INVESTIGATING THE EXPERIENCE OF WATER: A CASE STUDY OF TEACHING AND LEARNING IN ELEMENTARY SCHOOL SCIENCE

by

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Approved by the Committee on the Degree of Doctor of Education

Date May 16th, 2018

Submitted in partial fulfillment of the
requirements for the Degree of Doctor of Education in
Teachers College, Columbia University

2018

ABSTRACT

INVESTIGATING THE EXPERIENCE OF WATER: A CASE STUDY OF TEACHING AND LEARNING IN ELEMENTARY SCHOOL SCIENCE

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Limited research has been done on the implementation of experiential learning to align with science and engineering practices. This research project developed an instrumental case study to examine the efficacy of an experiential education framework for teaching and learning water science and engineering practices in the elementary science classroom. This study investigates the process of a practicing scientist mentoring a 6th grade elementary science teacher and their participation in professional development activities, strategies used for preparation and practice, classroom implementation, and the consequences of student learning with two sections of science students. Data collection and analysis of teacher background surveys, unit plans provided by the teacher, classroom and field observations, and a semi-structured interview were data sources for the study. Student evidence was collected from pre/post drawing assessments, pre/posttests, reflections, and student artifacts. The findings indicated that personal, intensive long term professional development sessions had an impact on the teacher's practice, where she was able to use the experiential framework as a guiding principle to create an outdoor and classroom-based unit on water in Earth systems. In her practice, she was able to use the framework to create analogies to make connections between natural water filtration and classroom models, and she used an integrated approach to discuss engineering and filter design. The scientist-teacher mentorship resulted in an increase in the teacher's confidence and ability to teach elementary science topics on water science. Students' conceptual understanding of water cycle components and processes progressed over the course of the unit from atmospheric level to subsurface level interactions. Students achieved an understanding of physical properties of matter and hydrogeological concepts of permeability and porosity. Students were able to understand systems thinking and developed dynamic thinking. Implications of this study indicate that the experiential learning framework is an effective pedagogical tool for teachers to introduce science and engineering practices as specified in the K-12 Framework. Using this framework, the classroom teacher was able to complete practices for planning and carrying out investigations, developing and using models, analyzing and interpreting data, and constructing and designing solutions.

ACKNOWLEDGEMENTS

I would like to dedicate this dissertation to my family. From my great grandparents to my parents, I was privileged to grow up in a family that came to this country and embraced all the wonders of nature. From a young age, I watched my great grandfather, grandmother and mother in the garden tending to flowers and trees with the same love and affection that they gave to my brothers and myself. I will forever be grateful to my mother for bringing me into her elementary art classroom at a young age and instilling in me a love of science and art that sustains to this day. Throughout this journey, I carried my father in my heart each day I wrote or spent time outside or on the water. Thank you for watching over me and reminding me how precious life is.

For my sponsor, Dr. Felicia Mensah, thank you for all your patience and understanding through this process. I truly feel as though I have learned from the best. To my advisor, Dr. O.R. Anderson, I am inspired by your dedication to science and ecology, thank you for your guidance on this journey.

I would like to express my gratitude to the “Avenue School” and “Betsy” for letting me inside of her classroom and allowing me to collaborate and educate an incredible group of elementary science students.

Thank you to my friends and colleagues in the sciences who supported me with their knowledge and insight and mixed drinks. Finally, I would like to thank my husband, Jared. No words can express the gratitude and love I have for you and for always being there to make me laugh, provide chocolate, and hold my hand through this journey. Thank you for your love and patience.

A.R.L.

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I – INTRODUCTION

Helping students to understand the world around them is a major conceptual construct in science education. Children bring a set of conceptual frameworks to the science classroom based on prior experiences of the natural world and begin to build understanding of science concepts through direct interactions with living things. Science learning occurs when students integrate new information with prior experiences in a way that is both scientifically accurate and personally meaningful (Pianta & Barnett, 2012; Quinn, Schweingruber, & Keller, 2012).

When I reflect on my own experience with school-based science education I struggle to figure out when I had that moment of epiphany and connected with the content and the community of science. Nothing from my school experience stands out because I never connected to the culture of school science. My own initial science learning was formed outside of the classroom from time spent in nature: collecting shells and crabs on the beach, digging in the dirt, and climbing the apple tree in my grandparent's backyard. In my adolescence, nature provided solace; reading and journaling under trees in Central Park and walking and reflecting on the banks of the East River.

It was not until I was an undergraduate, that I embraced the culture of science with my professor, advisor and mentor, Dr. Richard Villamil. As my professor in Microbiology, Botany, Aquatic Ecology and Environmental Science, he connected us to the science community through experiences like snow shoeing through the Green Mountains, canoeing and sampling on Lake Champlain, and investigating the ecology and geology of south Florida. These meaningful experiences shaped my perceptions of the Earth as a dynamic and nurturing system that exists and operates as one universe. Amidst concerns about standards and testing, authentic outdoor experiences are underutilized as a teaching tool for direct student engagement with science phenomena. The role of the science educator is to mediate scientific knowledge for learners, to help them to make personal sense of the ways in which knowledge claims are generated and validated (Driver, Asoko, Leach, Scott, & Mortimer, 1994, p. 6).

Experiential Education

Experiential education is defined within the context of the learner interacting with the environment and then making meaning by connecting to the experience in which they are embedded (Dewey, 2007; Hunt, 1995; Joplin, 1981; Kolb, 2014). It is through this interaction, that learners enact scientific inquiry, exemplifying the diverse ways in which scientists propose explanations and evidence from their study of the natural world (National Science Foundation [NSF], 2001).

The experiential learning model (Kolb, 2014) encourages the learner to participate in identifying and activating new discoveries, while concurrently exploring scientific processes through the components and context of each experience.

In practice, the experiential learning model provides a framework for scientific instruction focused on fostering children's natural curiosity and the development of skills to produce, interpret and quantify information from the world around them.

Used in this context, the experiential framework aligns well with the recent vision of science education, The K-12 Framework (Quinn, Schweingruber, & Keller, 2012) and the Next Generation Science Standards (NGSS, 2013). Released in 2013, the NGSS takes the K-12 framework and applies it to a set of performance expectations where emphasis is placed on building critical thinking and communication skills through scientific practices. This standards-based approach integrates science disciplines within three dimensions of learning: science and engineering practices, crosscutting concepts, and disciplinary core ideas, with an objective to engage students through the nature and practice of science in the context of their own world (NGSS, 2013; Singer, Marx, Krajcik, & Chambers, 2000). The K-12 framework presents a vision of education where students progressively engage in scientific and engineering practices to address the challenges that face humanity and enrich their understanding of the core ideas (NGSS, 2013; Quinn, Schweingruber & Keller, 2012).

In the local context of NYC, the New York City Department of Education (NYCDOE) 6-12 science scope and sequence encourages teachers to develop their student's scientific literacy by connecting them to the urban ecosystem through inquiry driven approaches and project-based learning (NYCDOE, 2016). It is through these investigations of the natural world that the framework organizes science and engineering practices that are essential for students to solve problems and understand concepts. These practices include asking scientific questions and defining engineering problems, developing and using models, planning and carrying out investigations, analyzing data, constructing explanations, engaging in argumentation from evidence, and communicating and organizing information.

Within the NGSS (2013) domain of Earth and Space science there is an emphasis placed on the increased needs of human society. The rise in population and industrialization have placed stressors on planetary resources, such as drinking water. Knowledge about our water resources is a critical component to understanding how the Earth works.

Research in water science education suggests that many students have misconceptions about the composition of the hydrosphere and how water flows, transforms and interacts in the natural world. Many students hold an incomplete representation of how water cycles on Earth – one where water only moves between the Earth's surface and the atmosphere, and subsurface reservoirs are not taken into consideration (Assaraf, & Orion, 2005b; Cardak, 2009; Dickerson, & Dawkins, 2004). Students' experiences with water at school and home do not allow them to understand the basic natural processes in which water is involved (Agelidou, Balafoutas, & Gialamas, 2001). Student understanding of the natural processes of hydrological systems are generally on a global scale and lack awareness of and connection to their own local water systems (Covitt, Gunckel, & Anderson, 2009; Dove, Everett, & Preece, 1999; Shepardson, Wee, Priddy, Schellenberger, & Harbor, 2007). The experiential learning framework provides a basis to connect students to their local water resources through authentic field experiences.

To support students in constructing scientific knowledge and practices, it is essential that elementary teachers develop a broad grasp of scientific content. Historically, elementary science standards have emphasized process skills, such as making observations and measurements of phenomena, creating hypotheses, and designing and carrying out experiments (National Research Council [NRC], 1996a). The educational shift of the NGSS (2013) presents a challenge to science teachers to integrate these three dimensions of learning through rigorous content to enrich science experiences through investigations and model simulations. These challenges include concerns about the application of NGSS due to their lack of content knowledge in engineering and ability to distinguish between scientific inquiry and engineering design. This shortcoming indicates a clear need to complement experiences of science practices with those of engineering practices (Bybee, 2014).

Partnerships between teachers and scientists can facilitate classroom implementation of these dimensions through authentic science experiences. In the classroom, scientists can provide accurate science content and data that adds to teachers understanding of the scientific process (Dashoush, 2015; NRC, 2006b). For the scientist, teachers can provide insight into the challenges of learning science in practice. For both participants, these partnerships have been viewed as a positive experience that contributes to an understanding of science content and pedagogical knowledge (Dashoush, 2015;

Halverson, & Tran, 2010; Houseal, Abd El Khalick, & Destefano, 2014; Jones, & Edmunds, 2006; Morrison, & Estes, 2007; NRC, 1996b).

As a practicing scientist, I have insight into the science community and the potential opportunities that will be available t students in the future. The vision of NGSS (2013) assumes that teachers will promote students to pursue careers in science and engineering and allowing them to participate as global citizens who engage in public policy issues and take part in global discussions that address challenges today. However, many teachers may not know how to support students to reach these goals of the standards (Spillane, & Louis, 2002).

Purpose and Rationale

The purpose of this instrumental case study is to examine the efficacy of an experiential education framework for teaching and learning science and engineering practices in a water education unit for an elementary science classroom. This study assesses the process of an elementary science teacher working directly with a practicing scientist, their participation in professional development activities, strategies used for preparation and practice, classroom implementation, and the consequences of student learning. Within this partnership, a primary goal for professional development is for the teacher to develop practical strategies that not only improve and promote their own learning, but also enhance the education of their students. The NRC (1996b) views the science teacher and practicing scientist as partners in the professional community dedicated to improving science education.

Factors that Determined the Origin of this Study

In 2012, I participated in a session of MSTC 6502 (the science education seminar for entering doctoral students at Teacher College) where Dr. Janell Catlin discussed her professional development work with the Harlem School Initiatives in Science, Technology, Engineering and Mathematics (STEM) education. As part of this initiative, Dr. Catlin had begun working with a curriculum out of the Museum of Science, Boston; Engineering is Elementary [EiE] (Lachapelle & Cunningham, 2007). EiE (2018) is an elementary science, project-based learning curriculum that introduces students to engineering and technology concepts through a storybook narrative. As part of our introduction to the EiE, Dr. Catlin had us participate in a technology activity and discussion about the definition of technology. Through discussions we defined this as anything man-made that can solve a problem or fulfill a desire. Of interest was the conception that technology can be an object, system or a process.

The EiE Curriculum

When I learned that EiE had a unit on water engineering, I knew that I wanted to pursue working with teachers and students to educate them about water and the environment. I contacted EiE to ask if any schools in NYC were using the *Water, Water, Everywhere* unit (Lachapelle & Cunningham, 2007). The company informed me that they did not track which kits had been purchased but had two recent orders for the water unit. They were able to provide me with information on these two schools as well as a listing of 30 other schools within the five boroughs of NYC that had purchased materials from them. Other than the school address, no other contact information was provided.

Tracking down contact information for school principals was a daunting task, but eventually I was able to track down emails and phone numbers for these principals and immediately began contacting them. I had many email correspondences with most of the schools on the list, and later planned to meet with the principals and observe classrooms at the two schools that had recently purchased the water unit. One recipient was a 100-year-old all girls private school using the unit as a one-time lab with third graders to bridge awareness and discussion about global water for the school's international day celebration.

The other site was a new gifted and talented school that was in its first year using the unit as part of their 6th grade technology classroom. The unit was being taught by the school principal, who had recently attended the EiE professional development in Boston. I went on to foster a relationship with the principal of the gifted and talented school, the Avenue School (pseudonym) and observed students participating in this curriculum over the entire course of the semester. For the last two sessions of the unit, the physical modeling of a water filter, the principal shifted students from the technology to the science classroom. The science teacher had an interest in water and had been using classroom science kits to integrate a few water and weather concepts into the science curricula to bridge it with the EiE content in the technology class. She had just scheduled a field trip for students to visit the NYC Department of Environmental Protection (NYCDEP) wastewater treatment plant. Having worked as a water ecologist at NYCDEP, I had a strong relationship with the education commissioner and continued to work with the agency in workshops, presentations, and events in my current role as a water scientist and epidemiologist. Partnering with the science teacher as a mentor was a good fit and was strongly encouraged by the education director at NYCDEP.

In their discussion on the role of the scientist in the professional development of science teachers, the NRC (1996b) recommended that before planning the professional development program, the scientist interacts with teachers and school administrators.

Over the course of this study, I proceeded in this manner, and consistently reached out to both the principal and assistant principal regarding the realities of program implementation within the school system, as well as ongoing correspondence and observations with the elementary science teacher.

My background was well suited for this partnership. As a science educator, I have over 10 years of experience working in non-formal marine and environmental science programs with upper elementary and middle school students, and five years of experience as an adjunct professor for undergraduate students in environmental and health sciences. Working full time as an environmental health scientist within the Bureau of Environmental Science and Engineering (ESE) for the City of New York, I conduct data surveillance and analysis, injury epidemiology, and program management and regulatory oversight of water quality and operations within the New York City (NYC) Water Supply and NYC Recreational Waters to ensure protection of human health and the environment. Every day the NYC Water Supply provides approximately one billion gallons of safe drinking water to the taps of 8.5 million residents and visitors through a gravity fed system; precipitation flows down the Adirondack Mountains through natural lakes and reservoirs, connecting to man-made aqueducts that lead into balancing reservoirs that hold, treat and output this water into city tunnels that feed into local service lines that lead into our home plumbing systems (NYCDEP, 2015). This combination of natural and manmade systems engineered to work together to deliver and treat our water is a prime example of technology and engineering that is essential to humans that we interact with every day.

To meet the performance expectations on Earth systems, the NGSS (2013) recommends that students demonstrate an understanding of the significant role of water in the Earth's processes by modeling the movement of water through the states of matter via a physical or conceptual manifestation (Quinn et al., 2012). The use of such explanatory models in classroom instruction engages students to participate in scientific reasoning by inventing and revising models of the natural world (Lehrer & Schauble, 2006).

Problem Statement

Limited Science Teaching Time

For the elementary grades, academic content and instructional time are often decided by the district or individual teachers. Recent national trends show a decline in instructional time spent on science in elementary grades, with a drop to an average of 2.3 hours per week, the lowest level on record since 1988. Within each state these levels vary, ranging from a low of 2.0 hours per week to a maximum of 3.5 hours per week (Blank, 2012). Due to these trends, state and national data show a correlation between decreased times in elementary science instruction and lower National Assessment of Educational Progress (NAEP*)* science scores. Throughout the first few years of teaching, lack of science content knowledge, time constraints, and accountability to state and local requirements often take precedence (Berg, & Mensah, 2014; Mensah, 2010). Students and teachers acquire a deeper understanding of scientific concepts when learning with an inquiry-based, or experiential instructional model (National Science Research Council, 1996b), but this requires that science is given priority in the elementary school curriculum. “Teachers focus on what works in terms of student involvement and classroom management rather than making theory and practice.” (Anderson, 2002, p. 9)

Limited Science Content Knowledge

Findings from the literature suggest that elementary school teachers have less scientific background than middle and high school teachers (Berg, & Mensah, 2014; NRC, 1996b). Many become certified with little or no undergraduate preparation in science. Teachers own knowledge, skills, and conceptions are still under construction. So, when the teacher themselves have not experienced different forms of scientific inquiry, they find it difficult to measure student outcomes for evaluation and assessment (Crawford, 2007). Research from the NRC (1996b) suggests that the more elementary school teachers believe they have increased their science content knowledge the more comfortable they were implementing inquiry-based instruction methods in the classrooms.

According to Bybee (2014), the expectations for K-12 instruction set forth in the NGSS (2013) require a shift in the educational system, where curriculum, teacher development, assessment and accountability will influence outcomes in student learning. A shift in instruction will move teaching away from covering many isolated facts to a focus on a smaller number of disciplinary core ideas and crosscutting concepts that can be used to explain phenomena and solve problems by engaging in science and engineering practices (Krajcik, Codere, Dahsah, Bayer, & Mun, 2014, p.157). The inclusion of science and engineering practices presents a challenge to teachers who have not worked within this discipline to balance all three dimensions in their instruction. Therefore, it is essential that teachers have in-depth knowledge of subject matter to adequately address the needs of their students, common misconceptions and the trajectory of their learning for understanding across science, technology, engineering and math (NRC, 2010). This is a challenge for elementary teachers, where there is already a decrease in the amount of time spent on science instruction; they will need to develop instructional sequences that combine Common Core with science standards to create an interdisciplinary context for science education (Reiser, 2013).

Coherence of instruction will not only depend on the instructor’s competency and understanding but the student’s experience of the nature of science (Kendall, 2011a). When there are discrepancies between teachers understanding of the content, it can result in shortcomings in student learning. For example, Fortner and Meyer (2000) found a strong correlation between teachers’ self-reported level of knowledge of water topics and prioritizing these topics for inclusion in their curriculum. Additionally, inconsistencies were discovered in the teacher's actual understanding of these topics; teachers were teaching what thought they knew about water which included incomplete conceptions.

Ideas and discoveries in science are constantly challenged, scientists can have different interpretations of the same concept and the public can have misconceptions about these differences.

Student Misconceptions of Science Content

Students share many of the same alternative views and misconceptions about the composition of the hydrosphere and how water flows, transforms and interacts in the natural world. Students have problems conceptualizing the interactions of the water cycle and how water is recycled on Earth through evaporation, condensation and groundwater infiltration. They hold an incomplete representation that water only moves between the Earth's surface and the atmosphere; subsurface reservoirs are not taken into consideration (Assaraf, & Orion, 2005a, 2005b; Cardak, 2009; Dickerson, & Dawkins, 2004).

Under the New York State Elementary Science curriculum, by the fourth grade, students should be able to recognize cycles, and observe, describe, and carry out experiments to investigate phenomena that causes water to be recycled by natural processes on Earth. This includes an understanding of groundwater as "water that moves downward into the ground" (New York State Department of Education, 2015). As students' progress to higher grades, the science standards evolve to include understanding and recognition of phenomena that occur from interactions among components of air, water, and land. The NGSS (2013) domain for 6th-8th grade Earth Science includes a performance expectation (MS-ESS2-4) that students be able to develop a conceptual or physical model that describes the cycling of water through Earths systems. Included within this framework is disciplinary core idea ESS2.C, The Role of Water in Earth's Surface Processes, with the intention that students develop an understanding of how the properties and movements of water shape Earth's surface and affect its systems. Though it appears comprehensive, this core idea presents the same fragmented view that students hold in their conceptions of water cycles, that Earth processes occur only at a surface level. Given that groundwater concepts are not well understood by teachers (Dickerson, Penick, Dawkins, & Van Sickle, 2007) and weakly represented in state standards and the science framework, it is reasonable to believe that there are great differences in student learning and understanding of water topics throughout the state.

Research Questions

The following research questions guide this case study:

1) How does an experiential learning framework facilitate the inclusion of science and engineering practices in the elementary science classroom?
    a) In regard to teacher professional development?
    b) In regard to teacher implementation and strategies?
2) How does the experiential learning framework foster the conceptual development of water science and engineering practices in elementary science students?

3) How does the experiential learning framework foster the development of systems thinking skills in elementary science students?

Organization of the Dissertation

In the following section (Chapter II), I provide an overview of the literature about implementing science and engineering in the elementary classroom. This includes studies about elementary teacher's science content knowledge, and pedagogical challenges of inclusion of interdisciplinary content from the Next Generation Science Standards and K-12 framework. The literature survey also provides articles about the scholarly evaluation and justification of partnerships between scientists and science teachers to establish a community of practice in the classroom and promote science education and learning through professional development and mentorship. This includes strategies used to infuse the experiential learning cycle into professional development and classroom practices.

Additionally, the literature includes studies about the cognitive challenges that elementary students face in understanding complex causal relationships and strategies used in practice to overcome these barriers to thinking and understanding in a systematic manner. These strategies are addressed in the literature through the scholarly description and justification of components of the experiential learning cycle in classroom implementation and the use of explanatory models and model-based inquiry as tools for understanding science. The literature survey also provides an overview of student conceptions and misconceptions of water in Earth systems and the scholarly justification of the use of authentic learning environments and visually based instructional methods in facilitating scientific understanding. The final section of Chapter II provides a description of the theoretical and conceptual frameworks utilized in this study, namely Experiential Education Theory (Dewey, 2007), Experiential Learning Theory (Kolb, 2014) and Constructivism and Social Constructivism (Driver, 1985, 1995; Karpov, 2014; Piaget, 1970).

Chapter III presents the research design and methodology used for this study- a case study. I provide a rationale for this methodology and describe the setting and participants, the curriculum that was modified as part of this study, data collection methods, data sources, methods of analysis, measures taken to ensure confidentiality, and efforts to preserve reliability, validity, and rigor.

Chapter IV is the findings chapter, and it focuses on all three of the research questions, which are dependent on the application of an experiential learning framework. The first research question relies on the teacher's interpretation of the experiential learning framework from participation in professional development sessions and in her classroom implementation. The second and third research questions focus on student learning and how participation in the experiential water unit impacted their conceptual understanding of water and engineering practices and development of systems thinking skills. This chapter draws on the theoretical frameworks of Experiential Education and Learning and Social Constructivism to explore how the efficacy of the teachers' approach to science content and learning impacted student-learning outcomes.

Chapter V provides a summary of the major findings and includes a discussion around the challenges and constraints that impacted the efficacy of the study.

The dissertation concludes with Chapter VI, which presents conclusions, implications, and recommendations on the use of the experiential learning framework as a model for elementary science and engineering practices.

II – LITERATURE REVIEW

The literature review is organized by research that is prevalent to teaching and learning. The first section provides an overview on the literature about the strategies and practices used to teach science in the elementary classroom. This section highlights the challenges encountered and approaches utilized to implement science standards and practices and how partnerships between scientists and teachers can help facilitate scientific reasoning. The pedagogical principle of learning by doing creates the setting to inform professional development which translates experiential learning into practice.

The second section provides an overview of the literature about learning science. This includes strategies used to develop cognition and learning so that students can think and understand the world around them in a systematic way. Through scientific inquiry, tools are explored that promote systematic thinking by developing and using explanatory models to promote scientific reasoning. This section also includes literature on student conceptions of water in Earth systems and the environments and methods that promote conceptual understanding by allowing experiential learning to take place. In the final section of the chapter, the theoretical and conceptual frameworks in this study are presented.

Teaching Science

Implementing Science and Engineering Practices

The inclusion of inquiry in K-12 science education was first suggested by Dewey (1995) as a teaching strategy to shift the science classroom away from rote memorization and move the learning of science towards thinking. The objective of his model was for teachers to act as facilitators, promoting scientific inquiry among students and encouraging them to become active learners by investigating, observing and answering their own questions about the world around them.

The NGSS (2013) presents a new vision of inquiry where students develop an understanding of the nature of science through questioning, investigating, evaluating and interpreting evidence through explanatory models and scientific argumentation to justify their findings (NGSS, 2013; Schweingruber, Duschl, & Shouse, 2007). It emphasizes a teaching approach where knowledge building is fostered through discourse and discussion to develop explanatory models and ideas to achieve performance expectations within science disciplines.

The expectations for K-12 instruction set forth in the NGSS (2013) require a shift in the education system, where curriculum, teacher development, assessment, and accountability will influence outcomes in student learning (Bybee, 2014). This shift also presents challenges along several themes in instruction and the time and expertise needed to develop instructional sequences that combine common core with science standards to create an interdisciplinary context (Bybee, 2014; Reiser, 2013; Schweingruber et al., 2007). To foster this shift to NGSS, Krajcik et al. (2014) note that:

> Instruction will move teaching away from covering many isolated facts to a focus on a smaller number of disciplinary core ideas and crosscutting concepts that can be used to explain phenomena and solve problems by engaging in science and engineering practices. (p. 157)

The inclusion of science and engineering practices presents a challenge to teachers who have not worked within this discipline to balance all three dimensions in their instruction. Teachers have concerns about lack of content knowledge in engineering and being able to distinguish between scientific inquiry and engineering (Bybee, 2014). There is a clear need to complement experiences with the science practices with those of engineering practices. However, teaching in this manner requires a high level of pedagogical content knowledge, including a deep understanding of the nature of science. The NRC (2010) believes that:

> Science, technology, engineering and math (STEM) teachers should have a deep knowledge of their subject matter and 'an understanding of how students' learning develops in that field, the kinds of misconceptions students may develop, and strategies for addressing students' evolving needs. (p. 47)

The goal of any teaching methodology is to facilitate student learning and understanding of this content, as well as developing their skills in, and understanding of the nature of science (Schweingruber et al., 2007). This is a challenge for elementary teachers, where barriers to instruction already include a decrease in the amount of time spent on science instruction, lack of science content knowledge, limited teacher preparation, lack of instructional time, the challenge of assessment and limited in-service professional development (Anderson, 2002; Crawford, 2007; Gunning, & Mensah, 2011; Howes, 2002; Mensah, 2010).

Scientist-Teacher Partnerships

Partnering with scientists can provide a powerful context to engage teachers in scientific practices and provide direct experiences which are modeled after ways we want them to teach their own students. For the scientist's learning, teachers can provide insight into pedagogical content knowledge and the challenges of learning science in practice. For both participants, these partnerships have been viewed as a positive experience that contributes to an understanding of content and pedagogical knowledge (Dashoush, 2015; Halverson, & Tran, 2010; Houseal, Abd-El-Khalick, & Destefano, 2014; Jones, & Edmunds, 2006; Morrison, & Estes, 2007; NRC, 1996b).

These collaborations foster the development of communities of practice around this shared expertise, and responsibility for planning, enacting and reflecting on instruction. An important factor in establishing the scientist- teacher partnership is how these communities of practice are negotiated. These partnerships are most successful when they are based on strong collaboration, where scientists take on the role of content experts and communication of goals and objectives are consistent between both partners (Loucks-Horsley, Hewson, Love and Stiles, 1998). Studies by both Abell (2000) and Halverson and Tran (2010) provide insight into tensions that can develop between educator and scientist. Both researchers acknowledge that open discourse, honesty and recognition of one another's area of expertise are essential principals to building a collaborative relationship.

One practice that is suggested to improve the quality of science learning experiences at the elementary level is the use of science specialists (Jones, &Edmunds, 2006; Ronan, 2014; Schwartz, Lederman, &Abd-El-Khalick, 2000). In her exploration of the impact that different science specialist models have on elementary school teacher's self-efficacy, Ronan (2014) recommends that the role of the science specialist be embraced by schools as a collaborator to develop the classroom teacher and not take over the teaching.

Scientist-teacher partnerships can develop marked improvement in not only the quality of science instruction and science content knowledge, but also student learning outcomes. For example, Frazier, Sterling and Bordeaux (2010) found that they were able to maximize the impact of science specialists by involving them in professional development with their 5th grade teachers. This collaboration resulted in a significant increase in standardized test scores. Outside of the United States, Schallies' (2010) research on professional development partnerships with teachers and climate scientists resulted in improvements in student learning in secondary schools. When teachers collaborated with scientists in authentic research environments working on the problem of carbon dioxide in the atmosphere, they were able to improve their understanding of these real-world problems on climate change where the scientist had subject matter expertise.

Scientist-Teacher Professional Development

Research suggests that a successful professional development strategy can be found in forming partnerships between the science teacher and practicing scientist as partners in the professional community dedicated to improving science education (Crosby, 1997; Dashoush, 2015; Loucks-Horsley, Hewson, Love, & Stiles 1998; Loucks-Horsley, Love, Stiles, Mundry, & Hewson, 2003; NRC, 1996b). It is through these partnerships that teachers and scientists can establish a community of practice that facilitates professional development in science education (Dashoush, 2015; Schweingruber et al., 2007).

Morrison and Estes (2007) discuss results in their study of middle school teacher’s experience of professional development guided by research scientists. Teachers in the study felt as though they had considerable gains in both content knowledge and process skills. The only challenge encountered was the use of some vocabulary words by the scientists that were not well understood by the teachers. Although science is dependent on context, what counts as science is defined by the local members of the community through discourse. The definition of science is constructed through these communities of discourse where each individual member brings their own set of experiences and beliefs to the group and create through social interaction ways of talking, thinking, acting and interacting (Kelly, Chen, & Crawford, 1998, p. 24).

Heller, Daehler, Wong, Shinohara, & Miratrix (2012) investigated professional development through thinking and analysis acros three separate interventions involving elementary science content on electrical circuits. Teachers were prompted to choose one of the three interventions: analyze the curriculum itself, student learning of the curriculum or the implementation of the curriculum in their own practice. The findings indicated that the integration of both content learning with analysis of student learning resulted in greater improvement in student scores than teacher reflection alone.

Experiential Professional Development

The NRC (2015) recommends that professional development actively engage educators in curriculum and assessment strategies that are content specific and based on the best available evidence. Professional development should connect to teacher’s own instructional practice in the context of core ideas and enable reflective collaboration that can adapt their work to the vision of the K-12 framework. Regarding elementary science teaching, the NRC recommends discussion around the relationships between science teaching and other subject areas:

> Understanding these relationships will allow teachers to take advantage of the synergies between science, mathematics, and English language arts by supporting development of students’ skills across the curriculum in the context of science learning activities. (p. 40)

In addition, they support the use of active engagement in professional development to promote active reflection and problem solving. It is important that programming incorporates models of professional development that are embedded in subject matter and involve active learning that connects to the teacher’s own practice. This leads to integration of knowledge and understanding of not only science, but also effective pedagogy (Reiser, 2013). The science teacher and practicing scientist are viewed as partners in the professional community dedicated to improving science education.

Experiential learning is a method based on the pedagogical principle of learning by doing and hands on learning (Roberts, 2005). In this process, students acquire knowledge from being actively engaged or after having experienced or taken part in a new activity or assignment (Maloof, 2006). Dewey (2007) notes that one of the major assumptions of experiential education is that learning is a continual process and not an outcome. He explains that as educators we must consider the capacities, needs and past experiences of our students to provide them with experiences that will give them access to opportunities for personal growth and contributions to society through cooperative enterprise. “Each individuals experience is viewed as a continuum that influences their future in a positive or negative way.” (p. 47)

Like the continuity that follows the process of experiential learning, learning progressions are an approach to science instruction and curricula that that considers children’s prior experiences and merges knowledge and practice by sequencing topics over successive grades (Schweingruber et al., 2007). The NRC (2015) recommends that professional development that incorporates learning progressions be viewed as a continuous process that builds and interacts with each moment of experience, supported by and enriched through the school community. Using a similar framework, Feiman-Nemser (2001) yielded positive results in her approach to professional development. Her method entailed a long-term approach to learning that was represented by a continuum that ran from initial preparation in teaching methods through the early years of teaching.

As a practicing scientist in the classroom, a primary goal for implementing professional development is to provide teachers with the skills to be able to understand and apply experiential education pedagogy and principles in their classrooms. Aspects of experiential learning in professional development that have been successful in practice include those that have incorporated collective participation such as meetings among teachers, peer observations, and peer and student feedback (Burke, 2013).

An experiential education framework focuses on adaptive modes of thinking that are explored through four different kinds of abilities present in all learners: concrete experience, reflective observation, abstract conceptualization and active experimentation Kolb (2014). This model stresses the importance of experience and reflection, while concurrently requiring that the participant be active in the construction of their own learning. “Learning involves transactions between the individual and the environment whereby experiences are transformed into knowledge and actions.” (p. 198)

This new approach can be challenging for teachers and students in the classroom. Experiential learning is centralized around the connection of the learner to the content, and many teachers tend to have difficulty shifting from a central leadership role to becoming more of a facilitator (Goodnough & Cashion, 2006; NRC, 2006b). The study presented in this paper serves to provide greater understanding of how the science teacher may use such an experience to alter their method of teaching.

In an example of classroom implementation, Dunton (2006) connected her elementary school student’s own world to that of the world of mathematics through the creation of a micro society. Students learned about how percentages are calculated to determine data on income and taxation. Dunton found that her students learned best when they connected schoolwork with the realities of their own experiences.

Experience and reflective observation are important components of the experiential learning cycle that are beneficial to teacher and student learning. Students are more likely to gain a better understanding of the natural world if they are engaged directly with the phenomenon, experiencing the world through all their senses (Markaki, 2014). Following these experiences, Walker (2005) discusses the importance of reflection in the promotion of learning and connects this process to debriefing. The role of the teacher is to facilitate the debriefing process after the experience to enable participants to identify their conceptions of the experience and individually and collectively explore the components as part of the learning process. Kolb (2014) also recommends that this reflective practice be continuous throughout the course of a lesson or unit and be structured in a way that connects content and experience.

Another strategy for experiential based professional development is to incorporate a metacognitive approach, where teachers reflect on their classroom practice and establish what areas need improvement. This approach emphasizes the process of experiential based professional development as opposed to the outcomes and allows teachers to participate in a way that provides meaningful insights and self-efficacy (Peery 2004). “Teachers learn by doing, reading, and reflecting (just as students do); by collaborating with other teachers; by looking closely at students and their work; and by sharing what they see." (Darling-Hammond & McLaughlin, 2011, p. 83)

Learning Science

Systems Thinking

The National Academy of Science and the International Council of Scientific Unions also encourage school science practice to embrace views that science be understood as a series of systems, synergistic, built upon the foundations of past achievements and tie the "global gap of well-being", the fate of humanity to the progression of scientific ways of knowing and spread of scientific culture (Cobern, & Loving, 2003, p.63).

How we think about these systems is defined by Senge (1990) as a conceptual framework of knowledge, principles and tools that enable us to observe the interrelations and mutual connections necessary to determine changeable patterns and repeated phenomenon. Viewed through this lens, systems thinking represent a model for understanding science. However, many researchers question whether students have the cognitive skills that would allow them to deal with complex systems (Kirschner, 1992; Kuhn, Black, Keselman, & Kaplan 2000; Kuhn & Pease, 2008).

Young elementary students possess basic cognitive forms of organizing and representing data that allow them to represent causality, but often do not have the theoretical knowledge or cognitive ability to see these patterns in the data they are collecting (Kirschner, 1992; Kuhn et al., 2000; Kuhn & Pease, 2008). For example, studies among elementary school students found that they were unable to understand complex causal relationships and patterns in natural phenomena (Agelidou, et al, 2001; Assaraf, &Orion 2005a; Grotzer, & Basca, 2003). These alternative conceptions and misconceptions were found throughout all grades; however, systems thinking skills were found to be least developed among elementary students (Assaraf, & Orion, 2010; Cardak, 2009).

In their study of third graders, Grotzer and Basca (2003) found that students were able to grasp simple causal relations, such as what affects what, but were unable to understand the underlying causal structures in branching and reciprocating patterns such as food webs, feedback loop, and cyclic patterns such as the decomposition process. Teachers in this study also held misconceptions about causal patterns in energy transfer in food webs, believing that all energy from the sun was continuously recycled in the food web, and that none was lost as heat in decomposition.

Developmentally, variables with temporal and spatial gaps present the greatest challenge to children (Kuhn, 1989). Causal relationships that are not obvious such as the actions of microbes as recyclers of carbon, nitrogen and water can be confusing to students. Students assume there is not a causal mechanism if they cannot see it. These hidden agents become confounding factors that can exacerbate difficulty in understanding these systems (Grotzer, & Basca 2003).

What the cognitive development literature ignores is the impact of instructional strategies and the use of teaching narratives to facilitate elementary students understanding of science phenomenon. Science learning occurs when students integrate new information with prior experiences in a way that is both scientifically accurate and personally meaningful. Students enter the classroom with alternative conceptual frameworks and worldviews that guide them in their scientific reasoning and decision-making. When the worldview of science that the teacher introduces conflicts with the student's prior knowledge schemes it can present a challenge to learning in the science classroom (Driver et al., 1994; Schweingruber et al., 2007).

Moreover, students come to school with existing schema of natural phenomena that can be informed and misinformed by cultural beliefs, pseudo-scientific perceptions, everyday life and their level of child development (Ado, & Mensah, 2015; Assaraf, Eshach, Orion, & Alamour, 2012; Bar, 1989; Driver, 1985; Lee, 1999; Schweingruber et al., 2007; Taiwo, 1999). In the case study presented in this paper, students physically and conceptually modeled water filtration systems. In designing and redesigning these representations, students needed to develop systems thinking skills to promote a scientific and conceptual understanding of what water flow looks like in nature and technology systems.

Strategies such as learning progressions are powerful tools that connect the sequence of student cognition and ideas with learning goals within science domains (Schweingruber et al., 2007). For example, Draper (1993) proposes a model for developing systems thinking that is based on emphasizing specific types of thinking in a developmental sequence. He identifies seven skills of systems thinking and associated levels of activity that progresses from a simplistic to deeper level-- structural thinking, dynamic thinking, generic thinking, operational thinking, scientific thinking, closed loop thinking, and continuum thinking.

Draper (1993) recommends that elementary grades begin the introduction of structural thinking to orient students towards recognizing simple causal relations-what affects what, where things flow, and which things accumulate. Having this prior knowledge, Draper posits that this baseline understanding of systems will foster their understanding of dynamic and generic thinking, where they begin to recognize causal loops and patterns that cause changes in behavior over time. The progression of the development of these skills lends itself to the student being able to grasp higher level thinking skills. Operational, scientific, closed loop, and continuum thinking are inducted when they begin to conceptualize models of phenomena.

Research findings support this framework as a means of identifying stages of cognitive understanding in the development of systems thinking and have informed instructional planning and curricula in Biology (Hmelo-Silver, Marathe, & Liu 2007); Earth Science (Assaraf, & Orion, 2005a, 2005b, 2010; Kali, 2003); biogeochemical and biological cycles (Assaraf, & Orion, 2010); watersheds (Shepardson, et al, 2007); and ecosystems (Covitt, Gunckel, & Anderson, 2009, Grotzer, & Basca, 2003).

Students’ preconceptions and personal understandings can impact the way they understand and retain information; children’s ideas should provide the basis of teaching and learning science in schools. These alternative conceptions are useful to inform teachers and design instruction on how to address and overcome these misunderstandings and illicit conceptual change (Agelidou, et.al, 2001; Driver, 1985; Karpov, 2014). Assaraf, & Orion (2005b) also suggest the use of an educational approach with a context that incorporates the student's own daily life into an understanding of the components of the system with the inclusion of knowledge integration activities such as concept maps, drawings, and summarizing the outdoor experiences.

Systems and System Modeling

A key component of the NGSS (2013) is the introduction of science and engineering practices to engage students in investigations and problem solving through the construction of explanatory models. Physical, graphical and conceptual models are all effective tools that have been used in the classroom for students to make sense of natural phenomenon (Lehrer, & Schauble, 2006). Kamarainen, Metcalf, Grotzer, & Dede (2013) equate models with an "intellectual sandbox" that scientists use to explore concepts, ideas and building structures of theories. They suggest that in the study of ecosystems, models be utilized as a tool for communication, collaboration, and argumentation in the classroom to compare model mechanisms to phenomenon in the real system.

System models are useful tools for science educators to elicit conceptual understanding among their students in using explanations and analogies. Modeling with elementary science students can be viewed as a representational tool to foster children's emerging capabilities, contributing to science learning by developing their ways of reasoning and organizing with scientific data (Lehrer, & Schauble, 2006).

Representations allow us to form mental models of images and concepts to promote better understanding of connections between systems and functions in our everyday world. Mental imagery facilitates memory; learners develop understanding of the world through construction and revision of mental models (Kuhn, 1989).

Mental images reflect a type of internal representation. When image content stored in long-term memory is retrieved and activated in working memory, characteristics of visual perception are enhanced as if it is being experienced in real time (Kosslyn, 1980, 1994, 2006).

Johnson-Laird (1981) observed that “by reflecting on the properties of relations represented in mental models, an individual may come to acquire higher-order knowledge of them.” (p. 191) This self-reflection can be defined through the term metacognition as the ability of oneself to describe knowledge about and control of one's own learning (Brown,1992). Metacognitive strategies assist learners in systemizing their metamemory-understanding how we remember what we know and actively constructing a pathway where memory and recall can be improved (Schraw, & Moshman, 1995). Self-control plays a key role in metacognition. According to Vygotsky (Karpov, 2014) reflective awareness and deliberate control are the dual aspects of metacognition; if someone can reflect on their own mental acts it is also likely to be able to access and apply them in a manner under their voluntary control. Sternberg (1985) attributes the ability to reflect on and control ones' cognitive actions as an important component of intellectual cognitive development; development of a set of learning strategies for remembering and monitoring their own learning activities.

These causal relations can be mediated with words or diagrams (Mayer, 1995) or through strategies such using the representation of water flow as analogy for electricity (Gentner, 1983). Teachers can utilize representational knowledge tools such as drawing exercises and concept maps as examples to connect to learner's prior knowledge (Novak, & Cañas, 2008).

Model-based inquiry. Information sources from data, evidence, models, and explanations are now part of how one interacts with science phenomena. Students may develop good practices of inquiry that model scientific practices, but the way that they believe that they think and approach a problem does not align with that of a working scientist. It is through scientific practice that students develop content knowledge (Clement, 2000; Duschl, 2008; Sandoval, & Reiser, 2004).

Buckley (2000) incorporates explanatory models into her biology class to explore the mechanisms of the human heart. As students interacted with this representation of the organ, they not only developed conceptual understanding of the functions of the heart, but also engaged in a student directed investigation, allowing them to develop critical thinking skills through their multiple interactions with the model. The use of these model revision cycles allows the learner to form an integrated understanding of the science content.

In her study on 5th graders' conceptions of plate tectonics, Gobert, & Buckley (2000) use a 'drawing to learn" strategy to elicit students' conceptual understanding of spatial, causal, and dynamic relationships in earth science. Student drawings and their explanations serve as artifacts that both teacher and students can refer to as a record of prior knowledge. In the context of model-based learning, Gobert and Buckley posit that these young students can understand and grasp the idea of chains and networks of causal relationships, as long as these spatial models are established early in the unit and serve as a conceptual reference to introduce the idea of an integrated model.

Stewart, Cartier & Passmore (2005) also explore the construct of model-based inquiry as a scientific practice framework for development, investigation, assessment and revision of models, and explanations in school science. The framework emphasizes how real-world scientists engage in inquiry beyond the use of controlled experiments and use existing models. These models serve as the basis of inquiry to be revised, used to construct explanations, and align understandings through scientific discourse.

In their study on the development of model-based inquiry, Lehrer, Schauble, & Lucas (2008) conducted a yearlong investigation of pond ecology with sixth graders where students developed a model system in a jar. Students developed questions to construct, test and revise their models by comparing them to real phenomenon as explored through multiple visits to a local pond.

Manz (2012) explored the co-construction of modeling practice and ecological concept of plant reproduction in her yearlong investigation with third graders in the school garden. Her findings suggested that for elementary students a broad set of representations, such as drawings and texts in addition to a physical microcosm are helpful in students being able to conceptualize how ecosystems operate.

Water in Earth Systems

An understanding of where water is found in the world is fundamental to conceptualizing water cycles and systems and understanding earth and environmental science (Assaraf, &Orion, 2005a, 2005b, 2010, 2012). A system maintains its existence and functions through the interaction of its parts (Assaraf, & Orion, 2005b). Grotzer, & Basca, (2003) believe that to understand and reason effectively about ecosystems, students need to comprehend a variety of causal patterns. Without an understanding of groundwater occurrence in nature, students are unable to grasp ideas around groundwater overuse, contamination and protection (Reinfried, 2006). Ecosystem processes such as water cycling operate at temporal and spatial levels that are difficult to observe or emulate through experimentation (Kamarainen et al. 2015). Students struggle with understanding causal relationships between water and land and visualizing hidden subsystems such as groundwater (Agelidou et al., 2001; Assaraf, & Orion, 2005a, 2005b). Hidden agents, such groundwater are generally perceived as disconnected from Earth systems (Assaraf, & Orion, 2005b; Dickerson, & Dawkins, 2004) with no relationship to the surrounding land, soil, rocks or vegetation and that the water cycle as a series of "unrelated pieces of knowledge." (Assaraf &Orion 2005a, p. 520)

Early studies of elementary science students’ conceptions of water cycles (Agelidou et al., 2001; Bar 1989) found misconceptions based on states of matter. Some described the cycle in terms of physical states such as melting and freezing, while others were unable to explain changes of the states of matter such as evaporation and condensation. Similar findings were found among fifth graders (Endreny, 2010) and pre-service elementary science educators (Cardak, 2009) where the water cycle was described in terms of only two to three transformations: evaporation, condensation, and precipitation between the atmosphere and the Earth. Students not only struggle to recognize simple cyclic patterns, but also their underlying mechanisms, the transformation of the states of matter and energy as water cycles through the Earth’s systems (Assaraf, & Orion, 2005b; Cardak, 2009; Dickerson, & Dawkins, 2004).

Authentic learning environments. The No Child Left inside Act (2015) presents the conception that the domain of environmental education is an essential feature to enhance student learning and problem- solving skills in science. Research supports that direct experiences in the natural world significantly decrease symptoms of stress, hyperactivity and impulsivity, and increases academic performance (Bogner, 1998; Kuo, Browning, & Penner, 2017; Kuo, & Taylor, 2004; Selhub, & Logan, 2012). An essential component of the experiential learning framework, concrete experience, is grounded in the conception of learning by interacting with the world around you.

In the science classroom, students generally develop an understanding of the natural processes of water systems on a global scale but hold a lack of awareness and connection to their own local water resources (Covitt, Gunckel, & Anderson, 2009; Dove, Everett, & Preece, 1999; Shepardson et al., 2007). Students' experiences with water at school and home do not allow them to understand the basic natural processes in which water is involved (Agelidou, et al., 2001). Field trips can be viewed as an example of short-term experiential education where learners are engaged directly with real world phenomenon. These research experiences allow learners to clarify and confirm what they have learned in the classroom (Scarce, 1997).

In a study of 5th grade students in an outdoor ecology programs, Bogner (1998) compared a one-day to a five-day exploration and found that both experiences provided considerable gains in ecological knowledge and stewardship. Outdoor learning experiences result in greater student involvement. Incorporating an authentic outdoor-based inquiry learning activity where students have direct contact with real phenomena enables students to develop a conceptual understanding of water cycles and the interconnections between components of the system (Assaraf, & Orion 2010; Bogner, 1998; Covit et al., 2009; Dove et al., 1999). Similarly, in a study of urban 5th graders conception of watersheds (Endreny, 2010) found that modeling watershed run-off events both inside and outside the classroom helped students develop a greater conceptual understanding of how water flows in nature. Participation in outdoor learning experience (Assaraf, & Orion, 2005b) increased students understanding of infiltration and run-off in the water cycle and their perception of natural phenomena.

Visually based instructional methods and tools such as field trips, hands on experiments and models were found to be effective tools to address misconceptions about water cycles and assist students in developing appropriate mental models of groundwater principles (Dickerson, Callahan, Sickle, & Hay, 2005). The study presented in this paper engages students in authentic learning environments as part of participation in the experiential water unit.

Drawing and Art as Experience

The rationale for the use of children's drawings is supported by Eisner (1969) as a means of interpretation, understanding them as a "reflection of individual personalities and responses to the world around them." (p.133) In addition, Dewey (1934) views art as not being a product, but a human experience. He discusses the importance of making the ordinary experiences in life artistic and interacting with the environment around you to understand theory:

> Flowers can be enjoyed without knowing about the interactions of soil, air, moisture, and seeds of which they are the result. But they cannot be understood without taking just these interactions into account—and theory is a matter of understanding. (p.12)

Building on this idea, he adds that we need to understand the importance of the environment we live in and interact and connect with it to keep life going. For Dewey the aesthetic and the intellectual are the same as they both focus on experiences.

Eisner (2002) advocates that the arts can help with the overall academic success of children. There is no right or wrong in the arts, as art is all about how we experience the world. These experiences vary from person to person, so different perspectives are celebrated. Eisner posits that the benefits of learning are best achieved through many sources, rather than one domain of knowledge. His rationale is that this approach fosters the development of problem solving skills in children, by introducing the idea that a problem can have many solutions, not just one.

Theoretical Framework

Experiential Education Theory

Grounded within his theory of constructivism, Jean Piaget (1970) included an experiential perspective of learning where students experience or interact with their ideas in the construction of knowledge. When provided with the opportunity to involve themselves in complex, problem-based learning, students can access their prior knowledge to connect to new information. In the process of encountering the experience, new concepts can potentially be constructed or outcomes of such an effort may help students synthesize concepts and understandings.

Dewey (2007) advocates the process of experiential learning through real life experience to construct knowledge. He finds fault with the organization of schools where learning objectives are based on classroom requirements to cover subject matter and testing constraints take precedence. Instead, he views learning as an active, educational, experiential, child-centered process.

It is through what Dewey (1958) refers to as primary experiences that learners connect to direct experiences of the world with all their senses, and secondary experiences where they take these experiences and reconfigure them into something with tangible specificity. Primary experience is the basis for natural science and observing the ways certain things interact is a part of the experience itself, ‘it is not experience which is experienced, but nature—stones, plants, animals, diseases, health, temperature, electricity, and so on.” (p. 276).

Dewey (2007) formulates and explains the criteria for the educative value of an experience through his theory of experiential education. This theory is based upon the idea of the continuum of experience; he describes experience as a “moving force” where experiences are continuous and cumulative, and learning occurs when new ideas are connected to prior knowledge. This view is like the thinking that surrounds the conception of learning progressions, an organizing framework for NGSS (2013) instruction and curriculum. The basis of this framework is that learning progresses through the investigation of a topic over time that builds cumulatively and in developmentally informed ways (Schweingruber, et al., 2007).

Dewey (2007) presents two principles central to his philosophy of experience: the principle of continuity and the principle of interaction. The first principle, continuity, imparts that experiences are a continuum, where each build upon the next, fostering growth and development through the progression. In contrast, the second principle, interaction, is based on situated learning; the interaction between the individual and the environment. Learning develops through this interaction. The transaction between the two principles, where they interact forms a situation where learning is gained through an experience.

It is through reflective thinking, the process of making sense of the experience that changes occur in the learner. Emphasizing the link between thinking and action, reflection and observation, the learner constructs meaning from experience. The use of reflection is a valuable research tool for the case study presented in this paper to assess how the teacher and her student understand hydrological systems, water quality data, and how these understandings change with new evidence.

Experiential Learning Theory

Based on Dewey’s (2007) experiential education theory, Kolb (2014) developed an experiential learning theory centered on based on the conception that learning takes place because of an experience (see Figure 2.1). This theory uses a learning cycle as a model to represent the continuum of experience, “the process where knowledge is created though the transformation of experience, knowledge results from the combination of grasping and transforming experience.” (p. 41) Learners grasp information through concrete experiences (CE) and abstract concepts (AC). Learners can then transform the experience or concept to make meaning in their own world through reflective observation (RO) and active experimentation (AE). The key components of the model are interaction and reflection. Knowledge is gained through the process of making sense of the experience.

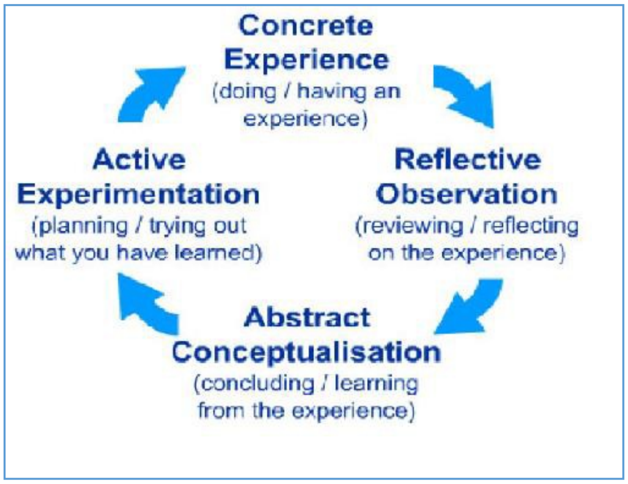


Figure 2.1. Experiential learning cycle. Experience as the source of learning and development (Kolb, 2014).

Like Dewey’s (2007) principle of continuum, Kolb’s (2014) experiential learning model supports an ongoing process of learning, where the setting provides the basis for the participant’s reflection. Participants who take an active role in the experience gain a deeper understanding of concepts and content than those who stand by and passively receive information.

The works of both Kolb (2014) and Schon (1987) emphasize the important role of reflection as a classroom tool to create situated learning for the individual, encouraging learners to consider a concrete experience from many different perspectives, their own individual feelings, as well as those of their classmates. Like Dewey’s principle of continuum, Kolb’s curriculum model supports an ongoing process of learning, where the setting provides the basis for the participant’s reflection. This reflective discourse occurs continuously, before, during and after their experience. Dewey’s idea of reflective thinking emphasizes the link between thinking and action, reflection and observation.

Through the processing and analysis of these perceptions, a new understanding can be conceptualized that can be used to guide the learners’ application of active experimentation with an experience in the same or different context. This reflective discourse occurs continuously, before, during and after their experience prompting the participant to process new ideas and apply these concepts to a new setting and new situations. People learn best through active involvement in the learning process and through thinking and discussing what they have learned.

Boud, Keogh, & Walker (1985) view reflection as a classroom tool to help students make sense of the experience and organize this process into a set of multiple states that includes: an initial recollection of the experience through discussion, attending to and managing any positive or negative feeling from the experience and then reevaluating the experience considering these first two stages. “This process involves identifying, changing, and modifying the knowledge, skills, and attitudes which result from experience, and linking and relating them to the stored knowledge, skills, and attitudes which are already part of our mental apparatus.” (Thatcher, 1990 p. 265)

For the purposes of the case study presented in this paper, experiential education theory (Dewey, 2007) and experiential learning theory (Kolb, 2014) combine as a framework to connect teacher professional development with student performance as outcomes from participation in an experiential water unit. Experiential education is a construct that associates the relationship between the individual, the teacher, and the environment as a pathway to knowledge (Dewey, 2007; Joplin 1981; Kolb, 2014).

Experiential education theory centers on the direct experience and focused reflection of the learner (Joplin, 1981), and requires students to be active participants in their learning. Experiential learning theory focuses more on the process, relying on the transformation of knowledge through activation and reflection for learning to occur (Kolb, 2014). Taken together Dewey (2007) and Kolb's (2014) theories are complementary and combine in this research to tell a story of the experience of the teacher, as a mentor and a learner, guiding students through their experiential learning cycle and gaining an understanding of how to implement experiential education in the science classroom.

Constructivism

This research study is guided by a constructivist perspective, where meanings are constructed by students' participation in a context-specific activity. Piaget (1970) postulated that an individual's construction of natural phenomena occurs from their interactions with other individuals and environments in their everyday lives. As the learner actively constructs meaning based on their interactions and experiences in the world, knowledge is constructed through making connections between old and new ideas.

According to Sawyer (2005) when children actively participate in the construction of their own knowledge, they acquire a deeper, more meaningful understanding of knowledge and motivation to learn. In the constructivist model of knowledge, learners look for meaning by negotiating the interaction of scientific and everyday concepts grounded in their individual understandings and social and cultural beliefs (Karpov, 2014). This internal construction of knowledge is also discussed by Driver (1985) where learning is not based on a connection with an external reality where humans encounter the world directly, but rather they do so through their internal representations of it, where "perception is the construction of a model of the world." (p.196)

Social constructivism. Piaget (1970) supports the idea that it is not through individual construction, but social discourse that children develop perceptions and worldviews. Learning science involves "developing the values and beliefs shared in the science community." (Lee, 1999, p.189) It is through this interaction, embedded in a community of practice and engaging in the language of science, and social discourse of scientific ideas that the individual can construct personal meaning (Driver, 1994).

This theoretical perspective also addresses children's cognitive understanding through the process of knowledge acquisition or what is referred to by the late psychologist Lev Vygotsky as the "zone of proximal development" (ZPD) (Karpov, 2014). This "zone" is the area of exploration that students might be cognitively prepared for but requires scaffolding; here, a teacher or more experienced peer interacts with them to develop an understanding. Vygotsky believed that the individual experience is secondary; it is the social experience that is the primary means of knowledge acquisition and transformation to higher cognitive function. These functions included meaning, memory, attention, thinking, and perception (Karpov, 2014).

Science is a community of practice, where participation in science activities is rooted in scientific culture. Enculturation is “socially negotiated” and co- constructed through participation with more skilled members through scaffolding. An individual, when embedded in this community and engaging in the language of science then has the ability to draw personal meaning from this interaction through the social discourse of scientific ideas. Brown, Collins, & Duguid (1989) discuss this same process of social negotiation, where the activities of a community of learners are socially constructed through *in-situ* norms and behaviors and interactions that provide a scaffold of knowledge that cannot be separated from the situation in which it develops. Brown, Collins, & Duguid make a clear distinction between science classroom activity within the school culture and the authentic activity of science practitioners. By working collaboratively to understand concepts, students participate in authentic activity. To connect to the activities and culture that give meaning to students outside of the classroom, students must be given the opportunity to enter into a community to observe and practice the behaviors, dialogue and actions of the culture through apprenticeship and participation to make sense of the tools of learning that are presented to them. Interactions of learners through discursive practices like argumentation enhance understanding of science and contribute to the construction of scientific knowledge.

Driver (1985) presents rationale to support the practice of argument in science education as a tool to socially construct and then reconstruct one’s personal knowledge and understanding of phenomenon. She disputes that argumentation is socially situated. Whatever claim one makes, it is co-constructed as part of the social context of the community of discourse. To reconcile the multiple science views, discourses and information sources that students are exposed to, they must be able to critically examine all of these ideas to make sense of them. Argumentation provides an arena for these science conversations. Through inductive reasoning and the use of the argumentation process, engagement in this learning environment provides scaffolding and a level of apprenticeship to promote scientific thinking and understanding (Driver, 1985).

III – METHODS

Research Approach

The research approach used for this study was a mixed-methods case study designed to explore the efficacy of an experiential learning framework for teaching and understanding water concepts in elementary school science. This research was designed to characterize and document outcomes of teaching and learning an experiential learning unit on water in Earth systems. The study presented in this paper investigates the process of an elementary science teacher working directly with a practicing scientist, in participation in professional development activities, strategies used for preparation and practice, classroom implementation, and the consequences of student learning.

The rationale for a mixed methods approach was to explore the breadth and depth of understanding among participants and the multiple ways that both the teacher and her students were interacting with the world around them. Creswell (2016) defines mixed methods research as an approach where the researcher “collects and analyzes data, integrates the findings and draws inferences using both qualitative and quantitative approaches methods in a single study or program of study.” (p.4)

Using a mixed methods design was useful to capture both qualitative and quantitative data. This combination allowed me to gather empirical evidence to identify general trends and then examine emerging questions and processes in depth through a variety of different qualitative data instruments collected from the teacher as well as individual students in each of the classroom sections to provide clarification for these outcomes (Creswell, 2017). Multiple forms of data collection served the purpose of triangulation of both qualitative and quantitative data, to characterize, support and compare findings (Fraenkel, & Wallen, 2006).

Data collected in this case study were analyzed both quantitatively and qualitatively to assess the impact of participation in the experiential learning unit on science teaching practice and science learning. To address both components of research question one, a qualitative-to-quantitative approach was most appropriate to generalize findings about participation in professional development, and document implementation and strategies used for the experiential water unit. To address research questions two and three, a quantitative-to-qualitative approach was most appropriate to explain results that address the consequences of the experiential water unit on student learning (Creswell, 2016).

Qualitative Methods

A qualitative research method is informed by different philosophical approaches and interpretative frameworks (Creswell, 2016). As Denzin and Lincoln (2011) explain, “qualitative research is a situated activity that locates the observer in the world, qualitative researchers study things in their natural settings, attempting to make sense of, or interpret, phenomena in terms of the meanings people bring to them.” (p.3) It was this construction of meaning about causal relationships in water systems that I explored as I engaged students in experiential learning environments and asked them how these experiences influenced their conceptual understanding and knowledge. Using an interactive research design--- the case study approach, that enabled me to conduct a site study to examine the experiences of both teacher and student learning within a bounded program (the experiential water unit) and gain a better understanding of all study participants construction of knowledge (McMillan & Schumacher,2014).

To meet Creswell and Clark (2007) and Merriam's (1998) criteria for a case study, multiple sources of data were collected to examine the events through triangulation and contribute to the validity of the research (Yin, 2003). The setting for this case study was bounded by the research location, the Avenue School, an elementary school based in Queens, New York.

Qualitative methods (field observations, interviews, and document analysis) were chosen for a more in-depth exploration and to understand the experiences of both the teacher and her students through an inductive style of data collection and analysis. Using this method allowed me to use tools such as interviews and field observations to answer emerging questions and build these responses into general themes which could then be interpreted for meaning (Creswell, 2016, 2017).

Quantitative Methods

The use of a quantitative research design enabled me to gather empirical evidence of teacher competency in classroom and field observations and establish relationships between the measured variables of student conceptions, and aptitude across and within both sections of elementary science students (Creswell, 2016). Since there was no direct control or manipulation of conditions, a non-experimental comparative design was utilized to study the differences between the two groups. This quantitative design allowed me to study relationships between different phenomenon and measure the impact that independent variables such as teacher competency had on learning outcomes (McMillan, & Schumacher, 2014).

Using a Likert scale, I was able to observe and measure teacher capability by analyzing the relationship between variables and the level of student engagement in scientifically oriented questions in field observations. The use of a pretest and posttest allowed me to generalize empirical findings within and across both groups of students. The unit content (see Table 3.1), draws from the three dimensions of learning from the NGSS framework the NYC 6-12 Earth Science Scope and Sequence (NYCDOE, 2016) and adaptations from the *Engineering is Elementary, Water, Water, Everywhere* curriculum (Lachapelle, & Cunningham, 2007) to promote conceptual understanding of porosity and permeability, engineering design, and representations of water in earth systems.

Table 3.1

Three Dimensions of the NGSS in the Experiential Water Unit

Disciplinary Core Ideas	Science and Engineering Practices	Crosscutting Concepts
ESS2.A: Earth Materials and Systems	Asking and defining questions	Systems and system models
ESS2.C: The Roles of Water in Earth's Surface	Developing and using models	Cause and Effect
ESS3.C: Human Impacts on Earth Systems	Planning and carrying out investigations	
ETS1: Engineering Design	Analyzing and interpreting data	
	Constructing explanations and designing solutions	

Participants and Setting

Participants for this case study were drawn from a gifted and talented school located in Queens, NY. Participants are the science teacher and two sections of 6th grade students. Students in both sections completed informed consent and assent forms to participate in this study (Appendix A). Table 3.2 provides a summary of school characteristics to provide context to the student participants. Lower and upper elementary levels are located on two separate campuses. The 6th through 8th grade campus is the site of three other middle schools and has a large schoolyard surrounding the building. The school, Avenue School (pseudonym), is also walking distance from Socrates Sculpture Park, where there is waterfront access to a natural area, Hallett's Cove.

Table 3.2

Summary of Avenue school characteristics 2016-2017

Characteristic	Measure
Grade levels served	K-8
Total enrollment	370
6th grade enrollment	90
% of students qualifying for free or reduced-price lunch	100%
% of Asian students	43%
% of Black students	6%
% of Hispanic students	9%
% of White students	32%
% of students designated as Limited English	1%
% of students with Special Needs	6%
% of teachers with fewer than 3 years of teaching	40%

The teacher participant for the study, Betsy (pseudonym), had been teaching mathematics and science at the Avenue school since the school opened in the fall of 2014. I was introduced to Betsy in the spring of 2015, while I was observing the EiE unit in the technology classroom at the Avenue School. The school principal had suggested that the following school year the unit be brought into the science classroom since Betsy had already been integrating themes of water and climate into her classroom. Betsy was the only science teacher at the Avenue School and was working with the New York City Department of Environmental Protection to plan a field trip to a local creek for her students to explore water and sewage treatment and the New York City water supply. Betsy had been using the FOSS© Water module in her classroom and expressed to me her frustration with the unit and how she had been deconstructing kit items to create individual science labs. It was in this initial meeting that we discussed the idea of having her revise and adapt the EiE water unit for the science classroom.

The setting for this study was on-site at the Avenue school and off-site at two different aquatic field locations, The Bronx River and Hallett's Cove. On-site, Betsy participated in four professional development sessions on-site after school hours. Professional development took place over four weekly sessions that lasted for one to two hours per session. Each session was conducted in the science classroom and facilitated by myself, a working scientist who is a specialist in the field of water ecology and environmental science.

Following the completion of these sessions, an experiential water unit was implemented in two sections of 6th grade elementary science students, over the course of the semester. The experiential unit consisted of a total of four to five classroom and field lessons which were based on four lessons adapted from the *EiE Water, Water, Everywhere* curriculum, NYC DOE and NGSS (2013) resources.

Using the EiE Curriculum

For this research study, an adaptation of the EiE, *Water*, *Water*, *Everywhere* unit was used to explore and discuss the concept of water filtration through connections between the scientific study of water and the water cycle, Earth's role in water processes, and the role of technology and engineering in providing clean and healthy water. Through an inquiry based, experiential learning unit, students explore systems through an investigation of filter materials and filter design to plan, construct, test and improve their own water filtration model (Lachapelle, & Cunningham, 2007).

Water is ubiquitous throughout the earth and holds a dynamic role in shaping Earths systems. To foster this understanding, it is imperative that students recognize the importance of water, where it originates and where it goes. Groundwater is a critical natural resource that provides source water for irrigation in agriculture, industry and public water supply. Water scarcity is not just a global environmental issue; it is a natural resource issue that persists in the United States, most prominently in the state California, where 40% of household drinking water is from groundwater. One solution California has considered is the use of groundwater banking, essentially a savings account for water supply. Without an understanding of groundwater occurrence in nature, students will be unable to grasp ideas around groundwater overuse, contamination and protection (Reinfried, 2006)

The unit adapted for this research, *Water, Water, Everywhere* introduces the problem of water pollution through the social and cultural context of a young girl in India observing the river near her home and extracting water to create a habitat for her pet turtle. This four-part unit explores and discusses the connections between the scientific study of water and the water cycle, the important role of environmental engineers in providing and maintaining clean and healthy water and encourages students to investigate filter materials and design to plan, construct, test and improve their own water filters (Lachapelle, & Cunningham, 2007).

In this study, the EiE unit was redesigned to incorporate the experiential learning cycle (Kolb, 2014), as a framework to carry out science and engineering practices from the NGSS (2013): planning and carrying out investigations, analyzing and interpreting data, developing and using models, and constructing explanations and designing solutions. The framework operates on a continuum grounded by a concrete experience, reflective observation, abstract conceptualization and active experimentation. Applying the framework created an opportunity to link together field components and laboratory work to embrace a more holistic view of stocks and flows in water systems. Integrating the NGSS into Betsy's unit plan design allowed us to connect content on water science and engineering practices within the larger context of water quality.

In making these adaptations, we created multiple ways for students to experience the world around them. Instead of experiencing the everyday world of the storybook protagonist, the student connects to their local environment and views the problem through their own worldview. They use the experiential framework to guide them through an investigation, analysis, and problem solving. The water filter design component of the EiE *Water, Water, Everywhere* unit aligns with the NYC Science Scope and Sequence, Grades 6-8 Engineering Design for Developing and Using Models and Conducting Investigations (NYCDOE, 2016). Additionally, these lessons align with the NGSS performance expectations for Earth Systems (MS-ESS2) and Engineering Design (MS-ETS1, MS-ETS2, MS-ETS3) and crosscutting concepts of systems and system models and patterns (NGSS, 2013). Table 3. 3 provides an overview of the adaptations made to the EiE curriculum.

Table 3.3

Adaptation of EiE Unit Plan to Experiential Water Unit

Lesson #	EiE	Experiential Water Unit
1	Saving Salila's Turtle	• Field Sampling at Bronx River • Field Sampling at Hallett's Cove • Core Ideas: Abiotic Factors, Water Quality • Science and Engineering Practices: Planning and Carrying Out Investigations, Analyzing and Interpreting Data
2	Who are Environmental Engineers?	• Using Field Data • Core Ideas: Abiotic Factors, Water Quality • Science and Engineering Practices: Planning and Carrying Out Investigations, Analyzing and Interpreting Data
3	Exploring Filter Materials	• Materials lab: Exploring Permeability and Porosity in Earth Materials • Core Ideas: Hydrology, Earth Science • Science and Engineering Practices: Planning and Carrying Out Investigations, Analyzing and Interpreting Data
4	Designing a water filter	• Design and redesign of water filter using earth materials • Core Ideas: Engineering Design, Model Based Inquiry, Hydrology • Science and Engineering Practices: Developing and Using Models, Planning and Carrying Out Investigations, Constructing Explanations and Designing Solution

Data Collection

To investigate how Betsy interpreted the professional development and integrated it into her classroom practice, data collection included qualitative instruments: a teacher survey, teacher artifacts, a semi-structured interview, and a personal field journal (kept by the researcher). For teacher data, quantitative instruments included the use of a Likert scale to evaluate strategies and implementation of the experiential unit through observations in the field and the classroom. To measure students' cognition and understanding of the scientific content, data collection included quantitative instruments: a pretest and post unit test, and pre and post-drawing assessments. Qualitative instruments included: observations of student discussion, and student artifacts in the form of field journals (developed by the researcher) and a water filter reflection assessment (developed by teacher).

Professional development timeline

Over the course of the two years that I worked with Betsy, there was extensive email communication and in person support. After our initial meeting in September of 2015, our continued correspondence included sending information about workshops, curriculum sources and direct contacts to assist her in setting up field trips and facilitate access to other professional development opportunities. Several times over the course of the next two semesters Betsy contacted me directly for guidance on curriculum and lesson plans on issues in environmental health and water quality. During the 2015-2016 academic year I assisted Betsy in her completion of a grant application for a Watershed

Forestry Bus Tour for her students. She was not selected for this grant, but later in the semester I was able to connect her with an educator-based watershed tour sponsored by the DEP for her to attend on her own. In addition, I provided in-person support for field trips to Newtown Creek and Socrates Sculpture Park to assist with water quality monitoring and observed three classroom sessions of the EiE water filter laboratory in its original curriculum format. During the 2016-17 academic year I conducted the experiential based case study presented in this paper, which included formal professional development hours in the classroom setting. Throughout the semester there was continued correspondence and exchange of resources. In the spring of 2017, I provided in person support as a judge for her students' green roof presentations.

Instrument design

The pre-and posttests were developed based on water concepts from the Engineering is Elementary curriculum. Other questions on both the pre- and posttest (Q1, Q2 and Q6) were taken from the Geoscience Concept Inventory (GCI), developed by Libarkin and Anderson (2005) and is a set of "conceptually based questions geared toward fundamental concepts in the Earth Sciences" (p.394). The system thinking hierarchical tool that was used to code the reflection rubric was developed and tested by Assaraf and Orion's (2005b, 2010) qualitative scale to assess the understanding of systems thinking of upper elementary level science students.

Published documentation of water cycle misconceptions (Agelidou, 2001; Assaraf, & Orion, 2005a, 2005b; Dickerson, & Dawkins, 2004) provided a basis for the development of test questions in this study that focused on misconceptions. The questions on the pretest and posttest focused on the following misconceptions:

- Water flows beneath the ground in the form of underground lakes, rivers, and streams
- Groundwater and surface water are separate.
- Groundwater contains soil and other particles and so it must be muddy.
- Groundwater only exists in areas where there is a lot of precipitation.

To answer research question one, research instruments included: (a) teacher background survey, (b) a unit plan and supporting lesson plan documents (provided by the teacher) (c) professional development reflection questions, (d) a teacher semi-structured interview and (e) classroom and field observations (assembled by the researcher). To answer research questions two and three student evidence included (f) pre and post-drawing assessment (g) pretest and posttest (h) water filter reflection assessment (provided by the teacher) (i) classroom and field observations (assembled by the researcher) and (j) student artifacts.

Qualitative Data

Teacher Data

Teacher data collection relied on qualitative methods to conduct general observations and develop understandings to integrate these instruments to make meaning within a larger context. To provide context and depth to research question one, I gathered baseline information about the teacher through a background survey (Appendix B), an open-ended questionnaire that was assembled by the researcher and administered during the week before the professional development sessions to provide information on subject matter and pedagogical content knowledge. There were 10 short answer questions that asked the teacher to provide information on her academic background, certification area, professional development experiences, and conceptual understanding of hydrological cycles and watersheds. The questionnaire was produced and administered using the online survey tool, Qualtrics©.

The purpose of research question one was to investigate how the participating teacher interpreted science and pedagogical content from the professional development sessions (Appendix C), into her classroom practice and impacted her own lifelong learning on the subject matter. The goal of this research question was to examine changes in the teacher's conceptual understanding and interpretation of the experiential learning framework and science content that was presented during professional development sessions.

To provide context and depth to sub-question 1a, I examined teacher artifacts (unit plan and reflections) from the four professional development sessions. Betsy was assigned two reflection questions to contemplate the professional development experience and create an essential question for the drawing assessment. This information was used to carry out lessons in the science classroom. One was assigned after the second professional development session and the other after the final session. The first reflection question was: *Please reflect about your thoughts about participation in professional development sessions to date and how you might use what you have learned in your own* *pedagogy*? The second set of reflection questions were: *How could you use the experiential learning cycle for the water filter lessons? How will you use the information on water systems, data analysis and next generation science standards in your classroom practice?*

As part of the Avenue school requirements, Betsy was asked to create a curriculum unit plan for the fall semester. For the purposes of this research, it was requested that Betsy structure and sequence a four to five-day water unit plan infused within the greater context of her Avenue school curriculum plan as a culminating project preceding the professional development sessions. The water unit plan was reviewed for scope and content and was used as a guiding document throughout the semester to keep lessons within sequence.

Qualitative methods were again utilized at the end of the semester, following the final sessions, tests and assessments of the unit, a semi-structured interview was conducted with Betsy (Appendix D). The semi-structured interview employed open-ended questions to support prompts to foster a richer understanding of the subject matter being discussed (Seidman, 1998).

Student Data

Qualitative instruments included water filter reflection assessments, and student artifacts (laboratory sheets, reflection essays, and field notebooks) collected at the end of the experiential learning unit. These instruments were used to assess students' conceptual understanding and interpretation of science and engineering practices.

The purpose of research question three was to evaluate the efficacy of system modeling as it was used in the experiential unit to model a physical water filter to illustrate how water flows through different substrates as it cycles through Earth's different systems. "Complex systems are an essential focus for science education, because they contain important ideas in national standards, and provide an integrating context across a number of science domains." (Assaraf, & Orion, 2010, p. 541) This question addresses the use of systems thinking to tackle commonly held misconceptions about water processes and interactions in natural and engineering systems. Students struggle with the development of systems thinking, the interactions and connections between water and land and visualizing hidden elements in earth systems, such as groundwater (Agelidou et al., 2001; Assaraf, & Orion, 2005a, 2005b). While these misconceptions are found throughout all grades, systems thinking skills are least developed among elementary students (Assaraf, & Orion, 2010, Cardak, 2009).

Conceptual and physical representations help students grasp and utilize concepts that are not immediately visible in the ecosystems they are investigating. Learners develop understanding of the world through construction and revision of mental models. Mental imagery facilitates memory and representations allow us to form mental models of images and concepts to promote better understanding of connections between systems and functions in our everyday world (Kuhn, 1989). By reflecting on the properties of relations represented in mental models, an individual may come to acquire higher-order knowledge of them (Johnson-Laird, 1981 p. 191). Research supports that elementary level students have the capacity to develop higher systems thinking ability (Assaraf, &

Orion 2005a, 2005b, 2010, 2012; Draper, 1993; Evaragorou et al., 2009; Hmelo-Silver et al., 2007; Kali et al., 2003). To answer this question, open ended pre and post test questions, and student artifacts from science notebooks were scored using a system thinking rubric (Appendix E).

Student Artifacts

In the science classroom, the use of metacognitive strategies are helpful for students to transfer understanding from scientific to everyday reasoning (Wiggins & McTighe, 2005). The use of a field notebook to record scientific observations is a useful tool in promoting this self-awareness and as a formative assessment. In the classroom, having students work on a water filtration model as a group allows them to problem solve with their peers to figure out the best materials and make conclusions based on their understanding of the porosity and permeability of materials and water flow from their field experiences. Having students share their observations in class is a highly productive way for them to interact with their peers and construct cognitive understanding. Student artifacts from science notebooks were scored using a rubric (Appendix F) adapted from Wiggins and McTighe (1998).

Water System Reflections

Water Filter Reflections were created in collaboration with the researcher and administered by the teacher (Appendix G). They were distributed at the end of the unit as a summative assessment. When students reflect on their own cognition and learning, it creates a sense of ownership and empowerment that they are in control of their accomplishments. Knowledge of cognition and factors that influence performance, are constructed through declarative, procedural and conditional knowledge (Karpov, 2014).

Quantitative Data

Teacher Data

Observations. Throughout the semester, Betsy was observed in her implementation and strategies to carry out the experiential unit across two sections of students. Observations were recorded inside the science classroom and outside the science classroom (field sampling at Hallett's Cove and the Bronx River) to document communication patterns, discourse and discussion between each group of students and student-teacher interactions. Her ability to engage students with content and promote scientific inquiry was scored quantitatively using a rubric with a Likert scale.

To provide context and depth to sub-question 1b, I observed her practice in the classroom and field with a rubric adapted from the Practices of Science Observation Protocol (P-SOP) protocol (Appendix H). The Likert scale ranged from 0 to 3 points and was used to guide documentation of observations to determine if the teacher was engaging students, if the students were on task, and if they were encountering struggles or misconceptions. A score of zero on the scale indicated the lowest level and 3 the highest level of student engagement in scientifically oriented questions. Student data was used to confirm outcomes of the efficacy of the teacher's approach to the science content and learning framework.

Student Data

The purpose of question two was to evaluate how participation in a teacher designed experiential learning unit contributed to students understanding of science and engineering practices, water quality and role of water in Earth's system processes. This question investigated student's perceptions of filtration and the processes and interactions of the hydrological cycle and the development of a conceptual understanding of the relationship between water technology, engineering design and natural water systems.

The objective was to address the misconceptions that many students hold about the composition of the hydrosphere and how water flows, transforms and interacts in the natural world. Students hold an incomplete conception of how water cycles on Earth--that water only moves between the Earth's surface and the atmosphere; subsurface reservoirs are not taken into consideration.

Additionally, there is a lack of understanding of the transformation of the states of matter and energy as water cycles throgh Earths systems (Assaraf, & Orion, 2005b; Cardak, 2009; Dickerson, & Dawkins, 2004).

To address this question, quantitative instruments of pre and posttests (Appendix I), and pre and post unit drawing assessments were administered at the start and end of the experiential water unit.

Pretest and posttest. Quantitative instruments were used to measure the evolution of student conceptions prior to and following participation of the experiential water unit. A pretest and posttest (Appendix I) were administered a week prior to the start of the unit and a week after the final unit session. These tests served as formative and summative assessments. The posttest contains the same questions as the pretest, with a new question on water filtration with visual drawings. Open-ended questions from the pre and posttest, were scored using a rubric (Appendix F) adapted from Wiggins and McTighe (1998).

Drawing assessment. Drawings were used as a learning strategy to connect a student's mental models to conceptual understanding, utilizing this as a blueprint to build representative models to solve problems. Students that were not comfortable drawing were encouraged to write responses. Researchers have used drawing tasks as an assessment instrument to investigate water concept misconceptions, and to establish a coding framework in analysis (Agelidou, et al, 2001; Assaraf, & Orion, 2005a; Cardak 2009; Rennie, & Jarvis, 1995; Shepardson, et. al 2007). Pre and post-drawing assessments were administered at the start and the end of the experiential learning unit. The pretest was used as a formative assessment and the posttest as a summative assessment to evaluate student's prior knowledge, elicit student's conceptions of water cycles, and provide a way for them to answer questions in a different context. In developing an understanding of the pathways and transformations of water as it cycles Earth's systems, a drawing of the cycle is used as a bridging activity for students to access and develop their mental models. These outcomes can inform teaching practices by providing information on student misconceptions. The drawing assessment can then be referenced to provide an artifact of students' preconceptions about water cycles. To avoid misinterpretations of drawings, Rennie and Jarvis (1995) recommend that students annotate or add sentences to their drawing to provide clarification of their understanding. Both the pre and post-drawing assessments were used as a research tool to evaluate students’ conceptual understanding of the phenomenon. Table 3.4 provides an overview of which data collection sources were used to answer each research question.

Table 3.4
Summary Data Collection Table

Research Question	Data Collection Procedure
(1) How does an experiential learning framework facilitate the inclusion of science and engineering practices in elementary science? a. In regard to teacher professional development. b. In regard to implementation and strategies.	Background survey Unit Plan Assignment Observations Reflection Questions Essential Question Semi-structured interview
(2) How does the experiential learning framework foster the conceptual development of water science and engineering practices in elementary science students?	Observations Pre/Post Test Pre/Post-drawing Reflection Assessment Student artifacts
(3) How does the experiential learning framework foster the development of systems thinking skills in elementary science students?	Observations Pre/Post Test Pre/Post-drawing Reflection Assessment Student artifacts

Methods of Analysis

Analysis was concurrent throughout the data collection process; researcher notes, and observations were continuously examined considering the development of new questions or the emergence of new themes and recurring patterns. This iterative process allows the data to inform the research process and guide the analysis (McMillan, & Schumacher, 2014). As part of this process, I kept a field notebook to write observer memos to myself when I witnessed emerging themes or patterns of behavior that I wanted to explore further and include as part of discussions with students and the interview process with the classroom teacher (Merriam, 1998).

Stake (1995) explains that qualitative research methods are best matched with the philosophical foundations of the instrumental case. With an instrumental case study, my objective was to offer a thick description of the study participants and setting to reconstruct the experience. Examination of the classroom teacher and two groups of students was intended to provide insight into how a scientist works with a science teacher to facilitate science education and content knowledge in water science and engineering.

Qualitative Analysis

To analyze and reconstruct this experience a qualitative case study format was used to frame the participants and setting as part of my analysis (Merriam, 1998; Creswell, & Clark, 2007). Data collected with qualitative research instruments, were prepared for qualitative analysis with NVivo 11© software. To learn how to use the software I attended three training sessions in the fall of 2017.

There was a great deal of preparation of documents before uploading them to NVivo 11$^{©}$. Initially I started with three documents, the teacher semi structured interview, the student reflections and open-ended pretest and posttest responses. Headings needed to be assigned to group questions from the semi structured interview, or sections in the student artifacts and reflections by theme. Preparing them in this way facilitated the creation of nodes of emerging themes in the software. Teacher data that was initially uploaded, the semi structured interview, resulted in the creation of 20 theme-based nodes based on the headings mentioned above. Once documents had been uploaded, I was also able to conduct queries on all the qualitative data to identify 642 keywords through word frequency counts. I omitted keywords such as water in the query since this term was dominant in the interview and test questions.

Working with NVivo 11©, it was difficult to visualize my themes in a way that was not dependent on viewing it directly in the software platform. After consulting with my academic advisor, I decided to use qualitative text analysis to code my data line by line and initiate open coding to identify topics and trends grounded in the data (Charmaz, 2014; Kuckartz, 2014).

Initial coding practices used line by line and open coded to identify topics and trends grounded in the data (Charmaz, 2014). Qualitative text analysis was used to identify thematic categories and subcategories (Boeije, 2010; Kuckartz, 2014). This inductive process was employed to identify themes and trends that emerge from the data, after collection, rather than being defined on the initial data (McMillan &Schumacher, 2014).

Three iterations of inductive and constant comparative review of teacher data (teacher background survey, semi structured interview, professional development reflections, field notes and observations) resulted in the compilation of broad themes, which were later refined and coded into 18 broad categories and 50 subcategories (Creswell, 2007). These categories were tracked and refined in a Microsoft Excel© spreadsheet.

Four iterations of inductive and constant comparative review were used to compare key similarities and difference in qualitative student data. Student artifacts, assessments and open ended pre and posttests were coded for emergent themes as well as the application of two different rubrics. This included a scoring rubric to evaluate the six facets of understanding of Wiggins and McTighe's (1998) (Appendix F). Scores ranged from one (naïve) to six (sophisticated) level of understanding. As well as a qualitative scale to measure the enactment of systems thinking skills, adapted from Assaraf and Orion's (2005a) Systems Thinking Scale (Appendix E).

The first two cycles of coding resulted in researcher generated themes as well as those that emerged from the participants own language, or what is referred to as in vivo codes (Kuckartz, 2014). Metaphors included: dirt sticking to soil, soil sticking to sand, gravel catching all the dirt, gravel as the best filter and water being stuck, blocked or trapped by sand and gravel. Coding of student data resulted in 15 broad categories and 18 subcategories. These categories were also tracked and refined in a Microsoft Excel © spreadsheet.

Due to some personal issues that the classroom teacher had with the school administration, she misplaced most of the teacher created water filter assessments. Approximately 10% of all water filter reflection assessments completed by students were returned to me, creating a data gap with this analysis. Themes found in these water filter assessments matched those found within the other forms of qualitative data. Triangulation of data offset this weakness with the strength of the other research instruments and converging of the same results (Creswell, & Clark, 2007).

Quantitative Analysis

Quantitative analysis was utilized for the drawing assessment to measure student understanding of water cycle components, processes and systems thinking skills. Analyses used a coding framework (Appendix J) created by the researcher adapted from Rennie and Jarvis (1995) and used components of Drapers (1993) systems thinking scale. This framework recorded students initials conceptions of phenomenon and included common concepts, relationships, processes and cycling patterns that one would find in the water cycle. Initially I conducted analysis for the drawing assessments myself and then employed the assistance of two colleagues that work as research scientists in water science and engineering. Inter-rater agreement was scored using a scale developed by Landis and Koch (1977).

A t-test statistic and one-way analysis of variance were used to compare and analyze patterns of statistically significant change or consistency between the pretest and posttest results within and between each 6th grade science classroom. These parametric statistical measures were evaluated with SPSS© statistical software. The t-test statistic allowed me to make statements about research question two by estimating the common variance between two means to determine whether the difference between them had statistical significance or was due to chance (Coladarci, & Cobb, 2004). Since data in the pre and posttest were similar, a two-sample paired or “pooled” t-test was used to test the difference between the means based on two independent random samples. Since there were two sections of the class participating in the unit, a t-test statistic will also be using to compare between the groups. Because the paired t-test value considers the correlation between the two scores, the between groups t-test value was used to measure effect size. One-way ANOVA was used to make comparisons between the samples as well. Like the t-test procedure, analysis was conducted for variance between the two groups as well as within the two groups.

Many students left blank spaces on both the pre and the posttest creating a confounding factor in evaluating results. To resolve this, I went back through the pre and posttest and grouped questions by subject matter and then conducted parametric statistics based on this new grouping.

The use of pretesting was a critical research instrument for this intervention. It helped to establish a baseline understanding of students' prior knowledge and conceptions around water concepts, processes and systems and aided the teacher in planning and implementation of water content. I do not believe that this instrument presented a threat to external validity, since the pretest was given one week before the start of the unit. Results between the two groups varied, this indicated to me that groups did not experience the intervention in the same way and learned differently because of pretesting, compared to what outcomes there may have been if no pretest had been given (Creswell, 2007).

Role of Researcher and Researcher Bias

As the researcher, I attempted to not introduce any bias into this study. As a scientist working in the field of environmental science and water engineering, I recognize that I harbor a strong bias in that I believe it is essential for students to have a conceptual understanding of where their water comes from, how it moves and transforms and how our actions impact water quality. To minimize my bias, I practiced what Creswell (2007) refers to as critical subjectivity; maintaining a high level of self-awareness throughout the research process. As a participant observer in all facets of classroom observations and discussions, I acknowledged I bring my own set of experiences and philosophies to the research setting that may influence outcomes (Guba and Lincoln, 1981).

I obtained a Master’s in Environmental Management and a second Master’s in Environmental Health prior to beginning doctoral work in science education. Therefore, as the researcher I was in the position to undertake an examination of methods and outcomes of learning in the science classroom. I also have experience in the elementary school and field setting, both as an informal science teacher and practicing scientist. As a participant observer, I have documented in a field notebook, elementary school students’ misconceptions about water in Earth systems and the teacher’s pedagogical science content knowledge following an experiential intervention in science. I have served as a mentor to the teacher, guiding her through professional development activities, assisting with grant applications to broaden science programming, assisted her with curriculum development, provided resources from the science industry, and helped her to identify common student misconceptions and assist her on strategies to resolve them.

Reliability/Validity/Trustworthiness

Reliability for this study was consistent using stable research instruments: a background survey, an interview, observations, a teacher unit plan, student labs, journals, drawing assessments, reflection essays and pretests and posttests to ensure triangulation (Fraenkel, & Wallen, 2006; Guba, & Lincoln, 1981; Yin, 2003). I consciously tried to not interfere with the integrity of the case study, however acknowledging my own bias and expectations of and desires for the study outcome may have consciously or unconsciously impacted the outcome and a threat to the internal validity of this case study (Stake, 1995).

Teacher unit plans provided a check on content understanding and application. Validation strategies included an investigative process where quantitative and qualitative data sources were collected and compared with one another for triangulation of emergent themes and empirical evidence. Colleagues within the NYC Bureau of Environmental Science and Engineering were solicited for qualitative assessment methods, such as member checking and coding of data sources (Creswell, 2007)

Limitations

Challenges included institutional constraints and stressors that NYCDOE placed on the Betsy due to an inapropriate sub-link that she accidently placed on the school server that violated school policy. I believe that these events threatened internal validity by history, events that impacted the teacher during the study that may have impacted the outcome.

Other limitations included the subject matter that I approached in this study, elementary teacher and scientist partnerships. There was not a breadth of literature on this topic from the perspective of the elementary science teacher and from the view of a scientist.

I also encountered challenges with the application of my theoretical framework, experiential learning, in creating professional development sessions. Although I have created training and professional development in collaboration with other educators and organizations, this is the first time that I developed materials on my own. For this study, I feel as though I customized the PD for the classroom teacher based on her area of interest and my research interest.

Limitations in analysis were due to my lack of familiarity with qualitative software and the challenges that I faced learning this new technology and applying it to my own data.

In addition, I encountered scheduling challenges for observation, data collection, analysis and writing and revision as I am an employed full time by the City of New York. Annual leave and sick time were used in excess to pursue this research. This included leave without pay. Table 3.5 provides an overview of the data collection timeline for the duration of the intervention.

Table 3.5

Data Collection Timeline

Pre-Water Unit		During Water Unit	Post-Water Unit
Teacher	Professional Development Sessions (4) Background Survey (one week before via Qualitrics®) Unit-Plan Assignment	Observations (Implementation & Strategies)	Semi-Structured Interview (two- weeks after)
Students	Pretest, Drawing Assessment (one week before unit starts)	Session 1: Concrete experience - Snapshot Day (Science notebooks and observations)	Posttest, Post- drawing assessment (one-week after unit ends)
		Session 2: Reflection and data debriefing (Science notebooks & observations)	Water Filter Reflection Assignment (one- week after)
		Session 3: Permeability Explore (Science notebooks & observations)	
		Session 4: Water Filters Lab (Science notebooks & observations)	

IV – FINDINGS

In this chapter, results are organized by research question, and both qualitative and quantitative data are presented together to formulate findings statements. These results are divided into two sections, teacher findings and student findings. Multiple data sources were coded in an analytical inductive manner to identify and describe emerging themes about the teacher's enactment of experiential learning through her practice and resulting student achievement in science and engineering (Charmaz, 2014). At the end of the chapter, these findings are summarized.

Teacher Background

Prior to coming to the Avenue School, Betsy taught elementary mathematics and science at a public school in Rhode Island. She does not have an academic background or certification in the sciences. Her New York State Teaching Certification is in students with disabilities and elementary education. Her academic background includes a Bachelor of Fine Arts in illustration and a Master of Childhood Education.

Her professional development includes participation in Urban Advantage (2017), a collaborative program that unites cultural institutions with classroom teachers to promote science and engineering practices and rigorous investigations. More recently, in July of 2016, Betsy participated in the Watershed Forestry Institute for teachers which is an immersive teacher professional development program that incorporates hands on learning of the New York City Watershed Forestry, water quality science, and drinking water supply systems (Watershed Agricultural Council, 2018).

From participating in these professional development experiences, Betsy developed a good understanding of the how NYC receives its drinking water. Subsequently she was able to articulate how water flows from the NYC watershed to the tap in the background survey. In addition, when she was asked in the survey about the pathway of a cycling water molecule, her conceptual understanding was well developed, incorporating surface and subsurface components of the water cycle:

> Water in a body of water is evaporated into the air where is condensates into clouds. Then when clouds reach saturation rainfall begins, creating precipitation. Some water may hit trees or non-permeable surfaces, causing it to runoff. Water that hits the ground in a permeable area will absorb into the ground or be evaporated again. (Teacher Background Survey, 8/23/16)

Changing the EiE Curriculum

In December of 2015, I observed Betsy in her classroom implementing a segment of the EiE water filter laboratory where students construct water filters. Betsy and I instantly connected through our love and fascination with water. She had grown up in Michigan near the Great Lakes and had fostered a personal connection to water throughout her life. I was able to relate to her personal experience, as the East and Hudson Rivers played a large role in my own water stewardship.

In the spring of 2016, I met with Betsy to discuss what worked and what did not work based on my observations and her experience with the lesson. In the original EiE *Water, Water Everywher*e curriculum, filter efficiency is rated based on a scoring system through indicators of color, cost and time. The engineering design problem is presented as one where students need to come up with a cost effective, simple model for a way to filter dirty water. Manmade materials such as cotton balls, coffee filters, and screens have a price assigned to each item. A final score is then calculated based on these three parameters.

As part of her 2015 implementation, Betsy had created a role play scenario where students approach a “store” and must purchase their materials for their filter. What Betsy and I both observed was that students enjoyed this role play element, but then had difficulty negotiating cost in their group discussion as well as a measure of filter efficiency in the design process. The result was that groups working together were unable to collaborate effectively and students expressed tension because of these constraints. In other words, the constraints of the EiE curriculum did not foster social constructivism, students involved in group work did not collaborate or engage in meaningful discourse. This approach did not connect to student interests or experiences.

We then discussed how to give the unit more depth by unifying concepts of natural systems with engineering design. At the corner of her classroom, Betsy had an area called “the dirt depot”, which she had students use for botany investigations. As part of the restructuring, we decided to include Earth materials (soil, sand, and gravel) instead of manmade materials to connect with the domain of Earth systems and crosscutting concepts of systems and system models in the NGSS (2013). Table 4.1 provides an overview of the adaptations made to the EiE *Water, Water, Everywhere* Curriculum.

Table 4.1

Changes to Engineering is Elementary water filter lab lessons

EiE unit	Adaptation	Rationale
Cost included as a measure of filter efficiency	Cost eliminated	Earth materials instead of manmade (cotton balls, cheesecloth) to connect to NGSS-Earth systems and system models
	Open ended inquiry	
Time included as a measure of filter efficiency	Materials: Sand, Gravel, Soil	
Materials used to filter dirty water- water clarity as a measure of efficiency: Cotton, Screens, Cheesecloth materials used		Land and water – landscapes (connection to standards K-8 science scope and sequence)

With this redesign, we also discussed the rigor of the curriculum. The EiE *Water, Water, Everywhere* curriculum aligns with the 3rd-5th grade band of the NGSS. As part of this band, students test and revise a design to come up with the best solution to a problem and then confirm their results. Adapting this component of the EiE unit for 6th graders entailed broadening problem-solving practices towards a more focused design criterion. One where students would be expected to use systematic methods in their design process, to compare and identify constraints of successful solutions. This adaptation would enable students to understand the larger context within which the problem is defined. These changes prompted Betsy to adapt her unit plan to connect to content on water science and engineering practices within the larger context of water quality. I suggested using the experiential learning cycle model as framework to link together field components and laboratory work to embrace a more holistic view of stocks and flows in water systems.

During the fall 2015 semester, I had also accompanied Betsy and her students on a field trip with NYC Department of Environmental Protection education staff to visit the Newtown Creek treatment facility to learn about water treatment and disinfection. At the facility, students viewed a PowerPoint that discussed the different steps in the treatment process, but unfortunately, they were unable to see the actual treatment operations directly. This was disappointing to the students and overall the experience did not link to the classroom content on water filters

The storybook, meant to provide real world context in EiE, did not connect to a context that was meaningful for urban elementary school students. Therefore, in all iterations of *Water, Water, Everywhere* the storybook was never used in any of the science and engineering lessons. For the 2016 redesign, Betsy decided to have students visit the Bronx River as their initial concrete experience. This anchoring activity would be utilized to introduce students to watersheds and field sampling by immersing them in authentic scientific inquiry through experiential learning.

To add another dimension to these investigations, we discussed having students participate in *A Day in the Life of the Hudson River and Harbor* at Hallett’s Cove as part of their field experience. Also referred to as Hudson River Snapshot Day, this annual event, hosted by the New York State Department of Environmental Conservation (DEC) and Columbia University, Lamont-Doherty Earth Observatory provides teacher training and school partnerships with environmental education programs to collect data on different parameters of the Hudson River estuary from Troy to New York Harbor to provide a snapshot in time of the water quality of the river. Lesson plans and data collection sheets are provided on the programs website for a wide range of parameters extending from water chemistry to fish and macro invertebrates to sediment sampling (Lamont Doherty Earth Observatory, 2018).

As part of this experience, we discussed having students collect a soil core sample to introduce them to earth materials and explore concepts of permeability and porosity.

Neither Betsy nor I knew how to use a soil core, but DEC had this equipment available to all Snapshot Day participants and Betsy was assured in her training that a representative would be on site to assist her in working with this equipment. The rationale for this data collection was that these concepts could later be incorporated as part of an exploration laboratory in class to investigate the properties of natural materials before leading into the water filter lesson.

Hallett’s Cove is a local waterbody with a sandy beachfront walking distance from the school site. The site did not directly connect to the Hudson River estuary but was connected by a tributary to the greater New York Harbor. My thought was that by visiting this site, students would be presented with a more realistic representation of a water system in a local context and could later reference this experience to connect it to the construction of their filtration model.

Because Betsy would also be teaching mathematics in the coming school year we discussed integrating more data analysis in students' reflective observation. Sample collection from more than one field site (Bronx River and Hallett's Cove) presented an opportunity for Betsy to include the science and engineering practice of analyzing and interpreting data. Using this approach, Betsy could have students' correlate sample results and explore differences and similarities across content as part of the water science units.

Teacher Findings from Professional Development Sessions

The following section presents findings on research question 1.a: How does an experiential learning framework facilitate the inclusion of science and engineering practices in elementary science in regard to professional development?

Professional Development Sessions

Four professional development (PD) sessions were conducted after school hours on September 7th, 9th, 14th and 16th in 2016. Each session was 1.5 hours in length and guided by the framework of the experiential learning cycle. The PD overview for each session (Appendix C) included in-session elements such as a presentation of information, hands-on experiences, debrief and discussion and post session elements such as readings and assignments. After each session debriefing, I reflected in my own field journal.

Teacher artifacts from the PD sessions included two written reflections, an essential question, and the culminating assignment, a final unit plan. This integrated unit plan, included the experiential water unit lessons within the context of her greater unit plan for the semester. The semi structured interview was conducted after the completion of the entire unit during the winter break in 2017 and included questions about the PD experience.

From the onset, Betsy had intended to incorporate water themes into her semester long unit plan. PD sessions were a means to assist her in the development of science content knowledge on water in Earth systems and engineering. In addition, the PD sessions provided pedagogical content knowledge on implementing an experiential education model and three-dimensional learning into her classroom practice. Her culminating PD assignment, a final unit plan, would provide Betsy with a blueprint for how she would be sequencing her lessons and insight to me on how she would be building cohesion through each unit concept using the experiential learning framework.

Session One: Introduction to Experiential Learning

The objective of the first PD session was to help Betsy improve her skills and confidence in understanding the experiential learning cycle. Specifically, I addressed the two main dimensions of the cycle and how they correspond to two of the different ways we learn: How we perceive new information or experience (concrete –abstract dimension) and how we process what we perceive (reflective-active dimension) (Kolb, 2014).

To facilitate this, I had Betsy experience all the stages of the learning cycle directly through a hands-on soil core sampling activity. I placed Betsy in the role of a hydrogeologist and had her investigate where we could find water in the schoolyard using a soil core sampler.

Figure 4.1. Session One: Soil Core Sampling Activity

To assist in the exploration, I created an authentic map of the different types of sediment surrounding the schoolyard (Appendix K) and a microcosm of the schoolyard (see Figure 4.1) composed of three layers of sediment (soil, sand and gravel) in a large square container. To engineer a soil core apparatus, Betsy was provided with a variety of materials (plastic test tubes of different height and diameter, binder clips, rubber bands, plastic stopper, pipe cleaners, and paper clips) and a worksheet (Appendix L) adapted from *TeachEngineering*© (2018), so that she could record data from her observations about the materials in each layer.

Betsy tried different combinations to create a soil core apparatus and found that a plastic test tube with a pipe cleaner wrapped around it and twisted to create a handle worked best. After ample time to engage in the activity, Betsy was asked to reflect on which materials worked best to create a soil core sampler and what types of sediments she observed in the different layers and record these findings on the soil core worksheet. We discussed the permeability and porosity of the different materials and how using the data on the worksheet could assist us to find out where one might find water resources in the layers. She noted that it was helpful for her to visualize the data observations through drawing characteristics of the materials (such as pore size) in the layers on the worksheet and how she might use a similar activity in her classroom implementation.

In my field journal I noted that after the reflection, Betsy was excited about applying the framework and continued to experiment with the model and kept thinking of new ways to redesign the soil core sampler for her students. We had discussed ways to connect biotic to abiotic factors and she indicated that she would like to do a pH lab with a rainbow of colors. This conception was based on the idea that she would demonstrate the acidity of different liquids with the colorimetric kits she had purchased. Colorimetric tests yield results based on a change in color. I suggested that she have the students' conduct the lab, so they could connect to the content, but she expressed concern that it would be too time consuming to do during the 45-minute time slot for science. I had made this suggestion based on my past classroom observations with Betsy. In her practice, she tended to operate along the lines of a more of a teacher centered than student centered classroom. My definition of a teacher-centered classroom is similar the conception held by Rodriguez (1997) as one that employs a traditional lecture format, and in the science classroom, the teacher follows cookbook prescribed science activities and teacher directives. The teacher-centered classroom contrasts an experiential based one, where learning is more engaging, and instruction is hands-on and minds-on.

Overall, during this PD session Betsy was very focused on how to use and adapt these activities. She did well recording data but needed helped with analysis. I noted this in my field journal as well because at the end of the session it was challenging for me pull her away from the concrete experience to make conclusions about the data and engage in reflection.

Session Two: Water Systems

In session two, the objective was for Betsy to build science content knowledge and conceptual understanding of the relationships between water systems. I still used the experiential framework as guidance in my lesson plan. Lessons proceeded on a continuum, initially Betsy was engaged in a concrete experience, which we would then reflect on and make conclusions about to guide us in the next steps of the lesson. To connect understanding of concepts to a local context, I used a map of the New York City Watershed to show the interrelationships between local water bodies that make up the larger water supply system. As a formative assessment, I used a drawing of a waterbody for Betsy to label to measure her understanding of the hydrological cycle. I also provided her with a poem on the cycle that she had seen before and later adapted into a song and dance and game for her students (Appendix M).

For the drawing assessment, I used an essential question for guidance: Where does water come from and where does it go to? She did a simple line drawing with arrows to indicate surface and atmospheric level interactions, and an arrow to indicate infiltration. Afterwards, we reflected on her drawing. Her conceptual understanding was well developed for surface level interactions and some subsurface connections. To build on her conceptual understanding, I used a three-dimensional learning approach to introduce a modeling activity. Applying the NGSS (2013) science and engineering practice of developing and using models, the disciplinary core idea of Earth materials and systems and the cross-cutting concept of systems and system models, we worked together to create a microcosm of an aquifer. In this activity items were provided (i.e., cellulose sponges, floral foam, scrub sponges, a bin, some rubber bands, and a pitcher of water) to explore how water flows through these different types of materials. The following is the narrative I provided during this activity to engage Betsy in an experience while using a visualization I created on groundwater for guidance (see Figure 4.2).

Imagine two sponges, stacked one on top of the other. The bottom sponge has been soaked in water and represents the saturated zone—all its pore spaces are filled with water. The top sponge has been wetted, but the water has been squeezed out, this represents the "unsaturated zone"—some of the spaces are filled with water, some are filled with air. The boundary between the two zones represents the water table. The water in the saturated sponge represents groundwater (Wisconsin Department of Natural Resources, 2016).

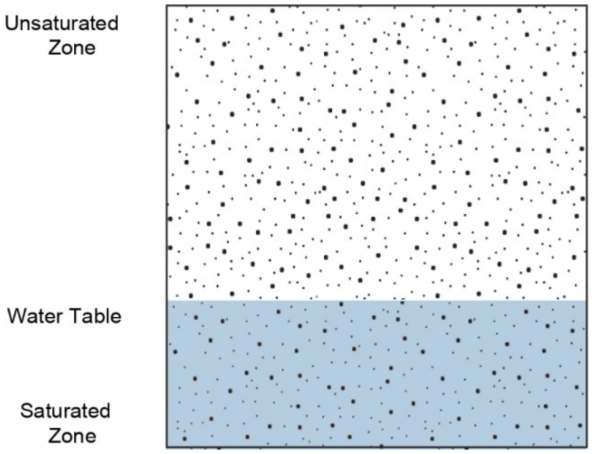


Figure 4.2. Where do we find groundwater handout. Groundwater Study Guide. Wisconsin Department of Natural Resources (2016)

After this exploration, Betsy was asked to rate the properties of the materials on a scale from of 0 to 5, where 0 would indicate water did not flow through and 5 the most porous and let the water through immediately. She indicated that the cellulose sponge was the most porous with a score of 4.5, followed by the scrub sponge with a score 3 and the floral foam with a score of 2. We recorded these observations on the whiteboard in the classroom. A few months later, when we reflected on the PD sessions in the semi-structured interview, I asked Betsy if these concrete experiences were helpful in developing her water science content knowledge and classroom implementation:

> Yes, the groundwater activities helped a lot with linking…like ok our watershed is surface runoff to infiltration to like making those pieces relate. Cause I think it’s easy with water to get really confused…and I think I cut a lot of stuff to make this more cohesive. I think identifying it from the start, that students thought – well all water evaporates- helped focus- Like ok so this is how this will be a higher-level unit, will be that we are focusing on this subterranean water more which is something we can see that they don’t know. (Teacher Interview 1/25/17)

In the debrief we discussed how to introduce some of the more complex groundwater concepts with the activities we used during the PD session. She was concerned her students would not understand how to make sense of groundwater systems. At the end of the debriefing, it began to storm outside. Rainwater generally has a high pH since it filters atmosphere components, so I encouraged her to collect rainwater for a pH lab. She expressed that day and a few times thereafter her lack of confidence in her chemistry skills with water quality measurements, but that she had the resources to order more advanced water quality monitoring kits for the semester. The chemistry kits that she had used to date and would continue to use over the course of the semester were simple tests based on colorimetric measures (aka color change) that could be compared to a visual test key. I provided her with the names of more advanced kits that could be ordered and offered to help her to learn how to use them.

Betsy said that she would be collecting some rainwater from her classroom windowsill and was going to take measurements the next day. She even showed me a rain gauge that she had purchased that could be put into the ground in the schoolyard to collect and measure water to use for this type of activity. Unfortunately, these ideas were never put into practice and a pH lab never transpired over the course of the semester.

In my field journal, I noted how meaningful this session was to me and how much I enjoyed teaching about water. I also made observations about Betsy:

> Betsy was very engaged and excited about the year ahead and asked a lot of questions about the NYC water supply. She struggled a bit with transformations and interactions in the water cycle and we discussed where her deficiencies were and how to introduce some of the more complex concepts with

> the activities I presented to her in today's PD session. She very much plans as she goes along and does not see how to interconnect the concepts with one another. She still views each as a fragmented unit and is focused on the field trips and experiences and less on debriefing and reflection. She is concerned her students won't understand how to make sense of the data because she is still grasping with understanding what it all means. I hope that the next session on data analysis and reflection can address some of these concerns. (Field Journal, 9/9/2016)

As homework, I asked her to write a reflection on how she intended to integrate what she had learned from the first two PD sessions into her pedagogy. She expressed:

> I will be changing some vocabulary to be more advanced and accurate. I like the idea of them [my students] drawing what they know and using that as an assessment tool. I think it was a good point that students don't understand how water moves underground. I like in general when students' misconceptions are considered. I like the idea of the sponges and modeling the ground and how water percolates. Immediately I will start using vocabulary, add percolation into the water cycle song I have and talk about water tables and underground water as part of the storm water process. (Betsy, Professional Development, Reflection after Session 1 and 2)

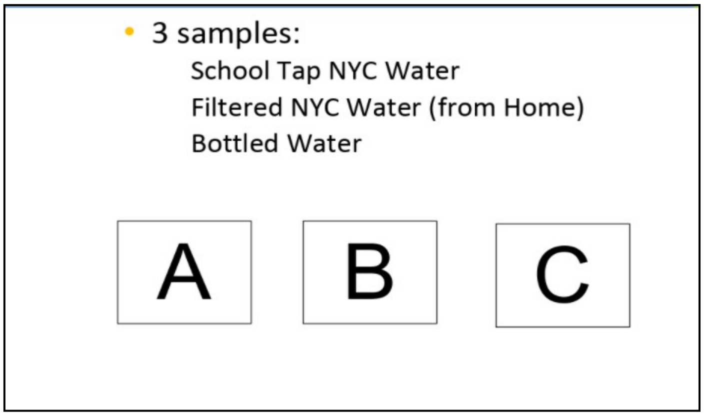
I was excited that Betsy was so enthusiastic about integrating new and broad ideas about learning by doing activities in these two PD session. What concerned me about our discussion and the written reflection she submitted was how she was focused on components and activities and not the big picture. To provide some guidance, I assigned a reading by Lehrer and Schauble (2006) on Cultivating Model-Based Reasoning in Science Education. My rationale was that this article would not only provide examples of the use of models in classroom practice, but also how microcosms and visual representations could be used to provide cohesion across specific units or individual concepts.

Session 3: Investigations and Analyzing and Interpreting Data

In PD session three, the objective was for Betsy to become comfortable using and analyzing real world data by engaging in an inquiry-based investigation. The first part of the session was focused on working directly with water quality datasets, and the second part was an exercise on how to develop an essential question. Again, my goal was to use the experiential learning framework as a guide for the lesson.

First, I reviewed the different water quality parameters used to assess the health of a waterbody, and had Betsy take part in a dissolved oxygen (DO) activity, comparing and analyzing NYCDEP water quality data from two different water systems, Harbor and Stream Water. I used an essential question to guide Betsy in her experience: How do you think water quality is affected by temperature?

We reviewed a frequency table that I had created of the water quality data on the computer overhead projector. Each field of data listed the sample date, air temperature and dissolved oxygen (DO) measurement. As we explored the dataset I asked Betsy to identify fluctuations in temperature and the concurrent DO levels at different times of the year. Viewing this correlation directly, I was able to illustrate the NGSS crosscutting concept of cause and effect.



- 3 samples:
  - School Tap NYC Water
  - Filtered NYC Water (from Home)
  - Bottled Water

Figure 4.3 Testing Abiotic Factors

Using guidance from the NGSS science and engineering practice of analyzing and interpreting data, I asked her how we could represent the data needed to answer the essential question. She decided to create a simple line graph on the whiteboard using the 12 months of the year on the X axis and measure of DO on the Y axis to create a visual model of this phenomenon. We reflected briefly on the results and how the use of a simple graph was effective in visualizing data. The next step in the session was taking this experience and applying it to active experimentation. Using the guiding question: What does measuring abiotic factors tell us about water quality across different types of water?

Betsy was instructed to test three different drinking water samples using a simple colorimetric water chemistry kit for the following abiotic parameters: chlorine, alkalinity, pH, hardness, and nitrate. Betsy only knew the samples as A, B, and C. She was not aware of the source for each sample: a school water fountain, bottled water, and filtered tap water (see Figure 4.3). After testing each sample, she recorded the data on a table on the whiteboard. All sample results were within normal ranges, the exception was the pH of the bottled water, 6.0, indicating that it was slightly acidic. We discussed the results and made conclusions about why one sample might have better water quality than the other. Betsy then guessed which source went with each sample and was very surprised that the filtered tap water was the cleanest.

After the data investigations I had her complete a worksheet activity on developing essential questions and assigned her homework which asked her to develop an essential question for the experiential water component of the unit plan. In my field journal, I noted:

> Today we did interpreting data and analysis with inquiry investigations, essential questions and looked at the relationship between DO, temperature and oxygen saturation. Betsy is not confident in her chemistry abilities and confused about Nitrogen. She expressed that she is intimidated by the chemistry and initially intends to have groups of students create posters where they write out what each abiotic factor is. This was disconcerting to me- how are students going to improve their science literacy and learn about how these factors affect water quality and living things by copying over text from books and resources? We discussed having students think more independently and asking each group to synthesize findings in their own words and have each person in the group present a core idea to the rest of the class. My concern was that students will become experts on the one specific parameter but miss the big picture. Her solution was to mix up the groups when they sample later. Not sure this suffices. She suggested an assessment where they match the abiotic factor to other items. I suggested scaffolding in some higher levels of interpretation as well, such as having them explore the interactions between factors. She wants to combine the most useful items from each poster into one for each parameter and put them in the hallway. I'm not sure how to advise her. I thought revisiting their conceptions later and revising, however, it's thoughts from text, not their own understanding. (Field Journal, 9/14/2016)

It was clear in my reflection that Betsy and I differed in our pedagogical approach of how to introduce abiotic factors to students. In practice, she implemented the plan that she had intended as this was what she was most comfortable with.

Session 4: Three-Dimensional Science: Learning for the Next Generation

Before we started the final session, Betsy shared her essential question from the assignment: In nature, where does water come from and where does it flow? We discussed incorporating this question as a guide for the drawing assessment and both agreed that the question would be a good fit for the research instrument. In addition, we discussed using this question as a touchstone that she could come back to over the course of the unit to connect students to content and concepts.

The objective for the fourth PD session was to introduce the NGSS and to highlight points of alignment between the NGSS and the experiential learning cycle using modeling instruction. The NGSS review included an overview of the architecture, where I used the middle school domain on Earth and Human Activity as an example. We discussed what was new about the standards, how traditional science focused on the development of individual skills, but for the NGSS practices, skills are carried out within a community with shared goals and norms about how to develop science knowledge (NGSS, 2013).

To illustrate modeling with the NGSS, we practiced with content that I had used in my own coursework. The practice was based on discussing the limitations and precision of a model as the representation of a system. The example was to assess whether a flashlight was an accurate representation of the sun. To facilitate, I asked her to identify the differences between the flashlight and sun.

We listed on the whiteboard the main differences and reflected on the properties of the sun and how they corresponded to the flashlight. I then presented her with an alternative item, a light bulb, and asked her to reflect on which one would be a more precise representation.

At the end of the session we discussed the final unit plan and her framework based around field activities and trips that illustrate the concepts of water systems, water quality and water filtration. The final unit plan that Betsy submitted (Appendix N), was well organized and the sequencing provided students with a learning progression on watersheds and water quality, modeling and water systems in the local context of New York State. Lessons in the final unit plan that comprised the experiential water unit and subsequent data that would be collected from students are highlighted in bold.

In addition to the unit plan, I assigned Betsy two final reflection questions. She responded to the reflection questions in the following manner. The first question was, how could you use the experiential learning cycle for the water filter lessons? Her response was:

> I can use experimental learning by allowing students to explore materials and make choices. By allowing them to do several builds they can see the interactions of materials and redesign their filter to be the most productive. This will allow them to use the information they gain from the hands-on experience. (Betsy, Professional Development, First Reflection after Session 3 and 4)

Similarly, the second reflection question was: How will you use the information on water systems, data analysis and next generation science standards in your classroom practice? Her response was:

> I will specifically use the standards relating to cycles, and the human impact on the environment. I will add the draw and explain tool combined with a few different models of water traveling through ground materials. I will have students use data analysis to look at water quality around the region at places we cannot visit as well as to look at the data that we can collect ourselves. This will help students to formulate lab reports and see the connections between their data and world data. (Betsy, Professional Development, Second Reflection after Session 3 and 4).

In my field journal, I noted:

> Reviewed NGSS with her. Not very captivated by it. Wanted to know if it was ok to just focus on one domain all semester. I pointed out that each disciplinary core idea might equal a session. She wants copies of the NGSS for engineering and earth systems. We discussed the unit plan and she has a framework based around field activities and trips that illustrate the concepts but there is still some fragmentation. It will be interesting to see how this evolves and comes together. She is constantly changing her unit plan. (Field Journal, 9/19/2016)

Professional Development Sessions Summary

The four PD sessions had a collective goal of developing science content knowledge in engineering and water in Earth systems and providing pedagogical content knowledge on implementing an experiential model and three-dimensional learning into Betsy’s classroom practice. After each session, Betsy asked to hold onto any worksheets or handouts that I used so that she could adapt them for her classroom practice. As a result, these teacher artifacts were not available as data for me to analyze the impact of the PD sessions.

My inexperience with this type of one-on-one teacher pedagogy and working with elementary students in a classroom setting may have contributed to the frustrations that I experienced when Betsy had difficulty with the content or was unable to make connections between water quality parameters and the hydrological cycle. However, overall, in my planning and practice I was responsive to her needs and did my best to address areas where she expressed interest or that she found challenging.

The immediate impact of the PD sessions was most apparent in Betsy’s practice in the laboratory sessions for the data debriefing after the field experiences and the materials exploration lab. I observed her making real world connections to the samples students had collected and prompting them think about the relationships that different abiotic factors had with one another. Using visualizations, she illustrated concepts of permeability and porosity and connected them to groundwater and aquifers.

The long-term impact of these PD sessions has been most evident in our continued communication. Betsy contacted me with questions about the geology and ecology of the southern state she was now teaching in. I had studied and conducted field sampling in the state as part of my undergraduate work and was happy that she had reached out to me as a resource. More recently Betsy shared photos with me of her students exploring the different soil layers of the schoolyard with a soil core. She said that she had purchased one and practiced on different areas of the schoolyard to make sure students would be able to do the activity on their own.

As she shared these new teaching experiences, the one element that stood out was that Betsy's practice had evolved. She had moved from a teacher centered classroom to one where she was acting as more of a facilitator and allowing her students to collaborate and explore in their field experiences.

Teacher Findings from Unit Implementation and Strategies

The following section presents findings on research question 1.b: How does an experiential learning framework facilitate the inclusion of science and engineering practices in the elementary science classroom in regard to teacher implementation and strategies?

Classroom Practice and Goals

During the 2016-2017 academic year, Betsy taught science for a total of 10 hours per week to three class sections. Class#1 and #2 were participants in this study since they were equivalent in student ability. Betsy's other class was a special education integrated class, or what is referred to as IOP. On some days she taught all three sections, IOP then class #1 and #2, and other days just class #1 and #2. The disadvantage for class #2 was that Betsy would be burnt out from the sessions before, but the advantage was also that by the second or third iteration of a lesson, she had refined some of the details and her instruction approach. Her teaching objective was to have students engage in hands-on inquiry in small groups to explore materials, carry out investigations, and report on their findings. Specifically, Betsy had the goal of working towards open inquiry.

Emergent Themes in Teacher Data

Findings for the teacher implementation and strategies of the experiential water unit are the result of qualitative coding for 18 emergent themes (Table 4.2) from review of multiple data sources, classroom observations, teacher interview and the background survey. Some of these themes make up the findings to answer research question 1.b

Table. 4.2

Emergent themes from qualitative text analysis of teacher data

Category/Theme
High Level work
Sequencing
Resources
Scientific Inquiry
Misconceptions
Social constructivism
Reflective observation
Abstract Conceptualization
Models
Teacher Centered Classroom
Engineering Design Process
Experiential Learning Cycle
Classroom Norms
Instruction
Connection to Nature
Connection to Real World - prior knowledge
Integrative Curriculum- Connection to Math
Analogy

Developing and using models. In the elementary classroom, I observed Betsy use visual representations as a strategy to engage students in concrete experiences. For example, in the materials lab, Betsy used the popular character of Sponge Bob© to create an opposite character, Brick Bob, to model water flow and permeability and porosity through materials. She used this same analogy later when a student expressed the properties of sand: So, you found sand to be absorbent- like a sponge? (Classroom observation, Class #2, 11/30/16)

Betsy noted that the most challenging aspect of the materials laboratory for her students was making the distinction between permeability and porosity. She stated that they did not understand other properties well. As a strategy, she created a series of drawings on the whiteboard to illustrate pore size and gravel:

> Betsy: Does this mean gravel is not porous? *(speaking to student)*
>
> Betsy: (*points to drawing*) Does this have pores?
> A pile of it has a lot of airspace. Gravel itself is not porous but has spaces. Water penetrates the spaces, not the rock.
>
> (Classroom observation, Class #2, 11/30/16)

When the next class came in to participate in the same lesson, students had the same misconception. Betsy used the same drawing to illustrate this concept again:

> Betsy: Did the water go through the gravel itself?
>
> Student: No
>
> Betsy: It went through the air pockets in between.
>
> (Classroom observation, Class #2, 11/30/16)

Throughout the water filter modeling lab, students were able to engage in active experimentation and construct explanations and design solutions. Betsy was cognizant of how students were able to use explanatory models to connect to the content:

> I think the best thing we did this year was deciding to go with just earth materials so that we can really push an understanding of porosity and filtration, of how kids were able to reference an aquifer from their water filter, and I think that was really a lot stronger. Students connected to content. It was a meaningful experience for them and there was task commitment. One section (class# 2) made their own model of a river during study hall period with leaves and rocks and soil. All the students really enjoyed this because they have a desire to build things and explore with models. (Teacher Interview, 1/25/2017)

In classroom observations, the Practices of Science Observation Protocol (P-SOP) (Forbes, Biggers, & Zangori, 2013) rubric was used to assess student engagement in scientific practices represented in the *Framework for K-12 Science Education* (Quinn, et al, 2012). The rubric ranges on a scale from 0 to 3, where 3 indicates the highest level of student engagement in scientifically oriented questions. Table 4.3 illustrates the use of the observation protocol for sessions two through four of the experiential water unit. While in the field, it was difficult to use the rubric to record data but overall student engagement in the concrete experiences was very high for both class sections.

Table 4.3

Experiential Water Unit Teacher Observations

Session	Class	Practices of Science Observation				
		Engagement with Investigation	Engaging Students in giving priority to evidence in response to questions	Engaging Students in formulating explanations from evidence to address scientifically oriented questions	Engaging Students in evaluating their explanations in light of alternative explanations	Engaging students in communicating and justifying their explanations
Session 2: Reflection and data debriefing	Class #1	2	1	1	0	1
	Class #2	2	2	1	0	1
Session 3: Permeability Explore	Class #1	3	2	2	2	2
	Class #2	3	2	1	1	1
Session 4: Water Filter Lab	Class #1	3	2	2	3	3
	Class #2	3	2	2	2	2

In the debriefing and reflections that followed their field experience at Hallett's cove, class #2 had difficulty engaging with the phenomenon, ranking a 1 on the P-SOP rubric. Specifically, they had a disconnect between how the waterbody was being used for fish and fishing (organisms and recreation) and how it connects to waterbodies that connect to waterbodies that we use for drinking water. The students had collected a fiddler crab (later named Grabby) during the field experience and brought the crab back to the classroom and placed it in an empty aquarium. I encouraged Betsy to use the context of the aquarium as a microcosm of the river, therefore giving context to how abiotic factors are impacting the habitat and, in the end, making her work more meaningful. She considered doing this since she wanted to appease her students' curiosity but did not end up using the tank. Her rationale was that she only had one tank and three sections of students and that if only one section conducted the experiments she would not be promoting equity. This same theme resonated in our interview: "I think it's hard because I have so many classes this year even if I have a great idea, I must do it with all three sections." (Teacher Interview, 1/25/2017)

When I asked Betsy if she thought students were able to make connections between field work, data collection and analysis, she expressed concern that it was hard for students to see tangible results and that may have impacted their understanding. She expressed the need for her students to see things visually to understand the science content and phenomenon: "It's hard for them to judge how health has affected (*water quality*) when they can't see it." (Teacher interview, 1/25/2017)

To rectify this in the future, she stated that she intends to do a controlled experiment where she would put motor oil on one set of seeds and not another: “I’m hoping we can bring them back and see how there is an effect. Like oh, this isn’t growing. That is a really concrete thing for them.” (Teacher Interview, 1/25/2017)

High level content. In our adaptation of the EiE curriculum for 6th graders and inclusion of the components of the experiential learning framework, Betsy encountered challenges connecting students to the water content. She cited the rigor of the content itself as one of the primary barriers to implementation:

> Like abiotic factors are very confusing for students and then water filtration with porosity, and again there are no materials for this age group on porosity, it’s very high-level stuff that’s out there to work with. (Teacher Interview, 1/25/2017)

When I asked her what interventions might work best in these instances, such as facilitating more or having students conduct research and making meaning on their own, she stated that: “I think it’s just difficult concept, and again there’s not always texts, or the texts they don’t understand.” (Teacher Interview, 1/25/2017)

Abstract conceptualization. Betsy was remorse about not being able to link to higher level concepts and phenomena: “A challenge is getting students to connect this work (concrete) to greater science concepts and phenomenon.” (Teacher Interview, 1/25/2017). Specifically, she felt that she did not have a strong grasp on the experiential learning cycle component of abstract conceptualization, learning by thinking and concluding:

> I think I could have had more guidance for the conceptualization. I think that I left (*incorporating that element of the experiential cycle framework*) it a little open. The abstract conceptualization allows higher levels of learning to occur. (Teacher Interview, 1/25/2017)

I asked if she thought students were able to grasp this skill in their science practice:

> I think the abstract conceptualization can take different forms and can be harder, but I think the other ones are pretty straightforward as far you know having an experience and then being able to budget in time that they're really observing, and I think that was important too because kids want to just go, go, go. And building in time that they are making observations, watching and listening, and I think that was something especially with water filters that you had to prompt in. That you must sit and look and write and consider and not rush that step. And I think those teams that embraced that found a lot more success and brought up a lot more questions. (Teacher Interview, 1/25/2017)

Concrete experiences. One adaptation that Betsy and I made to the EiE curriculum was the inclusion of a field component. Following the trajectory of the experiential cycle, the field experiences were the anchoring activity for the experiential water unit. Betsy acknowledged the importance of this component in her practice and how this initial experience connected students to engage in practice. She expressed her view on this component: "In these stages, concrete examples are meaningful because the content I am teaching is advanced and difficult for students to understand." (Teacher Interview, 1/25/2017)

Betsy felt that concrete experiences were essential for students at this age and that through these field experiences, students felt ownership over their own learning and made a personal connection: “Experiential learning is valuable because it lets students build background knowledge through hands on activities.” (Teacher Interview, 1/25/2017)

Chawla (2008) maintains that experiences in nature are a way for individuals to gain awareness about their environment and acquire knowledge. Values and experiences of nature give individuals the determination to act to solve present and future environmental problems. In her assessment of the experiential learning cycle, Betsy felt that she had the best understanding of concrete experiences. However, in practice she encountered many challenges.

As a participant observer, it was difficult to use an observation rubric in the field, so I recorded observations afterwards. There were two iterations of the field sampling on Hudson River Snapshot day. Gathering materials and walking over to the site was well organized and in both class sections there were parents who were volunteering to assist. Each group of students was assigned to sample an abiotic factor they had been researching and had done a poster about. They were given reagents for their factor, a clipboard, and a data sheet to make general ecological observations. Two pieces of equipment were loaned to Betsy from The New York State Department of Environmental Conservation (DEC), a seine net and a soil core. Betsy and I had created a soil core worksheet like what I had used with her in the professional development. We had agreed beforehand that Betsy would do the seine demonstration and I would do the soil core and then have the students participate.

The agenda for the field experience was for students to initially collect their water sample and test their abiotic factor and then make other ecological observations on their own. In the first class session, Betsy was enthusiastic, but she had difficulty managing students and keeping them engaged in discussions. She kept putting me on the spot to talk about results from the different abiotic factors instead of allowing students to share out and make conclusions. She demonstrated seining with one seine net and only one pair of waders. In lieu of this, she had asked students to bring in rain boots and push their pants up. The students enjoyed getting messy and splashing in the water, but this detracted from the experience of sampling with the seine net and making ecological observations of the catch.

With the soil core, the ground was very dry, and I had a difficult time penetrating down to get a core sample. It took me several attempts and students were very distracted. In the second iteration with class #2, I did the initial core while Betsy was reviewing directions, so I was able to get right to showing and discussing the core layers with the students. Two parents had showed up last minute and although it was helpful to have an extra set of eyes, I wasn't sure how they could help or give students guidance. DEC had sent an individual with the equipment, but she did not help us out with any of the equipment issues and seemed to just stress Betsy out. Betsy was impatient with class #2 even though the second session went much smoother. When we discussed further, Betsy admitted her own personal bias towards this kind of work. She stated: "I tend to be more about the experience and less about everyone having the same concrete understanding." (Teacher Interview, 1/25/2017)

Further, she talked about the difficulty that she had with implementation in the field:

> Field experiences are hard because it has so many variables. I need to let it be what it wants to be, as a way of observing rather than trying to force it to make a clear statement. I think that can be confusing to kids. It might be better as just being a method of valuing data and observation. (Teacher Interview, 1/25/2017)

Learning from reflection. Betsy views reflective observation (Boud, Keogh, & Walker, 1985; Dewey, 1934) as critical to understanding and an essential component in the continuum of the experiential learning cycle:

> You need them both (*concrete experience and reflective observation*), that’s what makes it higher level work as opposed to other labs where you tell them what to do. They do the experience, and then you tell them why it’s important. In which case you don’t know if there is understanding. (Teacher Interview, 1/25/2017)

In her implementation of the experiential water unit, Betsy made time for student debriefing after Hudson River Snapshot Day and in each iteration of their water filter design. From her perspective, the students needed to be prompted: “For me, the reflecting and observing is more meaningful because it’s harder to get them to do that and that’s a new skill for them.” (Teacher Interview, 1/25/2017)

In her debriefing and reflection with class #2 after Snapshot day, I observed Betsy applying some of the knowledge and skills that she had gained from the third professional development session on investigating and analyzing data:

> Data tells us a story. These stories bring about questions. Commonalities and differences in data across different trials inform our understanding of the water body. (Classroom Observation, Class #2, 10/20/16)

During this reflection with class #2, there was a high level of student engagement (level 2 on the P-SOP observation scale) working with the data related to natural phenomenon. However, in Betsy's practice she had difficulty engaging students in scientific inquiry to formulate explanations from the evidence. She struggled to illustrate commonalities between abiotic factors. I did step in at this point and took on the role of a teacher to discuss some of the inter-relationships between parameters that we sampled, such as temperature and dissolved oxygen and phosphates and turbidity.

After class, I met with Betsy to debrief about the day and discuss next steps. She expressed that did not have confidence in her students' understanding beyond differences and similarities to move onto interrelationships between abiotic factors. When we discussed these concepts, I thought she had a good understanding, however she lacked confidence in her ability and was just starting to comprehend these interrelationships.

Having never been a K-12 classroom teacher, it was difficult for me grasp, but understood that she did not want to teach concepts that she herself was not confident about teaching to her students.

Sequencing. One of the key themes that emerged for Betsy was her struggle making links in her practice from the field testing to the water filters lab:

> The biggest challenge I place on myself is making everything link together. It’s a lot of high level work. There are a lot of things that are going on simultaneously and I think that this is difficult. (Teacher Interview, 1/25/2017)

However, Betsy was able to make connections between what she had experienced in the PD sessions and her classroom implementation of the unit: “So, focusing on groundwater helped a lot with linking, like our watershed is surface runoff to infiltration to making those pieces relate.” (Teacher Interview, 1/25/2017)

Another strategy we identified to make curriculum more cohesive was how she could use formative assessments (such as the pretest and pre-drawing task) to inform her lesson planning. After reviewing results from the pretest, I found that students had different conceptions for question #15, which showed a diagram with a potato plant in a cup that had originally been filled with water and asked students to explain why the cup no longer contained water. Most students answered that the water got sucked up by the roots. A few students answered that it was due to evaporation. Both answers were marked as correct. When I reviewed other questions that addressed evaporation, it was evident from the results that students did indeed have a clear understanding of evaporation and the transformation of water in the water cycle.

I met with Betsy to discuss these tests results and progressive misconceptions, illustrating the example from the pretest about roots and water and evaporation. When I interviewed Betsy at the end of the unit, I asked her if having the pretest as a formative assessment was helpful:

> I think identifying it from the start, that students thought, well all water evaporates, helped me to focus. Like, ok, this is how it will be a higher-level unit, we will be focusing on this subterranean water, which something we can see that they don't know. So, then we didn't need to talk about evaporation at length, they understood, or they had misconceptions because they told me when it rains, and you go outside, that entire puddle is going to evaporate by morning. (Teacher Interview, 1/25/2017)

Integrative approach. The use of an integrative approach allows more curricular flexibility and the capacity to view critical thinking within large complex themes to facilitate comprehension (Mathison & Freeman, 1998). The benefit of this approach was illustrated to me during the first lab session where Betsy used the term pour rate to describe the velocity of water being poured into the filter:

> Student: It seems like the dirt, when poured too quickly made it worse, slowly, less sediment leaks into the water.
> Betsy: Does everyone agree that rate is a factor?
> (Classroom observations, Class #1, 11/29/16)

By using the term 'rate' in the context of pouring the water into the filter, she was applying the NGSS science and engineering practice of using mathematics and computational thinking to express a quantitative relationship between time and volume. Application of this integrative approach was most evident when Betsy worked with class

#1, where she integrated themes from the mathematics class that she taught with these students. This correlation emerged to me after I had transcribed recorded classroom sessions and was conducting qualitative text analysis. In her debrief with class #1 to discuss strategies they used in their filter design, Betsy presented students with an alternate scenario and used mathematical terminology to illustrate how to problem solve:

Betsy: What if you had a taller water bottle? What if I gave you a 2-liter bottle, (*displays one that is on her desk)* or what if you were able to build your own thing and like tape a bunch of bottles together and make it really tall? Would you have made more layers and kept going

Students: Yes
Betsy: How long do you think it would take *(to filter the water*)?
Student: A year!
Betsy: So, math problem, looking at rate, at the rate of how slow these things are, do you think it's a proportional rate, that if your filter was this big (*shows 2-liter bottle*) would the time take twice as long if you made it twice as tall?
Student: (*screams out)* Yes! Maybe.
Betsy: Maybe, I don't know. So, there's a math experiment that could be done there on rate as well.
(Classroom observations, Class #1, 12/1/16)

Facilitating crosscutting concepts. During the class #1water filter debriefing there was an in-depth discussion about the NGSS crosscutting concept of patterns. The K-12 framework for science education defines the concept of observed patterns in nature as those that provide an organizational and classification schema and prompts questions about the relationships and causes underlying them (Quinn et al. 2012, p.84). At the 6th grade level, patterns can be used to identify cause and effect relationships. In the reflection discussion Betsy was able to prompt questions about the relationship between patterns and the filter design when students shared out their design strategies:

Student 1: In our last filter we decided to make a pattern in our filter– sand, dirt, gravel, and then kept going and I kind of feel like layers…. because the sand um ...the sand and the color. I feel like the sand changed the color of the water. …and then it went through again and again, and it got cleaner and cleaner.

Betsy: Alright. So, you feel like the sand was responsible for removing color. Because the first go around we kind of figured out how to get the chunks out, right? And then you were really grappling with how to remove the color.

Student 2: So, we also had the same idea. We all started with the sand and it could like hold up the dirt because the sand was so little from before. The dirt was stuck in the layers and sort of like a pattern but not really.

Betsy: So, this is a question, does it help to make a pattern? Like when people had a pattern for the structure of their layers. Is that beneficial or is that just pretty? So, it's something to think about. I don't know if we have any answer to that?

(Classroom observations, Class #1, 12/1/16)

For the students, creating a pattern for the structure of their layers was an essential tool to determine the efficacy of their water filter model. The makeup of the pattern materials either inhibited or facilitated the flow of water through the model. Identifying a pattern in the layers is a cause and effect relationship. This was something that I think the students were able to grasp in their experimentation. Betsy, acknowledges this relationship but does not make any direct conclusions, leaving it open to interpretation by the students. Since this was a reflection discussion, I felt that it should not have been left open to interpretation, this was a concluding activity where students were sharing their strategies. Abstract conceptualization could have been inducted to make definitive statements about which patterns create the most effective water filter model.

Factors in Practice

In one of the water filter lab observations, I witnessed a group of students who had a lot of tension about making design decisions and did not having consensus. Betsy intervened and scored high on the P-SOP scale, facilitating scientific inquiry and teamwork within this group by engaging students in communicating and justifying their explanations. When I asked her to tell me about how she addressed this scenario or other ones that might emerge she responded:

> I ask who can justify their reasons. If you couldn’t justify it you shouldn’t get to make the decision and then we all said, well ok we have multiple trials, so do it one way and then do it the other person’s way. But not allowing them to bail, because immediately their choice will be well I’m doing it myself then. And well you can’t, you won’t get any materials, it’s not a choice. (Teacher Interview, 1/25/2017)

Through the lens of Vygotsky’s social constructivist theory (Karpov, 2014) the role of the teacher as the knowledgeable other is to guide effective learning. Using these combined findings as a metric, it becomes apparent that although Betsy’s pedagogical approach provided direction to students, her lack of confidence in some of the subject matter may have impacted levels of student achievement and conceptual understanding on science ideas in water engineering and filtration. I observed this directly with Betsy when she struggled to connect the concrete experiences to the other experiential components and making real world connections to science content. In her own self-reflection Betsy commented:

> I bit off more than I can chew in writing curriculum, but these individual labs and tests such as water filters are the best developed part. In the future, I need to make all my teaching fit with specific essential questions and goals as to how students can apply then to earth science. (Teacher Interview, 1/25/2017)

The same concepts that Betsy struggled with in the professional development were carried over to the classroom; connecting concepts, making conclusions and final reflections. Students initially had difficulty transferring concepts of permeability and porosity to real water systems and applications to real materials in active experimentation. Betsy noted this when I inquired about what aspects of the water filtration lab she felt that students struggled with the most**:**

> Concepts like why sand sticks together or why it is better to have water move slowly through the filter were harder to adapt for this age level. (Teacher Interview, 1/25/2017)

However, these concepts (electrostatic energy and permeability and porosity) are inclusive within NYC and NYS science standards and developmentally appropriate for this age group and a gifted and talented classroom. Furthermore, conceptual understanding of these concepts was evident across the posttests, science notebooks and reflection assessments. What students appeared to have difficulty with was connecting all these ideas together to represent conceptual models of water and Earth systems. This shortcoming could have been facilitated by connecting conclusions from the experiential water unit to big ideas about water and Earth systems using the learning cycle component, abstract conceptualization.

Institutional Constraints

What became most evident throughout the course of observing Betsy was the social and emotional impact that institutional and administrative barriers at the Avenue

School had on her effectiveness as an educator (Berg, &Mensah, 2014). The science classroom had no sink, and materials such as bags of sand and dirt and gravel had to be brought up 5 flights of stairs. In a school with no elevator, and a classroom with no sink, making a water-based unit using Earth materials was a challenging task.

As a new school, enrollment at the Avenue school was increasing each year. Due to this expansion, Betsy went from teaching two sections of science, one being an integrated special education (IOP) class with an occupational therapist and a para professional to teaching three sections of science. But it was a change in school administration that emerged as the primary confounding factor impacting her implementation and practice in the science classroom. Mid semester, the administrator switched Betsy's class schedule. She went from teaching four times a week to five times a week. This resulted in omitting a meeting time for one of the groups in this study and having to shift her unit plan. Betsy was able to conform her lesson plans; however, scheduling conflicts and time management became a greater challenge when she was concurrently asked to take over teaching two sections of social studies, a domain that she had no prior experience or background knowledge.

Later that same month, Betsy posted an item on the school website for her mathematics students that had an unknown sub link that was not appropriate for children. As a result, she was suspended from using the school website, email and server for the rest of the semester pending a hearing with the administration. This stressful and emotionally tolling time for Betsy coincided with the last part of the water filtration unit, the final laboratory and summative assessments. Betsy asked me to send her copies of the lesson plans and activities to her personal email, so she could conduct class. This whole scenario ended up pushing her two weeks behind schedule in her classroom implementation. In my observations at this time, I found Betsy struggling with classroom management, frequently losing patience, screaming at students and going off sequence and curriculum. Because of these combined stressors and administrative constraints, Betsy left her position with the Avenue school that was used for this study and left the state of New York in July of 2017. In September of 2017, she began teaching at a progressive private school, teaching science to 5th-8th graders in the southern United States.

Summary of Teacher Findings

Teacher Professional Development

In this section on teacher findings, the initial impact of the PD sessions was most evident in Betsy's unit plan. She incorporated aspects of the experiential learning framework in her design, adding in concrete experiences with field sampling and then added in time with the laboratory components for reflection, abstract conceptualization and active experimentation with the filter materials and constructing the water filter model. Betsy found that even though she had difficulty facilitating abstract conceptualization, when students took the time to make observations they allowed a higher level of learning to occur and were able to and make conclusions about the subject matter they were working with.

These lessons also incorporated NGSS science and engineering practices: field experiences enabled students to plan and carry out investigations on the water quality at each sampling location, and debriefing and reflection from these experiences provided an opportunity for students to analyze and interpret the data across different abiotic factors. In the laboratory, students were developing and using explanatory models, revising their models, constructing explanations and designing solutions to problems they encountered with their filter design. In laboratory reflection and debriefing students communicated their findings, which included strategies used and at times engaging in argument from evidence when they shared their results with other groups that used different strategies for their water filter design.

Betsy's reflections from the initial PD sessions informed the unit plan and highlighted strategies on how she would incorporate NGSS science and engineering practices on developing models and communicating information in content and pedagogy on subsurface interactions in the water cycle and groundwater flow. She focused on building literacy through the addition of vocabulary words and using a model to illustrate permeability and porosity. She also began to make connections between the water table and storm water, building an understanding of the interrelationships between these components and the conception of how water flows in Earth systems. When asked specifically how she would incorporate the experiential learning framework and three-dimensional learning in the water filter lessons, Betsy was focused on active experimentation and constructing explanations and designing solutions, having students build and revise their models to inform them about engineering through the development of these process skills.

The essential question that she created - how does water flow in nature? - would not only guide the draw and explain assessment, but also provide a theme for the unit. Using this theme, the intent was for students to be able to conceptualize the different layers of the Earth that water travels through in subsurface interactions. In the materials laboratory, this essential question was used to guide the students as they discovered the properties of the different Earth materials.

The observations and interview data gave me perspective on how the content and pedagogy from the PD sessions influenced Betsy’s classroom practice. What stood out to me the most was how she incorporated analyzing and interpreting data into the field debriefing and reflection sessions. This was chemistry content that she had expressed she did not feel confident about and she did a great job explaining why data is important and how we can use it to inform our results. Although she did look to me to intervene about some of the factors she did not feel as confident about such as Nitrogen, when I did explain these concepts I did not feel like I was stepping on her toes. Betsy did not seem angry that I took the lead, and at one point in our partnership even expressed that she considered me to be more of a co-teacher than the one the school had assigned to her science classroom.

The PD sessions seemed to have had a greater long-term impact on Betsy and her lifelong learning. I have watched her evolve in her science content knowledge through her own discovery process and as a result appear to be more confident in her practice.

The partnership that we formed as part of the PD sessions has also had a long-term impact. She has reached out to me for guidance and as a resource to discuss specific content and teaching strategies and has expanded on what we developed in her 6th grade classroom at the Avenue School for an entire new set of students.

Implementation and Strategies

In this section on teacher findings, teacher observation and interview data provided the most insight into Betsy's grasp of content and pedagogy to inform her implementation and strategies of the experiential water unit. In general, Betsy tried to make connections to nature to make the lessons more meaningful to her students.

However, her teaching competence was impacted by her level of comfort with the content. In other words, when she was not confident with her own conceptual understanding, she was not comfortable teaching the concepts. This was evident in the field debriefing sessions when she had difficulty connecting some of the abiotic factors and again in the materials laboratory when trying to link the conception of layers of Earth materials back to the field experience. It was frustrating to observe her struggles connecting content because of her own lack of science content knowledge in this area, but I was also grateful that she allowed me to intervene and attempt to clarify concepts to the students.

Having never taught as a classroom teacher in elementary science, my perceptions of student construction of knowledge was based primarily on cognitive development and my interactions with students as non-formal marine educator. In the materials lab, I witnessed students struggle to make these connections between the concrete experience and the lab in class discussion, but when I observed individual groups, they were able to use Betsy's analogies (SpongeBob© and Brick Bob) as direct reference for understanding the properties of Earth materials and the flow of water through them.

In her practice, I observed Betsy integrate NGSS crosscutting concepts of patterns, cause and effect and scale, proportion and quantity. In transcribing and analyzing classroom sessions, I discovered that Betsy had used an integrative approach incorporating units of measure and NGSS science and engineering practices of mathematical and computational thinking in her discussions with class #1 on water filter design. This was the same class that she had taught mathematics to and it was clear in my observations that she felt very comfortable working with these students. Her level of confidence with mathematics and ease with this group may have been a contributing factor to her ability to integrate concepts into the lesson.

Another theme that emerged in the findings were the barriers to teaching that Betsy encountered due to time limitations and having three full sections of science classes. To have consistency between the class lessons, any ad hoc experiment that she thought would be useful to illustrate a concept would need to be replicated. For example, Betsy and I discussed having her use a 10- gallon fish tank as a microcosm of the river as an alternative to collecting samples in the field and to add dimension to the data set to compare results. Betsy added to this by suggesting that we add different elements to the microcosm that would impact water quality such as cooking oil to represent an oil spill and subsequent water pollution. I appreciated her creativity but when she thought about it in practice, she realized not only would this be time consuming but difficult to replicate across all three classes.

This was a consistent theme as well, biting off more than she can chew. Betsy was excited about the unit and discovering new elements to incorporate into the lessons, but factors such as extra field equipment or exploring different types of sand were additions that were difficult to integrate into practice, because she was just becoming acquainted with these materials and equipment along with her students.

What resonated to me in her practice was Betsy's enthusiasm for science and love for her students. That was why it was so upsetting to see how disruptive the administrative issues that she personally encountered impacted her confidence and rigor in the science classroom. Although these issues occurred at the tail end of the experiential water unit, Betsy's enthusiasm waned, and she became disorganized, misplacing or losing posttests and water reflection assessments that had been returned to her by students. Before Betsy left New York, we had lunch together to talk about the experiential unit. She admitted to me that she has a bias towards class #1 and felt more comfortable with these students. This was evident in my observations, but I also felt that with all the laboratory components of the unit, class #2 had the advantage of being taught the second or third iteration of the content. The result was that I found class #2 had a more student-centered classroom environment, and that Betsy's comfort level with the content facilitated open inquiry. However, this group also tended to have more classroom management issues, which also might be due to teacher burnout by the time we got the second or third iteration of the unit.

Implementation of the experiential framework with the water unit was an effective pedagogical tool in creating a conceptual understanding of water cycling and promoting NGSS science and engineering practices such as justifying explanations, problem solving and alterative questioning among elementary science students. Student reflections and observations highlighted how some groups of students were able to approach filtration challenges by working together to come up with alternative questions, explanations and solutions.

Amidst the teacher struggles with implementation of the laboratory units, the actual active experimentation was student-directed within each lab group. Each group varied in ability and level of cooperation amongst the participants. A few groups had the teacher working with them where she was participating by providing direct instructions and demonstrations of her own. This resulted in some groups being neglected, and others being unable to participate in scientific discussion and construct their own understanding of the subject matter. The most beneficial aspect of these laboratories was built in the lesson plan on environmental engineering, that each group had the opportunity to revise their filter, with three or more iterations of their design.

The next section on students’ findings illustrates the impact of Betsy’s practice on student achievement. Using the experiential learning framework as a guide, students were engaged in examining elements of water in Earth systems and conducted investigations to implement NGSS science and engineering practices in the classroom.

Student Findings

The findings in this section address research question two: How does the experiential learning framework foster the conceptual development of water science and engineering practices in elementary science students?

Emergent Themes in Student Data

Findings for the student data are the result of qualitative coding for 15 emergent themes and three in vivo codes for recurrent themes (Table 4.4) from review of multiple data sources: open ended questions from pre and posttests, classroom observations, reflection assessments and student artifacts. Some of these themes make up the findings to answer research question two.

Table 4.4

Emergent themes from qualitative text analysis of student data

Category/Theme
Authentic Science Inquiry
Concrete experience
Scientific Observations
Filter Design
Filter Strategies
Stuck/ Traps/ Blocks
Water Cycle
Clean Water
Process Skills
Active Experimentation
Models
Abstract Conceptualization
Filtration
Systems Thinking
Transfer
In vivo Codes
dirt sticking to soil
gravel catching all the dirt
gravel as the best filter
water stuck, blocked, trapped by sand and gravel

Conceptual Development

Across both sections of students (N = 56), initial conceptions of the water cycle were focused on atmospheric level transformations, and there was a lack of understanding of how water moves in nature, specifically that water flows and percolates through the earth. Evidence from multiple research instruments indicated that at the completion of the experiential water unit, students increased their conceptual understanding of water cycle components and the processes of condensation and infiltration. Although initial understanding of where water is found in the world was well understood on the pretest, in the posttest, understanding was expanded to include local water systems, with the students naming water bodies such as Hallett’s Cove, Catskill Watershed, the East River, Hudson River and Atlantic Ocean.

Open response questions on both the pre and posttest, reflection assessment, and science notebooks were scored using a rubric from Wiggins and McTighe’s (1998) six facets of understanding (Appendix F). Across science notebooks the average level of understanding for both class #1 and class #2 was level 2, intuitive. Scores for reflections fell between level 2, intuitive and level 3, developed (average of 2.5 respectively). Both groups increased their level of understanding from the pretest to posttest from a level 1, naïve to level 2, intuitive. This minimal amount of movement might have been due to Betsy not providing opportunities in the unit for students to develop an in-depth or sophisticated understanding of concepts. Students did explore the concepts on their own by asking me questions after class and in their own time looking at resources Betsy provided in their classroom library and on their computers.

Pre and Posttests

Tests were scored out of a total of 100 points. There was a total of 21 questions on the pretest and 22 questions on the posttest. This was due to the addition of a multiple-choice question based on the student’s water modeling labs. On the pretest, questions 1-18, open ended and multiple questions were worth 4.72 points each, on the posttest, questions 1-16 open ended and multiple choice were worth 4.72 points each, questions 17-19 were worth 3.15 point each. On both tests, the water cycle diagram questions were worth 1.26 points each for a total of 5.4 points, the true false questions were worth 0.5

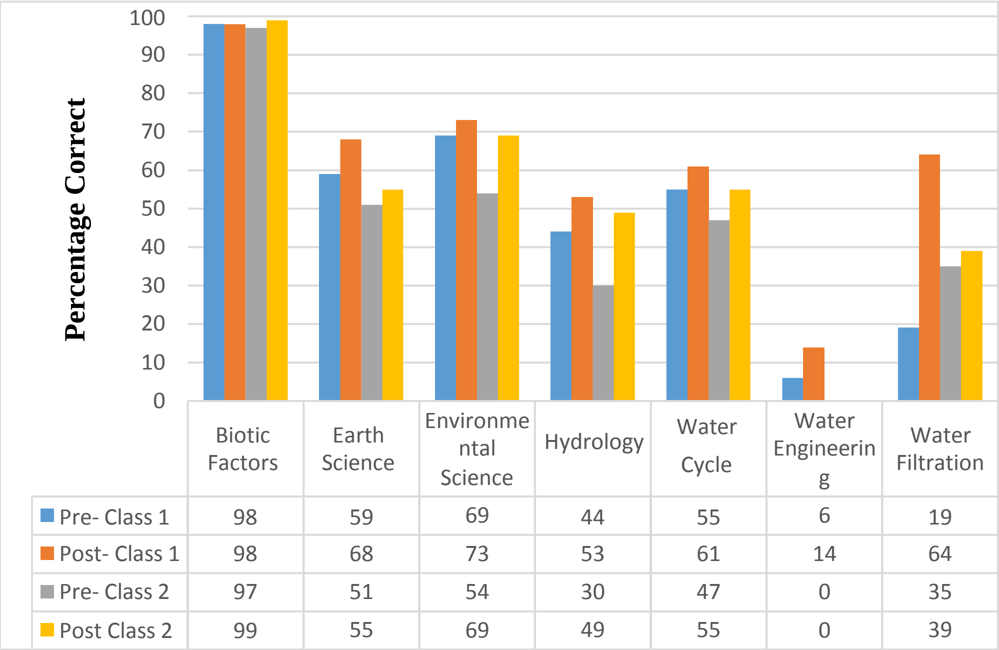
points each for a total of 5 points and the final water to the tap question was worth 5 points. Results indicated that pre and posttest scores were low across both sections of students, but all students had improved their test scores after participating in the unit. An analysis of variance found that there was no significant difference between groups for the pretest F (4.63), p = 0.03579 as well as for the posttest F (2.80), p = 0.100. Pretest and post test scores were higher for class #1 (M = 66.7, 69.4) than for class #2 (M = 60.7, 65.9). An analysis of variance found that there was no significant difference within groups for class #1 F (3.96), p = 0.05 as well as for class #2 F (1.28), p = 0.62. Results indicated groups were not equivalent in their prior knowledge of test concepts, but the degree of variance was not considerable.

When I reviewed the data, I found that many of the open-ended questions were left blank on both tests in both sections. Considering this finding, I went back and analyzed the data based on multiple choices responses only. Viewed through this lens, I conducted paired t-tests within each group and unpaired tests between the groups.

Responses showed an increase in test score values (Class #1, M = 75, 77; Class #2, M = 71, 73) but no statistical significance within the groups. Like results for all responses, between the groups, academic performance was higher in Class #1 than Class #2 for both the pre-and posttest ($p = 0.0574$).

To explore the data in a more meaningful way, I grouped the responses by concept/subject area, level of understanding and question type (Table 4.5). Number sequencing beyond the number twenty, (i.e. 20.1, 21.1) was used to accommodate scoring for multi-part questions in the true/ false section. The number of questions increased by one on the post test, however the point distribution remained the same. Level of understanding was based on the original question source. Questions ranked as low level were adapted from 4th grade Regent's exams, intermediate level from 6th grade exams and EiE content, and high level from 8th grade regents and undergraduate level testing. Concepts were reviewed for outcomes using principle component analysis.

Results for both sections of students (see Figure 4.4) indicated that conceptual understanding was most increased around concepts of hydrology (Class #1 44%;53%; Class #2 30%; 49%). Between sections there was a notable difference in understanding for the concept of water filtration (Class #1 19; 64%; Class #2 35%; 39%) and water engineering (Class #1 6%; 14%, 0%; Class #2 0%; 0%). These concepts were most prevalent to the experiential water unit.



	Biotic Factors	Earth Science	Environmental Science	Hydrology	Water Cycle	Water Engineering	Water Filtration
🟦 Pre- Class 1	98	59	69	44	55	6	19
🟧 Post- Class 1	98	68	73	53	61	14	64
⬜ Pre- Class 2	97	51	54	30	47	0	35
🟨 Post Class 2	99	55	69	49	55	0	39

Figure 4.4. Increase in Concept Level Understanding- Pre/Posttest- All Students

Table 4.5

Pre and Post Test Questions by Concept Level

Question Number	Concept	Level	Question Type
1	Water Cycle	Low	Multiple Choice
2	Earth Science	High	Multiple Choice
3	Biotic Factors	Low	Multiple Choice
4	Earth Science	High	Multiple Choice
5	Environmental Science	Intermediate	Open
6	Water Chemistry	Low	Multiple Choice
7	Hydrology	High	Multiple Choice
8	Water Cycle	Intermediate	Open
9	Water Cycle	Intermediate	Multiple Choice
10	Earth Science	High	Multiple Choice
11	Water Cycle	Intermediate	Multiple Choice
12	Earth Science	Intermediate	Open
13	Hydrology	High	Multiple Choice
14	Environmental Science	Intermediate	Multiple Choice
15	Biotic Factors	Low	Open
16	Hydrology	High	Multiple Choice
17	Water Filtration	Intermediate	Multiple Choice
18	Water Filtration	Intermediate	Multiple Choice
19	Water Cycle	Low	Multiple Choice
19	Water Filtration	Intermediate	Multiple Choice
20	Water Cycle	Low	Multiple Choice
21	Water Engineering	Intermediate	Open
20.1	Hydrology	High	Open
21.1	Hydrology	High	Open
20.2	Hydrology	High	Open

Question Number	Concept	Level	Question Type
21.2	Hydrology	High	Open
20.3	Hydrology	High	Open
21.3	Hydrology	High	Open
20.4	Hydrology	High	Open
21.4	Hydrology	High	Open
20.5	Water Cycle	High	Open
21.5	Water Cycle	High	Open
20.6	Environmental Science	High	Open
21.6	Environmental Science	High	Open
20.7	Water Cycle	High	Open
21.7	Water Cycle	High	Open
20.8	Water Cycle	High	Open
21.8	Water Cycle	High	Open
20.9	Environmental Science	High	Open
21.9	Environmental Science	High	Open
20.10	Environmental Science	High	Open
21.10	Environmental Science	High	Open
22	Water Engineering	Intermediate	Open

However, review of other research instruments indicated that class #1did not transfer any understanding from the unit to their conception of water engineering, and class #2 did not transfer any understanding from the unit to their conception of water filtration.

Water Engineering and Water Filtration Models

Figure 4.5 Water Filter Lab Modeling Materials

For the water filter lab sessions, groups of 4-5 students were each given a bin with a plastic water bottle filter setup, a cup of soil, sand and gravel, a ruler, a measuring cup and a dirty water sample to clean through their filter design (see Figure 4.5).

For each model build, students were required to create a blueprint of their filter design (see Figure 4.6). This design was checked by Betsy or myself and students had to justify and explain the changes they made in their design before getting materials to build their model with and pour water through the filter. After each iteration they were required to record observations and results in their science notebook.

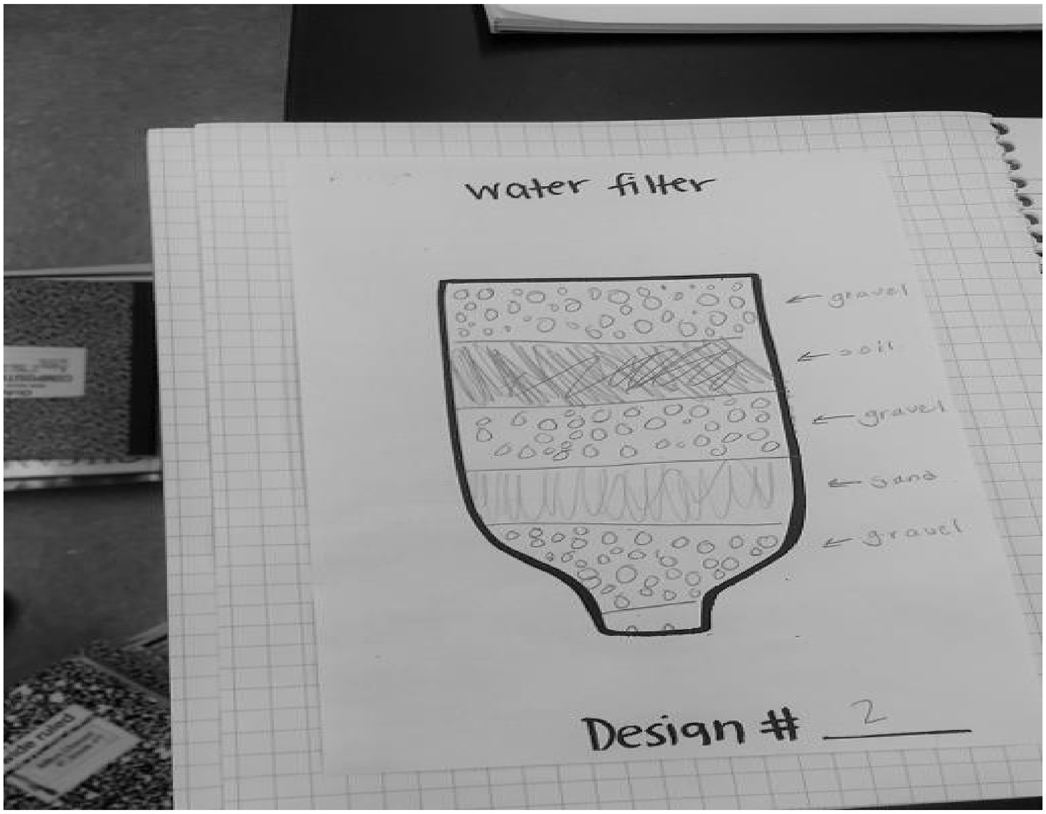


Figure 4.6 Example of Blueprint for Second Water Filter Design

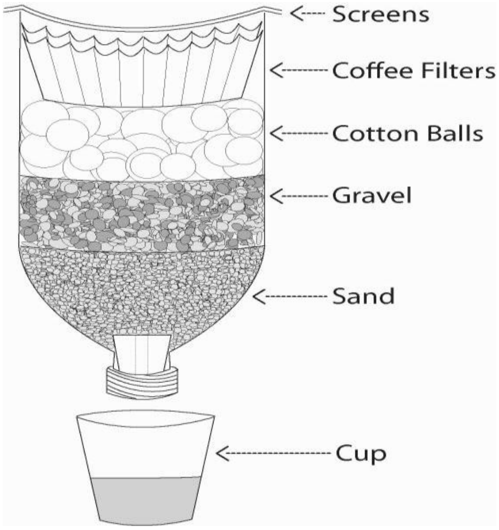


Figure 4.7. Question 19 Posttest-Water Filter Schematic

Posttest questions 17, 18, and 19 all addressed the concept of water filtration. On the pretest, these conceptions were based on the use of simple tools, such as screens, to determine filter efficacy. On the posttest, examples were used directly from their water filter modeling lab, using a visualization of the filters themselves for guidance (see Figure 4.7). For most students there was a low level of understanding on question 19. This question asked students to problem solve to determine what material was blocking the flow through the filter. The lab materials provided to students included sand and gravel in their filter model filter design. I had assumed that from their own experience of having sand blocking their filter design, students would comprehend that paper and cotton, materials that many of them might use daily, were very friable and porous and that sand was the correct answer.

This was an incorrect assumption, as many students responded that paper or cotton was blocking the flow. These two materials were not used in the experiential unit but were part of the original EiE curriculum. Having most likely used both materials in their own experiences, I began to question if students had misconceptions about permeability and porosity, key concepts in understanding water flow through earth materials.

Exploring conceptions of permeability and porosity.

The one conception that did not change from the pre to the posttest was multiple choice question #16. This question asked students where groundwater was found on Earth. The answer to this question states that groundwater is found only where there is soil since water cannot move through rock. However, over ¾ of all students answered incorrectly and chose the response that groundwater is found almost anywhere under the Earth’s surface. This misconception might indicate that students’ conception was that water could move through rock, but this finding was inconsistent with results from multiple choice question #7, which asks students what the most important factor was in determining the amount of groundwater that can be stored within a rock. The following answers were provided in multiple choice question #7: (a) the rock's geologic age, (b) the rock's hardness, (c) the rocks porosity and (d) the rocks color. The correct response being option C, the rocks porosity. Correct responses for question #7 increased 73% from the pre to the post test, indicating that students had increased their understanding of the concept of porosity.

In contrast, understanding of the concept of permeability was not as apparent. For example, question #4, which asks about clay soil in relation to pore size and permeability was found to be incorrect for 79% of students on the pretest and 72% on the posttest. Coding for emergent themes across other data sources (science notebooks and observations) resulted in similar findings.

Among the students that responded correctly to question #19 on water filter design, two of them also illustrated an understanding of permeability in the materials lab. These two individuals were part of a group that during the materials lab, were asked what their conception was of properties of the materials they had tested:

> Student- 46: What our team thinks, space in between grains of sand are harder to go through.

> Student-41: I agree, sediment, little grains, each drop takes a while to get through.
>
> (Classroom observations, Class #1, 11/29/16)

In her response, to question #19, student-41 even elaborated to justify her explanation, stating: Not totally blocking it though but slowing it down. During the next period when they began the water filter lab, I asked student-46 about her filter design, she was able to transfer this understanding of the materials properties into her design:

> Student- 46: Our water is clear- we have purified the water with gravel/ soil/sand/gravel
> Amanda Why are you using so much gravel?
> Student-41: The gravel will catch the soil
>
> (Class #1, Water Filter Lab 1, 11/29/2016)

Another student that responded correctly to question #19, demonstrated a conceptual understanding of permeability and porosity in their answer to question #8 on the posttest, about the water cycle question:

> The droplet travels through the rocks pores as it descends into the earth. When it reaches the underground soil, it travels through the pores in the soil until it reaches the underground water system. (Student-17, Class #2)

This same student was able to formulate explanations from evidence to justify why his groups' third water filter design was not effective, validating his explanation based on the material properties to filter water: "The water came out cleaner than the first water trials, but it still wasn't clean. I think the reason is because we included too much soil and a mixture of the sands, since the blue sand is better for water filtering than the other sand." (Class #2, Water Filter Lab 3, 12/1/16)

Exploring other data sources, I found that both student-41 and 46 also included sediments and soil in their post-drawing assessments with arrows descending to indicate infiltration. In contrast, I found a student in class #2 that did not get question #19 correct yet understood materials lab:

> Betsy: Did the water go through the gravel itself?
> Student-1: No
> Betsy: Air pockets in
> Student-5: Sand- the sand came out first- came out mushy, then the water came out
> Betsy: Did other people have sand mushy through the filter?
> Student-5: grains are packed together- water loosens if you go to the beach, sand it packed together
> Betsy: Like a sand castle when wet
> (Class #2, Materials Lab, 11/29/2016)

Triangulation of data provided evidence that misconceptions about permeability and porosity was not prevalent among all students (Creswell, & Clark, 2007). Across both sections of students, 36% of students in class #1 answered question #19 correctly, compared to 46% of class #2 students. Class sequencing may have contributed to this variance. In its third iteration, students in class #2 received instruction and analogies that had been cultivated through each iteration.

Misconceptions. In both the pretest and posttest, the most common misconceptions were found on open ended questions #8 which asked about the pathway of a water molecule as it lands on the schoolyard and question #21/ 22 which asks how water gets to our tap.

For question #8, on the pretest the most common finding was that students only acquainted the water cycle with atmospheric components. There was a conception of downward flow with runoff but no understanding of subsurface interactions (infiltration, groundwater, aquifers):

> Would probably evaporate and go back in the clouds to save up for another day. (Student-1- pretest)

> Well after it rains, which is called precipitation, the next step begins: collection, which is basically what makes puddles. After that, the step called evaporation happens, the water turns into a gas and rises into the air. Once it reaches the clouds, the next step to take effect: condensation. The gas turns into a droplet and once again rains. (Student- 49 -pretest)

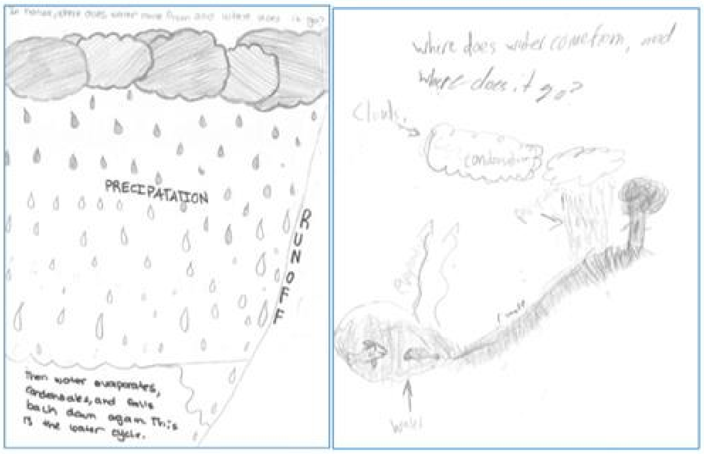


Figure 4.8. Pre-Drawing Assessments. Student-34, Class #1 (Left), Student-17, Class #2 (Right) Assessments

This same misconception was also prevalent across both groups of students in the pre-drawing assessment (see Figure 4.8). When asked where water flows in nature, Student-34 labeled precipitation and runoff and noted that when water evaporates, condensates and falls back down again, this is the water cycle. Student-17 labeled a series of arrows with the words clouds, condensation, precipitation, runoff and evaporation all linked in a continuous cycle.

The most common alternate conception on the posttest was around the emergent theme of sewers. Combined sewer overflow and sewers had been part of lessons after the water filtration unit. Sewers were mentioned in their explanations about the water cycle (Question #8) and as a misconception on how water gets to their tap (Question #21/22). For example, the following students' comments were related to these two common misconceptions:

> It can end up in the sewers/combined sewer overflows where if it is a rainstorm will probably end up in the tubes that pour the dirty water back into the river. It also might evaporate. (Student -41, class #1- posttest)

> The water is running down the slightly sloped areas of the schoolyard. It makes its way through the tiny pieces of asphalt. Then it runs onto the sidewalk and into the sewer. (Student- 45, class #1-posttest)

> Water gets to your tap by rainwater. The water goes through sewers and this water goes through a series of pipes that leads to your sink and comes out of the tap. (Student- 8, class #2- posttest)

> Water gets to our tap by sewers. Though our water runs on combined sewers. (Student- 26, class #2- posttest)

In contrast, the post-draw assessment specifically showed evidence of an increase in student understanding of basic water cycle components and processes across both sections of students. Like the pretest and posttests, student understanding of water cycles and systems in the pre-drawing activity was focused on the atmospheric component of the cycle (i.e., evaporation, condensation, and rainfall) but ignored the groundwater, biosphere, and environmental components.

I had given Betsy a United States Geological Survey (USGS) poster of the water cycle for her classroom (see Figure 4.9). Since we were exploring geological components, and not the urban water cycle, I felt that this was a good representation of elements that we would be covering during the semester. Students learned about the urban water cycle as well when Betsy introduced them to the New York City Water Supply through a map entitled *New York City's Water Story: From Mountain Top to Tap* that was provided to us from colleagues at the New York City Department of Environmental Protection.

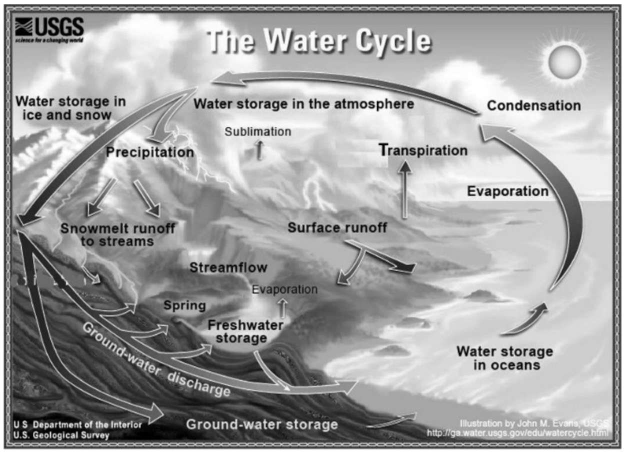


Figure 4.9. The Water Cycle Example Used in Betsy's Classroom. United States Geological Survey (2017)

In the post-drawing assessment, results indicated that 70% of the students, who had initially presented only the atmospheric component of the hydro cycle, significantly increased their understanding of the other components and processes of the water cycle. For scoring the drawing assessments, the maximum drawing score was 25 points. Drawings between the two class sections were calculated with an unpaired t-test with no significant difference between the two groups for the pretest p= 0.9011, class #1 (M =14.38, SD = 7.60) and for class #2 (M = 14.14, SD = 7.11), but there was a statistical significance for the post test, p=0.0005, class #1 (M = 18.21, SD = 4.39) and class #2 (M= 13.00, SD = 6.05). Within the groups, a two-tailed t-test was used to calculate between the pre and posttest. Results for class #1 indicated statistical significance between the two assessments, M = 14.38; 18.21, p = 0.0122, but this was not the case with class #2, M = 14.14; 13.00, p = 0.3298. Scores for class #2 decreased across all drawing components, except for water cycle processes. Scores for class #1 increased across all categories, but it was most pronounced in the systems thinking components of dynamic thinking and cyclic perceptions.

Experiencing the Framework

Betsy expressed that she felt that the concrete experiences were the most meaningful to students. This finding was confirmed when I explored student’s science notebooks, and their responses to the reflection question, what can we learn by doing fieldwork?

> We can actually live the experience and not just listen to someone talking. If we learn how to do things in the field early then we can grow up and excel in other classes relating to science (Student-18, class #2- science notebook).

> We can learn from doing fieldwork because when we experience everything instead of copying off a board and losing it or listening to instructions then forgetting it. (Student-27, class #2- science notebook).

The concrete experience also provided an opportunity for students to carry out an inquiry-based investigation about water quality:

> From doing fieldwork, we can conduct hands-on experiments and find results by ourselves. We might get different answers, showing that maybe our experiment proves something else. (Student-37, class #1- science notebook).

> We can take real-world data so that we have accurate data. It also provides a snapshot of what scientists do in the real world. (Student-12, class #2- science notebook).

Students also demonstrated that they were able to reflect on their experience of developing and using water filter models and make conclusions about the efficiency of their design by constructing explanations and designing solutions:

> Our conclusion is that the third sample was the most successful because it was the least dirty. We think that the gravel played the most important role because it took all the dirty water and took out the dirt from the water (Student-37, class #1- science notebook).

> Out of our trials, our 3rd is the cleanest and most successful. The water coming from this filter is the lightest in color signifying it was the cleanest out of

> the total. It also had the least amount of dirt which tells us that our 3rd one is the most effective. In our trials it was most important for gravel to be on the bottom. It was also important to add sand and dirt as sand seems to clean the color of the water. (Student-55, class #1- science notebook).

Systems Thinking Skills

Findings in this section address research question 3: How does the experiential learning framework foster the development of systems thinking skills in elementary science students? To measure the enactment of systems thinking skills, a qualitative scale was adapted based on Assaraf and Orion's (2005a) Systems Thinking Scale (Appendix E). Across all the research instruments there was evidence of systems thinking in both class sections, but it was most pronounced in science notebooks, reflections, posttests and both pre and post-drawing assessments (Table 4.6).

Table 4.6

Characterizing Systems Thinking Skills by Class and Instrument

Research Instrument	Class Section	CP (%)	RC (%)	OCPR (%)	G (%)	D (%)	HD (%)	CY (%)	RP (%)
Science Notebook	Class #1	55	73	27	0	0	0	0	0
	Class #2	44	67	0	0	0	0	0	0
Reflections	Class #1	43	100	100	0	0	0	0	0
	Class #2	75	100	100	33	16	0	66	0
Pre-test	Class #1	0	0	0	0	16	10	13	0
	Class #2	21	5	5	0	26	0	0	0
Post test	Class #1	56	6	6	0	25	0	19	
	Class #2	42	16	0	0	16	0	0	0
Pre-Draw	Class #1	25	---	47	59	14	---	28	
	Class #2	32	-----	48	48	14		3	----
Post - Draw	Class #1	18	----	38	37	48	----	24	
	Class #2	26	-----	58	59	14	----	39	-----

CP= ability to identify components of a system and processes with the system; RC= ability to identify relationships among system components; OCPR= ability to organize systems components and processes within a framework of relationships; G=ability to make generalizations; D= ability to identify dynamic relationships within the system; HD= understanding hidden dimensions of the system; CY= ability to understand the cyclic nature of the system; RP=thinking temporally: retrospection and prediction.

In scoring the drawing assessments, the resulting inter-rater agreement between myself and two colleagues had a kappa statistic of 0.48. Using the Landis and Koch (1977) rating scale, there was moderate agreeability. For this scale, moderate agreement (0.41-0.60) is above poor, slight and fair agreement, indicating a slightly elevated level that did not reach a substantial or near perfect rating. Noticing a trend in rater responses for class #1 I calculated inter-rater agreement solely looking at the systems thinking class of dynamic thinking (D)- the ability to identify dynamic relationships within the system (Assaraf & Orion, 2005a). The kappa statistic for this individual factor was 0.72 on the Landis Koch rating scale, indicating substantial agreement for this factor. Class #1 had a significant increase from their pre to their posttest rating for this specific factor.

In reflection assessments, students were asked to identify where they see filtering in nature. Two students from each class responded in a way that connected this understanding back to classroom practice and the ability to identify relationships among the system’s components (RC):

> When it rains, and it runs through the forest, or in a stream with rocks, the leaves and rocks naturally filter it, like in our models, how the water flowed through the gravel. (Student- 49, Class #1)

> In nature we can see filtering when rain water infiltrates into the ground like how our water infiltrated into the bottom of our filter. (Student-26, Class #2)

In another reflection question, students were asked what they thought was most important in their engineering design. One student responded in a way that indicated his/her ability to organize system components and processes within a framework of relationships (OCPR):

> I think it was important to think about the layers and which order each material goes because each material has a special function that they are supposed to do in our water filter. (Student- 38, Class#2)

When asked what they were able to learn by building and revising their water filters, one student was able to make a real-world connection directly to a water system: “By building and revising our water filter we learned about how aquifers can help water get filtered if they have the right porosity.” (Student-23, Class #2).

Between both class sections, class #1 had higher scores for post-drawing assessments, this was primarily due to an increase in points for the elements of systems thinking – dynamic (D) system relationships and cyclic (CY) thinking in their drawings. This this same trend for dynamic thinking was prevalent in class #2 responses for the pre and posttest question #8 on water cycle processes:

> After landing on the schoolyard, the water would probably either evaporate or find the nearest soil and infiltrate. Then the water cycle starts all over again. (Student- 6, Class #2- posttest)

> First, it will be on the schoolyard downstairs. Then it will either infiltrate or runoff. If it runs off, then it will end up in the ocean and the cycle will start all over again. However, if it infiltrates, it may do the same or keep going down into the soil. This is the molecules path. (Student-10, Class #2- posttest)

There was also a higher level of systems thinking in some responses for question #21/22 about where tap water comes from. These responses incorporated both identification (CP) and organization of components (RC) in systems thinking:

> The water is first collected and then filtered in a water filter system. Once they ensure the safety of the consumption of these water, it get put into a distribution system where they distribute our water to the tap. (Student-29, Class #2- posttest)

This same ability to identify and organize system components and processes within a framework of relationships (OCPR) was carried over from the integrative approach Betsy utilized in in the water filter lab with class #1. For example, one student in class #1, reflected on his practice using NGSS mathematical and computational thinking. When asked what they were able to learn by building and revising his own water filter the student replied:

> I was able to find out key points in building filters, such as the types of sediments to use, the pouring speed, the pattern, and the layers. (Student-49, Class #1)

Pour rate was mentioned again when they were asked what they thought was most important in designing the water filter:

> How fast we were pouring the water, the sediments, and a pattern, because rain it goes across different sediments, and it comes little by little, over patterns. (Student-49, Class #1)

Summary of Student Findings

Conceptual Understanding

The experiential water unit intervention helped to change student conceptions of the natural water cycle and water in Earth systems. By connecting to student's interests and experience, water quality monitoring in the field and system modeling in the laboratory engaged them in the practices of science and engineering. By allowing the students to continuously reflect, talk and write about observations throughout the experience, students were able to make meaning out of the classroom community they were interacting with. Situated in a larger community and exchanging ideas, the students began to change their conceptions. By constantly re-examining and reflecting, students not only achieved personal growth and development, but they fostered a sense of humanity among their peers.

Initial misconceptions of water cycle components and processes progressed over the course of the unit from atmospheric level to subsurface level interactions. Students embraced the components of the experiential learning framework and enacted scientific inquiry to understand the physical properties of matter and hydrogeological concepts of permeability and porosity in surface and groundwater systems.

In their concrete experiences, reflection and experimentation students learned to analyze and interpret water quality data. They used NGSS science and engineering practices to develop effective water filtration models by constructing explanations and designing solutions through multiple iterations of experimentation, reflection and abstract conceptualization to make conclusions and revise their filter design.

Quantitative measures showed that student achievement varied between the two groups of classes. Results on the pretest indicated that class #1 had greater prior knowledge of the subject matter than class #2. This impacted outcomes in academic performance, where overall class #1 had higher test scores overall for both the pre and posttest than class #2. However, although not statistically significant, there was a greater increase from pretest to posttest scores for class #2.

Between the two groups, there was also a distinction between the level of transfer of conceptual understanding about water filtration and water engineering from participation in the unit to the posttest. Overall, both groups increased their conceptual understanding of the subjects of Earth Science and Hydrology.

Systems Thinking Skills

Findings from all research instruments indicated that students were able to foster an understanding of systems and identify relationships between system components.

Through NGSS cross cutting concepts of cause and effect and systems and system models, students were able to make connections between engineering design and efficiency of their water filter model to the operation of real world water in Earth systems such as aquifers. By unifying water cycle components with their processes, students built a more comprehensive understanding of how water flows in nature, as well as in the urban environment.

Although both classes of students were able to generalize about system classes, dynamic and cyclic thinking was most developed in class #1. Triangulation across the reflection, pre and posttest and the pre and post drawing assessment validated that this outcome was consistent and not due to chance. These students took mathematics with Betsy five times a week and often used mathematical and computational thinking to identify relationships between systems components.

Making real-world connections to their concrete experiences facilitated both sections of students in their understanding of the NGSS crosscutting concept of systems and system models. Concrete experiences provided a unifying concept to enable students to grasp and explore system thinking skills in their learning and development.

V – DISCUSSION

In this final chapter of the dissertation, I present a discussion of the findings from this case study of Betsy and her students participating in an experiential water unit. Here, I focus on factors that facilitated and hindered my ability to teach professional development sessions and Betsy's constraints and limitations in her practice and ability to transition from teacher centered to a student-centered classroom. Student outcomes are focused on conceptual understanding and systems thinking skills that developed over the course of the unit and how their experiences shaped their progress. This chapter is organized by teacher practice and development, and how these outcomes impacted student achievement

Teacher Practice and Development

Professional Development Sessions

Through the application of the theoretical framework of experiential education and learning (Dewey, 2007; Kolb, 2014) and social constructivism (Karpov, 2014), the professional development (PD) approach used in these sessions combined elements of demonstration, observation, collaboration, reflection and debriefing. It cannot be overlooked that four PD sessions do not hold the same impact as longer sustained education. The literature suggests that the traditional approach of short term PD does not allow rigorous, cumulative learning (Knapp, 2003), and that to be most effective and improve teacher practices, PD must be sustained, coherent and intense (Garet, Porter, Desimone, Birman & Yoon, 2001; Supovitz, Mayer, & Kahle, 2000; Duncan, Lee, Scarloss, & Shapley, 2007). In their review of nine different studies of professional development outcomes, Yoon, Duncan, Lee, Scarloss and Shapley (2007) found that sessions that lasted 14 or fewer hours showed no significant impact on student learning.

However, in this research study, the impact of four sessions of professional development was supplemented by the continued scientist-teacher partnership with Betsy that was sustained during the duration of the study and persists today. In total, the mentorship extended well beyond 14 hours and was intensive and personalized. This approach was unique and it would be difficult to replicate across more than one set of teachers. The basis of this continuum of learning emulates the long-term approach advocated by Feiman-Nemser (2001) but also builds on the foundation of experiential learning, that it is a process that does not have an end, but which continues throughout the life of an individual (Kolb, 2014; Thatcher,1990).

This same long-term professional development approach is supported to address education reform (Putnam, & Borko, 2000). Reform was considered in this study, resulting in the PD sessions adopting a standards-based approach, and the scope of the session content incorporating pedagogy and learning theory from the NYC scope and sequence, K-12 engineering practices (Quinn et al., 2012) as well as the NGSS (2013). As part of new science education reform, the NGSS (2013), incorporates engineering design, an area that many elementary science teachers lack familiarity with (Bybee, 2014).

In my practice with Betsy, I wanted work with her to develop science and engineering practices and specific to her needs, address her difficulty with data analysis and creating and implementing summative assessments. I embraced the essence of the experiential framework (Dewey, 2007; Kolb, 2014) and incorporated Betsy's background in art as a method to introduce developing and using models. This was explored in PD sessions through the grounding activity to design and use a soil core sampler in session one, a water cycle activity and drawing in session two, groundwater models in session three, and designing system models in session four.

What I observed was that Betsy was engaged in the concrete experience and active experimentation but often became stuck within this paradigm. She had difficulty stopping to reflect on what she had done and making conclusions about her observations. Throughout this first session and the course of all the professional development, I frequently had to intervene and prompt her with the essential or guiding question that framed the session and engage her in discussion. She continued to struggle with this aspect throughout the professional development sessions, and overall it was challenging to keep her on track.

When I reflected on my own practice, I wondered what I could have done to facilitate better learning outcomes. I had focused on Betsy having concrete experiences that promoted active experimentation grounding them in connections to big ideas in nature and had inducted the experiential learning cycle to illicit reflection and abstract conceptualization into each session. Following each session, we debriefed on what had worked well and what needed improvement in the next iteration.

Wiggins and McTighe (2005) remind me of what I did right. Through the formative assessments, I was able to facilitate un-coverage and to promote teaching for understanding. For example, uncovering students' initial understandings and misunderstandings about the water cycle assisted Betsy in the enactment of her lesson plans. Students had a good understanding of evaporation and the atmospheric processes but had the misconception that it ceased at that level. There was no infiltration into the ground or continuous cycling.

Factors that Influenced the Implementation of the Experiential Water Unit

Although her final unit plan was comprehensive, Betsy did not provide much detail for how she would implement the water unit beyond the use of worksheets and what modeling materials she would use. She struggled to see the cohesion between the field experiences and the classroom sessions and taught in a way that did not consistently connect to prior knowledge. Like her personal experience in the PD sessions, Betsy became very focused on the hands-on activities that students would be participating in as part of their field experiences, paying less attention to student learning and having then develop in-depth understandings (Levitt, 2002). By emphasizing the individual activities as opposed to the big picture, Betsy was committing one what Wiggins and McTighe (2005) refer to as one of the "twin sins" of instructional design (p. 16); her activity focused on teaching that was fixated on the process skills required to engage in the activity instead of finding meaning within the activity.

Students actively construct their understandings of the world and these constructions are significantly influenced by prior knowledge, beliefs, attitudes, and experiences (Schwartz, Lederman, & Crawford, 2004, p. 40). When student understandings of science conflict with views held by the teacher it can create a challenging learning environment (Driver et al., 1994; Schweingruber et al., 2007).

According to Meyer (1987) teachers struggle to assist students in constructing understandings of groundwater and related concepts that resemble those held by scientists. This big idea, that water movement is continuous, became the basis for understanding that I personally reinforced in my mentoring with Betsy in each debriefing and each iteration of the water filter lab. In her practice, Betsy had difficulty linking concepts between water bodies the students had visited, the water cycle and water filtration models. In other words, without a comprehensive understanding of groundwater formation and movement in practice, I observed Betsy approach water systems and system modeling concepts in a fragmented manner.

Social constructivism theory posits that a teacher in a constructivist classroom is concurrently learning from their students as much as their students are learning from them (Karpov, 2014). In her practice, Betsy enacts science- in-the-making (Kelly et al 1988, p.34) where science discourse is viewed in moment to moment interactions, and science and education are situationally defined through the student’s ways of knowing, thinking and communicating. This was most evident in her lab debriefings, where Betsy prompted open-ended questions about strategies used for filtration design that incorporated NGSS crosscutting concepts such as patterns and cause and effect to link the domains of science and mathematics.

To promote open inquiry, she further developed these questions to introduce physical variables such as pour and proportional rate teaching students at the “ceiling level “of their zone of proximal development (Karpov, 2014).

Like Kolb’s (2014) assertion that learning, and knowledge are the byproduct of the transformation of experience, it was through the reorganization of this fragmented knowledge, that learning occurred in both Betsy and her students. diSessa (1988) argues that all knowledge is fragmented and that children hold neither conceptions nor misconceptions of the Earth that ‘‘pieces of knowledge” both are small, self-explanatory, and loosely connected ‘‘rather than one or even any small number of integrated structures one might call theories.” (p. 52)

Science Content Knowledge

One of the guiding principles of the Committee on Science and Mathematics Teacher Preparation (2001) specifies that scientists, mathematicians, and engineers need to become more involved in providing content knowledge to teachers. This was a primary objective in the development of the scientist-teacher partnership between myself and Betsy.

Like many other elementary teachers, Betsy’s lack of science content knowledge affected her level of confidence in teaching science (Cochran, & Jones, 1998). According to Berg and Mensah (2014) for elementary science teachers that do not have a science background, working with a more knowledgeable other is instrumental to improving and evolving their practice.

How one judges their own performance and capabilities or “self-efficacy” influences their success in the classroom, and mediates of the effects of prior achievement, knowledge, and skills on subsequent achievement. Science teaching efficacy is influenced by a strong science background, desire to implement reform- based instruction, and elementary science teaching experience (Bandura, 1986, p.391).

Teaching Without a Science Background

Observing Betsy for the past two years, there were times where I witnessed her struggle with being a facilitator and making her classroom more student centered. Her classroom management in the field and lab activities came across as teacher-directed and lecture-based and did not promote active participation or scientific inquiry in student learning. In her practice, reflection was a new skill for her as well as her students. There were instances where I observed her engaging students in inquiry-based investigations through questioning but would then either tell them the answers directly or not allot time for them to engage in discussion and reflect.

This may be due in part to Betsy’s lack of academic background in science. Adult mediators such as teachers determine how a child learns and develops (Karpov, 2014). Attention to our own students’ experiences and perceptions is integral to the practice of teaching. With the focus in science education on children’s thinking Howes (2002) states:

“if one is to plan productively and assess authentically, one needs to know what students are thinking throughout instruction.” (p. 864)

The NSES (1996) also support this view, that teachers of science need to anticipate typical misunderstandings and to judge the appropriateness of concepts for the developmental level of their students (p. 62).

Having her own set of misconceptions and conceptual understandings in science, Betsy’s classroom management tended to skew towards the science concepts and teaching methods that she was most comfortable with. In her case study of elementary teachers, Garrett (2008) discusses how teachers practice transitions, and classroom management beliefs and practices are viewed on a continuum from teacher-centered to student-centered. Through her implementation of the experiential framework, Betsy’s teaching evolved when she was provided with guidance on how to modify her practice. As a result, student learning increased. Evidence from this study indicated that when students engaged in a socially constructed learning environment, through hands-on activities, small group work, and discussion they were able to engage with science content, think critically, problem solve and provide explanations for their scientific claims by engaging in a community of practice with their peers

In her implementation of concrete experiences, Betsy acknowledged that conducting lessons at field sites is difficult, but that this was the element of science teaching that she enjoyed that most. The addition of professional development sessions on top of her already existing background knowledge was not an asset to implementation.

In her own self-reflection she felt that she could have conducted the field experiences differently, having students focus more on their experience and observations, and less on process skills.

Overall, Betsy had a lot of anxiety about her lack of experience in science. At times during the interview, it felt as though she was projecting her own difficulties back onto her students. She stated many times how hard or difficult the content was and then expressed this in the context of the ability of students.

Although she had taught mathematics and science in Rhode Island before arriving at the Avenue School, at times it became evident that many of the challenges I observed in the science classroom had less to do with practice and more with Betsy not having an academic or professional background in science. It was apparent that administrative practices at the public school in Rhode Island were responsible for instituting out-of-field teaching: assigning teachers to teach subjects that do not match their training or education (Ingersoll, 1998, 2008). In his analyses of data from the National Center for Education Statistics, Schools and Staffing Survey, Ingersoll (1998) found that lower income public schools and smaller schools have a higher incidence of out of field teachers in grades 9-12 and that those individuals are more likely to be new to their career in teaching.

Throughout his research, Ingersoll, found this to be a commonly and accepted practice, especially in disadvantaged schools. As a new small school with less than 400 students, the Avenue School had access to fewer overall resources than larger schools. According to Ingersoll (2008), middle schools have a higher rate of out of field teachers assigned than high schools. This might explain why a teacher with an art and special education background was teaching math and science.

However, at the Avenue School this was not an isolated phenomenon. Betsy's new co-teacher, Nora, was a graduate student in English literature. She was out of field as well, teaching science and mathematics to special education students. Observing them work together was frustrating. There was a constant power struggle over who was teaching the class and lessons were packed with too much information and fragmented. Problems with implementation reflected Betsy's own misconceptions and struggles to connect science concepts for understanding.

Often blamed on problems of recruitment and retention, administrative practices and organizational characteristics account for much of the problem of out of field teaching (Ingersoll, 2002, 2008; National Governors Association, 2004). Recruitment and teaching assignments are the primary responsibility of the principal. So, if a teacher leaves mid semester, the onus is on the principal to backfill the position. This was the scenario at the Avenue School. The social studies teacher left suddenly in the middle of the semester. It was the principal's decision to assign a readily available teacher. By selecting Betsy, the principal was able to save time and money for the school.

Teacher quality. Ingersoll (2008) found that among elementary school teachers, lack of certification in the subject area they were teaching was the greatest indicator of out-of- field teaching than a related college major or minor. According to the New York State Department of Education (2009), there is no certification to teach elementary level science. The elementary teacher is a generalist and is responsible to teach all subject areas. Like Betsy’s certification, elementary teachers have proficiency in childhood education and rarely a concentration in science education.

Teacher quality provisions of the reauthorized No Child Left Behind (NCLB) Act of 2001 define a “highly qualified teacher” as someone who has a bachelor’s degree, teaching certification, and a level of competency in the subject area they are teaching (NCLB, 2002). In her analysis, Darling- Hammond (2000) reviewed national data to justify this explanation of teacher quality.

She explored variables of full state certification and college undergraduate or graduate major in the subject being taught to assess teacher quality. Her findings indicated that full certification and a major in the field were positively correlated with student achievement.

Teacher qualification is also an important component of student performance. Stronge, Ward, Tucker, and Hindman (2007) explored the meaning of teacher quality in the context of student achievement on state assessment test scores across eleven third grade classrooms in Virginia. Their findings indicated that the most effective teachers continuously altered their lesson presentation and format to accommodate all types of learners and asked students more high-level questions.

Betsy lacked science certification, but what she lacked in experience, she made up for in character. Her students liked and respected her, and it was evident that they enjoyed participating in her science class. I considered that maybe my own bias was getting in the way of defining what makes a qualified teacher.

Teacher quality and student achievement. The phenomenon of out-of-field teaching is not isolated to the United States. In her observations of out of field and specialized teachers across classrooms in South Africa and Australia, du Plessis (2015) investigated how out of field teaching influences Vygotsky's definition of the role of the teacher as the "knowledgeable other" (Karpov, 2014). She found that out-of-field teachers in science classrooms not only had difficulty learning content but finding effective ways to teach the subject matter. Findings from this study Her findings indicated that the quality of teaching was influenced by the teacher's difficulty connecting concepts, and their lack of depth and of understanding of interconnected concepts. Findings from this study indicated that the most significant form of help for science teachers teaching outside their field of specialization was assistance from more experienced colleagues.

Childs and McNicholl (2007) observed this same occurrence in their study of novice and experienced science teachers teaching outside of their area of specialization. Teachers in the study were not only confounded by learning what to teach also but how to teach it. Their findings indicated a strong relationship between teacher explanations and student misconceptions. Teachers in their study recognized that having in depth science content knowledge enabled them to draw on a broader range of alternative explanations to help students to develop scientific understanding. They understood that being able to first understand a concept allowed more flexibility in their pedagogy to incorporate anecdotes, analogies or illustrations to bring their subject to life.

According to the New York State Boards Association (2015), NYC has the highest proportion of High School teachers without certification in each subject area than the rest of the state of New York. Their findings indicated that in NYC, 4% of teachers lacked subject specific certification in science and 35% in technology. This deficit in technology certification is three times higher than the rest of New York State. A statewide survey of school superintendents indicated that 59% said they had difficulty finding qualified teachers in science, specifically, in specialty areas of physics, chemistry and earth science.

Connecting Three-Dimensional and Experiential Learning

In her implementation, Betsy used NGSS crosscutting concepts in the experiential water unit. Nixon, Luft and Ross (2017) recommend the use of the NGSS crosscutting concepts when teaching out of field teachers to broaden their science content knowledge and connect to science ideas. Crosscutting concepts of systems and systems modeling, patterns and cause and effect were prevalent in the professional development sessions. They were enacted through the soil core and aquifer modeling, and correlation of water quality factors.

In their discussion on the logic of interdisciplinary studies, Mathison and Freeman (1998) state the importance of the use of themes in integrated and integrative approaches to learning to facilitate “critical thinking within large complex themes as necessary background to fact acquisition.” (p.13)

Although both class sections adopted systems thinking skills, class #1 reflection and drawing assessments indicated that they had a clearer understanding of the dynamic and cyclic nature of continuous water movement and conceptual understanding of these interactions being part of a system.

Some interesting findings were with class #1, the class that had mathematics with Betsy five times a week with Betsy. With these students, Betsy used NGSS cross cutting concepts of scale, proportion and quantity, patterns and cause and effect and science and engineering practices of mathematics and computational thinking. She also used terms from mathematics like ratio, proportion and rate to illustrate water properties and processes in the students engineering models. Whether she was aware of it or not, she was facilitating transfer of physical concepts to new problems and settings. This illustrated what Wiggins and McTighe (2005) discuss as one of the fundamental principles to transfer, the ability to transfer what one has learned to a different context.

Bransford, Brown, and Cocking (2000) define transfer as developing competence in an area of inquiry whereby one can organize knowledge in manner that facilitates retrieval and application. To develop this level of competence, students need the opportunity to foster a deep level of understanding of subject matter to transform information into useable knowledge (p. 16).

Students from this class illustrated transfer of their learning in mathematics class to the new setting of the science classroom. They were able to connect fragmented facts and skills that they had acquired over the course of the semester to amount to an understanding of these concepts as well as systems thinking skills. These big ideas around water movement as part of a continuous system provided the basis for transfer.

Strategies Betsy used for planning the permeability and porosity explore unit were well organized in lesson plans and presentation. She did a great job using drawings to illustrate science and engineering practices and inducting analogy to explain and differentiate between the permeability and porosity of materials with the use of Sponge Bob© and a Brick Bob. This was a useful strategy to bridge conceptual understanding with students’ real world.

Student Achievement

Conceptual Understanding

Overall, students most significantly improved their understanding of water science concepts of permeability and porosity, condensation, infiltration and systems thinking skills of cyclic and dynamic thinking. Although there were some differences between the two class sections test scores there was not a significant increase in their scores between the pre and posttests.

A factor that may have played a role in this perceived variance, was that the pretest data indicated groups were not equivalent in their understanding of water science competencies, and that class #1had a greater understanding. Due to these data gaps, I had concerns that there was not true understanding of the interaction of the parts beyond the scope of those they could name. In addition, many of the open-ended questions were left blank, and the new questions that asked them to apply what they had learned in creating water filters to real world problems lacked transfer.

There was statistically significant increase in scores for both sections of students for the post drawing assessment, indicating that participation in the experiential learning unit developed their understanding of the systematic structure of the water cycle. With these assessments, students were provided with an essential question and predicated on the big idea of water movement, prompting them to illustrate how water cycles in nature. Eisner (1985) believes that scientists are motivated by aesthetic means not epistemological ones, and that creativity is born through the process of inquiry. It is this same “creation of coherence” (p.220) that prompts an emotional response and guides the learning experiences, in school and in the classroom.

Class #1 had a larger increase in their pre to post drawing assessment score. Whether it was Betsy’s familiarity with this group or her integration of crosscutting concepts of scale, proportion and quantity from the math class she taught these students five days a week, it was evident that she was more comfortable teaching this group of students. She rarely had any classroom management issues with them.

According to Chang (2012), children’s drawings convey their levels of conceptual understandings and illustrates how they conceptualize a science experience. This was evident in students drawing assessments, where learning and transfer were most pronounced. This finding is consistent with other researchers that have used draw and explain activities with elementary students to assess conceptual understanding of hydrological cycle (Assaraf, Eshach, Orion, & Almour, 2012; Assaraf & Orion, 2010).

The drawings also served as a formative assessment to inform Betsy's teaching practice. Triangulated with the pretests, drawings measured student's level of understanding of natural phenomenon, through their understanding of evaporation in the water cycle, as well as gaps in their understanding of subsurface interactions (Cardak, 2009; Chang 2012). Consistent with findings in the literature, elementary students best understood atmospheric components such as evaporation and condensation (Bar and Travis, 1991). Students' conceptions of groundwater were like those found by Dickerson and Dawkins (2004) where students viewed groundwater as kind of pool, lake or pipe or static, subsurface lake (Agelidou et al., 2001).

Bransford, Brown, and Cocking (2000) believe that organizing information in a conceptual framework facilitates transfer. The use of the experiential learning framework provided focus for students and taught in this holistic manner one can see how each part connects to a whole concept or big idea. Through their field experiences, students were provided with meaningful experiences of key aspects of the subject matter "suggesting logical organization and structure appropriate to the learner's level of experience" (Walker& Soltis, 2009, p.48).

Systems Thinking

Initial results from both pretests and pre-drawing assessments indicated that students understood various water processes, but that they did not understand the systematic structure of the water cycle as a whole (Cardak, 2009). Most students viewed groundwater a disconnected system with no relationship to the surrounding land, soil, rocks or vegetation (Assaraf, Ben-Zvi & Orion, 2005).

Elementary students' conceptions of groundwater are further confounded by their inability to conduct spatial reasoning (Kuhn, 1989); they encounter difficulty forming mental models of components that they cannot see with the naked eye (Dickerson, & Dawkins, 2004; Grotzer, & Basca 2003). The ability of elementary students in this study were consistent with findings in the literature, that children of this age can use models as representations of systems to construct explanations and solutions of water filter efficiency, allowing them to problem solve complex concepts using model-based reasoning (Quillin, &Thomas, 2015; Schwarz, et al.,2009).

It is recommended that systems thinking be introduced at the elementary school level so that students can begin to develop a continuum of understanding of relationships between Earth components that will develop to a higher level as they progress in school (Assaraf, & Orion, 2005b: Draper, 1993). Counter to their argument that elementary school students do not have the cognitive ability to understand complex systems (Kirschner, 1992; Kuhn, Black, Keselman, & Kaplan 2000; Kuhn & Pease, 2008) students in this study were able to comprehend cyclic and dynamic thinking.

Development of these systems thinking skills are instrumental for students to understand the systematic structure of the water cycle (Assaraf, & Orion, 2005b).

Through the construction of science knowledge and development of behaviors of scientists I observed elementary science students as they planned and executed, questioned and examined their experiments, models and designs. But what resonated the most was how excited and noisy they became as they began to engage in a community of practice by collaborating in their endeavors. They were arguing with one another, becoming competitive and finally turning to a more knowledgeable other for mediation and guidance. This is how scientists are made.

Multiple Assessments

The use of multiple assessments was instrumental in confirming student achievement and learning. Sleeter (2005), Fennimore (1997) and Wiggins and McTighe (2005) all advocate the use of authentic assessment as a learner-based approach that focuses on the success of the student. Each author presents different approaches to address the use of authentic assessment, but most notable is that more than one approach, the triangulation of evidence, such as classroom observations, projects, portfolios and tests, provide the strongest indicator of student performance.

Wiggins and McTighe (2005) argue that understanding can only be developed through multiple methods of ongoing assessment. They encourage educators to think of assessment as a tool they can use to document and validate acceptable evidence of student learning, not just a set of content and activities to be covered. This has been my same approach in creating research instruments for this case study. The instruments were based on a combination of expert knowledge, standards and real-world experience. Each piece of evidence on its own would not provide a clear conception of understanding. But taken together I can see how students' observations in the laboratory correspond to their notebook assignments, reflection essays and post drawings. These assessment tools show what students know and can do and how conceptual understanding is articulated through transfer.

Sleeter (2005) discusses the sense of empowerment that can be gained by educators if they themselves identify what high quality work looks like and create a set of criteria to guide student's work and give feedback. Throughout the case study, it was not transparent to me how Betsy used both the research instruments and assessments she created on her own to measure student performance. Other than the research instruments, Betsy informed me that she had created a water health quiz in the beginning of the semester and graded student science notebooks and their water filter reflections. During the interview, when I asked about student outcomes she informed me that everyone passed and did very well.

Although unit test scores did improve over the course of the semester, there was no statistical significance between the two tests. In their discussion on assessment strategies, Cox-Peterson and Olson (2002) indicate that the scope of closed-end tests themselves do not provide information about student understanding. This was why triangulation of the unit tests with the drawing assessments, science notebooks, observations and reflections provided evidence of a deeper understanding of the subject matter.

One assessment strategy that stood out to me the most was questioning. In student debriefing and discussions Betsy tended to use short answer questions resulting in a great amount of “teacher talk” and not enabling much student thinking. She tended not use wait time to allow students to answer and did not hold off on responding to the questions on her own (Cox-Peterson, & Olson, 2002).

High levels of thinking occurred among her students when they took over the conversation and Betsy merely facilitated or provided prompts. In their reflective journal entries on why field work is important, students provided insight into what they experienced and why it was so rewarding to them. Many students reflected on how this learning experience made them feel like real scientists, using the tools that scientists use and making scientific observations.

The integration of art and science in early childhood is vital in laying a strong academic foundation for curriculum alignment in upper grades and a deeper conceptual understanding and attainment of scientific literacy.

Cox-Peterson and Olson (2002) advocate the use of student drawings as an assessment strategy, due to its flexibility for all communities and types of learners. Used in conjunction with other assessment strategies, they can provide insight into student’s conceptual understanding. They strongly believe that using only traditional assessments misrepresents students understanding and advocate that alternative forms of assessment be used in addition to written tests. As pre-instruction assessments, the pre-unit and drawing tests provided insight into student thinking about water cycles and systems to provide feedback to Betsy to guide her practice. Having these drawings in student portfolios also allowed them to self-assess how their prior thinking may or may not have changed over the course of the experiential water unit. As evident in the post drawing assessments, there was a considerable gain in student understanding of concepts and interrelationships among water systems.

When used as a tool for academic exploration, multiple assessments gave Betsy the capacity to consider what her students can and cannot do, how they can be supported in these efforts and what potential outcomes might be for tasks that scaffold above their capacity. Dewey posits that with authentic assessment, we must present the learner with an authentic problem, one that arouses engagement and experimentation, and has situational or personal meaning to the learner themselves, not just a course requirement (Wiggins & McTighe, 2005). The trajectory from ongoing to authentic assessment fosters real accomplishment and meaningful engagement for the teacher and the student.

VI – CONCLUSIONS

Summary of Major Findings

The findings of this research highlight an elementary science teachers' efficacy in applying experiential teaching methods to facilitate three-dimensional learning. Learning through experiential methods was meaningful to both Betsy and the students and a valuable framework to facilitate student engagement in NGSS science and engineering practices. Students were able to grasp a conceptual understanding of water within a local context and develop and use models to gain a systematic understanding of water components and processes in Earth systems.

Teacher

Overall, for Betsy, the use of experiential education theory (Dewey, 2007) and the experiential learning model (Kolb, 2014) for guidance was an effective teaching approach for elementary school science. In our discussion and reflection, she acknowledged the importance of abstract conceptualization and that in future iterations she would need to build in more time for this and prompt in time for in depth reflection.

Using the experiential learning model (Kolb, 2014) and applying the theoretical underpinnings of experiential education (Dewey, 2007) provided a foundation to create a continuum of learning in classroom for implementing field experiences that explored science phenomenon in water science and engineering. Betsy's personal and professional interest in facilitating field experiences as part of science education were validated through her interest and stewardship of water and the environment. As a result, she intends to promote the experiential learning framework to fellow educators. Betsy's self-efficacy (Bandura, 1986) has evolved, she has become more confident in her science knowledge and pedagogy and the long-term impact of her participation in this study has already transferred to other domains of learning.

In her implementation, the experiential learning was effective in creating baseline knowledge and understanding on water systems, cycles, earth systems, energy flow and filtration to her students; essential components to understanding more complex concepts within the NYC science scope and sequence as they progress in their learning towards higher order conceptual understanding in weather, water chemistry, physics and earth science (Schweingruber et al., 2007).

The flexibility and universality of the experiential learning framework made it an effective model for teaching and learning about water systems, engineering practices and the nature of science in elementary school science. Learning from the experience was not an individual effort for Betsy, it was a collaboration between her and myself to facilitate model-based reasoning, scientific inquiry and conceptual understanding of water in Earth systems.

Teacher- scientist partnership. Being a scientist is part of my identity, but in many instances in my professional and academic life I fought to find a sense of belonging as an environmental scientist among my peers in engineering, physics and chemistry. It occurred to me that this was something that Betsy and I had in common. I watched as she struggled to find a sense of belonging and identity as a science teacher. This was only further confounded by her very limited academic background in the sciences. Betsy was both competitive and insecure in her interactions with her peers. Among the other teachers, she was viewed as bold, creative and innovative. Her objective was to make science fun and foster students' sense of discovery before hormones and testing took over in the coming years. Both of us had fallen in love with science through our sense of wonder and enchantment with nature. In the science classroom I was cognizant that this was Betsy's domain and that I was there to support her. She often referred to me as her co-teacher-- a role that I embraced and found to be truly gratifying when students came to me with questions during a lesson. I considered this opportunity to mentor Betsy as my role and duty as a member of the scientific community.

In addition, being in the elementary science classroom improved my own understanding and communication of science concepts and strategies used to foster understanding such as analogies and crosscutting concepts. Throughout this experience I was mindful of not only establishing knowledge of science and engineering practices but also how Betsy could bring these topics to life and reinterpret them in the classroom.

Throughout this experience I viewed Betsy as a learner and witnessed the impact of our partnership in her continued pursuit to learn about different domains of science and t integrate these findings along with the water filtration lab into her classroom practice with a new group of students. The scientist- teacher partnership impacted my perception and understanding of the realities of teaching elementary students in a NYC public school. I have emerged with the utmost respect for elementary teachers and this work has inspired me to continue to create mentorships with science teachers.

Students

The students in both class sections were able to develop conceptual understanding of water science and engineering and water in Earth systems through science discourse and enculturation into the community of science practice (Brown, et al, 1989; Driver, 1995).

Students converted concrete experiences into learning by developing their initial misconceptions about water cycling from surface and atmospheric to understanding foundational components of hydrology and groundwater (Assaraf and Orion, 2005a; Kolb, 2014). Through the development and use of models, students grasped an understanding of systems and systems thinking, which they were able to articulate in their learning outcomes and academic progress.

Implications of Curriculum Development

The original EiE curriculum, *Water, Water, Everywhere,* introduces the problem of water pollution through the social and cultural context of a young girl in India observing the Ganges River near her home and extracting water to create a habitat for her pet turtle. The unit then goes on to discuss the important role of environmental engineers in providing and maintaining clean and healthy water (Lachapelle, & Cunningham, 2007). In our revision of the EiE unit, *Water, Water, Everywhere,* water pollution is presented in a local context. The rationale for this change was that students within urban environments such as New York City do not always have a direct access to the natural environment and that they would not be able to connect with an environment on the other side of the world. Within the subcultures that influence a student's understanding of science-- their family, peers, school, the mass media, and the physical, social and economic environments-- all have defining components of norms, beliefs and values that students construct and negotiate within their realities (Aikenhead, 1996).

By providing field opportunities to experience water and nature through local authentic environments, students were be able to connect to the concepts in a meaningful way, and one that impacts their own lives. This revision was instrumental in transitioning student understanding of water in our world, where pretest responses were focused on water bodies such as the Pacific and Atlantic Ocean, post unit test responses included local water bodies such as the Hallett's Cove, Catskill Watershed and the Hudson River.

The other major adaptation was eliminating content on the role of environmental engineers. The rationale was that by participating in hands on experiments in the labs and problem solving using the engineering design model, the students themselves would be playing the role of the environmental engineer.

Using inquiry-based strategies, the adaptations were developed to interconnect students with everyday experiences and authentic activity where students are doing science; thinking, learning, participating, and formulating their own questions (Meyer, & Crawford, 2011). In addition, these adaptations presented opportunities for students to develop a real world understanding of the diverse fields in science by observing the world of environmental ecologists, engineers and educators through participation in concrete experiences. Students also were able to broaden their view of the different domains of science. That not all science is applied in the same manner, not all scientists do the same kind of work, and that learning science is a dynamic process.

Implications of Study

There is limited research related to scientists working with elementary science teachers to mentor their practice in water engineering one that fosters science content knowledge on water and Earth systems using the experiential learning model (Crosby, 1997; Dashoush, 2015; Loucks-Horsley, et al. 1998; Loucks-Horsley et al., 2003; NRC, 1996b). This study will serve to provide a greater understanding of how teachers can utilize experiential education and learning models to teach NGSS science and engineering practices. These experiences can be used to expand their students scientific content knowledge and progression of conceptual understanding.

A successful outcome of this research project would be that student and teacher participation in these experiences builds a foundation of scientific inquiry that sets the tone for a continuum in the development of environmental stewardship and a conceptual understanding of water systems in all types of learning environments.

Even with access to intensive and personalized professional development and preparation, many of the barriers to instruction persisted in this case study due to institutional constraints. Without certification criteria for elementary school science, out-of-field teaching will continue in schools across New York State. This case study illustrates the impact that lack of an academic background in science can have on elementary teacher quality and student achievement. Certification in elementary school science would eliminate the need for such personalized and intensive professional development to achieve the goals of science education. Furthermore, there is a necessity for high quality science experiences in early childhood so that children can develop the foundation needed for conceptual understanding of science across domains.

For Betsy, the challenges that she encountered with both school administration and scientific conceptual understanding were overcome, and overall it appeared that this was a confidence building experience for her (Bandura, 1986; Gunning, & Mensah, 2010). I have watched her thrive and I am excited that she will continue to take on challenges in her profession. The collaborative partnership of the scientist-teacher has contributed to my understanding of the struggles faced by elementary science teachers in classroom management, access to materials and working with students of different abilities (Anderson, 2002; Crawford, 2007; Gunning, & Mensah, 2010; Howes, 2002; Mensah, 2010). It has made me think about how I communicate in science and providing professional development to elementary teachers, especially in my writing and presentation of information.

The experiential learning framework is an effective pedagogy for water science explanatory models and for the inclusion of science and engineering practices as specified in the K-12 framework. In its implementation there is alignment to the Next

Generation Science Standards of crosscutting concepts in inquiry-based investigations, systems and system models, and energy and matter of flows, cycles and conservation.

Limitations of Study

From my search of the literature, the implementation of experiential education has predominantly been within adult education and training settings outside of the domain of science (Kolb, 2014). By introducing experiential methods into the elementary science classroom elementary, I was able further the scope of the educational process and engage students in a meaningful and motivating context. Learning through experiential practice can become significantly more dynamic as it allows the development of skills such as confidence, independence and students' autonomy and enhances positive attitudes toward learning (Koutsoukos, Fragoulis, & Valkanos, 2014).

Using the experiential learning cycle as a framework to guide teaching and learning in professional development sessions and teaching in the classroom was a challenging endeavor, but it merged well with the experiential water unit objects. Implementation of the concrete experience, reflective observation and active experimentation were built into Betsy's unit plan, but abstract conceptualization was a bit more difficult. Asking why something happened requires a deeper level of understanding. Conducting analysis in this manner was something that both Betsy and her students were not used to doing. It was evident that my difficulty actualizing this component in the professional development sessions with Betsy carried over to her classroom practice as well.

As schools and districts begin to integrate aspects of the NGSS (2013) into their teaching practice, there are limited resources available on how to carry out the performance expectations and the three dimensions of learning in the literature (Reiser, 2013). Merging three-dimensional learning with experiential education, I was able to examine the efficacy of experiential teaching methods and connect students to a more dynamic process of learning.

Further Research

Further research is needed to address experiential teaching methods that facilitate an understanding of water engineering in the elementary science classroom. To foster this, long-term experiential professional development should be explored to create a continuum of in-depth rigorous instruction to study how it impacts science teacher implementation and practice (Bransford et al., 2000).

The scientist-teacher partnership is not well documented in the literature. Further research should expand to include the development of these relationships to enhance both the teacher and scientists understanding of the role of science in our educational systems.

Based on the findings from this study, elementary students have the capacity to understand systems thinking concepts about water cycles and systems. Further research in this area would reinforce this finding. To facilitate this, the use of multiple assessments such as unit tests, questioning and drawing tests would confirm that students have a deep understanding of system components, processes and relationships between them. Water system assessments that have traditionally been used in upper level elementary students such as knowledge integration activities (Kali, Orion, & Eylon, 2003) and concept maps (Assaraf, & Orion, 2005b) should also be considered to further the breadth and depth of scientific knowledge.

Conclusions

From this instrumental case study, I have explored the efficacy of an experiential education framework for teaching and learning elementary science.

By providing an intensive and personalized continuum of professional development, the teacher in this study improved in her conceptual understanding and self-efficacy within the sciences. Multiple sources of data provide evidence of the impact of a scientist-teacher partnership and mentorship on her initial and long-term development of science and engineering practices that sustain to this day. Through the alignment of NGSS crosscutting practices and the application of an integrative approach to learning, the teacher was able to use the experiential learning framework to improve her practice.

Immersing science content within an experiential framework provided a structure for field excursions to local natural resources, where students developed a sense of stewardship and understanding of water systems. Using multiple assessments, results indicate that students developed a deeper conceptual understanding of hydrology, earth science, environmental science and water filtration.

I feel that this research is important because it adds to the literature base on students' environmental science learning and how they conceptualize water in Earth systems. By introducing systems and system modeling in the context of water and engineering of water filters, students increased their understanding of model construction and design which were leveraged to promote a systematic understanding. By engaging in multiple iterations of their water filter design, students conducted inquiry-based investigations and problem-solving skills, building on the tenets of experiential theory that knowledge is gained through experience.

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APPENDICES

Appendix A- IRB- Informed Consent

Teachers College, Columbia University 525 West 120th Street

New York NY 10027

212 678 3000

www.tc.edu

INFORMED CONSENT

DESCRIPTION OF THE RESEARCH: You are invited to participate in a research study on how participation in an experiential water unit affects conceptual understanding. You will be asked to participate in a 20-30-minute interview in person that will be audio-taped. All interview subjects will have a pseudonym. As the student researcher, Amanda Levy will be the only one who is able to identify the subjects in the research data. Audio files will be destroyed after this dissertation research project is completed. The research will be conducted by science education doctoral student

Amanda Levy, MS, MPH. The research will be conducted at the 30th Avenue School upper level campus located at 31-51 21 Street Queens, NY 11106 in classrooms on-site that will be reserved in advance.

RISKS AND BENEFITS: The research has the same amount of risk students will encounter during a usual classroom activity. Potential risks may be that the process of being interviewed may cause stress or anxiety for the individual. If the subject appears to be distressed by the conversation, I will suggest that we take a break or end the interview. The potential benefits to this study are that it will allow individuals to share their individual experience of the unit and clarify any misconceptions they hold about the water science content. The study allows these individuals to have a voice for themselves and inform future classroom content and research in the domain of environmental science.

PAYMENTS: NOT APPLICABLE

DATA STORAGE TO PROTECT CONFIDENTIALITY: Coding and data materials will be stored at the researchers (Amanda Levy's) home in a locked file drawer. All interview subjects will have a pseudonym. As the student researcher, Amanda Levy will be the only one who is able to identify the subjects in the research data. Audio files will be destroyed after this dissertation research project is completed.

TIME INVOLVEMENT: Your participation will take approximately 20-30 minutes for the interview.

HOW WILL RESULTS BE USED: The results of the study will be used as part of dissertation paper for coursework to meet qualifications for a doctorate of education in the Department of Mathematics, Science, & Technology at Teachers College, Columbia University.

Teachers College, Columbia University 525 West 120th Street

New York NY 10027 212 678 3000

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PARTICIPANT'S RIGHTS

Principal Investigator: Amanda Levy, MS, MPH / Dr. OR. Anderson, Ph.D.

Research Title: Investigating the Experience of Water: A Case Study of Teacher Professional Development and Student Achievement in Elementary School Science

I have read and discussed the Research Description with the researcher. I have had the opportunity to ask questions about the purposes and procedures regarding this study. My participation in research is voluntary. I may refuse to participate or withdraw from participation at any time without jeopardy to future medical care, employment, student status or other entitlements.

I may withdraw me from the research at his/her professional discretion. If, during the study, significant new information that has been developed becomes available which may relate to my willingness to continue to participate, the investigator will provide this information to me.

Any information derived from the research project that personally identifies me will not be voluntarily released or disclosed without my separate consent, except as specifically required by law.

If at any time I have any questions regarding the research or my participation, I can contact the investigator, who will answer my questions. The investigator's phone number is (646) 509-9470.

If at any time I have comments, or concerns regarding the conduct of the research or questions about my rights as a research subject, I should contact the Teachers College, Columbia University Institutional Review Board /IRB. The phone number for the IRB is

(212) 678-4105. Or, I can write to the IRB at Teachers College, Columbia University, 525 W. 120th Street, New York, NY, 10027, Box 151.

I should receive a copy of the Research Description and this Participant's Rights document.

If video and/or audio taping is part of this research, I () consent to be audio/video taped. I ( ) do NOT consent to being video/audio taped. The written, video and/or audio taped materials will be viewed only by the principal investigator and members of the research team.

Written, video and/or audio taped materials ( ) may be viewed in an educational setting outside the research

( ) may NOT be viewed in an educational setting outside the research.

My signature means that I agree to participate in this study.

Participant's signature: ______________________________Date:______

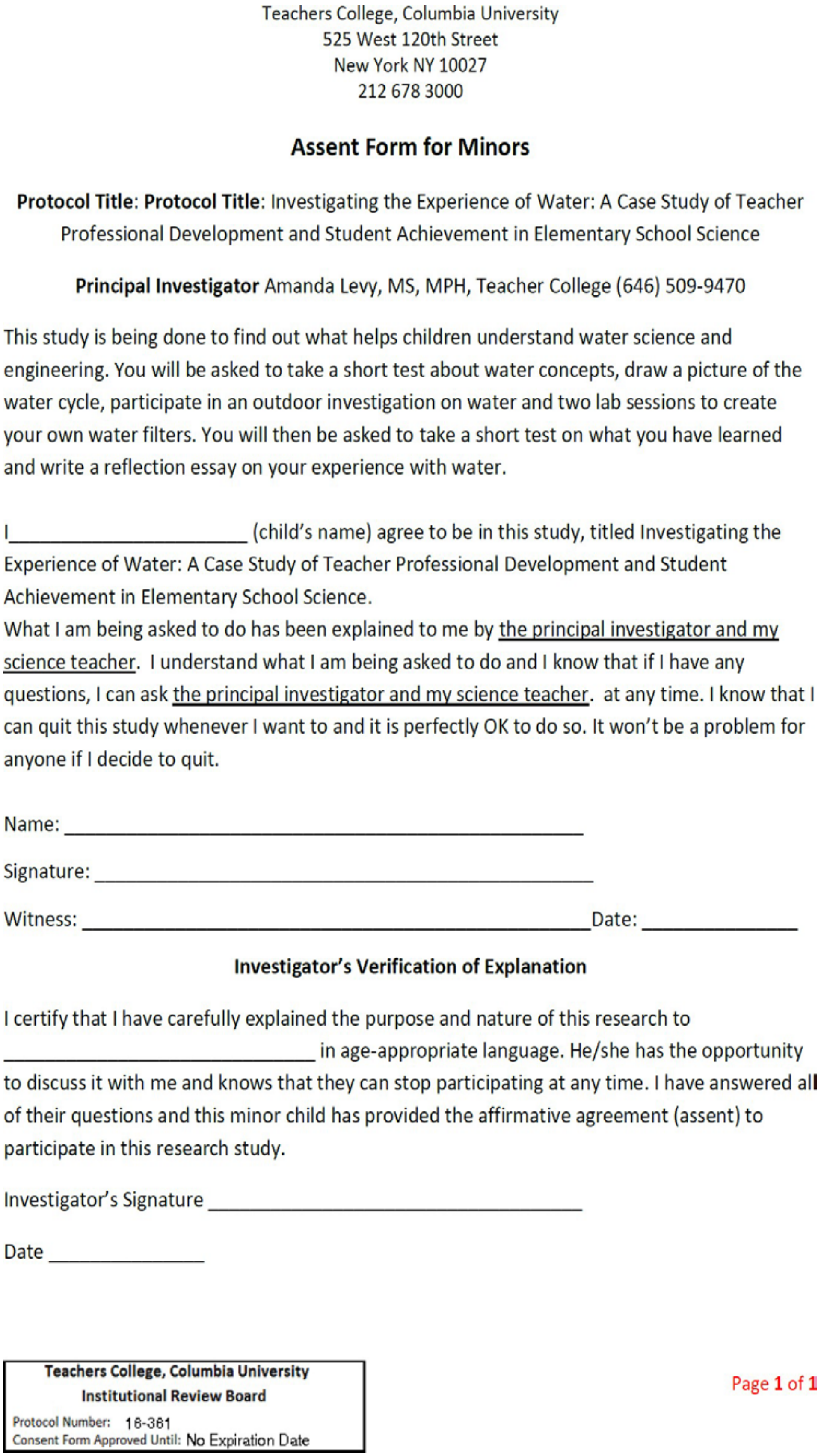
Name: ____

If necessary:

Guardian's Signature/consent: ____________________________________

Date:__/______/______

Name:____



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525 West 120th Street
New York NY 10027
212 678 3000

Assent Form for Minors

Protocol Title: **Protocol Title**: Investigating the Experience of Water: A Case Study of Teacher Professional Development and Student Achievement in Elementary School Science

Principal Investigator Amanda Levy, MS, MPH, Teacher College (646) 509-9470

This study is being done to find out what helps children understand water science and engineering. You will be asked to take a short test about water concepts, draw a picture of the water cycle, participate in an outdoor investigation on water and two lab sessions to create your own water filters. You will then be asked to take a short test on what you have learned and write a reflection essay on your experience with water.

I______________________ (child's name) agree to be in this study, titled Investigating the Experience of Water: A Case Study of Teacher Professional Development and Student Achievement in Elementary School Science.
What I am being asked to do has been explained to me by the principal investigator and my science teacher. I understand what I am being asked to do and I know that if I have any questions, I can ask the principal investigator and my science teacher. at any time. I know that I can quit this study whenever I want to and it is perfectly OK to do so. It won't be a problem for anyone if I decide to quit.

Name: ____

Signature: ____

Witness: ____Date: ______________

Investigator's Verification of Explanation

I certify that I have carefully explained the purpose and nature of this research to ____________________________ in age-appropriate language. He/she has the opportunity to discuss it with me and knows that they can stop participating at any time. I have answered all of their questions and this minor child has provided the affirmative agreement (assent) to participate in this research study.

Investigator's Signature __________________________________

Date ______________

Teachers College, Columbia University
Institutional Review Board
Protocol Number: 18-381
Consent Form Approved Until: No Expiration Date

Appendix B-Teacher Background Survey

Name: Date:

School: Contact Information:

What is your teaching certification in?

How many years have you been teaching?

What higher education degree(s) do you hold?

How many hours per week do you spend teaching science?

What types of resources do you consult for lesson plans?

Have you participated in any professional development training?

If yes. Please provide details about your experience(s)

Describe your understanding of how NYC water gets to the tap in your home

Describe and draw the pathway of a water molecule from the ocean to land and back again

What is your experience with water concepts as a topic in your pedagogy?

What is your personal experience with water?

Appendix C- Professional Development Overview

Objectives:

Fostering teacher’s science understanding and pedagogical content knowledge in science

Applications of the experiential learning cycle as a framework for teaching and learning

The use of system models to represent science concepts, practices and processes

The use of inquiry-based investigations to explore data and construct scientific explanations and negotiate meaning

Session one: Introduction to the experiential learning framework

In Session:

- Soil Core Sampling activity
  - Overview of Soil
  - Concrete Experience
  - Reflection, Conceptualization, Active Experimentation
  - Assessment and Review Post session:
- What is your learning style?
  - Extended learning style activity - Kolb Learning Styles Questionnaire

Session two: Water systems and modeling

In session:

- Science Content Review:

- Water Cycles and transformations
- Groundwater
- The NYC Drinking Water system
- Systems thinking and water engineering
- Experiential Components:
- Hydrological Cycle Worksheet
- Water at the Window Activity
- Simple Groundwater model demo Post Session
- Assignment: *Reflection*: How would you/ would you use what has been reviewed so far in your own pedagogy?
- Reading: Cultivating Model Based Reasoning in Science Education (Lehrer & Schauble, 2006)

Session three: Inquiry Based Investigations

In Session:

- Exercise on developing guiding questions
- Exploring Abiotic Factors
- Compare and Analyze Water Quality Data
- NYC DEP Harbor Water Quality
    - NYC DEP Stream Quality Data – p 95 Watershed Water Quality Annual Report

Post Session

- Assignment- develop a guiding question for the experiential water component
- Reading (Excerpts from): Stevens, D. D., & Cooper, J. E. (2009). Journal Keeping: How to Use Reflective Writing for Effective Learning, Teaching, Professional Insight, and Positive Change. Stylus Publishing, LLC

Session Four: Review NYC and Next Generation Science Standards

- Models and Systems (NGSS and k-12 framework)
- Crosscutting concepts
- Why is sequencing important
- Assignment: Reflection Question 2:
- Assignment: Infuse experiential water learning unit into existing curriculum plan

Appendix D- Teacher Interview Protocol

Name:	Date:
School:	Contact Information:

Experiential learning framework implementation

1. Do you feel that the experiential learning cycle is a useful tool for learning about science phenomenon?
2. Do you feel like you have a good grasp of the underlying components of the learning cycle? (What are the four components?)
3. Do you feel like you were able to implement all the components of the cycle in the classroom?
4. Do you think that using the cycle as a framework was a useful tool for your pedagogy?
5. What was the most difficult aspect of implementation?
6. Which component of the cycle was most meaningful for you? For your students?
7. Were you able to make direct connections with crosscutting concepts and

disciplinary core ideas from the NGSS?

8. Were you able to connect the experiential component with the modeling activity?

Confounding factors

1. Did you encounter any barriers to carrying out the water unit?
2. What was your experience working with your administration on the intervention?

Learning processes and outcomes

1. Is there a tension (student anxiety, competition, or difficulty to grasp) in the class when it comes to science?
2. Do your students find science in general, interesting?
3. How do you reach out to your difficult students? Is there any way you make students think critically?
4. How is the academic performance of these students in science?
5. Did your students find working on the water filter or any other or taking field trips interesting?
6. Did you discuss with your students, re: field work, data collection and making meaning out of those?

7. Do you think students were able to grasp an understanding of the underlying structures of the water cycle?

8. Do you think students were able to make connections between the different filtration systems?

9. How much do you think you were able to give the guidance the students need?

10. Do you think there has been a change in attitude among students toward being more positive (interested, or actually engaged) about water resources and/or scientific data collection? And, developing an overall scientific attitude?

11. In what way(s) was the intervention most useful, if at all? What was the area that you felt needs most improvement?

Appendix E- Systems thinking coding scale

These research components will be assessed with a qualitative scale that is based on Assaraf and Orion’s (2005a) Systems Thinking Hierarchal Model (STH) of eight emerging themes in systems thinking and characteristics and the expression of each of them in the context of the hydro-cycle system:

1. The ability to identify the components of a system and processes within the system.
2. The ability to identify relationships among the system’s components
3. The ability to organize the systems’ components and processes within a framework of relationships
4. The ability to make generalizations: Such generalization might be expressed within the hydro-cycle system by the understanding that this system is dynamic and cyclic.
5. The ability to identify dynamic relationships within the system
6. Understanding the hidden dimensions of the system
7. The ability to understand the cyclic nature of systems
8. Thinking temporally: retrospection and prediction

Appendix F- Pre/Post Test Open Ended Question Scoring Rubric: Six facets of understanding of Wiggins and McTighe (1998)

Six facets of understanding of Wiggins and McTighe-Rubric for Open Response Questions

Level 0	No Response Question is left blank.
Level 1- Naïve	A superficial account, restatement of the question. A diagram is present, but not cross-sectional. Labels are minimal or not present.
Level 2- Intuitive	An incomplete account with limited support. A diagram is present, but not cross-sectional. Labels are present but may or may not correctly represent groundwater characteristics. Explanation of characteristics is pertinent, but it lacks development, clarity and depth.
Level 3- Developed	An account that reflects in-depth, supported ideas. A cross-sectional diagram is present. Labels are present and correctly represent groundwater characteristics. Explanation correctly cites and develops terminology and characteristics. Knowledge and understanding of characteristics is evident but lacking conceptual development and sufficiently supported theory.
Level 4- In depth	An account revealing understanding and theorization going beyond what was taught. A cross-sectional diagram is present with labels correctly representing characteristics. Terminology is correctly cited and represented. Explanation is developed, clear and supported. Understanding of characteristics is conceptual and includes 3-dimensional description.

Level 5- Sophisticated	An account revealing thorough, intuitive, conceptual understanding. A developed cross- section with correct cited and depicted terminology. Explanation is inventive, insightful, fully supported and goes beyond information given. Connections are obvious, justified and based on soundly presented theory. Goes above and beyond.

Appendix G – Water Filter Reflection Assessment

Water Filters Reflection Assessment

Sediments and Permeability

1) In class we explored the properties of sand, soil and gravel. What do these materials have in common? What is different?

2) Where do we see filtering in nature?

Designing a Water Filter

3) What was important to thinking about in designing your water filter?

4) How is your filter design similar/ different to how a water system works?

5) What were you able to learn by building and revising your own water filter?

Appendix H- Observation rubric

Classroom Observation Protocol

To measure the epistemic dimensions of elementary classroom science this research study will use the Practices of Science Observation Protocol (P-SOP) developed by Forbes, Biggers & Zangori (2013) to characterize essential features of inquiry and scientific practices represented in the *Framework for K-12 Science Education* (Quinn, Schweingruber & Keller, 2012). This 20-item tool quantifies the five features of inquiry on a four-point Likert scale ranging from 0 to 3, where 3 indicates the highest level of student engagement in scientifically oriented questions.

1. Engagement with Investigation				
a. Students engage with an investigation question **that is contextualized, motivating, and meaningful for the students.**	0	1	2	3
b. Students engage with an investigation question **that focuses on standards- based content/ phenomena.**	0	1	2	3
c. Students engage with an investigation questions **that is answerable through scientific inquiry.**	0	1	2	3

d. Students engage with an investigation question **that is feasible and answerable in the context of the classroom**	0	1	2	3
2. Engaging Students in giving priority to evidence in response to questions				
a. Students engage with phenomenon of interest	0	1	2	3
b. Students work with data related to phenomenon of interest	0	1	2	3
c. Students generate evidence by organizing and analyzing data	0	1	2	3
d. Students reflect upon and verify the data collection process, accuracy of data, and transformation of evidence from data.	0	1	2	3
3. Engaging Students in **formulating explanations from evidence** to address scientifically oriented questions				
a. Students formulate explanations about phenomenon of interest **that are based on evidence.**	0	1	2	3
b. Students formulate explanations about phenomenon of interest **that answer investigation question.**	0	1	2	3
c. Students formulate explanations about phenomenon of interest **that propose new understanding.**	0	1	2	3
d. Students formulate explanations about phenomenon of interest **that build on their existing knowledge.**	0	1	2	3

4. Engaging Students in evaluating their explanations in light of alternative explanations				
a. Students evaluate their explanations by comparing to alternative explanations to consider **whether evidence supports their proposed explanation.**	0	1	2	3
b. Students evaluate their explanations by comparing to alternative explanations to consider **whether their proposed explanation answers the investigation question.**	0	1	2	3
c. Students evaluate their explanations by comparing to alternative explanations to consider **any bias or flaws in reasoning connecting evidence with their proposed explanation.**	0	1	2	3
d. Students evaluate their explanations by comparing to alternative explanations to consider **whether alternative explanations can be reasonably derived from the same evidence.**	0	1	2	3
5. Engaging Students in communicating and justifying their explanations				
a. Students clearly state and justify **their explanation process.**	0	1	2	3
b. Students clearly state and justify **their procedures, data and evidence.**	0	1	2	3
c. Students clearly state and justify **their proposed explanation and supporting evidence.**	0	1	2	3
d. Students clearly state and justify **their review of alternative explanations.**	0	1	2	3

Appendix I- Student Pre/Post test

1) Sleet, rain, snow, and hail are forms of (3):

a) Erosion
b) evaporation
c) groundwater
d) precipitation

2) Earth's hydrosphere is a layer of (1):

a) rock
b) air
c) lava
d) water

3) A soil sample contains living & nonliving materials. Which material was once living? (2)

a) sand particles
b) decomposing leaves
c) small pebbles
d) water droplets

4) Why does water move very slowly downward through clay soil? (5)?

a) Clay soil is composed of low-density minerals.
b) Clay soil is composed of very hard pieces of matter.
c) Clay soil has large pore spaces between pieces of matter.
d) Clay soil has very small pieces of matter.

5) **Name places where you would find water in the world (9).**

6) Water is boiled in a pan on a stove. The state of matter of the water changes from (2):

a) liquid to solid
b) solid to liquid
c) gas to liquid
d) liquid to gas

7) Which is most important in determining the amount of groundwater that can be stored within a rock (5)?

a) the rock's geologic age
b) the rock's hardness
c) the rock's porosity
d) the rock's color

8) Describe the path a molecule of water might follow through the water cycle starting from rain as it lands on the schoolyard downstairs (9).

9) Which of the following BEST describes the water cycle?

a) Collection Evaporation Precipitation Condensation
b) Condensation Evaporation Precipitation Collection
c) Precipitation Collection Evaporation Condensation
d) Evaporation Precipitation Collection Condensation

10) **When it rains, water will runoff the surface of the ground if the soil is (5):**

a) highly permeable
b) steeply sloped
c) covered with trees
d) loose and sandy

11) On a hot and sunny day, a boy poured a glass of cold water. A few minutes later, the glass was wet and slippery on the outside. How did the water get there (7)?

a) It rained.
b) It condensed.
c) It evaporated.
d) It leaked through the glass

12) The four major systems of the Earth are the geosphere, hydrosphere, atmosphere, and biosphere. Describe each of these major systems (9).

13) What is groundwater (8)?

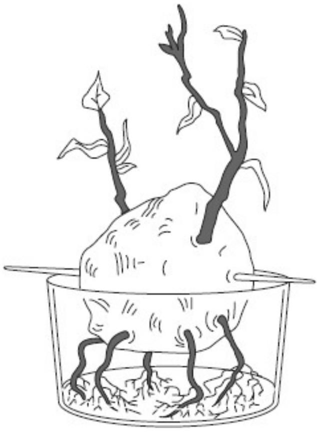
a) Liquid water that resides beneath the Earth’s surface.
b) Muddy mixture of water and dirt that lies beneath the Earth's surface.
c) Only the water found in underground lakes and rivers that is clean enough

to drink.
d) Only water that is moving beneath the Earth's surface.

14) Why is it important to stop pollution of the soil (7)?

a) Animals that live in the soil might die.
b) Humans eat plants that have grown in the soil.
c) When water flows through polluted soil it might become polluted.
d) All of the above are reasons why it is important to stop pollution of soil.

15) The diagram below shows a potato plant in a cup. The cup was originally filled to the top with water. Explain why the cup no longer contains water (2)

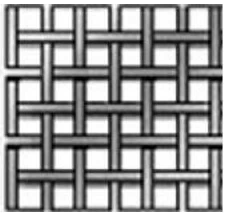


16) Where is groundwater found (8)?

a) Only in wet climates.
b) Only where there is soil since water cannot move through rock.
c) Groundwater can exist in rock or soil but will not be found beneath the Earth’s surface.
d) Almost anywhere beneath the Earth’s surface.

View the object below to answer questions 14 and 15.

A girl has designed a water filter using a metal window screen. She wants to clean brown water with lots of small pieces of dirt floating in it. She pours the dirty water through the metal screen, but it does not change (7).



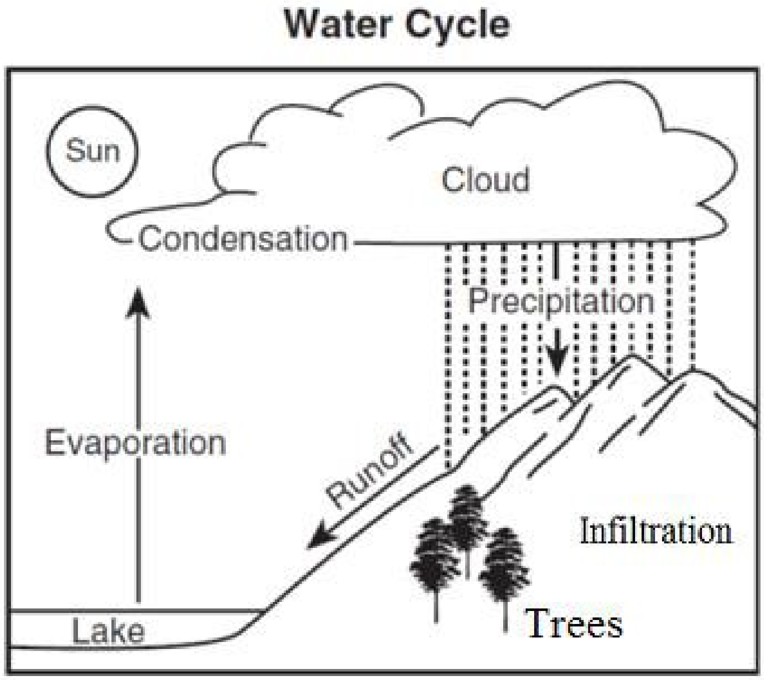
17) What would be the BEST thing she could do to remove the small pieces of dirt?

a) Scoop out the particles with a spoon
b) Use a filter material with larger holes
c) Use a filter material with smaller hole
d) It is not possible to remove the small pieces of dirt

18) What would be the BEST thing she could do to remove the brown color?

a) Clean the water with soap
b) Use a filter material that is softer.
c) Use a filter material with smaller holes.
d) It is not possible to remove the brown color.

19) Five processes in the water cycle are labeled in the diagram below. (4)



The first column of the chart below describes what happens during each process in the water cycle. Complete the chart by filling in the word for **each** process. An example is shown for the process in the first row.

What Happens During the Process	Water Cycle Process
Water falls from the cloud to the ground.	Precipitatio

	n
Liquid water flows over Earth’s surface.	
Liquid water changes into water vapor.	
Water vapor changes into liquid water.	
Liquid water that flows over the Earth’s surface that percolates through the soil and into pores and hollows of permeable rocks.	

20) Please mark next to the statement whether you think it is TRUE (T) or FALSE (F) **(6, 8)**

a) Most of the underground water persists in the small pores of the rock, similarly to a well-watered sponge.
b) Underground water is similar to underground lakes that are located in spaces inside the soil.
c) Rocks don’t influence the composition of water that penetrates them.
d) Ground water can be found only in raining areas
e) Clouds are the starting point of the water cycle and the tap at home is the end point.
f) If the population on earth will continue to grow, water consumption will increase, thus decreasing the amount of water on earth
g) Ocean is the starting point of the water cycle and groundwater is the end point.
h) Water on the earth exists in different phases and moves between the atmosphere, underground, land, and oceans.
i) Human consumption of water is quickly decreasing the amount of water on earth.
j) Global warming is causing a decrease in all water on the earth.

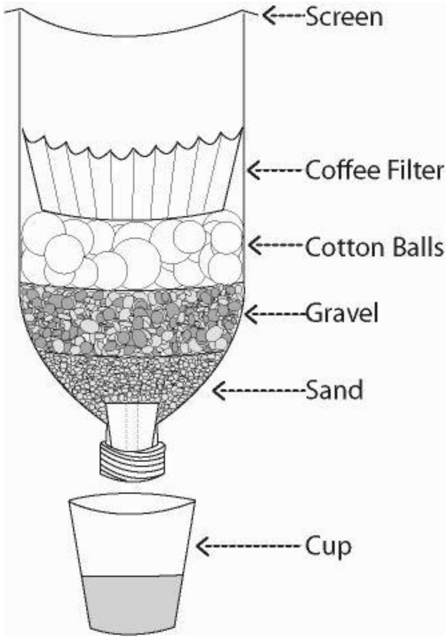
21) Explain how water gets to your tap

Post test

(Posttest contains ALL of the same questions with the addition of the last one below and- exchange these below for 17 and 18 on the pretest)

17) Two students make a water filter. A diagram of their filter is shown below. They pour murky brown water with leaves in it into the top of their filter. The leaves don't come through, but the water that comes out is still brown. What is the MOST LIKELY problem?

a) Only chemicals can remove color from water.
b) A filter can NOT change the color of the water.
c) The filter is not catching things that are very tiny.
d) The sand in the filter is turning the water brown again.

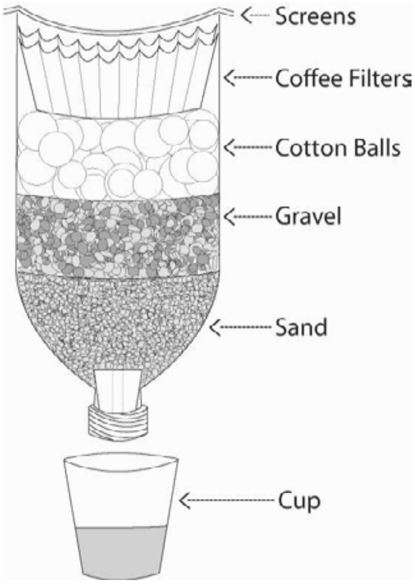


18) What can the students do to help get the brown color out of the water?

a) Add soap to the water
b) Add more sand to the filter
c) Remove the sand from the filter
d) The students cannot get the brown color out of the water

19) The students try adding more of each of the materials to their filter. A diagram of their new filter is shown to the right. They pour dirty water into the top of their filter. The water fills up the top of the filter and comes out the bottom too slowly. What is MOST LIKELY the problem?

a) Too much sand is blocking the water.
b) Too many screens are blocking the water.
c) Too much paper is soaking up all the water.
d) Too much cotton is soaking up all the water.



1 Adapted from. New York State 8th Grade Science Regents, 2015

2. Adapted from New York State, Grade 4 Elementary Level Science Test, 2003

3. Adapted from New York State, Grade 4 Elementary Level Science Test, 2004

4. Adapted from New York State, Grade 4 Elementary Level Science Test, 2015

5. Adapted from Troy New York School District, Earth Science Regents Prep, Unit 8

6.Adapted from Assaraf and Orion – A Designed Based Research of an Earth Systems based environmental curriculum Eurasia Journal of Mathematics, Science and Technology Education, 2009 5(10), 47-62

7.Adapted from Engineering is Elementary Pre/Post Test

8.Adapted from Geoscience Concept Inventory (GCI), developed by Libarkin, J. C., & Anderson, S. W. (2005). Assessment of learning in entry-level geoscience courses: Results from the Geoscience Concept Inventory. *Journal of Geoscience Education*, *53*(4), 394.

9.Adapted from NYC 6-12 Science Scope and Sequence.

Appendix J- Drawings Rubric

Drawings were scored using the following framework, where low scores indicate a lack of understanding of water systems, and high scores indicate a level of competency adapted from Assaraf and Orion's (2005a, 2005b), Rennie & Jarvis (1995) and Draper (1993). Drawing level rubric was created based on adaptations of a coding framework by Cardak (2009). **Low scores indicate a lack of understanding of water systems, and high scores indicate a level of competency.**

Water Cycle Component	**Point Value**
Plant	0
Human	0
Animal	0
Ocean	1
River	1
Rock	2
Soil	2
Glacier	3
Spring	3
Groundwater	3
Water Cycle Processes	**Point Value**
Clouds	0
Rain	0
Sun	0
Melting	0
Evaporation	1
Surface Flow/ Runoff	1
Condensation	1
Penetration	2
Underground flow	2

Dissolution (identifies transformation from gas to liquid, solid to liquid)	3
Transpiration	3
Infiltration	3
Capillarity	3
System Relationships	**Point Value**
Structural Thinking Simple causal relationships (i.e.: atmospheric- evaporation, condensation)	1
Identifying stocks and flows (runoff, infiltration, transpiration)	2
Detailed flow structures ***this is rare*** (any mathematical annotations or measurements)	3
Dynamic Thinking Able to identify that water cycle is continuous, no beginning or end.	2
Generic Thinking Causal loops (able to identify how variables in system are interrelated- i.e.: atmospheric- evaporation, condensation)	1
Recognizing and using stock-and-flow generic structures (runoff, infiltration, transpiration)	2
Cyclic perceptions	**Point Value**
Atmospheric cycle	0
Connection via rain on the land	1
Connection via rivers from land to sea	2
Connection via underground water flow/infiltration or plant transpiration	3

Drawing Level Rubric -Cardak (2009)

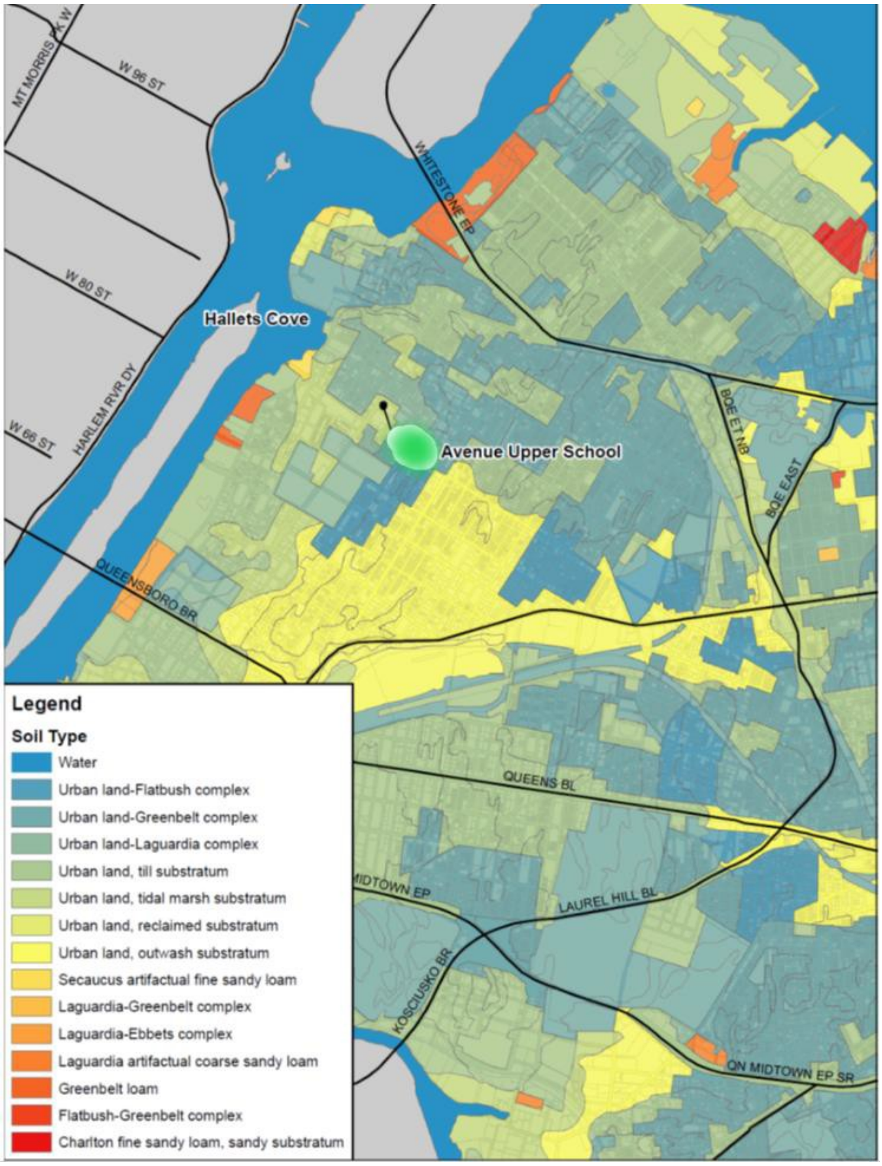
- **Level 1: No Drawing** (I don't know or no response)

- **Level 2: Non-representational drawing** (may contain identifiable elements of the water cycle, but no true representation or diagram)

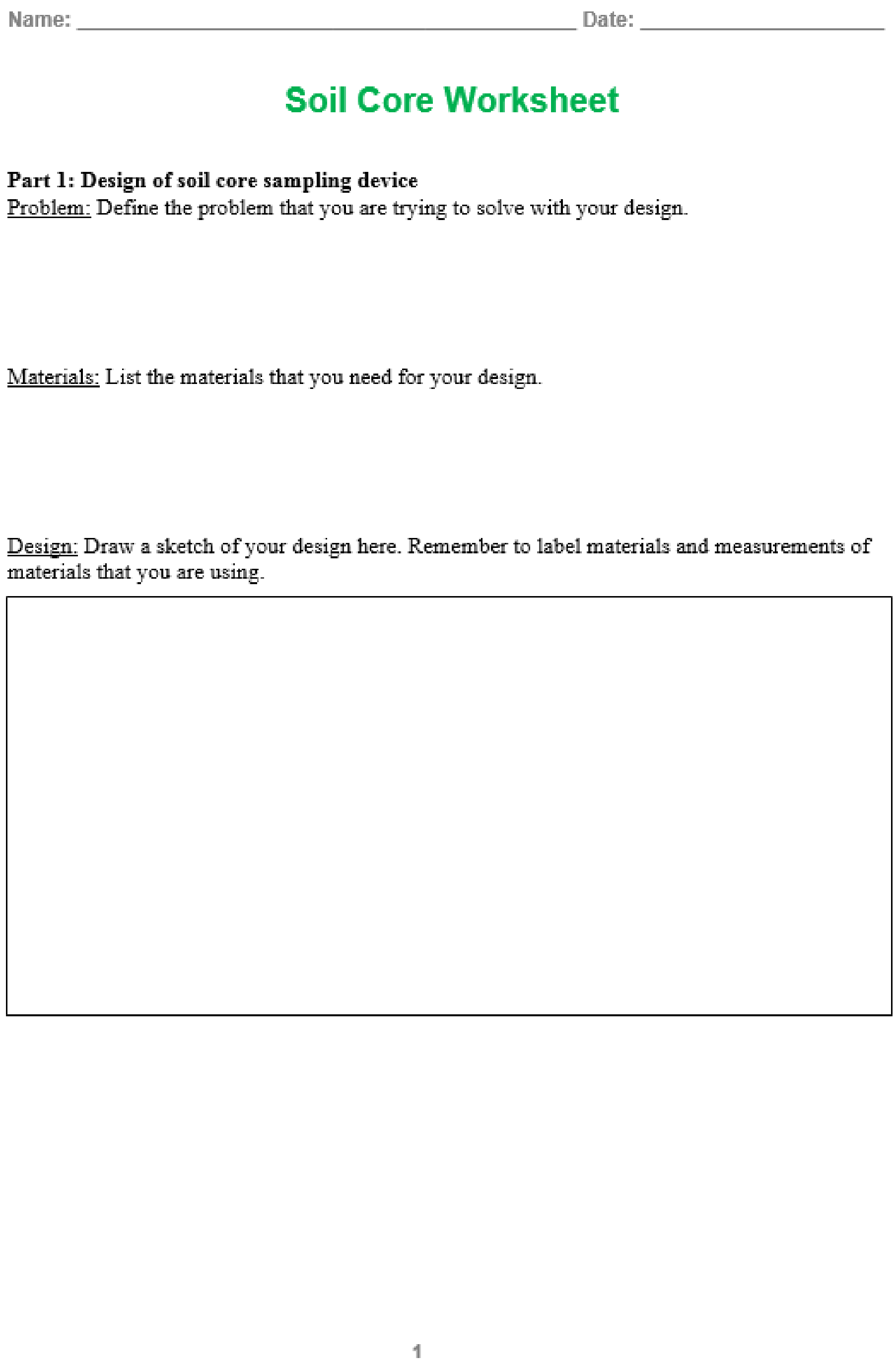
-

- **Level 3: Drawings with misconceptions:** Show some degree of understanding about water cycles but demonstrate some misconception (Cardak defines as “understandings not held by scientists or stated in science texts” (p.867)
- **Level 4: Partial Drawings:** Partial understanding of concepts. Fragmented perception of water cycle, incomplete but including elements such as clouds, precipitation, evaporation, and atmosphere.
- **Level 5: Comprehensive representation drawings**: Most realistic drawings. Show sound understanding of water cycle, containing seven or more elements.

Appendix K- Soil Map of Schoolyard



Appendix L- Soil Core Worksheet Adapted from Teach Engineering



Name: ____ **Date:** ______________________

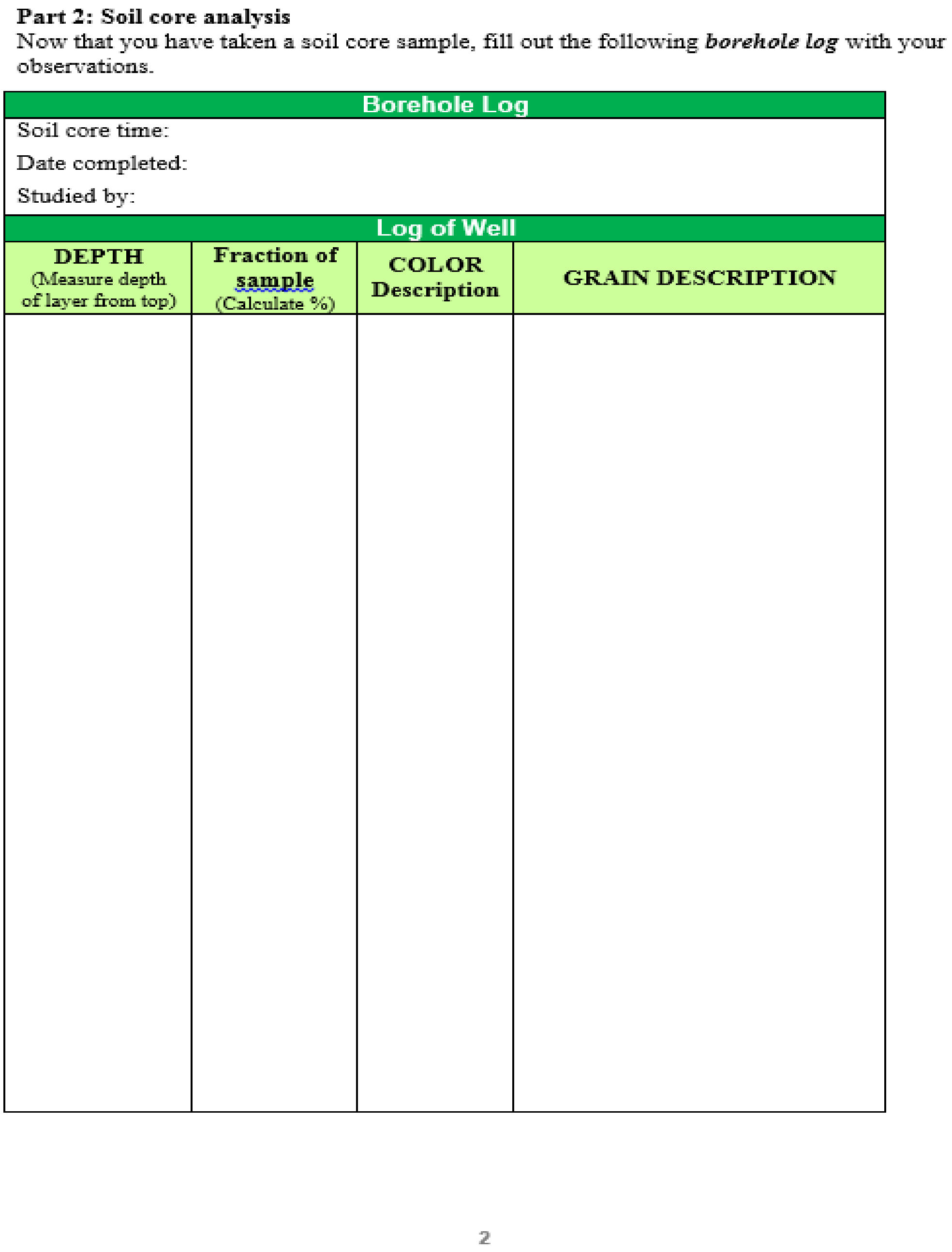
Soil Core Worksheet

Part 1: Design of soil core sampling device

Problem: Define the problem that you are trying to solve with your design.

Materials: List the materials that you need for your design.

Design: Draw a sketch of your design here. Remember to label materials and measurements of materials that you are using.



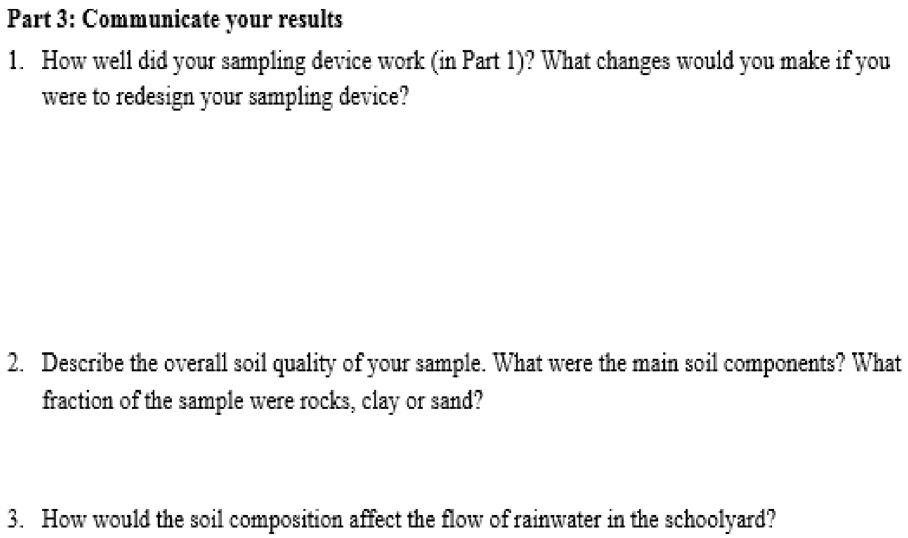
Part 2: Soil core analysis
Now that you have taken a soil core sample, fill out the following ***borehole log*** with your observations.

Borehole Log

Soil core time:
Date completed:
Studied by:

Log of Well

DEPTH (Measure depth of layer from top)	**Fraction of sample** (Calculate %)	**COLOR Description**	**GRAIN DESCRIPTION**



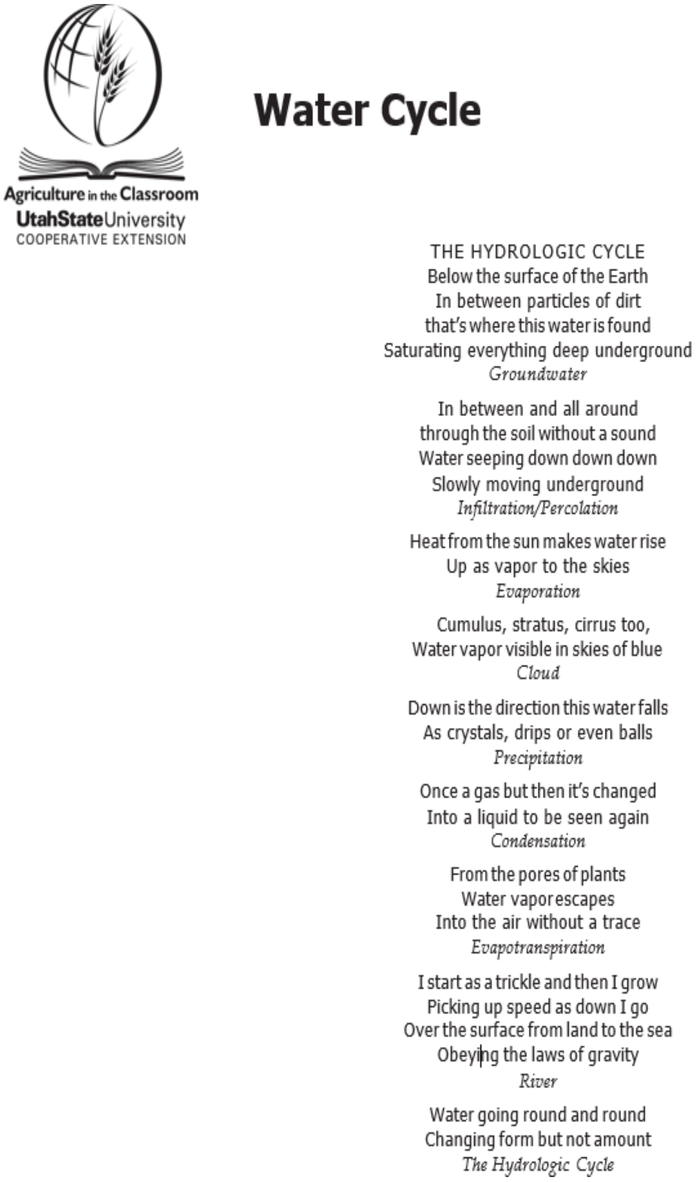
Part 3: Communicate your results

1. How well did your sampling device work (in Part 1)? What changes would you make if you were to redesign your sampling device?

2. Describe the overall soil quality of your sample. What were the main soil components? What fraction of the sample were rocks, clay or sand?

3. How would the soil composition affect the flow of rainwater in the schoolyard?

Appendix M – Water Cycle Poem and dance/game that Betsy adapted



Agriculture in the Classroom
UtahStateUniversity
COOPERATIVE EXTENSION

Water Cycle

THE HYDROLOGIC CYCLE
Below the surface of the Earth
In between particles of dirt
that's where this water is found
Saturating everything deep underground
Groundwater

In between and all around
through the soil without a sound
Water seeping down down down
Slowly moving underground
Infiltration/Percolation

Heat from the sun makes water rise
Up as vapor to the skies
Evaporation

Cumulus, stratus, cirrus too,
Water vapor visible in skies of blue
Cloud

Down is the direction this water falls
As crystals, drips or even balls
Precipitation

Once a gas but then it's changed
Into a liquid to be seen again
Condensation

From the pores of plants
Water vapor escapes
Into the air without a trace
Evapotranspiration

I start as a trickle and then I grow
Picking up speed as down I go
Over the surface from land to the sea
Obeying the laws of gravity
River

Water going round and round
Changing form but not amount
The Hydrologic Cycle

Here is the water game- I don't really have a written copy on hand.

Have kids stand and do the motions with you, then they should be able to chorally do the steps alone without you.

Waterbody - arms out front, hands joined making a circle evaporation- wiggle fingers up and raise hands
condensation - touch fingers together to make a little cloud in the air precipitation - wiggle fingers pointing downward
runoff - make a wave motion with hands
infiltration - wiggle fingers down at your hips (I made this part up) Back to water body

See how fast students can all do it together.

Then ask if they know how to play rock paper scissors (or teach that.)
Everyone will start as a water body. You find someone in the same state as you, and you challenge them to a match. You play 1 round of rock paper scissors (sometimes we clarify if we say 'Rock Paper Scissors Shoot or Rock Paper Scissors says shoot" just to see they all play the same.

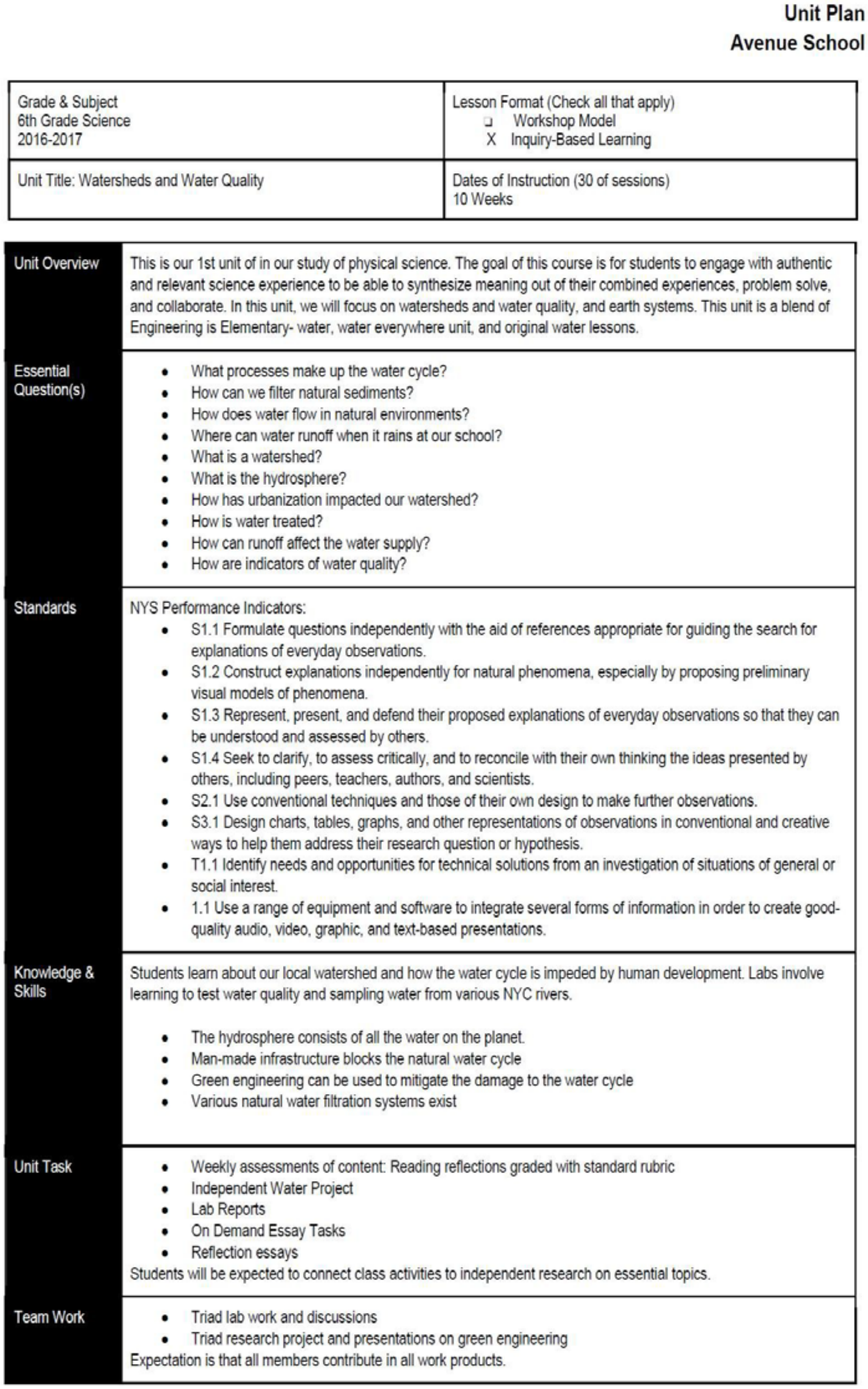
If you win, you go to the next stage.and find someone in that form to challenge. If you lose, you stay in the same stage and find another person. If you get back to water body, you KEEP going through the cycle.

Get all students to show you they are ready with water body, then let them start. Let them play until you can tell at least some kids have gotten all the way through. Stop kids and ask them to raise their hand if they made it all the way through, made it to infiltration, etc. identifying where people got or if they went through many times.

What does that tell us about water? Have students discuss THE END

-Betsy

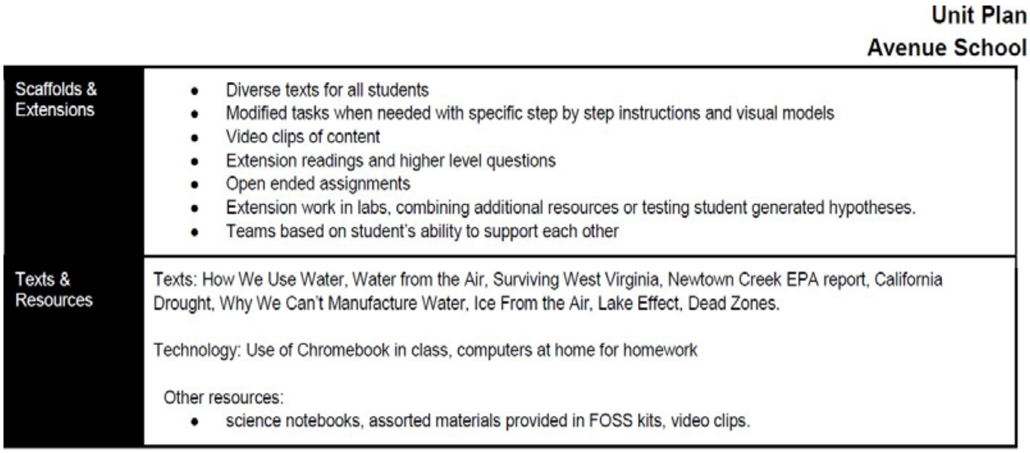
Appendix N- Avenue School Unit Plan



Unit Plan
Avenue School

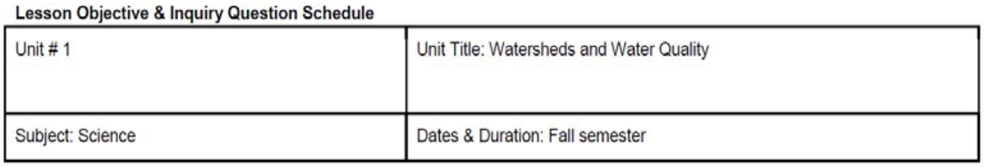
Grade & Subject 6th Grade Science 2016-2017	Lesson Format (Check all that apply) ☐ Workshop Model X Inquiry-Based Learning
Unit Title: Watersheds and Water Quality	Dates of Instruction (30 of sessions) 10 Weeks

Unit Overview	This is our 1st unit of in our study of physical science. The goal of this course is for students to engage with authentic and relevant science experience to be able to synthesize meaning out of their combined experiences, problem solve, and collaborate. In this unit, we will focus on watersheds and water quality, and earth systems. This unit is a blend of Engineering is Elementary- water, water everywhere unit, and original water lessons.
Essential Question(s)	• What processes make up the water cycle? • How can we filter natural sediments? • How does water flow in natural environments? • Where can water runoff when it rains at our school? • What is a watershed? • What is the hydrosphere? • How has urbanization impacted our watershed? • How is water treated? • How can runoff affect the water supply? • How are indicators of water quality?
Standards	NYS Performance Indicators: • S1.1 Formulate questions independently with the aid of references appropriate for guiding the search for explanations of everyday observations. • S1.2 Construct explanations independently for natural phenomena, especially by proposing preliminary visual models of phenomena. • S1.3 Represent, present, and defend their proposed explanations of everyday observations so that they can be understood and assessed by others. • S1.4 Seek to clarify, to assess critically, and to reconcile with their own thinking the ideas presented by others, including peers, teachers, authors, and scientists. • S2.1 Use conventional techniques and those of their own design to make further observations. • S3.1 Design charts, tables, graphs, and other representations of observations in conventional and creative ways to help them address their research question or hypothesis. • T1.1 Identify needs and opportunities for technical solutions from an investigation of situations of general or social interest. • 1.1 Use a range of equipment and software to integrate several forms of information in order to create good-quality audio, video, graphic, and text-based presentations.
Knowledge & Skills	Students learn about our local watershed and how the water cycle is impeded by human development. Labs involve learning to test water quality and sampling water from various NYC rivers. • The hydrosphere consists of all the water on the planet. • Man-made infrastructure blocks the natural water cycle • Green engineering can be used to mitigate the damage to the water cycle • Various natural water filtration systems exist
Unit Task	• Weekly assessments of content: Reading reflections graded with standard rubric • Independent Water Project • Lab Reports • On Demand Essay Tasks • Reflection essays Students will be expected to connect class activities to independent research on essential topics.
Team Work	• Triad lab work and discussions • Triad research project and presentations on green engineering Expectation is that all members contribute in all work products.



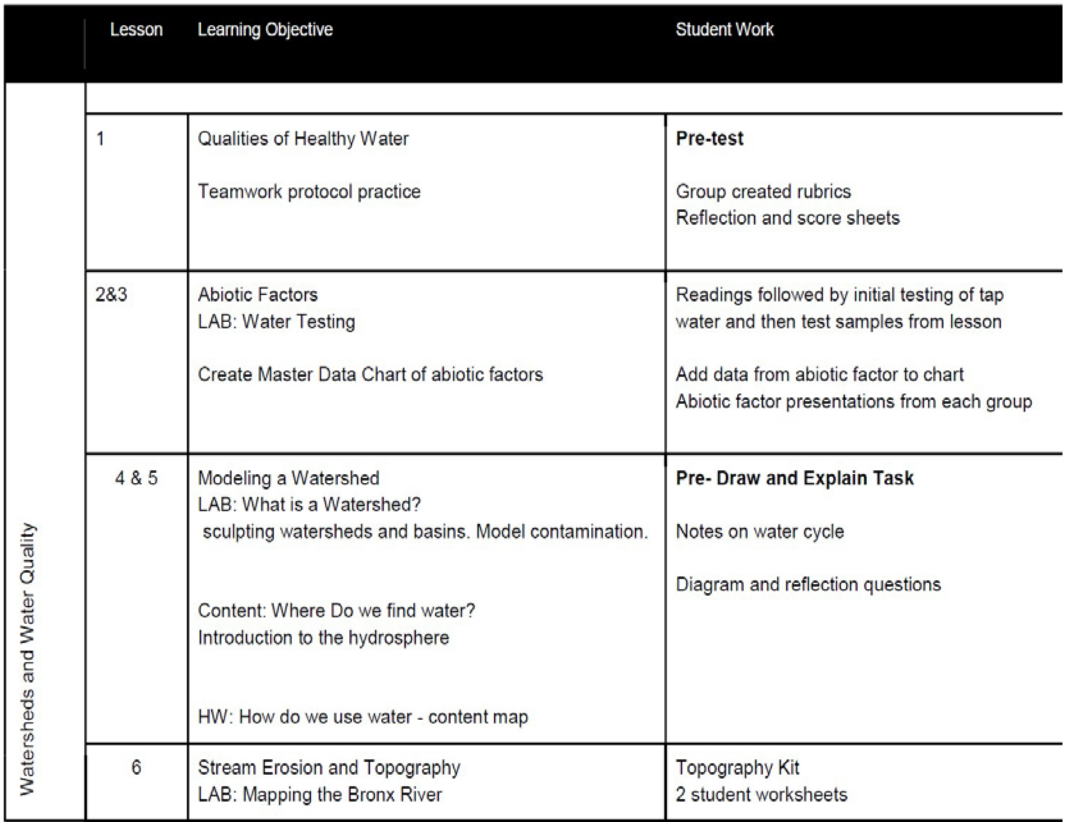
Unit Plan
Avenue School

Scaffolds & Extensions	- Diverse texts for all students - Modified tasks when needed with specific step by step instructions and visual models - Video clips of content - Extension readings and higher level questions - Open ended assignments - Extension work in labs, combining additional resources or testing student generated hypotheses. - Teams based on student's ability to support each other
Texts & Resources	Texts: How We Use Water, Water from the Air, Surviving West Virginia, Newtown Creek EPA report, California Drought, Why We Can't Manufacture Water, Ice From the Air, Lake Effect, Dead Zones. Technology: Use of Chromebook in class, computers at home for homework Other resources: - science notebooks, assorted materials provided in FOSS kits, video clips.

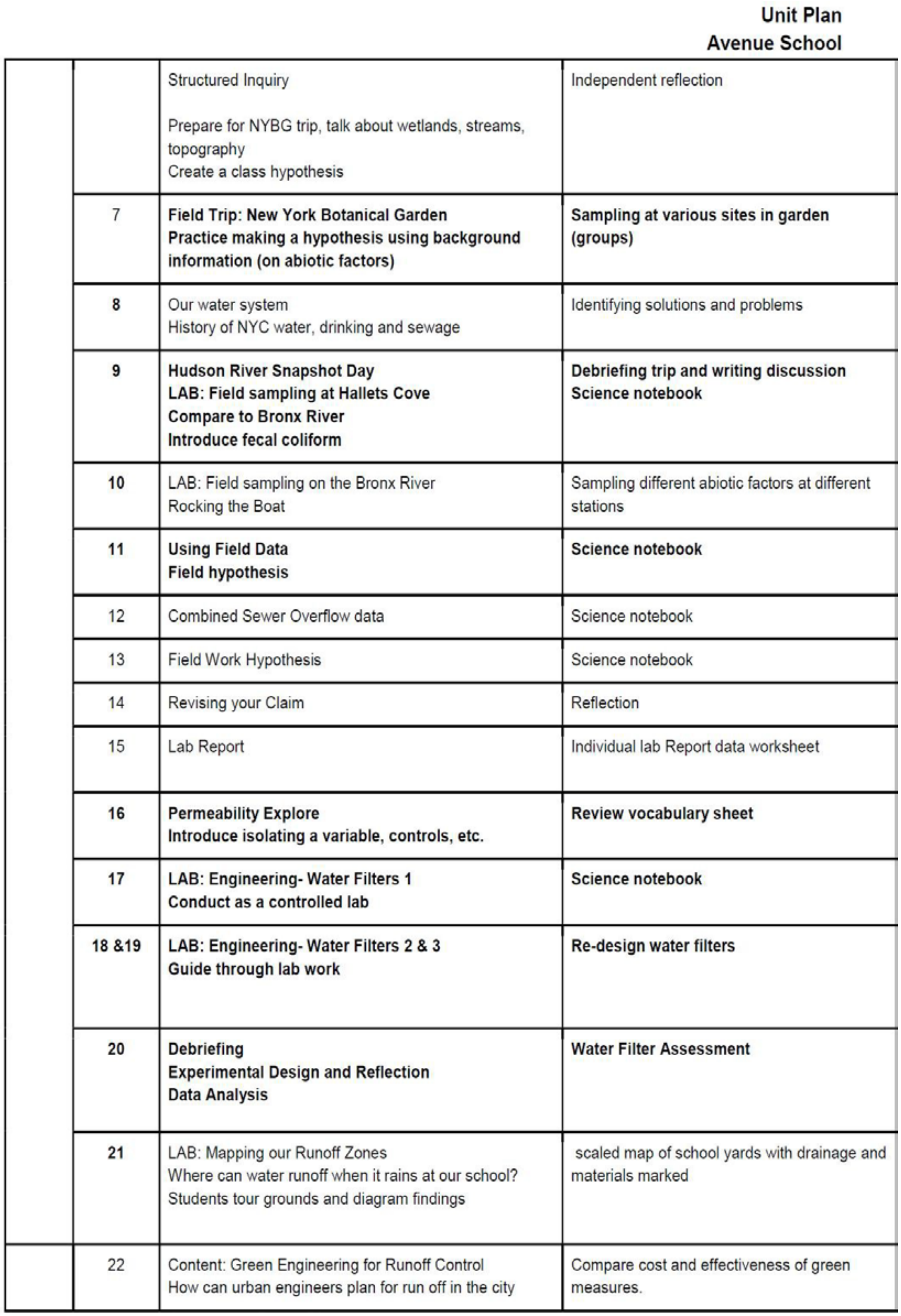


Lesson Objective & Inquiry Question Schedule

Unit # 1	Unit Title: Watersheds and Water Quality
Subject: Science	Dates & Duration: Fall semester

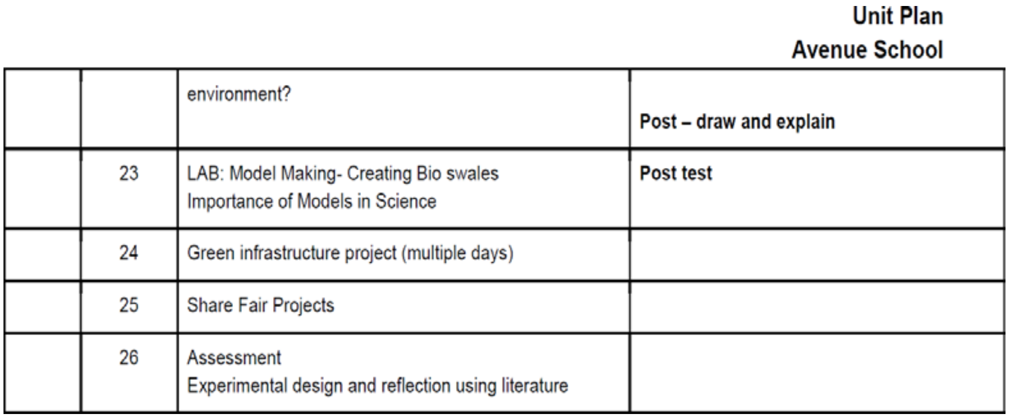


	Lesson	Learning Objective	Student Work
Watersheds and Water Quality			
	1	Qualities of Healthy Water Teamwork protocol practice	**Pre-test** Group created rubrics Reflection and score sheets
	2&3	Abiotic Factors LAB: Water Testing Create Master Data Chart of abiotic factors	Readings followed by initial testing of tap water and then test samples from lesson Add data from abiotic factor to chart Abiotic factor presentations from each group
	4 & 5	Modeling a Watershed LAB: What is a Watershed? sculpting watersheds and basins. Model contamination. Content: Where Do we find water? Introduction to the hydrosphere HW: How do we use water - content map	**Pre- Draw and Explain Task** Notes on water cycle Diagram and reflection questions
	6	Stream Erosion and Topography LAB: Mapping the Bronx River	Topography Kit 2 student worksheets



Unit Plan
Avenue School

		Structured Inquiry Prepare for NYBG trip, talk about wetlands, streams, topography Create a class hypothesis	Independent reflection
	7	**Field Trip: New York Botanical Garden** **Practice making a hypothesis using background information (on abiotic factors)**	**Sampling at various sites in garden (groups)**
	8	Our water system History of NYC water, drinking and sewage	Identifying solutions and problems
	9	**Hudson River Snapshot Day** **LAB: Field sampling at Hallets Cove** **Compare to Bronx River** **Introduce fecal coliform**	**Debriefing trip and writing discussion** **Science notebook**
	10	LAB: Field sampling on the Bronx River Rocking the Boat	Sampling different abiotic factors at different stations
	11	**Using Field Data** **Field hypothesis**	**Science notebook**
	12	Combined Sewer Overflow data	Science notebook
	13	Field Work Hypothesis	Science notebook
	14	Revising your Claim	Reflection
	15	Lab Report	Individual lab Report data worksheet
	16	**Permeability Explore** **Introduce isolating a variable, controls, etc.**	**Review vocabulary sheet**
	17	**LAB: Engineering- Water Filters 1** **Conduct as a controlled lab**	**Science notebook**
	18 &19	**LAB: Engineering- Water Filters 2 & 3** **Guide through lab work**	**Re-design water filters**
	20	**Debriefing** **Experimental Design and Reflection** **Data Analysis**	**Water Filter Assessment**
	21	LAB: Mapping our Runoff Zones Where can water runoff when it rains at our school? Students tour grounds and diagram findings	scaled map of school yards with drainage and materials marked
	22	Content: Green Engineering for Runoff Control How can urban engineers plan for run off in the city	Compare cost and effectiveness of green measures.



Unit Plan
Avenue School

		environment?	**Post – draw and explain**
	23	LAB: Model Making- Creating Bio swales Importance of Models in Science	**Post test**
	24	Green infrastructure project (multiple days)	
	25	Share Fair Projects	
	26	Assessment Experimental design and reflection using literature	