assaraf & Orion, 2005). Each element of the framework will be discussed.
Figure 1. Water cycle system framework. Adapted from *Next Generation of Science Standards* (Achieve, 2013).

**Disciplinary Core Idea (Earth’s Materials and Systems)**

The Framework and NGSS organized Earth and space science (ESS) into three main ideas: Earth’s Place in the Universe, Earth’s Systems, and Earth and Human Activity. The core idea of Earth’s Systems incorporates studying the processes affecting the Earth’s conditions and its continuous changes, including the role of water with these never-ending changes. Earth materials and systems is one of the disciplinary core ideas within Earth’s
Systems. The study of Earth’s materials and systems focuses on the subsystems (atmosphere, hydrosphere, geosphere, and biosphere), which are interconnected by complex dynamic relationships and interactions. These interactions and relationships among these earth subsystems is a study of systems thinking (National Research Council, 2007).

By the end of fifth grade, NGSS (Achieve, 2013) states that students should understand the multiple interactions of these major subsystems and their effects on Earth’s surface materials and processes. For this reason, the four spheres—the geosphere, biosphere, atmosphere, and hydrosphere—are included in the framework. There are multiple connecting arrows that show all the possible interactions and relationships that can occur between and among the four subsystems. The crosscutting concepts and the systems thinking components are located within the arrows, to illustrate the essential concepts and components needed for implementing a systems thinking approach.

The Systems Thinking Components

The System Thinking Hierarchical (STH) Model created by Ben-Zvi Assaraf and Orion (2005) has been used to illustrate the development of systems thinking with elementary, middle, and high school students studying the topic of the water cycle. Here, the STH model components are being used to investigate what elementary in-service and pre-service teachers may know about the water cycle and systems thinking.

The STH model has eight characteristics of systems thinking that include three hierarchical levels: Level 1, the analysis level, which includes the ability to identify the system’s components and processes; Level 2, the synthesis level, which includes the ability
to identify relationships between separate components, the ability to identify dynamic relationships between the system’s components, the ability to understand the cyclic nature of systems, and the ability to organize components and place them within a network of relationships; and Level 3, the implementation level, which includes the ability to make generalizations and to understand the hidden components of the system and the system’s evolution in time (prediction and retrospection). These levels are proposed as a structure for implementing teaching interventions within curriculum development, with each group of skills serving as a basis for developing the next level of systems thinking. Ben-Zvi Assaraf and Orion (2005) have suggested that these levels are hierarchical in the development of systems thinking, stating that elementary, middle, and high school students did not demonstrate growth in higher levels until they first accomplished the beginning levels. Although more research is needed to determine the feasibility of the hierarchical nature of the STH model, the model’s components were used here as a framework for determining elementary in-service and pre-service teachers’ knowledge of the water cycle and the classification of the various levels of knowledge.

**Crosscutting Concepts**

The seven crosscutting concepts recognized in the Framework and NGSS provide students with an organizational framework (National Research Council, 2012), connecting knowledge across various disciplines, creating a coherent and scientifically based view of the world. They also illustrate the concepts needed for studying systems in science. Each of the descriptions of the crosscutting concepts highlights their use in developing a cumulative,
logical, and usable understanding of complex systems (National Research Council, 2012). If teachers utilize the crosscutting concepts for their intended purpose, teachers will create a systems thinking approach to their instruction and, therefore, develop system thinkers.

Within this study, the crosscutting concepts also add to the framework for evaluating elementary in-service and pre-service teachers knowledge of systems thinking. Each of the crosscutting concepts defines the concepts needed for developing systems thinking in the first component of the STH model (Ben-Zvi Assaraf & Orion, 2005). For example, level 1 of the STH model indicates that an individual identifying the components and processes of a system displays an analysis level of systems thinking knowledge. The crosscutting concept of patterns assists the individual in identifying the components and processes if the individual can recognize and understand the patterns of that system. Level 2 of the STH model states that if an individual understands the relationships within the system and recognizes cyclic thinking, they have moved to the next level of knowledge of systems thinking. Three crosscutting concepts could help an individual develop this level of systems thinking—for example, these crosscutting concepts could help identify structures and understanding of the functions of a system, of the cause and effect reactions that happen within a system, and of ways the models illustrate these concepts within a particular system. To develop Level 3 knowledge of the STH model, an individual needs to demonstrate the ability to make generalizations about the system and understand the hidden and time dimensions of a system. Several crosscutting concepts could help an individual develop this level of systems thinking. For example, the understanding of scale, proportion, and quantity
is essential for understanding the hidden and time dimensions. For an individual to have the ability to make generalizations about system behavior, they must understand the relationships of energy and matter: flows, cycles, and conservation of that system. These are just a few examples of how the crosscutting concepts connect with the STH model of developing systems thinking. These crosscutting concepts in combination with the STH model will be utilized as a framework for qualitative analysis.

**Developing Systems Thinking In Elementary School**

The development of systems thinking can be a challenge for students and adults. The implementation of systems thinking at the elementary level presents even more difficulties due to the lack of abstract thinking skills when applied to complex systems and limited language competency of students (Ben-Zvi Assaraf & Orion, 2010). Educators in recent years have recognized the limited or nonexistent understanding of complex systems among students, encouraging the implementation of the study of systems at all levels of K-12 science curriculum (e.g., Hmelo-Silver & Azevedo, 2006; Jacobson & Wilensky, 2006; Lesh, 2006). Several researchers have advocated for the introduction of systems study to be focused at the elementary level (Ben-Zvi Assaraf & Orion, 2010; English, 2006; Forrester, 2007). Sheehy, Wylie, Mcguinness, and Orchard (2000) acknowledge that they had mistakenly believed that children were not at a level of sophistication until adolescence to develop systems thinking skills.
Barriers to Developing Systems Thinking

Research in systems thinking has identified three possible developmental barriers students encountered that must be overcome if individuals are to reach higher levels of systems thinking. These barriers include: (1) identifying multiple levels of interactions and relationships; (2) explaining the functions and behavior of the system; and (3) identifying the hidden dimensions of a system (the invisible parts of the system). These skills work together when developing a more comprehensive understanding of systems to reach the higher levels of systems thinking. As an example, to distinguish and understand more elaborate relationships within the system, an individual must comprehend the functions and behaviors of the structural aspects of the system and recognize the impact of the hidden dimensions of the system.

Identifying Interrelationships Within Systems

Students who tend to explain simple causal relationships among system components and have difficulty making connections within the system are often missing the complexity of the system (Perkins & Grotzer, 2000). In a study by Ben-Zvi Assaraf and Orion (2004, 2010), elementary, middle and high school students had difficulty explaining the relationships between the processes of the water cycle, describing the processes as unrelated parts. Students within these studies had difficulty explaining the connections of the water cycle with other earth subsystems and their relationships. These studies found elementary students tended to focus only on the atmospheric components of the system. The inability to recognize the relationships among subsystems such as groundwater, surface water, and water
in biotic systems (Ben-Zvi Assaraf & Orion, 2010; Orion & Ault, 2007), creates difficulties understanding the function of these structures, which contributes to a lack of understanding of the overall behavior of this system.

In studies about complex ecological systems such as food chains (Reiner & Eilam, 2001), system (Hogan & Thomas, 2001), food webs/nutrient cycles (Hogan & Fisherkeller, 1996), and energy flows (Leach et al., 1996), students also had difficulties describing relationships beyond linear flow, single causality, and visible structures. Both adults and students indicated simple linear one-way causal structural relationships instead of recognizing the more intricate interrelationships of patterns that exist in complex systems (Booth Sweeney & Sterman, 2007; Brazelton, 1992; Grotzer & Bell-Basca 2003). The inability to understand the multiple interrelationships of components signifies a lack of systems thinking. Students and adults that lack systems thinking tend to concentrate on descriptive surface features when describing relationships within systems. Difficulty identifying the multiple relationships between components of the system signifies a lower level of systems thinking.

**Identifying the Function and Behavior of a System**

In studies of the water cycle, elementary and middle school students had difficulty explaining the systems components and processes (e.g., functions and behaviors of the system), within a framework of relationships known as cyclic thinking (Ben-Zvi Assaraf & Orion, 2005, 2010). Cyclic thinking is associated with the synthesis level (e.g., STH Model), describing the dynamic cyclic relationships between and among the subsystems of the water
cycle instead of seeing the relationships as more mechanical. Kali et al. (2003) found that middle school students described the rock cycle as being a system of unrelated parts or pieces, indicating a lack of understanding of a dynamic system. There was little difference between the middle school students’ and pre-service teachers’ knowledge of function and behaviors of the complex systems (e.g., aquaria and human respiratory system). One of the most interesting findings was the different viewpoint between the expert groups regarding the functions and behaviors of these systems. In the aquaria system, study biologists tended to focus on abstract biological processes and mechanics of the system and the hobbyists emphasized the concrete aspects in relation to the maintenance of the fish. The biologists’ view of the aquarium was a system view due an understanding of the dynamic interdependencies of the components within the system. In contrast, hobbyists provided a more focused explanation regarding the relationships between and among structures and their associated functions and behaviors (Hmelo-Silver & Pfiiffer, 2004). These results suggest that being an expert in complex systems is different from being an expert of knowledge of principles in that particular area of science or topic. An expert in complex systems or systems thinking understands the relationships among the different levels of a system, while understanding that the behavior of the system arises as a function of spatial and temporal interactions between the components, and an individual must be able to use this knowledge to think about the properties of the whole system (Hmelo-Silver, Marathe & Liu, 2007).
Identifying Hidden Dimensions

Parts of systems may be extremely large (e.g., water cycle movement of water across landscapes, river systems, and oceans) and some components of the same system can be so incredibly small (e.g., molecule movement within the water cycle) that they are invisible to the observable eye. The boundary of the system must be selected to identify the part of the system to study (Boardman & Sauser, 2008; NSES, 1996) to make it manageable for investigation. Defining and understanding the boundaries of the system can be a challenge for students since these skills require knowledge of scale.

Even though the crosscutting concept of scale, proportion, and quantity of the NGSS (2013) is an interdisciplinary theme, our knowledge of how students develop concepts of scale and their application of scale across different science areas is limited (Jones & Taylor, 2009). Scale is not limited to size and distance but also covers other quantities such as time, weight, surface area, and temperature (Jones, Taylor, Tretter & Oppewal, 2008). In the study of systems, scale includes the hidden dimensions of the system, which are the components of the system either too large or too small to be observed naturally. This concept of scale has been proven difficult to master for both students and teachers (Tretter, Jones, Andre, Negishi, and Minogue, 2006). For example, Hmelo et al. (2000) found sixth-grade students had difficulty with macro and micro components of the human respiratory system. This lack of knowledge of scale creates the challenge of understanding the hidden dimensions of the system, which leads to a lack of understanding of the entire system.
Describing water in terms of its structure, properties, and processes can be difficult due to its invisibility within the water cycle (Ben-Zvi Assaraf & Orion, 2005; Covitt et al., 2009). Covitt et al. (2009) discovered that middle and high school students were able to describe visible movements of water (e.g., rain and runoff) but had difficulty applying key principles such as the law of conservation of matter when describing movement of water and materials between visible and invisible parts of the system, suggesting difficulty with scale. This difficulty of scale was displayed when these same students had little awareness of parts of the system that are too small (e.g., molecules in solution) or too large (e.g., watersheds). Groundwater proved to be a problematic part of the water cycle for children, who described its location as being in underground sewers, lakes, streams, or layers (Ben-Zvi Assaraf & Orion, 2005, 2010; Covitt et al., 2009; Dickerson, Penick, Dawkins, Van Sickel, & Hay, 2005; Dickerson & Dawkins, 2004; Dickerson, Callahan, & Van Sickel, 2007). This inaccurate view of size and scale of aquifers leads children to the idea that groundwater is a dead end of the water cycle (Ben-Zvi Assaraf & Orion, 2005; Dickerson et al., 2005; Dickerson & Dawkins, 2004).

These barriers should not be viewed as separate elements but as areas to be addressed in classroom instruction to assist in the development of systems thinking skills. The most sophisticated of these skills require explicit classroom instruction and scaffolding to provide students with the foundation to develop these systems thinking skills (Hmelo-Silver and Azevedo, 2006). Some empirical evidence has shown that growth of these skills can be developed. With a careful selection of instructional strategies, tools (representations), and
purposeful selection of system contexts (environmental problems), students’ systems thinking will improve (Wilensky & Reisman, 2006; Ben-Zvi Assaraf & Orion, 2005, 2010; Evagorou et al., 2009; Hmelo-Silver & Azevedo (2006). For these reasons, it is imperative to understand the knowledge of complex systems that elementary teachers and elementary pre-service teachers have and if they think about a complex system in terms of systems thinking.

**Research Methods**

The purpose of this study was to investigate elementary in-service and pre-service teachers’ knowledge of the water cycle and systems thinking.

**Research Questions**

The specific questions that guide this study are as follows:

RQ1: What understandings do elementary in-service and pre-service teachers have about the water cycle?

RQ2: How do elementary in-service and pre-service teachers apply systems thinking about the water cycle?

**Study Context**

The water cycle is an example of a complex system and was chosen as the complex system for this study because of its emphasis within the Framework and the NGSS as a major earth science topic to be addressed in elementary grades.
Design

Four assessments were used to elicit elementary in-service and pre-service teachers’ knowledge about the water cycle and their application of systems thinking. Semi-structured interviews were conducted with a purposeful sample of in-service and pre-service teachers to clarify systems thinking levels and explore systems thinking within a proposed lesson on the water cycle (see Figure 2).

![Components of the Study Design](image)

*Figure 2. Components of the study design.*
The mixed methods design was chosen to provide details about how systems thinking is applied to instructional planning about a complex system (e.g., water cycle).

**Participants**

Elementary teachers teaching grades 3-5 from three districts surrounding a southeastern university were recruited to participate in this study. Sixty-seven in-service teachers (n=67) volunteered. The teacher sample included 65 females and two males. Sixty-two were Caucasian, four African American, and one Hispanic.

Elementary pre-service teachers from a southeastern university were recruited. Sixty-nine elementary pre-service teachers (n=69) volunteered, including sixty-six females and two males, all Caucasian. The pre-service teachers were in the last two years of an undergraduate teacher education program.

**Selection of Interview Participants**

After the analysis of the assessments, a purposeful sample was selected for interviews. The interviews were designed to explore systems thinking and pedagogical decisions; the researcher selected a participant from each group of systems thinking levels (high and low) indicated by the overall mean scores. Two teachers (one high and one low) and two pre-service teachers (one high and one low) were selected for interviews. These participants were selected to provide additional information about the ways in which participants defined a system and discussed systems thinking, and their pedagogical ideas for teaching systems thinking in an elementary classroom.
Assessments: Water Cycle Diagnostic Test, Cyclic Thinking Questionnaire (CTQ), Groundwater Dynamic Nature Questionnaire (GDN) and Interviews

The participants completed four assessments that included the Water Cycle Diagnostic Test (WCDT) (Schaffer, 2013), the Cyclic Thinking Questionnaire (CTQ), the Groundwater Dynamic Nature Questionnaire (GDN) (Ben-Zvi Assaraf & Orion, 2005, 2010) and interviews. The WCDT test assessed elementary in-service and pre-service teachers’ knowledge of processes and interactions between the two subsystems of the atmosphere and hydrosphere within the water cycle. Items from the Cyclic Thinking (CTQ) and Groundwater Dynamic Nature Questionnaires (GDN) were used to assess in-service and pre-service teachers’ knowledge of systems thinking, including interactions among the four subsystems of the water cycle (e.g., hydrosphere, biosphere, geosphere, and atmosphere).

Water Cycle Diagnostics Test Assessment

The Water Cycle Diagnostics Test (WCDT) (Appendix 1) developed by Schaffer (2013) was used to examine systems thinking in the context of the water cycle. This three-tiered diagnostic test on the water cycle was designed to determine elementary pre-service teachers and secondary science teachers’ conceptual knowledge of the water cycle, to diagnose their alternative conceptions, and to assess the strength of these alternative conceptions. The WCDT assessment was not designed to assess all levels of systems thinking as indicated by the STH model of Ben-Zvi Assaraf and Orion (2005). A selection of twenty questions that focused on identifying individual components and processes of the atmosphere and hydrosphere and their relationships within the water cycle was chosen from the WCDT. These questions also addressed the analysis and synthesis levels of the STH
model of systems thinking. The system components and processes identified with this assessment included transpiration, evaporation, and phase changes of water, condensation, formation of clouds, global climate change, and movement of water through the water cycle.

Validity and Reliability of Water Cycle Diagnosis Test

An atmospheric oceanic scientist and three science education specialists completed content validity of the Water Cycle Diagnosis Test (WCDT) of the selected twenty questions through a review process of assessment questions. The review process verified content as internally consistent.

The selected twenty questions from the WCDT were tested for reliability using the in-service and pre-service teachers’ sample (N=136). The reliability calculated by a Cronbach’s alpha was 0.739, which is above the acceptable threshold of 0.50 set for multiple choice item instruments (Nunally, 1978).

Assessment: Cyclic Thinking Questionnaire (CTQ) and Groundwater Dynamic Nature Questionnaire (GDN)

Ben-Zvi Assaraf and Orion (2005) used the Cyclic Thinking Questionnaire (CTQ) and The Groundwater Dynamic Nature (GDN) Questionnaire to assess students’ (elementary and middle) understanding of systems thinking. The Cyclic Thinking Questionnaire (CTQ) was developed to identify students’ understanding of the cyclic nature of the hydrosphere and the conservation of matter within the earth systems. The Groundwater Dynamic Nature Questionnaire (GDN) identified students’ previous knowledge and understanding of the dynamic nature of the groundwater system, and its relationship with humans. The questionnaires provided statements for participants to select agree, uncertain, or disagree
and provided a written response. These questionnaires were used to assess the application of systems thinking in these previous studies.

**Validity and Reliability of The Cyclic Thinking Questionnaire (CTQ) and The Groundwater Dynamic Nature Questionnaire (GDN)**

The items on the Cyclic Thinking Questionnaire (CTQ) and Groundwater Dynamic Nature Questionnaire (GDN) were developed from established categories based on interviews from a pilot research study and review of literature conducted by Ben-Zvi Assaraf and Orion (2005). Thirty original items were reviewed for content validation by three researchers specializing in the area of Earth science education. Both of these questionnaires were used in a previous study with seventy middle school students (Ben-Zvi Assaraf & Orion, 2005). The Cyclic Thinking Questionnaire (CTQ) was used with forty-eight elementary students (Ben-Zvi Assaraf & Orion, 2010).

Four items from the CTQ were used to evaluate specific statement themes (e.g., cycle, surface flow, global warming, and population growth) of teachers’ knowledge of systems thinking relating to cyclical thinking. Three items from the GDN were selected to determine these groundwater statement themes (groundwater storage, pollution of wells, and rain penetration). Five science educators reviewed the selected items of the assessments for accuracy of identified statement themes of systems thinking. The combined assessment of seven items will be referred to as The Systems Thinking Assessment (Appendix 2). The Systems Thinking Assessment had a reliability Cronbach’s Alpha score of 0.621.
Interviews

Semi-structured interviews were used to clarify and verify the systems thinking levels determined during the coding process and to determine participants’ knowledge of systems and ideas for implementing systems thinking into elementary science classrooms.

Teachers were asked the following questions:

1. How would you define a system in science?
2. Can you give me an example?
3. What makes this a system?
4. How can elementary teachers teach students to understand systems?
5. Is the water cycle a system? If so, how? If not, explain.
6. What are all the components and processes of the water cycle that should be taught to fifth grade students?
7. How do these components and processes work together?
8. Here is an image. Describe how the image relates to the water cycle. How does it represent this idea of a system?
9. The NGSS states that systems thinking should be at the forefront of science instruction. What do you foresee as the challenges about teaching systems thinking as an elementary teacher?

Validity and Reliability of Interview Protocol

Two science educators checked the clarity and accuracy of systems thinking elicited with the interview protocol. A pilot study conducted by the researcher validated the clarity of the interview protocol.

Analyses

Analyses of Water Cycle Diagnosis Test (WCDT)

The frequencies of responses were determined for responses on the Water Cycle Diagnosis Test (WCDT).
Analysis Systems Thinking Assessment

The Systems Thinking Assessment was analyzed by the Systems Thinking Rubric, which determined the following four levels of systems thinking (e.g., Intermediate, Beginning, Recognizing, and Novice Levels). The analysis of this assessment followed four stages. The first stage defined the percentages and frequencies of the agreement statements for each statement theme. The second stage was the analysis of systems thinking levels according to The Systems Thinking Rubric (e.g., described below) for each statement theme. Next, the overall mean scores of teachers’ systems thinking levels were determined. The final stage of analysis was a comparison of systems thinking levels between teacher groups by completing one-way ANOVA and Chi Square tests. The analysis of each of the agreement statements, levels of systems thinking of each item, mean scores of systems thinking levels, and comparison of systems thinking levels between teacher groups are discussed in the results section.

Systems Thinking Rubric

The systems thinking rubric creation process followed an inductive analysis (Patton, 1990) in which patterns, themes, and categories of analysis were extracted from the data. The researcher formulated a tentative understanding of the data by reading and re-reading the data (Roth, 1995). Several iterations of data reading yielded seven levels of systems thinking. These levels were established by evaluating the participant statements based on components from the STH model of systems thinking, the interactions identified between components and processes of the subsystems, and the NGSS crosscutting concepts. A science educator and researcher used the rubric to code 10% of randomly selected participant data. As part of the verification methodology (Strauss, 1987), the researcher and science
educator repeated this process five times (coding, discussion, revision) until inter-rater reliability of 10% of the randomly selected data was reached at 86%. A Pearson Correlation score of .856 and a \( p \) value of .000 verified reliability of coding.

The final rubric for The Systems Thinking Assessment resulted in four levels (e.g., novice, beginning, intermediate, and advanced). The four levels are identified in Table 1 with a brief description and examples from both groups of teachers’ statements. Each participant response was coded into and can be found in one distinct level.
Table 1
Rubric of Systems Thinking — Elementary In-service and Pre-service Teachers’ Levels
(Simplified version of rubric—detailed rubric in Appendix 3)

<table>
<thead>
<tr>
<th>Levels of Systems Thinking</th>
<th>Level Description</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Novice (Level 0)</td>
<td>No response or indication of not knowing</td>
<td>I have no clue or it seems it should be that way</td>
</tr>
<tr>
<td>Recognition (Level 1)</td>
<td>Identification of ONE component or a process OR identification of a pattern in the system AND no explanation of relationship between components or processes</td>
<td>there is no beginning or end to the water cycle a cycle constantly flows or continuous cycle always the same amount of water on earth (none is gained or lost)</td>
</tr>
<tr>
<td>Beginning (Level 2)</td>
<td>Identifies at least TWO components or processes BUT the indication is of one directional cause and effect (A causes B) OR recognition of an interaction between only two components</td>
<td>(A) evaporation is constantly going, therefore there is no increase in the amount of (B) water acquired (A causes B)</td>
</tr>
<tr>
<td>Intermediate (Level 3)</td>
<td>Identifies THREE or MORE components or processes AND interaction involves at least two or more components OR recognition of multiple interactions</td>
<td>the (A) water (B) evaporates (C) ocean water is rising due to (D) global warming</td>
</tr>
</tbody>
</table>

Comparison of Systems Thinking Rubric and Systems Thinking Hierarchical (STH) Model

The final levels of Systems Thinking Rubric were compared to the levels of the Systems Thinking Hierarchical (STH) Model of Ben-Zvi Assaraf and Orion (2005) (Figure
3). An individual at the intermediate and implementation levels are able to explain processes that take place under the surface and in the atmosphere, which are invisible processes and known as the hidden dimensions. The intermediate level also has elements of the synthesis level that includes identifying components and processes and the dynamic relationships that occur between them. Individuals that provide explanations at the beginning level were able to identify more than one component and process but their explanation does not reach the synthesis level since the relationships described only included one-directional cause and effect interactions between two components. An individual at the synthesis level describes the relationships within a framework and applies extensive knowledge of cyclic thinking. The recognition level is correlated with the analysis level since explanations at these levels identify at least one component or process recognizing a pattern of the system but do not provide identified relationships or interactions occurring with the pattern. The novice level is not identified on the STH Model. The novice level was identified as individuals who provided explanations of no application of systems thinking and indicated no knowledge of the topic. The results that follow are presented using the Systems Thinking Rubric levels.
Figure 3: This figure compares the STH Model (Ben-Zvi Assaraf & Orion, 2005) systems thinking levels to the Systems Thinking Rubric established by teacher responses in this study.

Analysis of Interviews

Interviews were transcribed and analyzed qualitatively. The method of analysis was based on a qualitative approach (Creswell, 2009) in the following procedure. Each interview was read and reviewed to search for themes, which represent the categories designed for conducting this phase of the research.
Reliability and Validity of Interview Analysis

Triangulating the results with the assessments and coding rubrics established validity of questions and results. All interviews were transcribed and checked for mistakes during the transcription process. The meanings of themes were constantly compared to the themes identified in the coding rubrics throughout the coding process. A second coder reviewed established themes of the interview transcripts to check for agreement and to establish inter-rater reliability. Accuracy of established themes were agreed upon between coder and researcher and inter-rater reliability of 86% was reached. Table 2 provides the systems thinking rubric levels established by teachers’ responses in this study and how they align with the STH Model, systems thinking components, systems thinking knowledge and the research tools used in this study for measuring these levels, components, and knowledge.

Table 2
Research Tools That Measured Systems Thinking Levels and Components

<table>
<thead>
<tr>
<th>Systems Thinking Rubric Levels</th>
<th>STH Model</th>
<th>System Thinking Components</th>
<th>Systems Thinking Knowledge</th>
<th>Research Tools</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intermediate (Level 3)</td>
<td>Implementation Level</td>
<td>Hidden Dimensions</td>
<td>Explain processes that take place under the surface or in the atmosphere-hidden dimensions of the water cycle</td>
<td>Systems Thinking Assessment &amp; Semi-structured interviews</td>
</tr>
<tr>
<td></td>
<td>Synthesis Level</td>
<td>Cyclic Thinking Relationships within the system</td>
<td>Explain the cyclic framework of relationships by explaining the process with at least two or more components</td>
<td></td>
</tr>
</tbody>
</table>
Table 2 Continued

<table>
<thead>
<tr>
<th>Beginning Level</th>
<th>Synthesis</th>
<th>System components and processes and simple relationships</th>
<th>Ability to identify processes and components of the system and identifying one directional cause and effect between two components</th>
<th>WCDT content assessment, Systems Thinking Assessment &amp; semi-structured interviews</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recognition Level</td>
<td>Analysis</td>
<td>System components and processes</td>
<td>Ability to identify processes and components of the system.</td>
<td>WCDT assessment, Systems Thinking Assessment, &amp; Semi-structured interviews</td>
</tr>
</tbody>
</table>

**Interviews**

There were four common themes identified in the analysis of the interviews. Themes included: (1) definition of water cycle systems as a continuous pattern ("circular"), (2) differences in high and low level systems thinkers (describing systems relationships and pictorial representations), (3) identified pedagogical approaches for teaching systems thinking, and (4) challenges identified by participants in teaching systems thinking. The first and second interview themes will be described with findings in the discussion section. The third and fourth themes are described below in the results.
Results

Identifying Components, Processes and Relationships - Atmosphere and Hydrosphere

The scores on the WCDT assessment were normally distributed with a mean of 9.64 ($SD = 3.66$). The highest overall possible score on the assessment was 20 points. A one-way ANOVA analysis was completed to compare the differences in systems thinking knowledge of the water cycle between in-service and pre-service teachers’ test scores of the WCDT assessment. There were significant differences between in-service ($M = 11.63, SD = 3.73$) and pre-service ($M = 7.68, SD = 2.27$) teachers’ knowledge of systems thinking about the water cycle, $F (1,133)=21.44, p=0.00$. On average in-service teachers scored 3.95 points higher than pre-service teachers.

Systems Thinking Assessment (Agreement Statements)

The results of the Systems Thinking Assessment are described below, according to these system components: 1) cycle, 2) surface flow, 3) global warming, 4) population growth, 5) groundwater storage, 6) well pollution, and 7) rain penetration (HI= Human Impact). Table 3 shows the combined agreement statement responses of both in-service and pre-service teachers. Table 4 shows the agreement statements of teachers’ separated by each group (in-service and pre-service teachers). Table 5 describes the systems thinking assessment components by each statement.
Table 3
Agreement Statements of Combine Teacher Responses (In-service and Pre-service Teachers) 
(n=135)

<table>
<thead>
<tr>
<th>System Components</th>
<th>Disagree</th>
<th>Uncertain</th>
<th>Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cycle</td>
<td>112 (83)</td>
<td>20 (14.8)</td>
<td>3 (2.2)</td>
</tr>
<tr>
<td>Surface flow</td>
<td>85 (63)</td>
<td>39 (28.9)</td>
<td>11 (8.1)</td>
</tr>
<tr>
<td>Global warming (HI)</td>
<td>63 (46.7)</td>
<td>56 (41.5)</td>
<td>16 (11.9)</td>
</tr>
<tr>
<td>Population growth (HI)</td>
<td>65 (48.1)</td>
<td>29 (21.5)</td>
<td>41 (30.4)</td>
</tr>
<tr>
<td>Groundwater storage</td>
<td>23 (17)</td>
<td>92 (68.1)</td>
<td>20 (14.8)</td>
</tr>
<tr>
<td>Well population (HI)</td>
<td>5 (3.7)</td>
<td>80 (59.3)</td>
<td>50 (37)</td>
</tr>
<tr>
<td>Rain penetration</td>
<td>6 (4.4)</td>
<td>45 (33.3)</td>
<td>84 (62.2)</td>
</tr>
</tbody>
</table>

Frequency (percentage)  
(HI- signifies system components that include Human Impact)

Table 4
Agreement Statements by In-service (n= 67) and Pre-service (n=68) Teachers

<table>
<thead>
<tr>
<th>System Components</th>
<th>In-service</th>
<th>Pre-service</th>
<th>In-service</th>
<th>Pre-service</th>
<th>In-service</th>
<th>Pre-service</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cycle</td>
<td>51 (76.1)</td>
<td>61 (88.4)</td>
<td>13 (19.4)</td>
<td>7 (10.1)</td>
<td>3 (4.5)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Surface flow</td>
<td>37 (55.2)</td>
<td>48 (69.6)</td>
<td>24 (35.8)</td>
<td>15 (21.7)</td>
<td>6 (9.0)</td>
<td>5 (7.2)</td>
</tr>
<tr>
<td>Global warming (HI)</td>
<td>30 (44.8)</td>
<td>43 (37.9)</td>
<td>27 (40.3)</td>
<td>29 (42.0)</td>
<td>10 (14.9)</td>
<td>6 (8.7)</td>
</tr>
<tr>
<td>Population growth (HI)</td>
<td>27 (40.3)</td>
<td>38 (55.1)</td>
<td>16 (23.9)</td>
<td>13 (18.8)</td>
<td>24 (35.8)</td>
<td>17 (24.6)</td>
</tr>
<tr>
<td>Groundwater storage</td>
<td>8 (11.9)</td>
<td>15 (21.7)</td>
<td>43 (64.2)</td>
<td>49 (71.0)</td>
<td>16 (23.9)</td>
<td>4 (5.8)</td>
</tr>
<tr>
<td>Well pollution (HI)</td>
<td>4 (6.0)</td>
<td>1 (1.4)</td>
<td>44 (65.7)</td>
<td>36 (52.2)</td>
<td>19 (28.4)</td>
<td>31 (44.9)</td>
</tr>
<tr>
<td>Rain penetration</td>
<td>3 (4.5)</td>
<td>3 (4.3)</td>
<td>18 (26.9)</td>
<td>27 (39.1)</td>
<td>46 (68.7)</td>
<td>38 (55.1)</td>
</tr>
</tbody>
</table>

Frequency (percentage)
Table 5  
*Systems Thinking Assessment Components and Descriptions*

<table>
<thead>
<tr>
<th>System Components</th>
<th>System Component Description on Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cycle</td>
<td>Clouds starting point—tap at home end point</td>
</tr>
<tr>
<td>Surface flow</td>
<td>Oceans are growing due to continual river flow into the ocean</td>
</tr>
<tr>
<td>Global warming (HI)</td>
<td>Evaporation increase (e.g., global warming)-decreasing water on earth</td>
</tr>
<tr>
<td>Population growth (HI)</td>
<td>Population growth- increases water consumption-decreasing water on earth</td>
</tr>
<tr>
<td>Groundwater storage</td>
<td>Most groundwater persists in small pores of rock—well-watered sponge</td>
</tr>
<tr>
<td>Well pollution (HI)</td>
<td>Part of wells in the state of NC contains polluted water</td>
</tr>
<tr>
<td>Rain Penetration</td>
<td>Rainfall on surface can penetrate soil the depth of several meters</td>
</tr>
</tbody>
</table>

To determine any differences between in-service and pre-service teacher selection of agreement statements on The Systems Thinking Assessment, a one-way ANOVA test was conducted. There were no significant differences in the selection of agreement between the two groups of teachers. The results from each of the seven statement themes between the teachers are reported in Table 6.
Table 6
Differences Between In-Service and Pre-Service Teachers Agreement Statements

<table>
<thead>
<tr>
<th>System Components</th>
<th>In-service Teachers Mean (SD)</th>
<th>Pre-service Teachers Mean (SD)</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cycle</td>
<td>0.85 (0.47)</td>
<td>0.90 (0.31)</td>
<td>F (1,133)= 0.463</td>
<td>p=0.497</td>
</tr>
<tr>
<td>Surface flow</td>
<td>0.43 (0.62)</td>
<td>0.85 (0.53)</td>
<td>F (1133)= 1.519</td>
<td>p= 0.220</td>
</tr>
<tr>
<td>Global warming</td>
<td>0.75 (0.70)</td>
<td>0.66 (0.64)</td>
<td>F (1133)= 0.535</td>
<td>p= 0.466</td>
</tr>
<tr>
<td>Population growth</td>
<td>1.12 (0.77)</td>
<td>1.06 (0.67)</td>
<td>F (1,133)=0.239</td>
<td>p=0.625</td>
</tr>
<tr>
<td>Groundwater storage</td>
<td>0.60 (0.85)</td>
<td>0.34 (0.59)</td>
<td>F (1,133)=4.213</td>
<td>p=0.042  *</td>
</tr>
<tr>
<td>Well pollution</td>
<td>0.63 (0.90)</td>
<td>0.93 (1.00)</td>
<td>F (1.133)=3.349</td>
<td>p=0.069</td>
</tr>
<tr>
<td>Rain penetration</td>
<td>1.42 (0.89)</td>
<td>1.16 (0.97)</td>
<td>F(1.133)= 2.549</td>
<td>p=0.113</td>
</tr>
</tbody>
</table>

* indicates significance

Systems Thinking Assessment (Written Statements)

The results of the Systems Thinking Assessment written responses for each system component are in the below tables shown by systems thinking levels of combined teacher scores (Table 7), and the comparison of systems thinking levels between the teacher groups (Table 8).
Table 7  
*In-Service and Pre-Service Teacher Combined Systems Thinking Levels*

<table>
<thead>
<tr>
<th>System Components</th>
<th>Novice Level</th>
<th>Recognizing Level</th>
<th>Beginning Level</th>
<th>Intermediate Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cycle</td>
<td>3 (2.2)</td>
<td>101 (74.3)</td>
<td>20 (14.7)</td>
<td>11 (8.1)</td>
</tr>
<tr>
<td>Surface flow</td>
<td>14 (10.3)</td>
<td>22 (16.2)</td>
<td>56 (41.2)</td>
<td>43 (31.6)</td>
</tr>
<tr>
<td>Global warming</td>
<td>32 (23.5)</td>
<td>13 (9.6)</td>
<td>51 (37.5)</td>
<td>39 (28.7)</td>
</tr>
<tr>
<td>Population growth</td>
<td>18 (13.2)</td>
<td>35 (25.7)</td>
<td>55 (40.4)</td>
<td>27 (19.9)</td>
</tr>
<tr>
<td>Groundwater storage</td>
<td>74 (54.4)</td>
<td>36 (26.5)</td>
<td>15 (11)</td>
<td>10 (7.4)</td>
</tr>
<tr>
<td>Well pollution</td>
<td>91 (66.9)</td>
<td>12 (8.8)</td>
<td>15 (11)</td>
<td>16 (11.8)</td>
</tr>
<tr>
<td>Rain Penetration</td>
<td>39 (28.7)</td>
<td>16 (11.8)</td>
<td>53 (39)</td>
<td>27 (19.9)</td>
</tr>
</tbody>
</table>

Comparison of Levels of Systems Thinking between Elementary In-service and Pre-service Teachers

A one-way ANOVA analysis was completed to determine possible differences between in-service and pre-service teachers systems thinking levels of each statement theme of The Systems Thinking Assessment. There was a statistical difference between the two groups’ levels on the following statement themes: 1) global warming, 2) population growth, and 3) rain penetration.
Table 8
Comparison of Systems Thinking Levels between In-service and Pre-service Teachers

<table>
<thead>
<tr>
<th>Statement Themes</th>
<th>In-service Teachers Mean (SD)</th>
<th>Pre-service Teachers Mean (SD)</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cycle</td>
<td>1.37 (0.76)</td>
<td>1.21 (0.51)</td>
<td>F (1,133)=2.292</td>
<td>p=0.132</td>
</tr>
<tr>
<td>Surface flow</td>
<td>1.99 (1.07)</td>
<td>1.91 (0.82)</td>
<td>F (1133)=0.200</td>
<td>p= 0.655</td>
</tr>
<tr>
<td>Global warming</td>
<td>2.03 (1.10)</td>
<td>1.41 (1.07)</td>
<td>F (1133)=10.963</td>
<td>p= 0.001 *</td>
</tr>
<tr>
<td>Population growth</td>
<td>1.94 (0.90)</td>
<td>1.41 (0.92)</td>
<td>F (1,133)=11.375</td>
<td>p=0.001 *</td>
</tr>
<tr>
<td>Groundwater storage</td>
<td>0.82 (1.03)</td>
<td>0.60 (0.83)</td>
<td>F (1,133)=1.836</td>
<td>p=0.178</td>
</tr>
<tr>
<td>Well pollution</td>
<td>0.67 (1.13)</td>
<td>0.71 (1.17)</td>
<td>F (1.133)=0.033</td>
<td>p=0.857</td>
</tr>
<tr>
<td>Rain penetration</td>
<td>1.89 (1.10)</td>
<td>1.13 (1.02)</td>
<td>F(1.133)=17.112</td>
<td>p=0.000 *</td>
</tr>
</tbody>
</table>

* indicates significance

Mean Scores of Systems Thinking Levels

The overall mean score was 1.38 in both in-service and pre-service teachers of systems thinking levels. Table 9 shows the levels of systems thinking determined from the mean scores and the frequency of participants’ scores of coded levels. Figure 4 compares the STH Model of systems thinking levels to Systems Thinking Rubric Levels.
Table 9
Mean Scores of Systems Thinking Levels of In-service and Pre-service Teachers

<table>
<thead>
<tr>
<th>Systems Thinking Levels</th>
<th>Pre-service</th>
<th>In-service</th>
</tr>
</thead>
<tbody>
<tr>
<td>Novice Level (0.00-1.00)</td>
<td>22 (32.3)</td>
<td>6 (8.9)</td>
</tr>
<tr>
<td>Recognition Level (1.00-2.00)</td>
<td>42 (61.7)</td>
<td>39 (58.2)</td>
</tr>
<tr>
<td>Beginning Level (2.00-3.00)</td>
<td>4 (5.88)</td>
<td>18 (26.8)</td>
</tr>
<tr>
<td>Intermediate Level (3.00)</td>
<td>0 (0.00)</td>
<td>0 (0.00)</td>
</tr>
</tbody>
</table>

The most frequent level for pre-service and in-service teachers was the recognition. There were no teachers from either group that had a mean score at the intermediate level.

Figure 4. Mean Systems Thinking Levels Compared Between STH Model and Developed Rubric

[Diagram showing the comparison between the STH Model and the Developed Rubric, with levels and descriptions for Implementation, Synthesis, Analysis, Intermediate, Beginning, Recognition, and Novice levels.]

Figure 4. Mean Systems Thinking Levels Compared Between STH Model and Developed Rubric
Comparison of Systems Thinking Levels Between In-Service and Pre-Service Teachers

The scores of systems thinking were categorized into two groups: high level with means equal to or greater than 1.38 and low level with means less than 1.38. A Chi-Square test was conducted to examine whether there was an association between teacher groups and systems thinking levels. Table 10 shows the results of these tests.

Table 10
*Differences in Systems Thinking*

<table>
<thead>
<tr>
<th></th>
<th>Frequency (percentages)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>High Level Systems</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>In-service Teachers</td>
<td>39 (54.1)</td>
<td></td>
</tr>
<tr>
<td>Pre-service Teachers</td>
<td>24 (33.3)</td>
<td>72</td>
</tr>
<tr>
<td><strong>Low Level Systems</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>In-service Teachers</td>
<td>28 (44.4)</td>
<td></td>
</tr>
<tr>
<td>Pre-service Teachers</td>
<td>44 (69.8)</td>
<td>63</td>
</tr>
</tbody>
</table>

The results from Table 10 show that there was a significant association between teacher groups and systems thinking levels, $\chi^2 (1, N = 135) = 7.12, p = .01$. More in-service teachers (54.1%) used high-level systems thinking than pre-service teachers (33.3%). In other words, more pre-service teachers (69.8%) provided explanations that were a lower level of systems thinking than in-service teachers (44.4%). Elementary in-service teachers had a slightly higher level of systems thinking than pre-service teachers.
Interviews of High and Low Systems Thinkers

The low level and high level system thinkers provided pedagogical ideas about teaching systems in an elementary classroom. All of the interviewees mentioned either creating a model (e.g., simple circuit or biome box for ecosystems) or using pictorial representations (e.g., diagrams, graphic organizers) to teach students about systems. Participants discussed using models and pictorial representations to illustrate parts of the systems, and then discussed how to use the representations to show how parts are connected.

Finally, participants discussed challenges for teaching about systems and applying systems thinking skills in their classrooms or future classrooms. All participants (low level and high level) described this topic as being difficult and hard to understand due to it being abstract (e.g., can’t see it). Both teachers (high and low level) mentioned the difficulty of teaching systems in elementary school because students had little prior knowledge of the topics as well as their own lack of knowledge.

Discussion

Teachers had difficulties with the following components of systems thinking: identifying components and processes, identifying multiple relationships within the system and subsystems as well as the hidden dimensions of the system, and understanding human impact on the system. The following sections discuss these systems thinking components.

Identifying Components and Processes

The WCDT assessment focused on identifying individual components and processes of the water cycle and unidirectional relationships of the two subsystems (e.g., atmosphere
and hydrosphere). The average score for all the teachers was 48% (x= 9.64). These results indicate that in-service and pre-service teachers had low levels of knowledge related to identifying individual components and processes of the water cycle and their relationships.

The results of the Systems Thinking Assessment showed that in-service and pre-service teachers had difficulty identifying at least one component or process in their written responses. Twenty-four percent of teachers scored at the novice level on the Systems Thinking Rubric. A novice level indicates teachers did not know anything about system components on the Systems Thinking Assessment. Forty-seven percent of the teachers scored at the recognition level, showing they had knowledge of pattern or cyclical process of the water cycle but identified only one component or process. These levels of novice and recognition are evidence that teachers had difficulty identifying components and processes of the water cycle. This also shows difficulty explaining relationships between the components and recognizing these processes as a dynamic pattern.

The lowest level of systems thinking includes the ability to identify components and processes of the system. Results from the WCDT assessment and the Systems Thinking Assessment found more than half of the teachers were identified at this level of systems thinking. Teaching about a complex system involves more than identifying components or processes; it involves understanding the interactions and relationships among the components. For example, the Earth consists of a set of subsystems (atmosphere, hydrosphere, geosphere, and biosphere), which are interconnected by a complex dynamic
relationship (National Research Council, 2007). Knowledge of one complex system (e.g., water cycle) requires the ability to apply systems thinking.

**Identifying Multiple Levels of Interactions Between Subsystems**

Understanding the water cycle involves not only being able to identify components and processes; it involves conceptualizing how water changes and moves among the subsystems (Schwartz et al., 2011). For example, middle and high school students had difficulty explaining the processes of the water cycle, seeing the processes as unrelated components (Ben-Zvi Assaraf & Orion, 2004). Students were able to explain various hydro-biogeological processes but lacked the dynamic, cyclic and systemic perceptions of the system. Ben-Zvi Assaraf and Orion (2004) indicated that students had difficulty understanding the relationships and connections with other subsystems of the earth.

In this study, it was found that both groups of teachers had difficulty identifying multiple interactions between the subsystems of the atmosphere, biosphere, geosphere, and hydrosphere. Teachers’ responses on the Systems Thinking Assessment for the system components of cycle and surface flow illustrated this lack of skill in identifying and describing multiple interactions. The cycle system component asked teachers if the water cycle has a start or ending point. Although 83% of teachers disagreed with this statement, their written responses illustrated an absence of systems thinking. For instance, 74.3% of teachers provided written responses coded at the recognition level. These statements represent the recognition level: “the cycle is ongoing there is not a beginning or end” or “the water cycle has no real start or ending because it is a continuous cycle” and “cycle means it
never ends.” These responses are accurate and represent the acknowledgement of the crosscutting concept of patterns but do not provide a systems thinking rationale (e.g., mentioning relationships with other subsystems) that impact this continuous process. Participants that provided a beginning or intermediate level response included components or processes that affect the continuous process of the water cycle but 19% of these responses only mention relationships within the subsystem of the atmosphere. For example, “water needs to evaporate into the atmosphere before the clouds can produce rainfall.” There were only 6% of teachers that discussed relationships among multiple subsystems; these relationships were between the subsystems of hydrosphere and geosphere in relation with the atmosphere. Here are two examples that illustrated these relationships: “water should start with the ocean and go through a cycle then return to the ocean with evaporation, condensation, then precipitation” and “The water cycle begins in the atmosphere first and then moves into the cloud also the water cycle continues once it hits earth because the water gets absorbed into the ground along with runoff.” These responses discussed relationships that included interactions with the atmosphere and other subsystems (e.g., hydrosphere and geosphere) but provided only a general description of the water cycle as being a continuous cycle. Interactions with the biosphere were not mentioned in any of the responses. It seems that teachers do not view humans, plants, or animals as part of this cyclical process.

Interviews verified teachers’ descriptions of the water cycle in general terms as a continuous pattern. When asked to define the water cycle system, teachers stated: “the water cycle is a system because everything is connected and it’s continuous and it’s like circular.”
And “they are connected and it’s continuous like a circle[sic] things happens and another thing happens works in a cycle and it happens in the atmosphere.” And “the water cycle is a system because all the different parts that are going together [sic] working together for the outcome of the water.” These general definitions of the water cycle system are similar to the recognition level responses of the “cycle” system component from the Systems Thinking Assessment, discussed above. For example, teachers at the recognition level discussed the water cycle as being a continuous process and having a pattern, but did not identify components or processes affecting this cyclical process. The interview responses revealed similar concepts about the system of the water cycle, as being circular, having parts that work together toward a common goal or for an outcome. Although when asked to name the specific components and processes of the water cycle system that fifth grade students should know about, teachers of both high and low levels of systems thinking stated the atmospheric processes of evaporation, condensation, and precipitation as the main processes—only one teacher mentioned components such as the oceans, lakes, rivers, and animals. A teacher with high scores on the assessment mentioned the process of transpiration. For example, “they need to know that you got evaporation, condensation, precipitation and this year they have transpiration, which goes along with plants—we make bracelets with each step to help students to remember the steps.” These examples reveal a view of the water cycle system as being “circular and continuous” and recognizing processes that continually happens in the system. But the ideas expressed by the teachers do not consider how the specific components and processes of this cyclical process cause stability and change of the patterns over time.
within the system, which affects this “circular” pattern. In essence teachers are missing the systems approach of that cycle itself, realizing that pattern is in fact not circular but an intricate web of relationships and interactions.

The system component of surface flow from the Systems Thinking Assessment asked teachers to explain if the continuous flow of rivers into the ocean each day causes the levels of the oceans to rise. Teachers’ responses were grouped into these three ideas: 1) interactions with two subsystems (e.g., atmosphere and hydrosphere), 2) law of conservation of matter, and 3) global warming. There were 63% of teachers that disagreed and 28.9% that indicated uncertainty with the effect of surface flow on this cyclical process of the water cycle. Thirty-two percent of teachers that disagreed with the effect of surface flow of rivers on the increase of ocean levels provided a response at the intermediate level, which indicates interactions affecting this process include more than one component or process from at least one subsystem. Interactions between two subsystems (atmosphere and hydrosphere) were represented by 23% of participants. For example, “rivers do continually flow into the ocean but the amount of water in the ocean is not growing because of that. As water is added to the oceans water is also taken by atmospheric processes.” This statement suggests a linear cause and effect relationship that details one relationship that involves evaporation with the cyclical process of the water cycle and does not consider other interactions or relationships between other subsystems that impact or may affect the flow of rivers. For example, the law of conservation of matter was also indicated by 16% of teachers in their responses to this surface flow statement, with examples such as: “the amount of water flowing into the ocean
would be a direct correlation to the water being evaporated from the ocean or other ways
water leaves the ocean somehow in the cycle it all levels out in the end” and “the amount of
water stays consistant [sic] but changes according to the process of the water cycle.” These
responses concerning the law of conservation again only mention evaporation as a process
that controls the amount of water in the cyclical process with no mention of other subsystems
that could affect the continuous flow; there was no mention of biosphere components or
processes and only 1% of responses indicated the geosphere, which mentions erosion and
runoff as contributing factors. Ice cap melting due to global warming was stated by 16% of
teachers as a cause for rising ocean levels. This is an example, “ocean water is growing by
the ice caps melting, contributing to more water that was once held in a different form.”

There were two areas identified within the interviews that clarified differences
between high and low systems thinkers in terms of describing interactions of the water cycle
with more than one subsystem. The high-level systems thinkers (in-service and pre-service
teachers) described components and processes that affect the water cycle and provided
descriptions that included multiple interactions with each of the subsystems (e.g., atmosphere
and biosphere). The low-level systems thinkers only discussed atmospheric components of
the water cycle. The high-level systems thinkers were able to describe multiple interactions
of the water cycle including various subsystems of the earth vs. the lower level systems
thinkers that only described atmospheric components of the water cycle.

There were differences in the descriptions of multiple interactions between
subsystems for high and low level systems thinkers. The pictorial representation used in the
interview was a photograph of a street drain showing street pollution and rainwater going into the drain. Participants were asked to describe how this photograph related to the concept of a system. High level system thinkers discussed multiple interactions (e.g., cause and effect) between the water cycle and biosphere (humans, pollution, ecosystem) as well as describing the movement of the water through the human-engineered system (street drain) to other parts of the natural water cycle (e.g., rivers, lakes, etc.) and continued to described how the rivers would be affected due to the pollution (e.g., contaminates from cars, trash, etc.). Low-level system thinkers noted confusion when asked to describe this pictorial representation (e.g., photograph) in relation to teaching the water cycle. The low-level system thinkers described precipitation and its interaction with the atmosphere (e.g., atmospheric components) with this photograph and then stated confusion about what happens next. The low level system thinkers indicated there was an interaction between the water cycle and the biosphere but they tended to indicate a lack of knowledge of the movement of water (e.g., where it goes and what happens), for instance, “water seeps through the ground or wherever it goes through all these different rocks—not like being purified but goes into the ground—somewhere along the process I know some pollutants get taken out—but then there’s acid rain so that means some of them don’t get taken out but the endless supply of water is being used in the process—this is how it could be contaminated or changed within the process—this is rain water going to a location where I guess it could be easier evaporated [sic]. I don’t know.” This lack of knowledge of the human impact on the water cycle and the misinterpretation of the processes of the subsystems (e.g., hydrosphere, biosphere, and
atmosphere) in terms of cleaning the water or changing the water could lead to confusion for students in the classroom when teachers are explaining the human engineering systems (e.g., street drain) in connection to the water cycle.

These findings suggest that elementary in-service and pre-service teachers have difficulty thinking beyond linear flow, and beyond single causality between subsystems other than the hydrosphere and atmosphere in terms of the water cycle. Similar results were found in students and adults in other systems thinking studies in which the focus was only on one-way casual structures instead of recognizing the web of interrelationships that exist in complex systems such as the water cycle (Booth Sweeney and Sterman, 2007; Brazelton, 1992; and Grotzer & Bell-Basca, 2003). The tendency to concentrate on the descriptive surface features of a system and the inability to make connections between other subsystems indicates a lack of systems thinking.

**Difficulty with Understanding Hidden Dimensions**

The water cycle as a system includes extremely large (e.g., water cycle movement of water across landscapes, river systems, and oceans) and incredibly small or (invisible) components (e.g., molecule movement within the water cycle). There are components either too large or too small to be observed directly. These components of a system have proven to be a challenge for adults (teachers in this case) and students to fully conceptualize. Difficulty connecting the phenomena occurring at the microscopic and macroscopic levels of a system can contribute to misunderstanding the complexity of these hidden dimensions (Wilensky & Resnick, 1999; Penner, 2000).
Water is a difficult concept to explain in terms of its structure, properties, and processes within the invisible parts of the water cycle (Ben-Zvi Assaraf & Orion, 2005; Covitt et al., 2009). Furthermore, the scale of groundwater can create inaccurate conceptions (Ben-Zvi Assaraf & Orion, 2005; Dickerson et al., 2005; Dickerson & Dawkins, 2004). Elementary in-service and pre-service teachers had difficulty with the hidden dimensions of water and the large and small scales of groundwater. The groundwater system component from the Systems Thinking Assessment indicated that most of the underground water was found in small pores of rocks like a well-watered sponge. Sixty-eight percent of teachers from both groups indicated uncertainty about this groundwater storage system component. Fifty-four percent of the teachers indicated “I really don’t know” and “I truly have no clue.” These findings indicate deficits in groundwater storage. Other studies have also found this with students (Ben-Zvi Assaraf & Orion, 2005; 2010; Covitt et al., 2009; Dickerson et al., 2005; Dickerson & Dawkins, 2004; Dickerson et al., 2007).

Teachers referred to groundwater as existing in underground rivers, being in large pockets underground, and having uncertainty about rocks being able to hold water. Responses to the system component of rain penetration showed teachers held inaccurate concepts about scale, quantity and proportion. The rain penetration system component stated that rain that falls to the surface and penetrates the soil and can reach a depth of several meters. There were 33.3% of both teacher groups that indicated uncertainty about this system component and 28.7% of written statements were at the novice level. Although 62.2% of teachers agreed with the statement, a majority (39%) of written statements were at
the beginning level. For example, “I have heard that it depends on the saturation of the ground already” and “I think it could reach down pretty far especially with heavy rainfall” and “If the soil is dry, it can absorb further in the ground” and “I think that rain penetrates and absorbs through the surface and can go very deep.” These examples show teachers know rain penetrates the soil but the understanding of scale, quantity, and proportion was not explicit in their discussions. There was only one response out of the 135 responses that indicated knowledge of the depth of groundwater. Here is the one example: “growing up my family owned a water well drilling and pump installation company well could be anywhere from 25 feet to 800 feet [sic].” This example provided knowledge of measurements but it still does not directly address “rain penetration.”

In this study, participants lacked an understanding of the invisible aspects of groundwater and the knowledge of how materials such as contaminants (pollutants) move through the subsystems. The system component of well pollution on the Systems Thinking Assessment asked participants if well water could contain pollutants. Findings showed that over half (66.9%) of participants’ written statements were at the novice level. Teachers provided the following statements: “I am not sure that this is true” and “I did not even know the state of NC still had wells.” These results support the work of Covitt et al. (2009), who reported that middle and high school students were able to describe visible movements of water (e.g., rain and runoff) but found that applying the law of conservation of matter to water and the materials it carries was more difficult. Covitt et al. (2009) suggested students’ problems with tracing water and materials it carries between visible and invisible parts of the
system are a result of difficulties in understanding scale. In-service and pre-service teachers in this study displayed similar misunderstandings and were unaware of the parts of a system that are outside human scale (e.g., molecules in solution) or (e.g., watersheds).

**Human Impact**

As discussed earlier, developing environmental literacy requires an individual to understand and participate in decision-making related to human impacts on environmental systems (Covitt et al., 2009). Covitt et al. (2009) identified two principles (cyclic thinking and human impact), which define a systems approach when studying the subsystems of Earth. These two principles of cyclic thinking and understanding human impact to the system work in tandem to develop an environmental understanding. Cyclic thinking includes knowledge of the cycling processes of the exchanges of energy and materials moving through all of the subsystems (atmosphere, hydrosphere, geosphere, and biosphere). The final principle refers to the understanding of how we as humans impact these subsystems and the cyclic processes within these subsystems (Orion & Ault, 2007). Teachers in this study demonstrated a limited understanding of the human impact on the complex system (e.g., water cycle).

There were three system components on the Systems Thinking Assessment that examined human impact of the cyclical process of the water cycle. The effects of human impact on various subsystems were identified for global warming, population growth, and well pollution. The global warming system component asked teachers to consider the following feedback loop: an increase of evaporation as an effect of global warming may
decrease amount of water on earth. The idea of global warming resulted in a range of teachers’ responses (46.7% disagreed, 41.5% were uncertain, and 11.9% agreed). Teachers’ written responses verified their uncertainty. The written responses were grouped into three ideas teachers had about global warming and its effect on the amount of water on earth. The law of conservation of matter was expressed by 35% of the teachers in their responses, which in general terms stated that the amount of water would not increase or decrease due to the cycling process of the water cycle. The second idea stated by teachers was the misinterpretation of the effects of global warming and their understanding of the law of conservation of matter. Eleven percent of teachers were uncertain about the increase or decrease of the amount of water on Earth due to the effects of global warming. Out of the 11% of teachers that expressed uncertainty about the increase or decrease of water on Earth, 35% stated that the water would increase due to increased rainfall resulting from increased evaporation. Thirty percent agreed that there would be a decrease of water on Earth, stating such ideas as: “global warming affect [sic] every aspect of nature on earth and with an increase in evaporation could lead to lakes drying up” and “I think in the end with global warming that there will be a big decrease of water supply I believe that evaporation will help dry up all the water that is on the Earth.” The third idea expressed by teachers in reference to global warming was the effect of ice cap melting as the main impact of global warming causing ocean levels to rise. Another significant finding about global warming was the 23.5% of written responses by both groups of teachers that were at the novice level, which consisted of statements from participants such as: “I do not know anything about global warming” or “I am unsure.”
All of these findings suggest that the human impact of global warming on the water cycle is a confusing topic for in-service and pre-service teachers. The cross-cutting concepts of cause and effect, feedback loops, and the cyclical flows of water were evidenced in teachers’ responses, but these interactions remained only with the two subsystems of the hydrosphere and atmosphere and the interactions within these two subsystems remained at the surface level. For instance, evaporation and precipitation were the main processes of the atmosphere that were discussed. Teachers stated that increases in evaporation would lead to more precipitation, but there was no discussion about the other possible impacts of increased evaporation, such as describing increased cloud cover, for example, or since water vapor is a greenhouse gas, how that would affect the processes of the water cycle. Also, ideas related to the effects of the hydrosphere were not well described. For example, there was no mention of the effects of melting ice caps except that this would lead to a rise in ocean levels. There was no discussion about what the loss of ice caps would mean for animals or humans (e.g., biosphere).

Population growth was another human impact systems component from the Systems Thinking Assessment that elicited indecisiveness from both groups of teachers about the impact of population growth on the amount of water on Earth. The assessment asked teachers to consider the following feedback loop: population growth increases lead to water consumption increases, which would lead to a decrease of the amount of water on Earth. In teachers’ selection response to this statement, 48.1% disagreed, 21.5% were uncertain, and 30.4% agreed. This distribution of percentages clearly indicates differences between both
groups of teachers about this idea of human impact on the water cycle. The written responses reveal two main ideas: one referring to the law of conservation stating that no water would be lost or decreased from the Earth due to it remaining in the system and the opposite view stating that we are impacting the system therefore decreasing the amount of water. Forty-seven percent of the written responses referred to the law of conservation of matter but the statements revealed confusion about this scientific principle. For example, “I don’t think the population will affect the amount of water usage on earth the water cycle is constant so there is always water” and “I mean we pee it out it’s a cycle one way or another it always in the cycle” and “I think population will increase but we will still have enough water because of rain and other various ways we accumulate water.” There were 3% of responses that referred to the system of the water cycle as producing or creating water. Here are some of those examples: “water is a natural resource so earth will keep producing it,” and “water will continued to be produced,” and “the water cycle will continue to produce enough water.” Although there are only a small percentage of these responses, it is still alarming to think that teachers have this idea about water resources. Twenty-five percent of the teachers stated the amount of water would decrease. For instance, “some nations are already suffering from a lack of water supply due to their location and resources more people does in my mind seem to link to more water consumption because its [sic] essential to life;” and “if the amount of water being consumed on a regular basis exceeds the amount of water being put back onto the earth’s surface this can create a problem,” and “currently the earth is facing a depletion of water. Humans are rising more and more each day without realizing it. If the population
continues to grow then so will the amount of water used” and finally, “decrease in potable water perhaps but not a decrease in actual water.” Some of the confusion from teachers may have stemmed from the wording of the statement. The statement refers to the amount of water on Earth, not specifying if it is referring to potable water, ocean water or the overall water of the entire system. The indecisiveness of teacher responses about this system component could be due to the wording of the statement, by not specifying the exact type of water. Even though this could be the reason for indecisiveness, there is still evidence of uncertainty about the impact as humans in terms of population growth on the water cycle system.

Conclusions

This study investigated how elementary in-service and pre-service teachers think about the water cycle and the degree to which they apply systems thinking. The findings in this study suggest that both teacher groups had similar problems applying systems thinking as reported in other studies (Ben-Zvi Assaraf & Orion, 2005, 2010; Kali et al., 2003; Penner, 2000; Booth Sweeney & Sterman, 2000; Covitt et al., 2009). The barriers identified in this study included the following: difficulty identifying components and processes, difficulty identifying multiple relationships and interactions within subsystems, difficulty understanding the hidden dimensions of the system, and difficulty understanding the impact of humans on the subsystems of the water cycle. A common problem emerged across topics, which was the discussion of interactions between only two subsystems (e.g., atmosphere and hydrosphere) or geosphere and groundwater. By the end of fifth grade the NGSS (Achieve,
2013) states that students should be able to develop models as examples in describing ways the geosphere, biosphere, hydrosphere, and/or atmosphere interact. If teachers choose to use the water cycle as the context and complex system to discuss these interactions between these subsystems, they should also be able to describe the multiple interactions and relationships that occur among all four subsystems themselves. Results from this study have shown that teachers tended to focus on atmospheric components about the water cycle, describing limited interactions between the atmosphere and hydrosphere, leaving out the geosphere and biosphere components that impact this system. This incomplete recognition of the multiple interactions between the subsystems signifies a lack of systems thinking, which could create a real challenge for implementation of these ideas in the classroom.

The results presented here show teachers were uncertain about conservation of matter. Teachers in this study talked about conservation of matter in various ways but also indicated some misinterpretations of the principle especially when applied in system contexts. This suggests a more systemic approach should be used when teaching this principle in science methods courses as well as when conducting professional development sessions with in-service teachers.

Although the NGSS has explicitly called for reforming our science classrooms with implementing a systems thinking approach, the document falls short of recognizing that teachers themselves need more instruction on this approach to be able to fully implement the system ideas and concepts. The NGSS does not provide suggestions for professional development models or ideas about how to restructure science methods courses to assist in
developing this new approach. More research is needed to define and describe the most effective pedagogical approaches to sequence instruction and design curricula to teach systems thinking. NGSS has provided the crosscutting concepts to assist educators in developing these skills with students. Although these crosscutting concepts have been documented for students in the study of systems, this study shows that teachers need more instruction on connecting these concepts to the implementation of systems instruction. This study has provided a framework for implementing a systems thinking approach for elementary instruction. Actual classroom implementation of the framework model of this study needs to be conducted to verify its effectiveness.

Elementary teachers are faced with the challenge of teaching about complex systems in their science classrooms everyday. The national efforts for reforming elementary science to reflect this systems thinking approach have not yet been realized. Clearly as this study and those of other researchers have shown, there is much left to be done in teacher education before this reform goal can be fully reached.
References


Appendix 1: Water Cycle Diagnosis Test

Directions: Please put all of your answers on the answer sheet provided.

1. Plants absorb water through their root system. What process allows plants to release large quantities of water vapor into the atmosphere?
   - Respiration
   - Perspiration
   - Evaporation
   * Transpiration

   The reason for your selection is because:
   - Plants transpire water vapor through stomata.*
   - Water evaporates from leaves into water vapor.
   - Water perspires from the plant and turns into water vapor.
   - Plants respires water vapor during photosynthesis.

2. Condensation happens when water vapor rises into the atmosphere and:
   - Cools*
   - Warms

   The reason for your selection is because:
   - Condensation is a cooling process like low humidity on a warm summer day.
   - Condensation is a warming process like high humidity on a warm summer day.
   - Water cools to its saturation point and condensation occurs.*
   - Water warms to its vaporization point and condensation occurs.

1. Most of the energy for the water cycle comes from the:
   a. Ocean
   b. Sun*
   c. Atmosphere
   d. Earth
The reason for your selection is because:
- The atmosphere’s heating processes from greenhouse gases.
- Earth’s internal heating from its core provides the energy.
- The movement of earth’s ocean currents and tides.
- Almost all the energy comes from the sun.*

5. Which process is the source for most of the water vapor going into the atmosphere?
   - Sublimation
   - Evaporation*  
   - Advection
   - Convection

The reason for your selection is because:
- The most common way for water vapor to enter the atmosphere.*
- Movement of wind currents.
- Transfer of energy in a fluid.
- The ability of water to change from a liquid to a gas.

9. The total volume of water on earth is:
   a. Almost constant* 
   b. Decreasing
   c. Increasing
   d. Varies over time

The reason for your selection is because:
  a. Water cycle is a closed system, so no water is lost or gained.*
  b. Water cycle is an open system so the total volume of water constantly changes either up or down.
  c. Water cycle is an open system that allows water to escape into the earth’s interior.
  d. Water cycle is an open system that allows water vapor from space to enter our atmosphere, and eventually fall to earth.
13. What directly forms due to the process of condensation?
   a. Water Vapor
   b. Clouds*
   c. Rain
   d. Snow

   The reason for your selection is because:
   • Decreases with temperature.*
   • Increases with temperature.
   • Increases with air pressure.
   • Reduces with air pressure.

14. On a hot summer day, you get a cold beverage from the refrigerator. You put the can down on a table, and a little while later you return and notice a puddle of water has formed around the outside of the can. Where did this water come from?
   a. From the ice melting inside the can
   b. From the beverage and ice melting from the can
   c. From the beverage and ice condensing inside the can
   d. From the air outside the beverage*

   The reason for your selection is because:
   a. Warming of beverage caused the beverage to expansion and spill out of the can.
   b. Ice on the outside of the beverage melted and created the puddle.
   c. The beverage warmed and caused water to condensate inside the can, and the extra water caused too much volume in the can and seeped out.
   d. Water vapor from the atmosphere cooled and condensed when coming into contact with the cold beverage.*

16. What is needed for clouds to develop?
   a. Water vapor and atmospheric dust*
   b. Ozone, water vapor, and nitrogen
   c. Low pressure with low relative humidity
   d. Oxygen and hydrogen
The reason for your selection is because:
  a. Essential elements needed to form water.
  b. Dust allows water droplets to come together.*
  c. Influenced by a variety of atmospheric gases in order to form.
  d. Atmospheric conditions needed for cloud formation.

20. The melting of floating sea ice due to global warming will probably cause:
  a. Sea level to rise
  b. Sea level to fall
  c. No change in current sea levels*

The reason for your selection is because:
  a. The extra water produced due to the melting will cause sea level to rise and flood coastal areas.
  b. The loss of the sea ice will lower sea level because ice weighs more than water.
  c. No change in sea level will happen because sea ice and water have the same volume.*

27. Water in clouds may change from liquid to solid:
  a. Only at 32°F/0°C.
  b. At 32°F/0°C and temperatures below 32°F/0°C.*
  c. At temperatures above 32°F/0°C.
  d. Water in clouds never freezes.

The reason for your selection is because:
  a. Water vapor does not freeze in clouds.
  b. Water droplets cool while falling to earth, and change into ice.
  c. Clouds can have supercooled water in them.*
  d. Water vapor goes directly to a solid without forming a liquid.
Appendix 2: Systems Thinking Assessment

Item Statements on the Systems Thinking Written Assessment

Item 1: Clouds are the starting point of the water cycle and the tap at home is its end point

Item 2: Amount of water in the oceans growing day by day due to rivers continually flowing into the ocean

Item 3: Increase of evaporation as an effect of global warming may decrease amount of water on earth

Item 4: Population growth increase-water consumption increase-decreasing amount of water on earth

Item 5: Most underground water persists in small pores of rock—well watered sponge

Item 8: Part of the wells in the state of NC contain polluted water

Item 9: Rain that falls on the surface and penetrates within the soil can reach a depth of several meters
Appendix 3: Systems Thinking Rubric Expanded Version

<table>
<thead>
<tr>
<th>Levels</th>
<th>Descriptions</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Novice Level</td>
<td>no response OR indication of not knowing Component/process not identified. Component or process may be included, but indicates not knowing (i.e. “I don’t know about global warming”)</td>
<td>I have no clue or it seems it should be that way</td>
</tr>
<tr>
<td>(Level 0)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recognition Level</td>
<td>identification of ONE component or a process OR identification of a pattern in the system (cycle is continuous—circle means never ending—does not recognize the components that contribute to the patterns or cycles) - AND no explanation of relationship between components or processes (no indication of cause and effect) explanation of relationship indicates inaccuracy — code 1A</td>
<td>there is no beginning or end to the water cycle a cycle constantly flows or continuous cycle always the same amount of water on earth (none is gained or lost)</td>
</tr>
<tr>
<td>(Level 1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beginning Level</td>
<td>identifies at least TWO components or processes of the system - there could be more than two components mentioned but if the relationship only involves two components it is a level 2 BUT there is only an indication of one directional cause and effect relationships between components or processes (A causes B) OR recognition of an interaction between only two components OR if the explanation has inaccuracy about the relationships then code level 2A in the other column Description of Level 2 response indicates limited knowledge of the flow, cycle or conservation of energy and matter within the system (ex. water moves and goes from place to place; water is continuous due to the heating of</td>
<td>(A) evaporation is constantly going, therefore there is no increase in the amount of (B) water acquired (A causes B) Example (A) polar ice caps are melting due to (B) global warming B causes A (one directional) Example of recognition of an interaction between two components</td>
</tr>
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</table>
Appendix 3 (continued)

<table>
<thead>
<tr>
<th>Level</th>
<th>Description</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intermediate Level (Level 3)</td>
<td>identifies TWO or MORE components or processes of the system AND indication of at least two components involved in the cause and effect relationships between components or processes (A causes B which causes C which affects D or A causes B which effects B) OR recognizes the system having feedback loops - ex. global warming accelerates evaporation, placing more water vapor in the atmosphere generating a stronger greenhouse effect. OR recognition of an multiple interaction between more than two components If explanation has an inaccuracy regarding the relationship of the cause and effect or the relationship code level 3A</td>
<td>(A) rivers do flow into the (C) ocean but because of (D) evaporation the levels are mainly constant</td>
</tr>
<tr>
<td></td>
<td>Description of Level 3 recognizes that (i.e., pollution, humans, un equal distribution of components) affect the systems’ cycles, flows, and conservation of energy and matter displays understanding of how these factors interact in multiple ways within the system level 3 explanation uses the above information to display an understanding of the water cycle as a system (made of parts that affect a whole- these parts work together to perform a function- can describe the system in terms of its components and interactions)</td>
<td>the (A) water (B) evaporates (C) ocean water is rising due to (D) global warming</td>
</tr>
</tbody>
</table>
SCIENCE TEACHERS SELECTION AND USE OF VISUAL REPRESENTATIONS

Diagrams, pictures, and maps are pedagogical tools that are often used for teaching science. These visual representations play an important role in illustrating and explaining science concepts, especially by making the abstract phenomena (e.g., systems) more concrete for learners (Coleman, McTique, and Smolkin, 2011). For instance, when studying a system in science, the idea of scale can be challenging either in terms of it being too large (e.g., watershed) or too small (e.g., water molecules) to observe in elementary classrooms; therefore, teachers must rely on visual representations as teaching tools.

Elementary teachers view the Internet as a valuable resource for finding instructional materials such as visual representations to use in lessons, especially in science (Wu & Chen, 2007). This use of technology has placed elementary teachers in a unique pedagogical role of selecting effective scientific visual representations to use in science instruction. The accuracy and appropriateness of teachers’ visual representations are emerging as key instructional tools for students to be able to understand complex ideas in a particular domain (Ainsworth, 1999).

The Framework (National Research Council, 2007) and The Next Generation of Science Standards (Achieve, 2013) have called for teaching students about the complexity of science, including using visual representations to teach modeling, size and scale, and systems thinking. Although research has been done with these ideas individually, little is known about the processes teachers use to select visual representations and the instructional practices used when they teach with representations (e.g., Acheson, 2003; Barry, 2002; Mckensie, 1998), particularly in complex areas of science.
Recent years have seen an increasing interest in teaching teachers to be graphically literate. The ability to construct, produce, present, read, and interpret charts, maps, graphs, and other visual presentations and graphical inscriptions is known as graphical literacy (Readence, Bean, & Baldwin, 2004). Current research has focused on student interpretation of visual representations and has not typically emphasized teachers’ graphical literacy as an important component of pedagogical knowledge. Teachers need skills for reading the salient components of images and representations and the ability to understand the messages being communicated, especially with the increase of electronic and digital forms of representations (Leu, Kinzer, Coiro, & Cammack, 2011; Unsworth, 2001). Teachers also need to be aware of how students conceptualize images and interpret complex models.

The present study examined teachers’ selection of images as pedagogical tools and explored how in-service and pre-service elementary teachers used visual representations in lesson plans. In particular, this study examined elementary teachers’ planning and use of representations in the context of systems thinking.

**Literature Review**

The language of science involves the use of verbal and written communication but more importantly the exchange of information in science education is reliant on using multiple visual representations (Ainsworth, 2006; Kress, Jewitt, Ogborn, & Tsatsarelis, 2001; Lemke, 2004; Yore & Hand, 2010) in pre-college science classrooms. Visual representations come in a multitude of forms, which can help students’ abilities to
communicate with this multimodal language (Ametller & Pinto, 2002). An individual must have the skills to interpret, construct, transform, and evaluate different visual representations to be literate in graphics and to develop representational competence (Kress et al., 2001; Lemke, 2004; Yore & Hand, 2010). The ability to read and understand graphics (e.g., representations) and effectively communicate the language of science leads to scientifically literate individuals who will be able to participate in decision-making practices concerning scientific issues facing our society (Krajcik & Sutherland, 2010; Norris & Phillips, 2003; Yore, Pimm, & Tuan, 2007).

The use of visual instruction can promote the learning and obtainment of knowledge with students more than those taught with only verbal language (Patrick, Carter, & Wiebe, 2005), while also helping students retain the concepts presented (Mayer, Bove, Bryman, Mars, & Tapangco, 1996). The role of visual instruction by teachers has at times served a minor role relative to written and verbal forms of communication in science (Walker, 1993; Trumbo, 1999). Winn (1994) labeled this as a verbal bias, explaining it as a pattern of teachers favoring the written word over the use of visuals. This neglect of visual processing could result in students failing to develop graphical understanding (Leu, 2000) and disregarding graphics rather than realizing the communicative potential of them (Schnotz, Picard, & Hron, 1993).

Developing representational competency in the context of systems thinking has been shown to be effective (Liu & Hmelo-Silver, 2009). When teaching about systems, representations play an essential role because of the complexity and abstract nature of the
systems under study. For example, systems include components and processes that have hidden dimensions and interactions with other subsystems. Multiple types of representations and modeling can shed light on these processes, hidden dimensions and interactions (Verhoeff, Waarlo, & Boersma, 2008). Elementary teachers teach about complex systems everyday in classrooms using representations; however little is known about their selection and the pedagogical approaches teachers use when teaching with representations.

**The Challenges of Representational Competency**

Elementary teachers face challenges promoting representational competency with elementary students. Engaging children in scientific practices is difficult for most elementary in-service and pre-service teachers since their own experience with science is limited, especially with the practice of scientific modeling (Kenyon, Davis, & Hug, 2011). Researchers have called for enhanced efforts to prepare in-service and pre-service to critique and adapt representations as instructional tools (Davis, 2006; Schwarz, Gunckel, Smith, Covitt, Bae, & Enfield, 2008).

The selection of appropriate representations depends on teachers’ own views and experiences with using representations. A recent study of elementary teachers found the most commonly used representation used in science instruction was a flow diagram (Coleman et al., 2011). The instructional practice used most often with this representation was categorized as teacher pointing. Teachers tended to point to the important features of the diagram that they wanted to highlight within the representation. Weiss, Banilower,
McMahon, & Smith (2001) hypothesized that this instructional practice of pointing to only certain aspects of the graphic may be due to elementary teachers' lack of confidence in their own science knowledge and reflect their lack of graphic literacy.

Winschitl and Thompson (2006) found that pre-service teachers viewed modeling through a familiar lens to their own science experiences—usually, the scientific method. This lens constrained their understanding of the use of representations and modeling, as they tended to see the process as a step-by-step process. Kenyon et al. (2011) found, through the use of pre- and post-tests of enacted instructional strategies that supported modeling experiences in methods courses, that pre-service teachers have dissimilar ideas about the usefulness of models and modeling for scientists versus teachers. Pre-service teachers recognized that scientists used models for sense making and communicating, whereas teachers (unlike scientists) viewed models as tools for communication only. Pre-service teachers did not view models as useful for helping them in their own sense making, or more importantly, they did not find the as helpful sense making tools for students.

Teo and Hug (2009) examined the views of models and modeling practices held by elementary and middle school pre-service teachers and found clear disparities. They reported that middle school pre-service teachers considered models helpful in developing and understanding scientific knowledge and acknowledged that models could be used to make predictions and revise ideas about science. Conversely, elementary pre-service teachers viewed the role of models as a means of experimenting and interpreting data. Davis, Petish, and Smith, (2006) suggested that the differences might be due to teachers’ preparation
courses. The main difference between the elementary and middle school pre-service teachers in the study was the emphasis on the content area. Middle school pre-service teachers graduated with a degree in a content area of science, whereas elementary pre-service teachers did not have this depth of content background, which may explain the differences discovered in this study. These studies suggest that elementary pre-service teachers do have ideas about the use of representations and modeling, but they may not have the content background or experiences to implement the reform-based instruction of using representations and modeling as indicated in the Framework (National Research Council, 2012) and NGSS (Achieve, 2013). A closer scrutiny into the views and knowledge of elementary in-service and pre-service teachers use of representations in science instruction is needed.

**Function of Visual Representations**

Graphics can serve a variety of functions such as decoration, representation, organization, interpretation, and transformation (Carney & Levin, 2002). This variety of functional aspects of visual representations has caused learners vary in comprehension and retention, which raises questions about the functions of representations (Harrison & Treagust, 2000). For example, if the purpose of the photograph is for decoration only, the instructional intention of promoting meaning will be lost (Pozzer-Ardenghi & Roth, 2005). As with any communication, the visual language has to be read and interpreted. There are several important pedagogical aspects to consider when teaching students graphic literacy, such as the importance of selection due to readability of the visual, and the pedagogical approaches of using the visual.
Selection of Visual Representation Based on Readability

The type and features of visual representation selected by teachers can prove to serve as powerful learning tools (Carney & Levin, 2002; Mayer, 1993). Visuals categorized by Mayer (1993) as explanatory included a verbal explanation of how scientific systems or processes work and these kinds of representations have been shown to produce a higher level of cognitive processing. Ametller and Pinto (2002) found certain features of graphics directly affect the message being communicated. For instance, the use of color, arrows used to display flow of events, the mixing of real and symbolic entities, highlighting of certain words or images, wording of verbal explanations, and the integration of more than one image have all shown to benefit students’ ability to understand the visual (Stylaïduo & Ormerod, 2002). Diagrams with relevant structures identified and highlighted can make the visual representation more comprehensible.

Students’ interpretations of photographs and realistic drawings have led to mixed results (Winn & Snyder, 1996). Photographs are problematic since they can promote a wide range of explanations. Pozzer-Ardenghi & Roth (2005) found three features that assist students with interpretation of photographs, such as the addition of captions, having students to read text in textbooks with photographs simultaneously, and finally, considering the context of the how the photographs are presented. Colorful decorative pictures have been hypothesized to have limited influence on cognitive processing and appear to have a greater influence on promoting emotional interest. Research has found that illustrations designed to promote interest and motivation toward content materials have not improved student learning (Park & Lim, 2007).
There is evidence that a student’s background and prior knowledge may also affect his or her ability to read and interpret graphics. Cheng, Lowe, & Scaife (2001) found that visual representations benefited students with less prior knowledge more so than students with more knowledge. McTigue (2009) found that middle school students with higher levels of background knowledge used embedded verbal cues in the text (e.g., look at the diagram now to examine the direction of the bloodflow with the body) more effectively.

These examples illustrate the importance of teachers having representational competency in order to select, construct, or transform representations to teach science. The explicit implementation of scientific representations is essential to children’s interpretational and cognitive development (e.g., Szechter and Liben, 2004).

**Pedagogical Approaches for Developing Representational Competency**

Recent research investigated the relationship between representational competency and content knowledge with secondary science students (Nitz, Ainsworth, Nerdel, & Prechtl, 2014). Students were asked to identify their perceptions of how often the following pedagogical approaches were used by teachers using representations: interpretation of visual representations, construction of visual representations, use of scientific texts, amount of technical terms used in class, use of symbolic representations and engaging in active construction of knowledge. The teaching practice of interpreting visual-graphic representation was the most common practice perceived by students. This teaching practice of interpretation of graphics provided students with explicit instruction of how to interpret graphics, which resulted in students developing more conceptual knowledge of both content
and representations. This teaching practice of interpreting visual-graphical representation with direct teacher guidance supports previous research (Hubber, Tytler, & Hastam, 2010; Prain & Waldrip, 2006; Tytler, Prain, & Peterson, 2007). There were positive effects on students’ content knowledge when students were engaged in active social construction of knowledge about the representations. The impact on representational competence during students’ group work was not as successful. The researchers reported that these results might be the consequence of the groups working autonomously. Students tended to pay more attention to the content versus the representational aspects of the domain. This result points to the importance of having the teacher mediate and scaffold instruction of the representational aspects while learning the content (Tytler et al., 2007; Waldrip, Prain, & Carolan, 2010).

There is emerging evidence of the positive impact that pedagogical approaches that use representations can have on the development of representational competence and systems thinking. Diagrams, student created drawings, and concept maps were used in studies that taught students about the complex systems of the rock cycle (Kali, Orion, & Eylon, 2003) and the water cycle (Ben-Zvi Assaraf & Orion, 2005, 2010). Students in these studies used reconstructed diagrams to record their understandings of interactions and relationships of the processes within the water cycle and rock cycle after implementation of indoor and outdoor lab investigations. Concept maps were used as pre- and post- assessments that increased knowledge of system thinking was assessed by an analysis of the links and connections of the processes involved in these systems. Student-created drawings of each system were also
used to demonstrate knowledge of relationships within the system. Students showed an increased knowledge of the relationships within the system by including elements from subsystems such as the biosphere (e.g., animals within the water cycle) and hidden dimensions by indicating groundwater aspects within their drawings. These examples show that pedagogical approaches that strive to develop representational competency can increase knowledge of science and of systems thinking.

**Theoretical Framework**

This research study used an adapted model of the theoretical framework based on the work of Treagust & Tsui (2013), Tsui & Treagust (2003, 2007, 2010), and Ainsworth (1999) to explore the application of systems thinking in the selection and use of instructional tools. This framework includes three dimensions: modes of representations, levels of representations, and domain knowledge of biology.

For the present study, the framework will consist of the Systems Thinking Elements from the Systems Thinking Hierarchical Model (STH Model) are applied to examine teachers’ conceptualizations of the water cycle (Ben-Zvi Assaraf & Orion, 2005) (dimension 1) for the domain of knowledge. The modes and levels of representations will remain the same. Finally, the addition of pedagogical approaches is being added around the cube since teachers are considering all three of these dimensions when deciding on how to select and implement the pedagogical tools of representations.
Figure 1.1 The Cube Model: For Learning and Applying Systems Thinking with Visual Representations

1. Dimension 1: The System Thinking Elements (Water Cycle)
2. Dimension 2: Modes of Visual Representations
3. Dimension 3: Levels of Representations Macro, Micro, and Symbolic
4. Dimension 4: “Knowledge in Pieces” Pedagogical Approaches
**Dimension 1: The System Thinking Elements**

The System Thinking Hierarchical Model (STH model) created by Ben-Zvi Assaraf and Orion (2005) has been used to illustrate development of systems thinking with elementary, middle, and high school students studying the topic of the water cycle. This study used key components from the STH model, called the Systems Thinking Elements, to investigate the proposed reasons for selection and use of pictorial representations on a lesson plan for teaching about the water cycle.

The STH model includes eight characteristics of systems thinking that include three hierarchical levels: Level 1, the analysis level, which includes the ability to identify the system’s components and processes; Level 2, the synthesis level, which includes the ability to identify relationships between separate components, the ability to identify dynamic relationships between the system’s components, the ability to understand the cyclic nature of systems, and finally the ability to organize components and place them within a network of relationships; and Level 3, the implementation level, which includes the ability to make generalizations, and to understand the hidden components of the system and the system’s evolution in time (prediction and retrospection). These levels were used in previous studies to determine development of systems thinking during a curriculum intervention. For this study, these levels were used as indicators of applying elements of systems thinking when selecting or proposing the use of the representation. If teachers indicated selection of representations based on identifying specific components or processes of the water cycle or
indicated they would use the representation to discuss interactions or relationships of the system, it was coded as using systems thinking elements.

**Dimension 2: Modes of Representations**

Treagust and Tsui (2013) identified a continuum of pictorial forms that moved from less to increased abstraction. The present study only examined elementary teachers’ selection and use of photographs, maps, and diagrams.

Learning about complex systems can take place using various strategies, often moving across the continuum of representations from concrete to more abstract. Verhoeff et al. (2008) used this strategy in their study of cellular biology that involved modeling with a systems thinking approach. In this study, Verhoeff et al. (2008) began the modeling process through an iteration of observing, evaluating, and revising models. The modeling process utilized multiple “modes” of visual representations and physical models. The systems approach required students to engage in thinking back and forth between computer-constructed models, real cells (observed through an electron microscope), student-created physical models, and visual representations such as diagrams found on the Internet. At each phase of the thinking back-and-forth process, students were required to discuss the process of breast-feeding at the cellular level using the multiple models (HTM) method of representation to explain the behaviors of each of the structures found in the cells, which led to students’ understanding the function of the cells that produce milk. This modeling process proved a powerful visualizing tool, which led students to translate meaning about this complex system using components of this study’s theoretical framework. For example, the
systems thinking modeling process improved students’ understanding of the dynamics of (cell) biological processes, which is the systems thinking element of understanding the hidden dimensions of the cellular process. The modeling process in this study used many of the modes of representations from concrete pictures to more abstract diagrams. The pedagogical approach used in this research example illustrates reform-based methods, such as having the students ask questions about the functions of the system while using the representations and evaluating the obtained information found in the representations. This pedagogical approach also illustrates, by using representations, it is possible to improve competence skills through the comparison of images and by using a back and forth thinking strategy.

Dimension 3:

Representations and models produced by scientists typically comprise one of three distinct representational levels that include macroscopic, sub-microscopic, and symbolic (Treagust and Tsui, 2013). The macroscopic level consists of what is observed for the study. Examples from systems thinking could be a photograph of a glass of ice water, which illustrates the macro the glass of water itself, which illustrates the representation as a component of the phenomena to be explored. The sub-microscopic level would include images of the molecules of condensation. A symbolic level representation of the water cycle system consists of qualitative abstractions used to represent the items of the sub-microscopic level often expressed in a mathematical formula.
Dimension 4: “Knowledge in Pieces” (Pedagogical Approaches)

The goal of the present study is to determine the initial ideas that elementary in-service and pre-service teachers hold about the selection and use of pictorial representations for a proposed lesson about the water cycle. Since this teaching method (e.g., selecting and using representations) and topic (e.g., water cycle as a complex system) are both novel to most elementary in-service and pre-service teachers, “knowledge in pieces” or pedagogical approaches framework is applied to the analyses. During a model-based physics course, diSessa (1993) used a “knowledge in pieces” perspective on learning that attempted to make sense of the ideas that emerged from pre-service teachers. “Knowledge in pieces” identifies small, discrete ideas about teaching, referred to by diSessa as pedagogical ideas that include appropriate or inappropriate beliefs about teaching science in this particular context of scientific modeling (Harlow, Bianchini, Swanson, & Dwyer, 2013). These pedagogical approaches arise from observations and experience to teaching and learning that build over time and occur prior to any formal instruction of teaching. Pedagogical approaches are being used as a part of the theoretical framework for this study and not pedagogical content knowledge (PCK; Shulman, 1986, 1987) since pedagogical approaches are not considered pieces of an expert knowledge base and they may not have been developed through formal instruction.
Research Methods

The purpose of this research study is to investigate elementary in-service and pre-service teachers’ pedagogical approaches on the selection and use of visual representations for a proposed lesson on a specific earth science complex system (e.g., water cycle).

Research Questions

The specific questions that guide this study are as follows:

RQ1: What visual representations do elementary in-service and pre-service teachers incorporate when planning for a lesson on the water cycle?

RQ2: What is the rationale for selection of visual representations for a proposed lesson on the water cycle?

RQ3: How do elementary in-service and pre-service teachers incorporate visual representations in a lesson plan about the water cycle?

Study Context

The study was designed to examine teachers’ use of representations about the water cycle. This topic was used because it is a topic commonly taught by most elementary teachers, is part of state and national standards, and is a complex system that includes components at multiple scales.

Design

This present study is a part of a larger series of studies that examine representational competency and systems thinking (Lee and Jones, in press). The design of the study included a card sort task that was used to assess elementary in-service and pre-service
teachers’ preferences for representations to be used in teaching the water cycle. A subsample of participants completed a semi-structured interview to elicit teachers’ pedagogical and pedagogical content knowledge that contributed to representations used in lesson planning. The mixed methods design was chosen to provide details about experienced and novice teachers’ reasoning about the use of representations and a more in depth examination of the contexts and reasons for preferences for representations used in lesson plans.

Participants

Elementary teachers of grades 3-5 from three districts surrounding a southeastern university were invited to participate in this study. Sixty-seven teachers (n=67) volunteered to participate. The in-service teacher sample included sixty-six females and two males. Sixty-two were Caucasian, four were African American, and one was Hispanic.

Elementary pre-service teachers enrolled in the last two years of a teacher education program at a southeastern university were invited to participate in the study. Sixty-nine elementary pre-service teachers (n=69) volunteered (66 females, 2 males; all Caucasian).

Assessments: Card Sort of Representations and Interviews

The card sort task was designed to assess preferences for visual representations, rationale for selection, and proposed use of the pictorial representations in a lesson on the water cycle. Interviews were done with a subsample of pre- and in-service teachers (described below).
Assessment: Card-Sort

The card-sorting task of visual representations builds on Kelly’s Personal Construct Theory (Kelly, 1955). This theory is based on the idea that methods used by people to categorize the world can be very different but there exists enough commonality to provide us with insight into determining how these differences may reveal individuality. The card sort assessment was used here to investigate patterns and relationships of elementary in-service and pre-service teachers’ sorting, ranking, and selecting of visual representations about the water cycle for use in instruction.

Selection of Visual Representations for Card-Sorting Assessment

A panel that included two teachers, two elementary science educators, a science educator with a specialization in earth science, and a climate scientist selected representations for the card sort task. The purpose of the panel was to establish a valid selection of images that represent components of the water cycle. The panel was asked to select five visual representations from the Internet to be used in a lesson with fifth grade students on the topic of the water cycle. Panelists individually selected pictorial representations.

The visual representations were analyzed to determine if any of the following features of the system were represented: the components and processes of the water cycle, interactions between the components, views of the entire system, illustrations of hidden dimensions (e.g., invisible to the human eye) of the system, visualizations of the system in natural settings, and representations of the human impact on the system. Of the pool of
possible representations selected by the panelists, 15 were selected for the card sort task (Table 1.1- describes the final set of pictorial representations). Specifically, representations were selected for the assessment to address the components of the system and represented different representational modes (maps, photographs, and diagrams). The final set of 15 visual representations were printed in color with an identifying code placed at the bottom of the card for the sorting phase of the research, which is described in more detail below in the administering assessments section.
Table 1.1

Visual Representations for Card-Sort Assessment

<table>
<thead>
<tr>
<th>Visual Representations</th>
<th>Description of Representation</th>
<th>Features of Systems Thinking</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="Image1" alt="Water cycle diagram" /></td>
<td>Water cycle overview diagram</td>
<td>Illustration of entire system as a circular pattern</td>
</tr>
<tr>
<td><img src="Image2" alt="USGS water cycle diagram" /></td>
<td>USGS water cycle diagram</td>
<td>Illustration of entire system and hidden dimensions</td>
</tr>
</tbody>
</table>


Table 1.1 Continued


Illustration of interactions between components-illustrating effects of flooding


Illustrates human impact on the system (urban water cycle)
Table 1.1 Continued

5 Adapted from Journey from Source to Sea. [online image] Blog. Retrieved February 23, 2015 from https://umngeniriverwalk.wordpress.com/page/19/

Drain pipe picture

Illustrates human impact on the system (illustrates drain pipe flowing into a water supply)


Eco kids diagram

Illustration of entire system and hidden dimensions
Table 1.1 Continued


Impact of geography on components of the water cycle (River Basins)


Illustrates entire system – hidden dimensions
Table 1.1 Continued

9. Condensation glass photograph

   Illustrates a component and/or a process of the system (condensation)

10. Rainy day photograph

    Illustrates components and processes in a natural setting (rainy day)

11. Transpiration bag photograph

    Illustrates a component and a process in a natural setting (transpiration)
<table>
<thead>
<tr>
<th>Table 1.1 Continued</th>
</tr>
</thead>
<tbody>
<tr>
<td>River photograph</td>
</tr>
</tbody>
</table>

| Mountain stream photograph | Illustrates a component of the system (image of a mountain stream) |
Table 1.1 Continued

<table>
<thead>
<tr>
<th>14</th>
<th>Street drain photograph</th>
<th>Illustrates human impact on the system (image of rain water traveling down a street into a drain)</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>15</th>
<th>Oil spilled bird photograph</th>
<th>Illustrates human impact on the system (bird covered in oil from an oil spill)</th>
</tr>
</thead>
</table>
The final selection included 5 diagrams, 8 photographs and 2 maps.

**Directions for Administering the Card-Sort Assessment.**

Participants were provided with the 15 visual representations in a manila envelope with directions and recording sheet. The directions stated:

Imagine that you are being asked to teach the following performance expectation from the Next Generation of Science Standards. E-ESS2-2. Develop a model using an example to describe ways the geosphere, biosphere, hydrosphere, and/or atmosphere interact. Examine the visual representations (e.g., photos, diagrams, and maps) and categorize them into groups of representations you would use or not use in a lesson on the water cycle. Please consider the following questions for your selection process.

What happens when it rains? How does the water cycle work? What are the processes of the water cycle? What other components of the earth are affected by the water cycle? What happens to water in nature? Where are all of the places that water could go or come from?

**Selection of Interview Participants**

Three in-service teachers and two pre-service teachers were selected for interviews based on their pedagogical preferences indicated by the coding rubric. The participants had indicated high percentages of teacher-centered and student-centered use with each diagrams and pictures.
Interviews

Interviews were also used to determine the pedagogical approaches that in-service and pre-service teachers applied to the task of planning a lesson and to obtain additional information about the rationales teachers used to select representations. Two science educators established the validity of the interview protocol through a pilot interview with two teachers and a review.

Teacher participants were told the following in the interview:

I am interested in learning more about how you plan and use visual representations when teaching about a system (e.g., water cycle). Here are some visual representations from the card sort task that were most and least frequently selected. Describe how you might use these visual representations in a lesson about the water cycle. How would you sequence the visual representations in a water cycle lesson? (Participants were given two visual representations (Urban water cycle diagram and River picture) that were not selected by a majority of in-service and pre-service teachers in the study.) Would you use these visual representations? Why or why not? Why do you think elementary in-service and pre-service teachers didn’t choose these visual representations for a water cycle lesson? What does “teacher-centered” teaching mean to you? What would teacher-centered teaching look like in a lesson where a teacher was using images? What does student-centered teaching mean to you? What would that look like in a lesson where a teacher was using images? Perhaps now more than ever, teachers have a variety of images to use in teaching science. What challenges do you experience when selecting images to use in a lesson?

Two science educators established the clarity and accuracy of the interview protocol.

Selection of Interview Participants.

A rubric was created as part of the analyses (described below) for the card-sorting task. Teachers were classified according to the degree to which they sorted the representations according to teacher- or student-centered uses. Three in-service teachers and
two pre-service teachers were selected for interviews based on their high teacher-centered and student-centered uses for representations.

**Background Information**

Participating in-service and pre-service teachers were asked background information about creating their own instructional materials for teaching science (e.g., making powerpoints to use on a smartboard), experience in using different types of representations (e.g., diagrams, photos, and maps) when teaching about the water cycle, confidence in teaching about the water cycle, and indication of times participants studied the water cycle. In-service teachers were asked how often they teach science in a regular school day.

**Creating Instructional Materials**

Table 2.0

*Designing Your Own Instructional Materials for Science Lessons (powerpoint, smartboard)*

<table>
<thead>
<tr>
<th>Indication of Time spent designing lessons</th>
<th>In-service Teachers</th>
<th>Pre-service Teachers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Almost every lesson</td>
<td>20 (29.9)</td>
<td>43 (63.2)</td>
</tr>
<tr>
<td>Some lessons</td>
<td>38 (56.7)</td>
<td>24 (34.8)</td>
</tr>
<tr>
<td>Rarely</td>
<td>7 (10.4)</td>
<td>1 (1.4)</td>
</tr>
<tr>
<td>Missing</td>
<td>1 (1.4)</td>
<td></td>
</tr>
</tbody>
</table>

*Note: Numbers represent frequency (percentages)*
Reported Uses of Representations

Table 2.1
Indicated Uses of Modes of Representations for Teaching the Water Cycle

<table>
<thead>
<tr>
<th>Groups of Teachers</th>
<th>Diagrams</th>
<th></th>
<th>Photos</th>
<th></th>
<th>Maps</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>In-service</td>
<td>Pre-service</td>
<td>In-service</td>
<td>Pre-service</td>
<td>In-service</td>
<td>Pre-service</td>
</tr>
<tr>
<td>Almost of Every Lesson</td>
<td>29 (43.3)</td>
<td>32 (46.4)</td>
<td>14 (20.9)</td>
<td>49 (71.0)</td>
<td>3 (4.5)</td>
<td>24 (34.8)</td>
</tr>
<tr>
<td>Some Lessons</td>
<td>27 (40.3)</td>
<td>35 (50.7)</td>
<td>38 (56.7)</td>
<td>19 (27.5)</td>
<td>39 (58.2)</td>
<td>39 (56.5)</td>
</tr>
<tr>
<td>Rarely</td>
<td>7 (10.4)</td>
<td>1 (1.4)</td>
<td>11 (16.4)</td>
<td>21 (31.3)</td>
<td>3 (4.5)</td>
<td>5 (7.2)</td>
</tr>
<tr>
<td>No indication</td>
<td>2 (3.0)</td>
<td>2 (3.0)</td>
<td>2 (3.0)</td>
<td>2 (3.0)</td>
<td>1 (1.4)</td>
<td>1 (1.4)</td>
</tr>
<tr>
<td>Missing</td>
<td>1 (1.4)</td>
<td>1 (1.4)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: Numbers represent frequency (percentages)

Reported Confidence in Teaching about Earth Science

Table 2.2
How confident do you feel about teaching earth science?

<table>
<thead>
<tr>
<th>Confidence levels</th>
<th>In-service</th>
<th>Pre-service</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extremely confident</td>
<td>3 (4.5)</td>
<td>1 (1.4)</td>
</tr>
<tr>
<td>Confident</td>
<td>17 (25.4)</td>
<td>6 (8.7)</td>
</tr>
<tr>
<td>Somewhat confident</td>
<td>27 (40.3)</td>
<td>29 (42.0)</td>
</tr>
<tr>
<td>Not confident</td>
<td>18 (26.9)</td>
<td>32 (46.4)</td>
</tr>
<tr>
<td>Missing</td>
<td>2 (3.0)</td>
<td></td>
</tr>
</tbody>
</table>

Note: Numbers represent frequency (percentages)
Times of Studying The Water Cycle

Table 2.3
Last Time Studying the Water Cycle

<table>
<thead>
<tr>
<th></th>
<th>In-service Teachers</th>
<th>Pre-service Teachers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elementary School</td>
<td>18 (26.9)</td>
<td>11 (15.9)</td>
</tr>
<tr>
<td>Middle School</td>
<td>13 (19.4)</td>
<td>21 (30.4)</td>
</tr>
<tr>
<td>High School</td>
<td>11 (16.4)</td>
<td>24 (34.8)</td>
</tr>
<tr>
<td>College</td>
<td>19 (28.4)</td>
<td>12 (17.4)</td>
</tr>
<tr>
<td>Professional</td>
<td>3 (4.5)</td>
<td></td>
</tr>
<tr>
<td>Development</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Missing</td>
<td>3 (4.5)</td>
<td>1 (1.4)</td>
</tr>
</tbody>
</table>

Note: Numbers represent frequency (percentages)

Reported Time Spent Teaching Science

Table 2.4
Estimated Time Spent Teaching Science in a Regular School Day

<table>
<thead>
<tr>
<th>Indicated Time Spent Each Day Teaching Science</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 minutes</td>
<td>9 (13.4)</td>
</tr>
<tr>
<td>30 minutes</td>
<td>16 (23.9)</td>
</tr>
<tr>
<td>45 minutes</td>
<td>21 (31.3)</td>
</tr>
<tr>
<td>one hour</td>
<td>9 (11.9)</td>
</tr>
<tr>
<td>n/a reading /SS teacher</td>
<td>2 (3.0)</td>
</tr>
<tr>
<td>None (departmentalize)</td>
<td>1 (1.5)</td>
</tr>
</tbody>
</table>

Note: Numbers represent frequency (percentages)
Analyses

Analysis of Card Sort Assessment

Two rubrics were developed based on teachers’ reasons for selection or non-selection of visual representations and the described pedagogical approaches. The creation of the selection rubric is discussed in a chapter from Models and Modeling of Scientific Representations (in preparation, Lee & Jones, 2015). The final themes for the selection of visual representations are indicated in the Table 3.1. Table 3.0 defines the pedagogical approaches indicated.

Rubric for Using Selected Visual Representations

Elementary in-service and pre-service teachers completed a card sort assessment for selecting and proposing how they would use visual representations in a proposed lesson on the water cycle. Both groups of teachers indicated a reason for selection or non-selection and how they would use the selected visual representation. A rubric was created to analyze the proposed uses of the selected representations. The rubric emerged from a content analysis that began with the researcher reading and re-reading the data to formulate a tentative understanding of the data (Roth, 1995). Several iterations of content analysis were conducted to establish five themes for coding. A science educator and researcher separately coded a randomly selected 10% data. As part of the verification methodology (Strauss, 1987), the coding was repeated three times (coding, discussion, revision) until an inter-rater reliability of 10% of the randomly selected data was reached at 97%.

The three themes that emerged from the coding are included in the table below. The indicated categories are not exclusive: a given response may fit in more than one category.
Table 3.0
Coding Uses of Visual Representations Rubric

<table>
<thead>
<tr>
<th>Thematic Categories</th>
<th>Description</th>
<th>Representation Use Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teacher Use- How does the teacher describe using the visual representation to teach the topic?</td>
<td>Responses refer to describing how the teacher would use the visual representation in a lesson.</td>
<td>I would explain the diagram to the students.</td>
</tr>
<tr>
<td></td>
<td>The actions of the teacher are more reflective of a teacher-centered classroom.</td>
<td>I would illustrate the process of condensation to students.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>I would use the image in a powerpoint slideshow.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>I would introduce the topic using the diagram.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>I would explain the terms.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>I would use it as a reference.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>I would display the image.</td>
</tr>
<tr>
<td>Student Use- How does the teacher describe using the pictorial representation to engage students?</td>
<td>Responses refer to using the visual representation to promote active engagement of students in the classroom. Responses promote the use of scientific practices such as discussions, investigations, making predictions and inferences in the classroom. The actions of the teacher are more reflective of a student-centered classroom.</td>
<td>I would have students investigate why this happened.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>I would have students discuss changes over time and make predictions about why.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Students would compare and contrast effects of water.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Discuss with students how a meteorologist can analyze and compare amounts of rainfall.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>I would use the image to have a discussion with students about runoff.</td>
</tr>
</tbody>
</table>
Table 3.0 Continued

| Systems Thinking Use-How does the teacher explain using the pictorial representation to teach systems thinking elements? | Responses refer to the pictorial representation to be used for representing a component or process of the water cycle system or identifying interactions within the system. | I would show how the water cycle & amount of rain affects so many things especially water levels. Use it as an explanation of how the parts connect the system itself. To show water as a cycle. To show runoff. |

Final Selection and Non-Selection Reasons for Visual Representations

Table 3.1

*Coding Rubric for Teachers’ Selection Reasons for Representations*

<table>
<thead>
<tr>
<th>Thematic Categories</th>
<th>Description</th>
<th>Teachers’ Selection Rationale</th>
</tr>
</thead>
</table>
| + Aesthetics        | Responses refer to color, brightness; to the look or appearance of the pictorial representation. | Colorful
Pleasing in appearance
Attractive
Clear graphic
Great visual |
| - Non-aesthetics    | Responses refer to unattractive aspects of the representation. | Ugly picture
Not appealing
Plain not attractive |
| +Understandably     | Responses refer to understandability, student accessibility, or development appropriateness. | Kid friendly example
Visual is easy to understand
Good vocabulary
Simple and concise
Lower grade students would be able to understand it. |
<table>
<thead>
<tr>
<th>Table 3.1 Continued</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Complexity</td>
</tr>
<tr>
<td>Responses refer to elements that may cause confusion (arrows, lack of labels, difficult terminology), are confusing, or are hard to understand.</td>
</tr>
<tr>
<td>+ Systems Thinking</td>
</tr>
<tr>
<td>Responses refer to a component or process of the water cycle system, or identify interactions within the system.</td>
</tr>
<tr>
<td>- Non-systems Thinking</td>
</tr>
<tr>
<td>Responses refer to a lack of conceptual connection between the representation and the water cycle.</td>
</tr>
<tr>
<td>+ Relevance</td>
</tr>
<tr>
<td>Responses refer to relevancy to students’ lives or as an illustration of real life examples.</td>
</tr>
<tr>
<td>- Non-relevance</td>
</tr>
<tr>
<td>Responses refer to the representation as not relevant or as uninteresting to students.</td>
</tr>
</tbody>
</table>

- Selection categories and reasons signified by + symbol
- Non-selection categories and reasons signified by - symbol
**Analysis of Interviews**

Interviews were transcribed and analyzed qualitatively (Creswell, 2009). Each interview was read and reviewed for themes. The emergent themes included selection reasons of aesthetics and understandably for diagrams and relevance for pictures. Pedagogical approaches of teacher-centered use of diagrams and student-centered use of pictures were highlighted.

**Reliability and Validity of Interview Analysis**

Triangulating the results with the card sort assessment and coding rubrics contributed to the validity of the assessments. All interviews were transcribed and checked for mistakes during the transcription process. The meanings of themes were constantly compared to the themes identified in the coding rubrics throughout the coding process. A second coder reviewed the established themes of the interview transcripts to check for agreement and to establish inter-rater reliability. Accuracy of established themes were agreed upon between coder and the researcher and inter-rater reliability of 96% was reached.

**Results**

**Selection of Visual Representations**

There were no differences between the in-service and pre-service teachers’ selection of visual representations (Table 4.0). The five visual representations that were most frequently selected included the water cycle overview diagram, eco kids diagram, condensation glass photograph, rainy day photograph, and street drain photograph. The two maps were the least selected visual representations. Table 4.0 displays the selection frequencies for the 15 visual representations.
Table 4.0  
*Ranking of Selected Visual Representations by In-service and Pre-service Teachers*

<table>
<thead>
<tr>
<th>Selected Visual Representation</th>
<th>Frequency (percentage)</th>
<th>Type of Representation</th>
<th>System Elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water cycle overview diagram</td>
<td>116 (85.3%)</td>
<td>Diagram</td>
<td>Illustration of entire system</td>
</tr>
<tr>
<td>Eco kids diagram</td>
<td>109 (80.1%)</td>
<td>Diagram</td>
<td>Illustration of entire system and hidden dimensions</td>
</tr>
<tr>
<td>Condensation glass photograph</td>
<td>105 (77.2%)</td>
<td>Photograph</td>
<td>Illustrates a component and/or a process of the system (condensation)</td>
</tr>
<tr>
<td>Rainy day photograph</td>
<td>103 (75.7%)</td>
<td>Photograph</td>
<td>Illustrates components and processes in a natural setting (rainy day)</td>
</tr>
<tr>
<td>Street drain photograph</td>
<td>86 (63.2%)</td>
<td>Photograph</td>
<td>Illustrates human impact to the system (image of rain water traveling down a street into a drain)</td>
</tr>
<tr>
<td>USGS water cycle diagram</td>
<td>81 (59.6%)</td>
<td>Diagram</td>
<td>Illustration of entire system and hidden dimensions</td>
</tr>
<tr>
<td>Raindrop diagram</td>
<td>80 (58.8%)</td>
<td>Diagram</td>
<td>Illustrates entire system – hidden dimensions</td>
</tr>
<tr>
<td>Drain pipe photograph</td>
<td>73 (53.7%)</td>
<td>Photograph</td>
<td>Illustrates human impact on the system (illustrates drain pipe flowing into a water supply)</td>
</tr>
<tr>
<td>Transpiration bag picture</td>
<td>69 (50.7%)</td>
<td>Photograph</td>
<td>Illustrates a component and a process in a natural setting (transpiration)</td>
</tr>
<tr>
<td>Urban water cycle</td>
<td>62 (45.6%)</td>
<td>Photograph</td>
<td>Illustrates human impact on the system (urban water cycle)</td>
</tr>
<tr>
<td>River photograph</td>
<td>56 (41.2%)</td>
<td>Photograph</td>
<td>Illustrates a component of the system (image of a river)</td>
</tr>
<tr>
<td>Oil spilled bird photograph</td>
<td>53 (39.0%)</td>
<td>Photograph</td>
<td>Illustrates human impact on the system</td>
</tr>
<tr>
<td>Flood map</td>
<td>30 (22.1%)</td>
<td>Map</td>
<td>Illustration of interactions between components-illuminating effects of flooding</td>
</tr>
<tr>
<td>River basin map</td>
<td>26 (19.1%)</td>
<td>Map</td>
<td>Impact of geography on components of the water cycle (River Basins)</td>
</tr>
</tbody>
</table>
Pictorial Representations Selection Rationale

The selection rationales were coded using the rubric described (table 3.1) and descriptive statistics test was run to determine frequencies of coded rationales. Rationales for selecting representations are shown in Table 4.1.

Table 4.1
Reasons for Selection of Visual Representations by In-service and Pre-service Teachers

<table>
<thead>
<tr>
<th>Representation</th>
<th>Aesthetics</th>
<th>Understandably</th>
<th>Systems Thinking</th>
<th>Relevance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water cycle overview diagram</td>
<td>60 (51.7%)</td>
<td>75 (64.7%)</td>
<td>60 (51.7%)</td>
<td>1 (0.9%)</td>
</tr>
<tr>
<td>N=116</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eco kids diagram</td>
<td>56 (51.4%)</td>
<td>64 (58.7%)</td>
<td>53 (48.6%)</td>
<td>4 (3.7%)</td>
</tr>
<tr>
<td>N=109</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Condensation glass picture</td>
<td>23 (21.9%)</td>
<td>7 (6.7%)</td>
<td>76 (72.4%)</td>
<td>29 (27.6%)</td>
</tr>
<tr>
<td>N=105</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rainy day picture</td>
<td>35 (34.0%)</td>
<td>3 (2.9%)</td>
<td>81 (78.6%)</td>
<td>23 (22.3%)</td>
</tr>
<tr>
<td>N=103</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Street drain picture</td>
<td>15 (17.4%)</td>
<td>0 (0)</td>
<td>42 (48.8%)</td>
<td>9 (10.5%)</td>
</tr>
<tr>
<td>N=86</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
There were no differences in the reasons for selection of the top five images being selected by in-service and pre-service teachers. In-service and pre-service teachers selected diagrams based on aesthetics, understandably, and systems thinking reasons. Photographs were also selected based on the aesthetics of the image, the presence of systems thinking, as well as relevancy to the topic being studied.

The Uses of Pictorial Representations When Teaching About the Water Cycle

The pedagogical approaches for using diagrams and pictures are shown in Table 4.2.

<table>
<thead>
<tr>
<th>Selected Visual Representation</th>
<th>Teacher Use</th>
<th>No Teacher Use</th>
<th>Student Use</th>
<th>No Student Use</th>
<th>Systems Thinking</th>
<th>No Systems Thinking</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water cycle overview diagram</td>
<td>81 (69.8%)</td>
<td>35 (30.2%)</td>
<td>15 (12.9%)</td>
<td>101 (87.1%)</td>
<td>57 (49.1%)</td>
<td>59 (50.9%)</td>
</tr>
<tr>
<td>Eco kids diagram</td>
<td>73 (66.1%)</td>
<td>37 (33.9%)</td>
<td>16 (14.7%)</td>
<td>93 (85.3%)</td>
<td>68 (62.4%)</td>
<td>41 (37.6%)</td>
</tr>
<tr>
<td>Condensation glass picture</td>
<td>56 (53.3%)</td>
<td>49 (46.7%)</td>
<td>24 (22.9%)</td>
<td>81 (77.1%)</td>
<td>74 (70.5%)</td>
<td>31 (29.5%)</td>
</tr>
<tr>
<td>Rainy day</td>
<td>58 (56.3%)</td>
<td>45 (43.7%)</td>
<td>22 (21.4%)</td>
<td>81 (78.6%)</td>
<td>76 (73.8%)</td>
<td>27 (26.2%)</td>
</tr>
<tr>
<td>Street drain picture</td>
<td>45 (52.3%)</td>
<td>41 (47.7%)</td>
<td>24 (27.9%)</td>
<td>62 (72.1%)</td>
<td>68 (79.1%)</td>
<td>18 (20.9%)</td>
</tr>
</tbody>
</table>

Note: Combined In-service and Pre-service Teachers Pedagogical Approaches
The pedagogical approaches proposed by in-service and pre-service teachers for using the images were similar; therefore the data were combined for subsequent analyses and discussion. The results showed that teachers planned to use diagrams and pictures in teacher-centered contexts. Teachers did not frequently indicate they would use a representation with a student-centered approach. Teacher-centered and student-centered pedagogical examples are defined in the discussion.

**Discussion**

**Selected Pictorial Representations**

Most of the experienced teachers in this study reported creating their own images for instruction (56.7%). But even with experience, both experienced and pre-service teachers tended to select and use images in similar ways. It is not clear whether experienced teachers lack a level of representational competence that could be expected to develop with experience, or perhaps pre-service teachers are prepared in teacher education programs such that they already have similar pedagogical skills in selecting representations as the experienced teachers. Another interpretation is that neither experienced nor inexperienced teachers have sufficient content knowledge or confidence in teaching science to move beyond the most fundamental uses of representations in teaching a lesson. Both groups of teachers indicated similar confidence ratings of somewhat confident (in-service 40.3% and pre-service 42.0%) when asked about their preparedness to teach earth science.
The most frequently selected five representations included two diagrams and three photographs. The most frequently selected diagram (water cycle overview diagram) illustrated the entire system in a circular pattern. The processes illustrated in the diagram included condensation, precipitation, surface runoff, evaporation (from oceans, lakes, & streams), groundwater, and transpiration from plants. The second most frequently selected diagram (eco kids diagram) also illustrated the system as parts being circular with the addition of the sun and different shaped lines and arrows indicating processes such as transpiration and evaporation. Groundwater flow was included as well as infiltration of water into the ground as groundwater in this diagram, indicating the hidden dimensions of the system. The three photographs chosen were the glass showing condensation, a rainy day image, and a photo of a street drain. The ranking of these modes of representations did not follow Treagust and Tsui (2013) proposed continuum of representational abstractness that moves from the least to the more abstract. Teachers in the present study were more likely to choose the abstract diagram for teaching about the water cycle.

Teachers selected the two top diagrams with high percentages at 85.3% (water cycle overview diagram) and 80.1% (eco kids diagram). Forty three percent of the in-service teachers reported using diagrams to teach about the water cycle and 46% of pre-service teachers reported using diagrams. Coleman et al. (2011) found that elementary teachers selected flow diagrams, analytical diagrams, and cutaway diagrams for teaching science. The results suggest that elementary teachers have a preference for using diagrams to teach science. This selection of diagrams with the use of color and arrows illustrating the flow of
events such as the flow of the processes of the water cycle as in these examples can assist students in their readability of these visuals (Stylaïduo & Ormerod, 2002).

Photographs were reported being used by in-service teachers by 20.9% and 71.0% pre-service teachers in almost every lesson when teaching about the water cycle in the background information. In-service and pre-service teachers selected the condensation glass photograph at 77.2%, rainy day photograph at 75.7%, and street drain photograph at 63.2% during the card-task assessment. This selection of photographs is not surprising due to the abundance of images available to teachers (Pozzer-Ardenghi & Roth, 2003). Photographs have been the most frequent type of representation (other than written language) used in biology textbooks since 1999 (Roth, Bowen, & McGinn, 1999). Even though other studies have shown that students may misinterpret photographs (Pozzer-Ardenghi & Roth, 2005) they can still have a powerful impact when representing science phenomena.

**Reasons Teachers Select Representations for Instruction:**

**Aesthetics**

When asked to explain why a particular representation was selected, the most frequently selected images were selected for aesthetics reasons. For example, teachers noted they picked the representation because, “(It was a) great picture to illustrate the water cycle to the students because it is bright colorful basic” and it was “colorful, kid friendly.” When photographs were selected aesthetic reasons were not as commonly given as reasons for selections. Instead, photographs were described as good pictures or visuals, For example
teachers stated, “gives a nice picture of condensation formed on the glass,” and “good visual of heavy clouds/a storm,” and “it was a good picture of runoff and how runoff happen.”

The aesthetics reasons given by teachers seemed to be superficial such as being “colorful and pretty.” Using images that are attractive could lead to a representation that serves the function of a decorative purpose, which may mean the loss of the intended meaning of the representation (Pozzer-Ardenghi & Roth, 2005).

Understandably

Diagrams were also selected based on their understandably. Teachers stated examples of understandably included, “clearly labeled diagram of water cycle,” and “basic simple explanation of the water cycle,” and “this image is very basic and easy for students to understand.” These statements reveal that teachers were looking for diagrams that were simple to understand. Although their statements suggest that teachers are considering the readability and interpretation of the representation, the concern in this selection may be in representing this complex system as simple.

Photographs were also selected due to understandably. These are examples of statements used by teachers’ to illustrate understandably: “it’s very clear and simple,” and “this image shows precipitation and runoffs could easily be explained.”

The complexity found in photographs has been indicated as important in other representational research. Pozzer-Ardenghi and Roth (2003) found that even though students were familiar with photographs, the interpretation of them could be difficult. Teachers in the present study also noted the difficulties that students have with interpretation as seen in these
statements, “not enough information,” and “I don’t really know how to relate these pictures to the topic,” and “shows water but not how it relates to the water cycle more about runoff.” When shown the river photograph during an interview, teachers stated that the photograph was confusing to them and therefore could be confusing to students stating, “the water is super brown which could be confusing to students because you are not sure what it’s supposed to be—are you looking at it because the water is muddy or because it is a river.” Another teacher stated that people (students and teachers) would have difficulties connecting the photo to the water cycle, “I don’t know what to do with it, and it’s easier to choose a chart or something with words on it.” Pozzer-Ardenghi and Roth (2003) found that using photographs without a caption or text caused students difficulty with interpretation. To accomplish this in the classroom, teachers need to understand the effect of photographs in the learning process by considering the way they are received by the reader. Teachers could use photographs in a lesson and have students engage in discussion about their interpretation of the representation. Students could develop their own captions or supplemental text to explain the representation and share it with their classmates to analyze the multiple interpretations that may stem from representation.

**Systems Thinking**

The teachers selected some representations because they represented components of systems thinking. Identified elements of systems thinking from participants’ responses were identifying components or processes of the system, identifying human impact on the system, and using the term the water cycle. Teachers reported selecting diagrams because they
illustrated the entire system as a circular pattern stating that the representation showed the “cycle” of the water cycle. However, on the diagram the arrow did not reflect the water cycle from a systems thinking perspective. Instead, the representation illustrated the system as a simple circular system, which does not truly reflect the complexity of the water cycle system. The identification of one component and/or process was the most popular systems thinking element mentioned for condensation glass and rainy day photographs. The street drain photograph was selected also for identifying the process of runoff but also because it includes the element of human impact on the system as another important reason for selection. According to systems thinking, identifying components and processes represents a lower level of systems thinking. The photograph of the street drain represented a higher level of systems thinking since it connected two subsystems of the hydrosphere and biosphere.

Relevance

Relevance was not a popular reason for selection of diagrams. Photographs were selected for relevance more so than diagrams. For example, participants stated the following: “it shows the presence of the water cycle in our everyday lives,” and “realistic picture of a glass of water children are familiar with it,” and “example of real clouds.” It seems logical that a photograph would be more relevant than diagrams, since photographs often represent “real life” circumstance. Cajas (1999) has argued that relevance is an acceptable reason for selecting photographs due to this connection of science to students’ everyday lives. This connection of scientific phenomena to students’ lives can help in their explanations and understandings.
Pedagogical Approaches of Visual Representations

The analysis of the pedagogical approaches showed there were three primary approaches to using visual representations. These included teacher-centered, (e.g., How the teacher describe using the pictorial representation to teach the topic?), student-centered, (e.g., How does the teacher describe using the pictorial representation to engage students?), and systems thinking (e.g., How does the teacher explain using the pictorial representation to teach systems thinking elements?).

Teacher-Centered Uses of Diagrams and Photos

Over half of the teachers indicated a teacher-centered use with diagrams and photos. Eighty-one teachers indicated they would use diagrams in a proposed lesson using a teacher-centered approach. Within a teacher-centered approach, 28% of the teachers reported they would use diagrams to display or illustrate the system. Teachers did not provide details in their descriptions of how the illustration would be used except for it to be displayed on a wall of the classroom or in a students’ science notebook. This suggests the function of the representation was to serve as a reference for students rather than as a tool for students to use to reflect on and actually decipher the representations’ meaning. Teachers also described using diagrams to introduce the topic of the water cycle to students at the beginning of the lesson. This finding, as mentioned earlier, contradicts the cube model proposed by Tsui and Treagust, (2013). Twenty-five percent of teachers discussed using diagrams to explain terms and vocabulary of the water cycle to students. This approach does not allow for students to read and interpret the graphic allowing them to create their own explanations of the scientific
system being represented. These approaches may fall short of helping students develop representational competency.

**Teacher-Centered Pedagogical Approaches of Photographs**

Teachers provided similar pedagogical uses during the interview as given in the rationale for the card sorting task. Teachers defined teacher-centered approaches as being more lecture based and less hands-on demonstrations (teacher showing students), and reported using images to explain terms, teach definitions, using images in a powerpoint to explain things, using images as a reference, and teachers taking the responsibility of selecting the images for instruction.

**Student-Centered Pedagogical Approach of Diagrams and Photos**

Student-centered pedagogical approaches were not used as often with the most commonly selected representations. The student-centered approaches included using diagrams as a model for students to create their own drawings of water cycle diagrams. It has been argued that this method of using representations promotes representational competence since students have to create their own representation by comparing and contrasting the original representation to a new context and then constructing their own representation of the system (Kozma & Russell, 2005). This method has been shown to be effective in systems thinking research (Ben-Zvi Assaraf & Orion, 2010). Teachers also suggested having students label the diagrams, having students make their own powerpoints using the diagrams, and using the diagrams for prompting discussion about the processes and significance of the water cycle system. These pedagogical approaches promote the
development of models by having students use diagrams as tools to elaborate on their own ideas and present them to others (Achieve, 2013).

A student-centered approach for photographs included using the photograph to prompt discussion of how the representation represents varying processes of the water cycle system after conducting actual experiments in the classroom. Teachers referred to the experiments as a method of providing a model of the specific processes of the system. For all three photographs, teachers described using the representations to promote questioning, making predictions and inferences about the occurrences happening or what to happens next in the system. These approaches promote representational competency by having students to analyze the features of the representation for the purpose of evaluating the scientific phenomena being represented (Kozma & Russell, 2005). The active engagement of social discourse with teacher guidance while using of representations has shown to promote a deeper meaning of content knowledge and representational competency simultaneously (Tytler et al., 2007; Waldrip et al., 2010).

Teachers also described using student-centered approaches with the representations during interviews. Student-centered descriptions included having students classifying representations, students using the representations to teach other students, students researching and finding their own representations and creating presentations (PowerPoint or an interactive notebook) to share with the class. Teachers also described student-centered approaches as involving students performing experiments and using the representations to explain results and findings of their investigations.
Systems Thinking

In-service and pre-service teachers described using diagrams to illustrate the water cycle as a cyclical process that has no beginning or end, and to show how the parts work together in the system. Teachers stated that they would explain specific components or processes of the cycle to students that were illustrated in the diagrams. For instance, teachers mention explaining components such as the effect of mountains on the water cycle, transpiration of plants, and significance of groundwater. Teachers’ described systems thinking elements of the isolated processes illustrated in each of the photographs (condensation glass and rainy day). For example, teachers discussed using the rainy day photo to examine the processes of precipitation and condensation as well as the types of clouds.

The street drain photograph revealed more sophisticated systems thinking elements by eliciting teachers to consider the interactions and relationships among the various components and processes of the system. For example, teachers mentioned using the photograph to ask students to consider the human engineered system (e.g., street drain) that controls runoff, stating that they would ask questions and allow students to make predictions of the movement of water shown and not shown in the photograph. Teachers discussed the effects of pollution, runoff, flooding, and underground water systems mentioning the crosscutting concept of cause and effect.
Conclusions

Elementary teachers use the graphical tools of diagrams, photographs, and other visual representations to communicate the science concepts and processes. As teachers strive to teach science outside the human experiential scale, it becomes necessary to use images to help students develop mental models about phenomena and systems. To accomplish this task, teachers must be able to construct, produce, and interpret graphics and to use them to develop representational competency with students.

Even though policy documents have stated the importance of using models, representations, and modeling in science instruction, the results of this study of teachers use of representations suggests that teachers may yet fall short of using representations to promote higher order thinking. The aesthetics rationale of color and brightness as one of the most important reasons to select a representation shows that in some cases selections are based on superficial reasons such as, “it is a pretty diagram”. Although color can be important for the readability of representations when it is used to highlight important features of the image, this was not the rationale for the aesthetics selection. The selections based on understandably of the diagram raises concern as well. This rationale suggests that teachers want to represent the system as simple when in fact it is quite complex. The circular nature of the most frequently selected diagram does not appropriately represent the dynamic nature of the water cycle system. Finally, the teacher-centered pedagogical approaches of using representations as displays and illustrations does not reflect methods that will promote graphical literacy or representational competency.
Teachers in this study have indicated an array of ideas for how they approach the selection and use of representations for teaching about the water cycle. Results indicate the need for more emphasis on teaching teachers about the salient features of graphics and the importance for communicating their scientific message. The student-centered pedagogical approaches expressed by teachers in this study should be built upon and encouraged as appropriate strategies for promoting representational competency and systems thinking.
References


INSTRUCTIONAL REPRESENTATIONS AS TOOLS TO TEACH SYSTEMS THINKING

Creating scientifically literate citizens who engage in public debate and participate in decision-making processes concerning complex scientific issues is a major goal of science education. The complexity of systems and the development of systems thinking in science is one of the multifaceted issues of science that is increasingly impacting us in our advancing global society. As our knowledge of science advances, there is an increasing need to understand complex systems, which includes (often dynamic) phenomena and their interrelationships (Hmelo-Silver & Pfeffer, 2004).

To be scientifically literate requires an individual to be able to read, write, and communicate the language of science (Krajcik & Sutherland, 2010; Norris & Phillips, 2003; Yore, Pimm, & Tuan, 2007). But the communication of science involves more than verbal discourse or written text. Science is multimodal which includes communicating with a variety of representations (e.g., graphs, diagrams, symbols, formulae, and pictorial). To effectively communicate this multimodal language, a student needs to interpret, construct, transform, and evaluate different scientific representations in order to conceptually understand science (Kress, Jewitt, Ogborn, & Tsatsarelis, 2001; Lemke, 2004; Yore & Hand, 2010). These skills help to build representational competence (RC) (Kozma, Chin, Russell, & Marx, 2000; Kozma & Russell, 1997, 2005) and contribute to becoming a scientifically literate individual.

Teaching and learning science in the K-12 classroom requires the use of a variety of external scientific representations (Ainsworth, 2006; Kress et al., 2001; Lemke, 2004; Yore
Developing students’ abilities to use and reason with these scientific representations is essential for learning science and developing representational competence. The study of systems in science necessitates the use of multiple representations due to their complexity in terms of scale, hidden dimensions, and the interplay of relationships among the components and processes of systems. Classroom instruction of systems and the development of systems thinking are dependent upon the selection, interpretation, explanation, and use of effective representations by teachers. This chapter discusses the importance of representational competence in the development of systems thinking among students and provides recommendations for the explicit use of representations when teaching about complex systems.

A Call for Systems Thinking

Systems thinking has been identified as crucial within a number of domains such as social sciences (e.g., Senge, 1990), medicine (e.g., Faughman & Elson, 1998), psychology (e.g., Emery, 1992), curriculum development (e.g., Ben-Zvi Assaraf & Orion, 2004), decision making (e.g., Graczyk, 1993), project management (e.g., Lewis, 1998), engineering (e.g., Fordyce, 1988) and mathematics (e.g., Ossimitz, 2000). Developing an understanding of the components and relationships that comprise complex systems such as ecosystems, moon phases, or energy transfer requires the ability to apply systems thinking (Evagorou, Korfiatis, Nicolaou & Constantinou, 2009). Research in this area has shown individuals need knowledge about the science domain (i.e., physics or biology) as well as higher-order thinking skills to fully conceptualize complex systems (Frank, 2000). Furthermore, research
has suggested that there is a link between the development of systems thinking and a conceptual understanding of science (Grotzer & Bell-Basca, 2003a). Goldstone and Wilensky (2008) maintain that learning about systems allows for cross-disciplinary inquiry across science areas. Although there is an increasing recognition that all areas of science require systems thinking to critically reason scientifically, there is limited research on how teachers and students develop systems thinking in the context of science education (Kali, Orion, & Eylon, 2003).

In the past ten years, science education researchers have begun to recognize the importance of students’ abilities to learn about complex systems, and instructional methods and tools being used to teach complex systems. This research includes systems thinking as it relates to technological systems (Frank, 2000; Sabelli, 2006), social systems (e.g., Booth Sweeny, 2000; Booth Sweeney & Sterman, 2007; Kim, 1999; Mandinach, 1989; Steed, 1992; Ullmer, 1986), biological systems (e.g., Verhoeff, Waarlo, & Boersma, 2008), and natural systems (e.g., Ben-Zvi Assaraf & Orion, 2005; Hmelo-Silver, Marathe, & Liu, 2007; Hmelo-Silver & Pfeffer, 2004; Ossimitz, 2000; Wilensky & Resnick, 1999).

**Advancement of Technology**

Investigating how systems work is not a new process for scientists or engineers; but with advances in technology and the use of modeling, our perspectives of science and the systems within science have been transformed. The advancement of modeling tools allows us to observe systems more closely and develop more precise predictions and inferences about the behaviors of systems. These superior models of natural phenomena are strongly
grounded in mathematical and computational reasoning, which expands our knowledge and our ability to understand natural systems, such as climate change (NRC, 2007). This change in contemporary science has resulted in the increased use of statistical modeling of natural phenomena for visualization of complex systems (Klahr & Simon, 1999). Historically, scientists relied on direct causal models; but advancement in scientific and technological understanding of modeling allows scientists to make comparisons of system models to examine system interaction and behavior in numerous scenarios (NRC, 2007). Technological advancements have provided us with interdisciplinary information from multiple perspectives, which leads to more accurate predictions regarding system behavior and enhances decision-making. This explosion in technology and availability of these models allows teachers to use these tools in new ways within science instruction.

**Call for Reform of the Use of Representations in Teaching Systems Thinking Described in Science Standards**

In 1996, *National Science Education Standards* (NSES) introduced the essential components of a system and the *Next Generation of Science Standards* (NGSS, 2013) elaborated on the essential aspects of systems for the next generation of science educators:

The natural and designed world is complex; it is too large and complicated to investigate and comprehend all at once. Scientists and students learn to define small portions for the convenience of investigation. The units of investigations can be referred to as “systems.” A system is an organized group of related objects or components that form a whole. Systems can consist, for example, of organisms, machines, fundamental particles, galaxies, ideas, and numbers. Systems have boundaries, components, resources, flow, and feedback. (NRC, 2012, pg. 91-92)
Systems and system modeling were included as part of the seven crosscutting concepts identified in the *Framework for K-12 Science Education* (NRC, 2012) and NGSS (2013) that provide students with the tools needed to create a more advanced understanding of the disciplinary core ideas of science. The seven crosscutting concepts identified in the Framework and NGSS (2013) include: 1) patterns; 2) cause and effect relationships; 3) scale, proportion and quantity; 4) systems and system models; 5) energy and matter — flows, cycles, and conservation; 6) structure and function; and 7) stability and change. Each of the crosscutting concepts is essential for investigating and understanding natural or designed systems; thus, application of these concepts contributes to the development of a systems thinker. The descriptions of each crosscutting concept explicitly explain how to use the crosscutting concepts to identify components of a system, the interactions of the components of a system, and the systems’ behavior as a whole regarding the interrelationships between the components (NRC, 2007).

Crosscutting concepts provide students with an organizational framework (NRC, 2012) much like a systems thinking “framework” that Senge (1990) described that can assist students with connecting knowledge across various disciplines, creating a coherent and scientifically based view of the world. The framework notes that these crosscutting concepts traditionally have been implicit in nature, hence the rationale for making them their own dimension. Framework developers weaved the crosscutting concepts into performance expectations at all grade levels, ensuring explicit instruction within the various science areas. These concepts also illustrate cross-disciplinary contexts helping students to develop a cumulative, logical, and usable understanding of science and engineering (NRC, 2012). If
teachers utilize the crosscutting concepts for their intended purpose then the implementation of systems thinking approaches would become a natural component of their instruction.

Visual representations are a major component of early modeling. The practice of developing and using models is one of the eight essential science and engineering practices while systems and systems models is one of the seven crosscutting concepts in the NGSS. Both scientists and engineers use models, which include sketches, diagrams, mathematical relationships, simulations, and physical models to study systems. These models are used to explore behaviors occurring within the system, make predictions about behavior, as well as make predictions about the relationships among the components of the system. Scientists and engineers use data to assess relationships to determine if revisions should be made in models (NRC, 2012). The use of models and representations for the study of systems is essential to the fields of science and engineering.

**Developing Systems Thinking and Representational Competence**

Although science educators are increasingly emphasizing systems thinking, there are relatively few studies that explore how students learn about complex systems; and teaching complex systems seems to be largely absent from most science classroom curricula (Jacobson & Wilensky, 2006). The limited research that exists on the development of systems thinking skills has focused on students of different ages including elementary (Ben-Zvi Assaraf & Orion, 2010), middle, high school (Penner, 2000; Frank, 2000; Ben-Zvi Assaraf & Orion, 2005; Booth Sweeney & Sterman, 2007) and college students (Booth Sweeney & Sterman, 2007). These studies have suggested that developing a systems
thinking approach involves having students examine, evaluate, and invent, which all apply higher-order thinking skills (Frank, 2000). Resnick (1987) defined characteristics of higher-order thinking as complex, capable of producing multiple solutions, involving degrees of judgment and uncertainty, utilizing self-regulation, finding structure in apparent disorder, and being fruitful. These skills are comparable to the mental activity involved in systems model building, analysis, and synthesis (Ben-Zvi Assaraf & Orion, 2010; Frank, 2000).

Some researchers have argued that systems thinking skills include cognitive abilities such as: (a) thinking in terms of dynamic processes, (i.e., delays, feedback loops, oscillations); (b) understanding how the behavior of the system arises from interaction of components over time (dynamic complexity); (c) discovering and representing feedback processes that underlie observed patterns of the system’s behavior; (d) identifying nonlinearities; and (g) scientific thinking, including being able to quantify relations and to hypothesize test assumptions and models (Booth Sweeney, 2000; Draper, 1993; Frank, 2000; Ossimitz, 2000). Ossimitz (2000) characterized systems thinking skills as having four central dimensions: (1) network thinking (thinking in feedback loops); (2) dynamic thinking (accounting for time lapse); (3) thinking in models; and (4) system-compatible action.

One of the key skills for systems thinking is having representational competence. Nitz, Ainsworth, Nerdel, & Prechtl (2014) have defined representational competence as key to interpreting, constructing, translating, and evaluating models. Virtually all definitions of systems thinking skills identify the ability to think in terms of models by either knowing how to interpret and build models or understanding the use of models to quantify relations and test
assumptions of the system. Representational competence modeling and systems thinking are intertwined skills that have reciprocal influence on each other.

Systems thinking and representational competence are both closely related to students’ conceptual understanding of a particular domain of study (Kozma & Russell, 1997; Stieff, 2011). Kozma and Russell (2005) proposed five levels of representational competence ranging from the novice use of surface-based representations portrayed with symbolic, syntactic, and semantic use of representations to an expert use of representations for reflective and rhetorical purposes. These representational competence developmental levels are not characterized as stage-like or uniform but are reliant on their time and utilization in the classroom. Representational skills can improve when instruction internalizes and integrates representations in physical, symbolic, and social contexts (Kozma & Russell, 2005).

Given the need for higher order thinking skills as a component of systems thinking, researchers are not in agreement about the age and cognitive abilities needed to master systems thinking. Evidence indicates that even highly educated adults with extensive mathematics and science backgrounds have poor systems thinking skills (e.g., Booth Sweeney & Sterman, 2000; Dorner, 1980). Booth Sweeney and Sterman (2000) used a systems-thinking inventory designed to assess knowledge of concepts, such as feedback, delays, stock and flow relationships and time delay. The study involved students at Massachusetts Institute of Technology business school prior to exposure to system dynamics concepts. The results showed that even highly educated individuals in science had poor
levels of understanding in concepts such as stock and flow relationships, time delays, and conservation of matter.

Other researchers, such as Sheehy, Wylie, McGuinness, and Orchard (2000), have noted that they had presumed incorrectly that young children could not reach an appropriate level of sophistication of systems thinking until adolescence, the proof of which came after they investigated primary children’s understanding of systems thinking in an environmental context, using methodologies that required minimal linguistic input. Through manipulation of simulations, their study revealed that even young students used some systems thinking skills. Although there is a limited amount of research investigating elementary children’s development of systems thinking skills (Ben-Zvi Assaraf & Orion, 2010), Forrester (2007) argues these skills should be developed early in elementary children since they still have open minds, are inquisitive, and have not been conditioned to see the world in terms of unidirectional cause and effect.

The measure of systems thinking skills and knowledge among students of all ages is still in its infancy. It is not yet clear how teachers develop the pedagogical content knowledge needed to teach systems thinking. Furthermore, how do teachers use representations to teach the complexities of systems that are inherent in science? In the sections that follow the assessments used by researchers to measure systems thinking skills that include representations such as survey instruments, interviews, student-created drawings, concept maps, word associations, and specialized tests measuring specific skills associated with systems thinking are discussed.
Using Representational Competence Abilities to Measure Systems Thinking Skills

Researchers often use representations such as student drawings, concept maps, diagrams, and student-reconstructed diagrams to measure the development of systems thinking skills in elementary and middle school age students (Ben-Zvi Assaraf & Orion, 2005; 2010; Kali et al., 2003).

In 2010, Ben-Zvi Assaraf and Orion used two types of student drawings to assess elementary students’ understanding of the interrelationships between components in the hydrocycle. Students were asked to draw “What happens to water in nature?” Pre- and post-instruction drawings were evaluated to determine the presence of systems thinking based on the following items in their drawings; (a) appearance of processes; (b) appearance of various earth systems; (c) appearance of human consumption or pollution; and (d) cyclic perceptions of the water cycle illustrated by connecting various components. Students’ pre-instruction drawings presented the hydrocycle with only atmospheric components (i.e., evaporation, condensation, and precipitation) with the exclusion of groundwater aspects. Post-instruction drawings included the addition of penetration and underground water flow revealing increased knowledge of these groundwater processes. The combination of drawings and interviews showed students had enhanced recognition of the relationships between these components in the subsystems of the hydrocycle.

Ben-Zvi Assaraf and Orion (2010) used the Ecology System Inventory (ESI), to assess elementary students’ perceptions of the hidden dimensions of the hydrosphere system (e.g., processes that take place under the surface) after outdoor instruction. The ESI
presented students with an image of an ecological system and asked to identify the components, relationships, and hidden dimensions of the hydrosphere. Students were asked to represent these components of the system by drawing them on the ESI. The results of the study showed the ESI was effective in measuring changes in systems knowledge.

Concept maps have long been used as a powerful research tool to examine how learners restructure knowledge (Martin, Mintzes, & Clavijo, 2000; Mason, 1992; Novak & Gowin, 1984; Roth, 1994). In particular, concept maps have been used to assess the development of systems thinking skills. Ben-Zvi Assaraf and Orion (2005) used concept maps pre- and post-instruction and found middle school students improved skills in: 1) identifying the system’s components and processes (number of concepts); 2) recognizing the appearance of the earth’s systems; 3) identifying dynamic relationships within the system (number of linkages); 4) identifying the appearance of the human aspect; 5) identifying the appearance of cyclic perception of the water cycle; and 6) organizing components and placing them within a framework of relationships. The use of concept maps provides another form of representation that can be used for assessing the development of systems thinking skills.

Kali et al. (2003) used a reconstructed diagram to measure students’ knowledge of the dynamic cyclic relationship of the transportation of earth materials within the complex system that includes the rock cycle. Students were engaged in an inquiry lab in the classroom that modeled the effect of transportation of pebbles in a river determined by the shape and size of the pebbles. As a follow-up activity, students used a diagram to
hypothesize about the transportation of various pebbles found in the local creek. During a field experience, students verified their hypotheses of rock movement by examining different locations at the river’s watershed. Students demonstrated their knowledge of the directional movement of the earth materials through the use of arrows on the reconstructed diagram. Post-test results indicated an increase in understanding the sequences and processes of material transportation as assessed through the use of these reconstructed diagrams.

These examples illustrate the use of representational competence in the measurement of systems thinking skills. For example, students used representations to describe scientific concepts, either by illustration or by adding more words and links to concept maps. Interviews revealed students’ abilities to explain their drawings and the representations’ appropriateness for a specific purpose when explaining the inclusion of the hidden dimensions from their pre- and post-drawings. In the above instances, students constructed and revised representations to indicate their knowledge of systems thinking. The ability to use a representation to identify, describe and explain a scientific concept and use a representation to support claims and draw inferences were described by Korma and Russell (2005) as specific skills for demonstrating representational competence. Each of these studies demonstrates how researchers have used representations to measure systems thinking development as well as to promote representational competence.

**Theoretical Models Used for Evaluating Systems Thinking STH Model and SBF Model**

One of the first challenges to teaching and assessing systems thinking is defining and modeling the process. Ben-Zvi Assaraf and Orion (2005) developed the “Systems Thinking
Hierarchical Model” (STH Model) to develop systems thinking while learning about complex systems. Several studies have used this model to assess the development of students’ levels of systems thinking.

The Systems Thinking Hierarchical model for developing systems thinking proposed by Ben-Zvi Assaraf and Orion (2005), utilized eight characteristics for developing a hierarchical systems thinking structure within the context of the hydrocycle. These eight characteristics were classified into four hierarchical levels: Level 1 includes the ability to identify the system’s components and processes; Level 2 includes the ability to identify relationships between separate components and the ability to identify dynamic relationships between the system’s components; Level 3 includes the ability to understand the cyclic nature of systems, the ability to organize components and place them within a network of relationships, and the ability to make generalizations; and Level 4 includes an understanding of the hidden components of the system and the system’s evolution in time (prediction and retrospection). These levels can be used as a structure for instruction with each group of skills serving as a basis for the development of the next higher level of systems thinking. Ben-Zvi Assaraf and Orion (2005) suggested that these levels are hierarchical in the development of systems thinking. They reported that elementary, middle, and high school students did not demonstrate growth in higher levels until they first accomplished the beginning levels.

Ben-Zvi Assaraf and Orion’s (2005) results raise questions about possible developmental stages that may exist in the development of systems thinking. For instance,
Booth Sweeney and Sterman (2007) claimed that when middle school students are probed with questions such as “What happens next?” they demonstrated an accurate understanding of interactions between objects and, more importantly, grasped how one thing influences another and how these interrelationships hold the system together. Based on their research, Booth Sweeney (2007) suggested that the development of systems thinking may not proceed in an ordered and organized sequence.

Another model used for learning about biological systems is known as the Structure-Behavior-Function (SBF) framework (Hmelo, Holton, & Kolodner, 2000; Hmelo & Pfeffer, 2004). This framework has been used in several studies investigating how students, adults, and experts understand complex biological systems. The SBF knowledge representation framework focuses on causal relations between structure and function, which is essential to understanding complex systems in biological contexts. The SBF has been used to describe structures and functions of a system and how they are related through actions (i.e., behaviors). The SBF representation framework also provides a way to analyze how different levels of structures, behaviors, and functions interact with one another within the overall system.

Evagorou et al. (2009) developed seven skills based on a combination of skills identified in the systems thinking literature (Ben-Zvi Assaraf & Orion, 2005; Essex Report, 2001; Hmelo-Silver & Pfeffer, 2004; Sheehy et al., 2000) to investigate eleven- and twelve-year olds’ development of systems thinking skills in the context of learning about a salt marsh utilizing a computer simulation game. This research study revealed that half of the
participating students demonstrated three out of the seven skills on a pre-test, which were skills related to the identification of system elements, spatial boundaries of a system, and identification of factors causing certain patterns within the simulation. Students were successful at recognizing elements of a system but could not identify subsystems of a salt marsh according to post-test results. Despite the fact that subsystems were a part of the structure of the systems, it proved to be more difficult than identifying the isolated elements, primarily since students were unable to comprehend the relationship of the connected parts of the system. This finding supports Ben-Zvi Assaraf and Orion’s (2005) claim that thinking skills are hierarchical and recognizes that understanding relationships is a higher-order skill that involves more than merely identifying the elements of a system. In this same study, Evagorou et al. (2009) found that elementary students displayed sophisticated systems thinking within this learning environment. Students showed improvement in both spatial and temporal boundaries and were able to infer the influence of change on a system.

The results reported by Evagorou et al. (2009) contrast with the findings of other studies which identify many of these skills as too difficult for younger students to attain (Ben-Zvi Assaraf & Orion, 2005). Evagorou et al. (2009) reported that the learning environment of the simulation was effective in allowing students to engage with higher-level skills such as making predictions of effects on distant elements of a system or inferring the cause of a change from its consequences (Grotzer & Bell-Basca, 2003b). Findings from this study and others question the hierarchical structure of developing system thinking skills, demonstrating that an appropriate learning environment can promote the development of
complex systems thinking even at an early age (Hmelo-Silver & Pfeffer, 2004). Although limited, research on the development of systems thinking with elementary students demonstrates that students at this age can develop systems thinking skills, possibly even more sophisticated skills, with appropriate instructional tools and a focus on systems thinking by the classroom teacher.

**Recommendations for Using Representational Competence for Developing Systems Thinking in Classrooms**

The implementation of systems thinking skills has often been neglected in the design of science learning environments (Golan & Reiser, 2004). Aikenhead (2006) suggested that this neglect in instruction is a result of instruction that emphasizes facts and principles of science content instead of focusing on skills and thinking related to socio-humanistic perspectives of science. In most formal educational settings, importance is placed on events rather than processes over time, on parts instead of systems, and on isolated processes rather than demonstrating systemic relationships (Hannon & Ruth, 2000). In many instances, students are left to figure out the connections and understanding of the interrelationships themselves, without appropriate scaffolding; students find thinking systemically to be difficult (Hmelo-Silver & Azevedo, 2006). Although a limited amount of research is being conducted to investigate the appropriate learning strategies to develop systems thinking, this chapter provides some research evidence for designing and implementing instructional strategies using representational competence skills that have proven to be effective in science classrooms.
A variety of different instructional strategies using representations in science classrooms to develop systems thinking have been used with students ranging from elementary to high school (Ben-Zvi Assaraf & Orion, 2005, 2010; Kali et al., 2003; Evagorou et al., 2009; Riess & Mischo, 2010; Verhoeff et al., 2008; Liu & Hmelo-Silver, 2009) including: computer modeling (simulations and hypermedia), authentic science context problems, multiple visual representations (photographs, diagrams, concept maps, and student drawings), hands-on experiences (indoor and outdoor inquiry-based labs), and knowledge integration activities (using representations).

Computer-based learning environments using modes of representations (e.g., simulations, hypermedia, modeling) were used successfully to promote the development of systems thinking while studying topics such as the ecosystem of a salt marsh (Evagorou et al., 2009), ecosystem forest (Riess & Mischo, 2010), cellular biology (Verhoeff et al., 2008), and the human respiratory system (Liu & Hmelo-Silver, 2009). Authentic science context, student scaffolding, multiple representations, and student reflections were implemented in combination in these studies, which led to a significant development of systems thinking. This combination of efforts is briefly discussed below as an effective classroom strategy to promote systems thinking and the development of representational competence.

The use of representations has been used in problem-based learning (a guided discovery approach of students working in groups to pose solutions for a presented problem) (Krajcik, Blumenfeld, Marx, Bass, Fredrick, & Soloway, 1998). In one case, Evagorou et al. (2009) challenged students to pose solutions for controlling mosquitoes for a village.
neighboring a salt marsh within a computer simulation. Students were provided with mosquito control as a real-life problem people encounter when living near a salt marsh. In another study that examined efforts to teach systems thinking, Liu & Hmelo-Silver (2009) had students investigate the human respiratory system by posing the question of “how do we breathe?” Verhoeff et al. (2008) had students examine the complexity of cellular biology by using a real-life context of breast-feeding. These authentic science contexts proved to be useful in providing students with real-life connections to the purpose of learning about systems.

The use of multiple representations has been associated with the development of systems thinking (Treagust & Tsui, 2013) and representational competence (Liu & Hmelo-Silver, 2009). A hypermedia platform using multiple representations of information and visuals electronically linked in nonlinear form has been proposed as effective in allowing multiple approaches of instruction (e.g., Moreno, 2006). For example, Liu and Hmelo-Silver (2009) conducted an experiment to investigate two different organizational formats (function-centered and structure-centered representations) in a hypermedia format using the Structure-Behavior-Function (SBF) conceptual representation framework of the human respiratory system and found students were able to identify and explain functions and behaviors of the hidden dimensions of this system using the function-centered format.

According to the SBF model (Hmelo et al., 2000; Hmelo & Pfeffer, 2004) structures are defined as the elements of the systems, behaviors are known as the mechanisms of a system and, then finally, functions are the outcomes or roles of the system. Liu and Hmelo-
Silver examined how these organizational formats impacted participants’ understanding of
salient (macro-level) phenomena involved in external respiration and non-salient (micro-
level) phenomena involved in internal respiration. The researchers organized the content in
the hypermedia in different formats using the SBF model. The function-centered format
provided a more holistic understanding of the human respiratory system, beginning with the
functions and behaviors at the top of a concept map, moving down to the structures oriented
with those functions and behaviors. This organizational format directed and scaffolded
students in the presentation of the information about this complex system. Students clicked
on questions, such as, “Why do we breathe?” (function), which led students to pages with
visuals and information answering the question explaining this particular function of the
system. This function-centered format was designed to continually lead students through the
process of going from functions to behaviors and finally, leading to the structures that make
up the system. In contrast, the structure-centered format followed the traditional format
much like a traditional textbook. The opening screen displayed a listing of the individual
structures of the human respiratory system as isolated components of the system. The format
directed students to click on an individual structure, which was linked to web pages
explaining the isolated structure and how the structure connects to their respective behaviors
and functions. The content information in both formats was identical, except for the
organization format of the presented information. The ability to distinguish between these
hidden dimensions of the system (micro-level) and the ability to distinguish between the
function and behaviors of systems were barriers for developing systems thinking. Positive
results were found in the use of the function-centered format on participants’ understanding of the non-salient (micro-level) phenomena of the internal respiratory system. These findings also contribute to our understanding of the role of students’ abilities in developing representational competence by comparing and contrasting various representations and their content information and being able to make connections across different representations by explaining the relationships between them (Kozma & Russell, 2005).

This SBF conceptual representation model could be applied in science instruction more broadly to help students understand other kinds of complex systems and representational competence by organizing the presented information in a function-centered structure, beginning with the functions and behaviors of a system, and then leading to the structures of the system. The selection of representations and how they are presented can play a critical role in scaffolding students’ understandings of a system.

The use of multiple visual representations has been shown to help people learn complex new ideas (Ainsworth, 2006). The process of modeling can take students through an iterative process of formation, revision, and elaboration of models that compare each model while assisting students in gaining a deeper understanding of the system. Verhoeff et al. (2008) used a systems approach of modeling for developing an understanding of cellular biology. The modeling process utilized multiple visual representations and physical models. The systems approach required students to engage in thinking back and forth between computer-constructed models, real cells (observed through an electron microscope), student-created physical models, and visual representations, such as diagrams found on the Internet.
In each phase of the process, students were required to engage in discourse, regarding the process of breast-feeding at the cellular level using the multiple models to explain the functions of each of the structures found in the cells, which led milk production. This modeling process proved to be a powerful visualization tool, which led students to understand both the dynamics of (cell) biological processes and the hierarchical structure of biological systems. Secondary science teachers could implement this systems approach to modeling by engaging students in the thinking back-and-forth strategy while reflecting on the visual representations, which differ in abstractness, with the inclusion of the biological objects themselves. While engaged in the modeling process, teachers can develop representational competence by having students make predictions, draw inferences and make connections among representations.

The use of multiple visual representations and the use of systems modeling with the explicit use of teacher scaffolding were shown to be effective instructional strategies for promoting systems thinking in science (Liu & Hmelo-Silver, 2009; Evagorou et al., 2009; Verhoeff et al., 2008; Riess & Mischo, 2010). Liu and Hmelo-Silver (2009) also emphasized the importance of teacher guidance in helping students focus on the science principles associated with the systems and making connections while exploring the hypermedia format. When using computer simulations of a salt marsh with elementary students, Evagorou et al. (2009) found that students who did not receive instruction or scaffolding from their teacher did not grow significantly in their development of systems. Another study by Riess and Mischo (2010) also reported that teachers were critical in developing representational
competence in systems contexts. Riess and Mischo (2010) used computer simulations to declare the most effective method (computer simulation, specific lessons, or a combination of both) to teach about ecosystems. Students were randomly assigned to a treatment groups for their assigned learning environment. The study confirmed the effectiveness of computer simulations when teacher guidance and scaffolding was provided to promote systems thinking and representational competence.

Computer simulations as effective representation tools allow students to manipulate and explore complex systems that may be too large or too small for direct observation. One of the challenges encountered by teachers is providing access to a system to collect data without having to devote excessive time and repeated field-study visits (NRC, 2000). Interactive simulations enable teachers to bypass this challenge (Evagorou et al., 2009). Students are able to have continuous access to the system, allowing them to explore the various parameters of the systems’ structures, functions, and behaviors.

Hands-on experiences (outside and inside labs) in combination with knowledge integration activities using representations can be used to illustrate the growth of systems thinking development. As discussed previously, Ben-Zvi Assaraf and Orion (2005) developed a Systems Thinking Hierarchical (STH) model built on eight characteristics of a sequential growth of levels in systems thinking. In studies of elementary and middle school students, there were difficulties in reaching the implementation level (highest level), which included skills such as making generalizations in regards to the system, describing the processes that occur in the hidden dimensions, and explanations of the relationship to time
(prediction and retrospect). Based on these studies, Ben-Zvi Assaraf and Orion (2010) suggested that elementary teachers begin instruction of systems at the analysis level (identify processes and structures) and then move on to the first two parts of the synthesis level (identifying relationships between two components and identifying dynamic relationships within the system). They argued that if elementary teachers can provide this foundation for systems thinking, then middle school teachers can focus their instruction on the implementation level. This hierarchical structure still needs to be evaluated and used with more students and within more studies of various complex systems to be empirically sound. Although its hierarchical structures need more scrutiny with research, the levels themselves provide a solid framework for designing systems curriculum in classrooms. Teachers can implement learning experiences such as labs, field experiences, and integration activities using representations to begin building this knowledge of systems thinking.

Even though the research is limited in the use of systems thinking strategies in classrooms, there are some common recommendations that science educators and teachers can utilize. The use of inquiry-based labs connecting indoor labs and outdoor field experiences, followed by knowledge integration activities, has been shown to be an essential component for developing systems thinking. Science educators and teachers are familiar with these methods; the main impetus of change should focus on how students think in terms of a system and the process of evaluating knowledge through the use of representations. The use of multiple visual representations and computer modeling have also shown to be effective methods for promoting systems thinking; again, scaffolding is a key component of
instruction to assist students in developing the skills necessary to make sufficient growth. This scaffolding can be implemented in various ways: through probing specific questions, engaging in dialog, and allowing time for knowledge integration activities that provide time for reflection of the functions and behaviors of the systems while explicitly using representations.

**Teachers’ Selection of Types of Representations**

There is a limited amount of research documenting the reasons why elementary teachers select specific representations when teaching about a complex system. The ability to select and explain a scientific concept found in a representation is one aspect of representational competence. The use of technology and the lack of science textbooks in elementary classrooms have placed elementary teachers in the position of creating their own instructional materials. In a recent study investigating the processes taken by elementary in-service teachers (n=67) and elementary pre-service teachers (n=69) regarding their selection of representations when planning a lesson on a complex system (e.g., water cycle) (Lee, Jones, & Chesnutt, 2015; in preparation) a rubric was created for categorizing teachers’ selection reasons.

For this study, elementary in-service and pre-service teachers completed a card sort task in which they selected pictorial representations (diagrams, photographs, and maps) to teach about the water cycle. A panel of experts selected 15 pictorial representations from the Internet for the card sort task to use in a lesson about the water cycle. The elementary in-
service and pre-service teachers described why they selected the representation. A rubric was developed to analyze reasons for selecting representations. The rubric emerged from a content analysis that began with the researcher reading and re-reading the data to formulate a tentative understanding of the data (Roth, 1995). Several iterations of content analysis were conducted to establish nine themes for coding of selection and non-selection rationale. A science educator and researcher separately coded a randomly selected 10% of data. As part of the verification methodology (Strauss, 1987), the coding was repeated three times (coding, discussion, revision) until inter-rater reliability was reached at 97%.

The four themes that emerged from the coding are included in Table 1. The indicated thematic categories are not exclusive: a given response may fit in more than one category.
<table>
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<tr>
<th>Thematic Categories</th>
<th>Description</th>
<th>Teachers’ Selection Rationale</th>
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| + Aesthetics        | Responses referring to color, brightness; refers to the look or appearance of the pictorial representation. | Colorful  
Pleasing in appearance  
Attractive  
Clear graphic  
Great visual |
| - Non-aesthetics    | Responses refer to unattractive aspects of the representation. | Ugly picture  
Not appealing  
Plain not attractive |
| + Understandably    | Responses refer to understandability, simple student accessibility, or developmentally appropriate. | Kid friendly example  
Visual is easy to understand  
Good vocabulary  
Simple and concise  
Lower grade students would be able to understand it |
| - Complexity        | Responses refer to elements that may cause confusion (arrows, lack of labels, difficult terminology), are confusing, or are hard to understand. | Too many arrows may lead to confusion  
Photos aren’t clear as to what they are showing me so I doubt an elementary student would understand I don’t understand it |
| + Systems Thinking  | Responses refer to representations of a component or process of the water cycle system, or identify interactions within the system. | Image gives a good description of mountain & runoff that goes into the ocean.  
It demonstrates how water system changes overtime.  
Shows water as a cycle  
Shows runoff  
Illustrates precipitation |
<table>
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<tr>
<th>Thinking</th>
<th>Responses refer to a lack of conceptual connection between the representation and the water cycle.</th>
<th>This image I think would be better for the topic of sewage and pollution. Not sure how to use it when talking about the water cycle. I don’t understand how it relates to the water cycle.</th>
</tr>
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<tr>
<td>+ Relevance</td>
<td>Responses refer to relevancy to students’ lives or as an illustration of real life examples.</td>
<td>It is detailed realistic Real example Student will relate to this picture something they see everyday</td>
</tr>
<tr>
<td>- Non-relevance</td>
<td>Responses refer to the representation as not relevant or as uninteresting to students.</td>
<td>The students wouldn’t be interested in this map. Runoff into a stream isn’t a picture that really needs to be seen. Not related to the curriculum.</td>
</tr>
</tbody>
</table>

*Note: Selection categories and reasons signified by + symbol; non-selection categories and reasons signified by – symbol*
Figure 1. Examples of Pictorial Representations
The rubric presented here can be used as a tool to help teachers recognize pedagogical preferences for selecting images to teach about complex systems. Two examples of representations were chosen from the study to illustrate the use of this coding rubric. The first example of a representation is a digital diagram titled *The Water Cycle* from the U.S. Geological Survey (USGS, 2014) website. The diagram illustrates the entire system of the water cycle, identifying the components and processes of the system, and shows the hidden dimensions of groundwater as well as processes such as transpiration. Teachers identified the following aesthetic and understandable reasons for selection of this diagram: “bright colorful basic,” “clearly labeled and easy to read,” and “colorful pleasing-to-eye informative.” The non-selection reasons of “non-aesthetic,” “complexity,” and “non-systems thinking” suggest teachers’ limited representational competence when selecting a diagram for classroom instruction about a complex system: “not very clear about what is what,” “seems a little complicated,” “to [sic] many arrows pointing different ways,” and “unclear where main points of cycle are condensation, evaporation, etc.” These statements regarding selection and non-selection reasons provide clear differences in how teachers view the same representation.

Teachers tended to select diagrams based on aesthetic and understandable reasons. The understandable reasons were related to the representation being easy to read or understand and being developmentally appropriate for students. These selection or non-selection aesthetics reasons by teachers suggest that the selection process is not necessarily about the science content being presented in the diagram but more about the appearance. This reason for selection suggests that teachers may not be considering the development of
representational competence in their selection process. Teachers’ can use the developed rubric as a way to critique their selection of representations when teaching about systems.

The second representation was a photograph from the Bird Education Network website (2010) of a bird that was involved in an oil spill in the ocean. The statements of teachers regarding the selection of this photograph revealed information about their selection process, but more importantly, also revealed information about their application of systems thinking. Teachers reported selecting the image because it showed “what can happen when oil is spilled or dumped in water,” “what polluted water can affect,” and “why we need to take care of our water.” These selection reasons expose teachers’ understanding of the human impact on the water cycle. The selection rationales also suggest teachers’ pedagogical applications for this representation such as using the photograph to lead students in a discussion of the relationships between pollution, animals, and humans, within the water cycle system. The non-selection reasons also offered information about teachers’ application and knowledge of systems thinking as well as their representational competence. Here are a few examples of the non-systems thinking as identified by the rubric: “what’s the purpose for this? Students may wonder the same thing as me, it is more about human pollution rather than the water cycle,” “nothing to do with the water cycle,” “an oil spill victim has little to do with the basic water cycle” and “not sure how to integrate this image.” These non-systems thinking statements by teachers suggest limited representational competence in understanding how to interpret this photograph and its relation to the water cycle system and applying systems thinking.
These two examples illustrate the need to understand more about why teachers select and use certain representations to teach about systems in science. Teachers need to be able to scaffold and support students’ use of the representations and provide experiences with multiple representations into instruction in order to help communicate the dynamics of systems and to promote systems thinking.

**Conclusions**

The recent call for teaching systems thinking challenges teachers to find ways to make the dynamic, complex, and less obvious components of the system understandable to students. Representations provide teachers with the tools to meet this challenge. But as discussed here, representations are imprecise models of systems and teachers need a level of representational competence to select images that move beyond aesthetics to accurately represent components of systems in ways that are developmentally appropriate for students.

Strategies that teachers can use to teach systems thinking include using authentic contexts and inquiry-based investigations in combination with representations. Keys to making connections to systems thinking include using models and modeling both as teacher pedagogical tools for whole class instruction and as a means for students to individually build representations as a part of the meaning making process. Representations allow students to search for components and processes, interrelationships between these components and processes, and hidden dimensions of the system.
Finally, this chapter offers some classroom recommendations for teachers such as establishing an authentic science context (problem) for students to investigate in regards to the system of study; using indoor and outdoor inquiry-based labs; connecting the experiences with knowledge integration activities; using multiple visual representations and modeling; and, of course, scaffolding students’ progress as they work to develop the skills of systems thinking and representational competence. These recommendations are not new to science educators or science teachers; the key difference in implementing these strategies is the explicit approach to systems thinking and the use of representations. The systems thinking instructional approaches should address the search for patterns in systems, visualize interactions among the system components, find cause and effect relationships, and conceptualize the hidden dimensions of a system.

Teachers and students have access to a plethora of representations through the Internet in unprecedented volumes. Science teacher educators have a new challenge to teach teachers how to select and use representations to teach accurate science content while modeling complex systems phenomena. Perhaps equally important is teaching students to be critical consumers and to use representations as learning tools.
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representations, multiple modality, and multimodal representational competency.