Summer 2012

The Nature and Role of Physical Models in Enhancing Sixth Grade Students' Mental Models of Groundwater and Groundwater Processes

Debra Lynne Foster Duffy
Old Dominion University

THE NATURE AND ROLE OF PHYSICAL MODELS IN ENHANCING SIXTH GRADE STUDENTS' MENTAL MODELS OF GROUNDWATER AND GROUNDWATER PROCESSES

by

Debra Lynne Foster Duffy
M.S. December 1991, Old Dominion University
B.S. May 1985, Old Dominion University

A Dissertation Submitted to the Faculty of
Old Dominion University in Partial Fulfillment of the
Requirement for the Degree of

DOCTOR OF PHILOSOPHY

EDUCATION TEACHING AND LEARNING

CURRICULUM AND INSTRUCTION

OLD DOMINION UNIVERSITY
August 2012

Approved by:

_____
Daniel Dickerson (director)

_____
G. Richard Whittecar (member)

_____
Amy Adcock (member)

ABSTRACT

THE NATURE AND ROLE OF PHYSICAL MODELS IN ENHANCING SIXTH GRADE STUDENTS' MENTAL MODELS OF GROUNDWATER AND GROUNDWATER PROCESSES

Debra Lynne Foster Duffy
Old Dominion University, 2012
Director: Dr. Daniel Dickerson

Through a non-experimental descriptive and comparative mixed-methods approach, this study investigated the experiences of sixth grade earth science students with groundwater physical models through an extended 5E learning cycle format. The data collection was based on a series of quantitative and qualitative research tools intended to investigate students' ideas and changes in ideas rather than measure their achievement. The measures included a groundwater survey, classroom observations, and one-on-one follow-up student interviews for triangulation of data sources. The research was carried out at a K-12 independent school in eastern Virginia using two classes of sixth grade earth science students (n=30).

The findings suggest that physical models help students identify the components porosity and permeability with respect to water flow in groundwater systems. Higher levels of system thinking were best demonstrated in model components that allowed students to experience groundwater pollution activities and pumping groundwater wells. However, the results also indicated that due to model constraints, students can develop misconceptions during the use of physical models, specifically more complex physical models as in the *Groundwater Exploration Activity Model*. A pure discovery learning format while using physical models without guidance or formative assessment probes can

lead to misconceptions about groundwater processes as well as confusion between model attributes and real world groundwater systems.

The implications of this study relate directly to the inclusion of groundwater in the new national science standards released in 2011; *A Framework for K-12 Science Standard; Practices, Crosscutting Concepts, and Core Ideas* (NRC, 2011). The new national standards, as in other educational reform efforts, will have the ability to affect curricular and instructional strategies in science education. From the results of this study, it was concluded that best practices for using groundwater physical models in groundwater instruction should be through an inquiry based approach such as a 5E learning cycle, that includes both teacher guidance and feedback during model activities and incorporates an Express phase with extensive formative assessment probes for student reflection of their learning process.

Director of Advisory Committee: Dr. Daniel Dickerson

ACKNOWLEDGEMENTS

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

The United States Geological Survey estimates that more than 50% of people in the United States use groundwater as their drinking water source and other household uses. Groundwater is used in many industrial operations and it is the primary water source for agriculture irrigation (http://water.usgs.gov/ogw/). Groundwater is a valuable life-supporting resource, yet it often neglected in water cycle and watershed instruction. As human population continues to grow at an exponential rate, so do human activities that have the potential to degrade and deplete groundwater resources. Educating the public of the importance of groundwater resources needs to be a priority that begins in K-12 education. Best practices for groundwater instruction are needed for establishing K-12 science curriculum on groundwater and groundwater processes.

Background

Problems in groundwater education

A major problem in understanding groundwater, like many geosciences phenomena, is its hidden nature. Students develop misconceptions about natural systems that are out of sight of their experiences. The inability to construct a mental model of the size, shape, and processes of a hidden phenomenon such as groundwater is at the root of students' misconceptions. Dickerson & Dawkins, (2004) found that students' alternative ideas on groundwater relative to those held by the scientific community survive regardless of geography, socioeconomic status, race, gender, and age in the United States.

The images of groundwater constructed by students often mimic surface water features such as static lakes or pools of water (Ben-zvi-Assarf and Orion, 2005), or as underground flowing rivers (Jameson, 2001). Dickerson, Callahan, Van Sickle, and Hay (2005) found that students' ideas about groundwater features such as pore spaces and well depth showed a wide range of scale and structure. Describing groundwater in terms of surface water features is not surprising given the fact that surface water is observable and tangible, whereas groundwater is an abstract concept and most students never have the opportunities to witness infiltration and interaction with porosity and permeability of geologic material.

Past the formal educational years there are limited opportunities for people to be exposed to groundwater education. For any ordinary citizen not directly concerned with groundwater management, correlating groundwater conditions to surface conditions is an easy way to conceptualize complicated phenomena. This comparison is reinforced each time the individual comes upon a reference to groundwater 'reservoirs' or 'flows,' or encounters experiences with a karst cavern (Meyer, 1987) with dripstone formations and clear underground lakes. Typically informal educational programs addressing local watershed protection lack connections between practices at home, groundwater processes, and the greater watershed. In a statewide survey, Suvedi, Krueger, Shrestha, & Bettinghouse (2000) found that Michigan citizens perceived land use practices as affecting groundwater quality at the national, state, and county level, but not at their household level. These perceptions held true across age, gender, and farming or non-farming citizens. An understanding of the connections between groundwater and

watersheds is essential to comprehending issues about water quality, sources of pollution, and the impact of land use practices and personal actions on natural water resources.

Theoretical Framework

System Thinking

Given the out-of-sight nature of groundwater, students not only have difficulty constructing mental models of groundwater processes, but also recognizing groundwater as component of a much larger Earth system; the water cycle. Ben-zvi-Assarf and Orion (2005) found that 70% of junior high students (n=1000) did not identify groundwater as a component of the water cycle, even when the students were familiar with the associated terminology. Shepardson, Wee, Priddy, Schellenberger, and Harbor (2006) had similar findings that showed students' conceptions of watershed hydrology was restricted to precipitation, evaporation, and condensation to describe the cycling of water.

In 1996, the National Science Education Standards promoted the study of Earth systems as a totality rather than a collection of parts to be studied in isolation (NRC, 1996). Earth Systems Education (ESE) has been a major effort to restructure science education since the early 1990s (Hyonyong, 2003). The ESE reform efforts are supported by both scientists and science educators as it provides an excellent opportunity for system thinking in environmental issues.

System thinking is defined as the process of understanding how components in a system influence one another within a whole. Ben-Zvi-Assaraf & Orion (2005; 2010) identified and organized characteristics of system thinking within the context of Earth systems into three hierarchical levels in a pyramid structure they named the System

Thinking Hierarchical (STH) model as shown in Table 1. Applying system thinking to

water cycle instruction, Ben-Zvi-Assaraf & Orion found students were able to move from

declarative knowledge of water cycle components (lower STH levels) to more procedural

knowledge of the water cycle system (higher STH levels).

Table 1

System Thinking Hierarchical Model of Earth Systems (Ben-Zvi-Assaraf & Orion, 2005;2010)

Level	Stages	Characteristics
Highest Level	Implementation	• Ability to make generalizations • Ability to understand the hidden dimensions • Ability to think temporally (retrospection and prediction)
	Synthesis of system components	• Ability to identify relationships among components • Ability to identify dynamic relationships within the system • Ability to understand cyclic nature of system
Lowest Level	Analysis of system components	• Ability to identify the components and processes of the system

This study is framed within the context of the STH model. It can be argued that

approaching groundwater instruction within the context of system thinking will allow

students to better understand surface water and groundwater interconnectedness with the

ability to predict the consequences of human impacts on the system. To help promote

system thinking in the sciences, teachers rely on a variety of instructional materials one of which is models to help promote student understanding.

Models in science education

Models play a large role in science and science education to promote understanding of natural phenomena that is difficult to see. Many types of models are used in science instruction, including physical, conceptual, mathematical, and virtual simulations (Leager, 2007). Students use models as a means for direct visual study and to verify and challenge their understandings of natural phenomena. Models are not only useful as visual aids to help explain abstract ideas but can be used in making predictions. Therefore as Windschitl & Braaten (2008) claim models are not just useful for teaching about science, but they are useful in learning about science. The ability for students to visually compare the consequences of their ideas, mental images, and predictions with authentic processes displayed in a model can be helpful in creating cognitive conflict and facilitating conceptual change (Zhou, 2010).

Groundwater physical models can afford students the opportunity to visually witness hidden groundwater processes, connections between groundwater and surface water, and consequences of human induced pollution. To what degree will interacting with a physical model promote a greater depth of knowledge and promote system thinking in student's ideas of groundwater processes was the goal of this research.

Problem Statement

Teaching groundwater concepts is difficult due to the hidden nature of the processes that take place underground and out of sight of students' mental images. The depiction of a water cycle in the 1996 National Science Education Standards document

focuses almost entirely on surface water processes with no mention of groundwater in the document (Dickerson et al., 2007). In the 2011 release of the new national science standards, *A Framework for K-12 Science Standards; Practices, Crosscutting Concepts, and Core Ideas* (NRC, 2011), groundwater is mentioned three times; as a component of the hydrosphere, as a component of the water cycle, and once in the context of a natural resource subject to human degradation. The new national standards, as in other educational reform efforts, will have the ability to affect curricular and instructional strategies in science education. Most state standards are modeled after the national standards and given the increase in groundwater content in the new framework, it is likely that individual states will follow the lead and include more groundwater topics in their standards content.

Practitioner studies regarding groundwater teaching and learning in K-12 context remain unidentified and thus resources for teachers are limited. However, Dickerson and Callahan (2006) note that drawing on current best-practice strategies used throughout science education can help correct student misconceptions. Strategies that incorporate hands-on activities and materials such as rock and sediment samples and three-dimensional physical models may help students create appropriate mental pictures of groundwater environments.

A variety of commercial groundwater physical models are available from science supply companies but such models are relatively expensive costing up to eight hundred dollars for one individual Plexiglas model. In the current economic climate, purchases such as these can be taxing on any science department budget. Investigating the role that physical groundwater models play in promoting student understanding of

groundwater processes will address best practices in groundwater model instruction and allow educators to make useful decisions in purchasing and implementing such models.

Research Questions

1. What role do groundwater physical models play in enhancing students' understanding of groundwater and groundwater processes?

2. How do students interact with groundwater physical models?

3. Which components of physical models help students develop mental models of groundwater processes that are consistent with those of hydrogeologists?

This research addressed the premise that sixth grade students' mental models about groundwater would change towards a more valid concept that incorporated system thinking given the opportunity to interact with three-dimensional physical groundwater models. To examine this proposal, a mixed-methods approach using a non-experimental descriptive and comparative design was employed.

Limitations

This study was limited in scope due to the small sample size in one location and all assertions were made solely within the context of the sample. The insights gained however aid in developing and refining instructional practices using physical models to teach groundwater concepts like porosity permeability, aquifers, and flow regimes that are crucial to the development of appropriate ideas of groundwater processes.

Overview of Chapters

This chapter has introduced the reader to concepts associated with groundwater education. Chapter II provides a comprehensive overview of empirical and practitioner research published in peer-reviewed journals. The literature review focuses mostly on recent literature within the last ten years on system thinking and spatial reasoning in earth systems and advances in instructional methods that promote conceptual change. An overview of methodologies and findings are reported as well as identified gaps in the literature. Chapter III provides a description of the methods that addressed each research question in this study. Participants, measures, and procedures of the study are detailed. Constructs in the study are operationally defined in this chapter as well. Instrument administration and measures of validity and reliability are outlined and an overview of data analysis and techniques are presented. Chapter IV presents the findings of this study, whereas chapter V discusses the results in light of the literature, describes limitations, directions for future research, and practical implications for the findings.

CHAPTER II

REVIEW OF THE LITERATURE

Introduction

The review of literature in this chapter presents an overview of the problems in groundwater education, conceptual change in students' mental models, system and cyclic thinking, and the use of curricular approaches and pedagogical strategies used to address student misconceptions of natural phenomena that are essentially hidden from their direct observations. The gaps in research are discussed relative to the target population of this study.

Problems in Groundwater Education

The problem of science standard documents and other curriculum materials

Teaching groundwater can be complicated by the manner in which groundwater is treated in science standards documents. The National Science Education Standards (NSES) promote the study of earth systems as a totality rather than a collection of parts to be studied in isolation (Hyonyong, 2003). However, Dickerson, Penick, Dawkins, & Van Sickle (2007) found that the NSES document's depiction of a water cycle focuses almost entirely on surface water processes and that the term groundwater is never mentioned in the document.

In the revised national standards, *Framework for Science Education; Concept and Connections (*NRC, 2011) groundwater is mentioned three times in the context of a freshwater source, a component of the hydrosphere, and in the context of a natural

resource subject to human degradation. In a survey of K-12 state science standards

(n=50) published before the release of the new *Framework*, Duffy & colleagues (2011)

found the occurrence of groundwater in standards documents across the United States ranged

from 0 to 14 with 44% (n = 22) of states having no mention of groundwater. Of the 46% of state

science standards documents (n = 28) where groundwater did occur, it did so mostly in the

context of a water cycle component or as a source of freshwater on Earth. Only two states placed

groundwater in the context of processes (e.g. storage and movement). The structure of most

state science standards are based on the national standards.

In addition to science standards, science textbooks and other imagery available to

classroom teachers often depict the hydrological cycle in limited settings or even

eliminate a groundwater component all together restricting the water cycle to only surface

features. Dickerson & Dawson (2004) explain the source of students' naïve conceptions

about groundwater can materialize from errors or misleading representations in

textbooks. In a textbook survey of science texts in grades four through high school and

across several science disciplines, Shepradson, Wee, Priddy, Schellenberger, & Harbor

(2009) found in all of the textbooks they surveyed the hydrological cycle was illustrated

within coastal and mountainous landscapes. Furthermore, the written text in all but one

textbook surveyed, did not align to the water cycle diagrams with the diagrams often

displaying additional or different content to what was explained in the written text. In

order for students to conceptualize the water cycle, these authors contend, they are forced

to interpret both the written text and the textbook diagram. With only ocean and

mountain landscapes portrayed as places the water cycle occurs and with limited

components of the water cycle represented, students are removed from the 'system'

thinking of the hydrological cycle.

These aspects joined with the negligible reference to groundwater processes in both

national and state science standards can force teachers to simplify water cycle instruction

and/or eliminate groundwater concepts in their lesson plans altogether.

The problems with teacher preparation and teacher content knowledge

Teachers can play an important role in teaching water cycle and groundwater

concepts. They can help students eliminate their misconceptions by providing an

adequate knowledge base and clear understanding of these concepts. Difficulties in

conceptualizing groundwater processes are not restricted only to students however;

classroom teachers can hold inappropriate views of groundwater and other environmental

phenomena as well. Such misconceptions held by classroom teachers are likely passed

on to their students (Rice & Neureiter, 2006; Shepardson et. al., 2006; Groves & Pugh,

2002).

Many times teachers enter the classroom with only a minor understanding of the

science behind environmental issues. In a study of 87 fifth and ninth grade science

teachers from the western Great Lakes region in northeastern Minnesota, Fortner &

Meyer (2000) found that hydrology and environmental topics were described by teachers

as being a high priority of what students should know, but were not accompanied by high

knowledge levels by the teachers. In addition, these authors discovered that topics

related to human uses and management of water resources were deemed low priority by

teachers, and teachers had low knowledge levels of these topics as well. As these

authors note, such topics of hydrology are the subject of economic and political decisions, and lack of knowledge speaks poorly for teachers' involvement in important resource use issues.

Teachers' groundwater misconceptions can be attributed to the lack of formal training in pre-service teacher education (Dickerson & Callahan, 2006; Dickerson, et.al, 2007). Elementary education teachers may complete a physical geology class in their course of study that would at most, consist of one chapter about groundwater and karst topography. Geology requirements for secondary education majors in earth sciences vary in both traditional and alternative education/licensure programs across the nation. Further, specialized geology courses such as hydrology are rarely required for science education majors (Dickerson & Callahan, 2006).

In a study of twenty-seven senior level pre-service high school teachers enrolled in a science methods course in the Midwest, Khalid (2003) found that most teachers possessed an array of misconceptions about the causes and effects of important environmental issues of the greenhouse effect, ozone depletion, and acid rain.

Graves & Pugh (2002) found that the integration of groundwater curricular content into to science methods courses did very little to improve understanding of groundwater processes in elementary pre-service teachers. Data was collected in this study for seven years, and although the pre-service teachers showed a slight gain in factual knowledge with the introduction of additional content material in the methods course, they still failed to develop adequate conceptual understanding of these issues.

The problems of student misconceptions about groundwater

Not only do teachers hold misconceptions but students come to the science classroom with misconceptions of natural systems as well. Gooding & Metz, (2011) explain that misconceptions originate as the learner builds explanations for new incoming information because the brain is attempting to assimilate new information by making connections to existing information. If the new information does not fit the learner's established pattern of thinking, it is refashioned to fit the existing pattern. In the case of groundwater, as in many concepts in the geosciences that are directly unobservable, students connect to more tangible features from mental images of their direct experiences. The representations of groundwater constructed by students often mimic surface water features such as static lakes or pools of water (Ben-zvi-Assarf & Orion, 2005), or as underground flowing rivers (Jameson, 2001, Covitt, Gunckel, & Anderson, 2009).

Black (2005) describes how many Earth science misconceptions are difficult to change even with comprehensive instruction and with increasing age due to the fact that many common Earth science phenomena require spatial reasoning. For example, students struggle with interpretation of two-dimensional diagrams that try to represent three-dimensional or moving concepts. Black tested 97 undergraduate non-science majors on spatial abilities typically found in Earth science misconceptions such as the inability to discriminate angular size in sun angles reaching the Earth and distinguishing landform patterns from aerial photographs. In a regression analysis, Black found that one-third of the total variance in students' scores were accounted for by spatial ability, an ability she claims has not been cultivated in traditional education.

Groundwater misconceptions involve the inability to construct a mental model of the size, shape, and flow of groundwater, a hidden phenomenon in student's experiences. Dickerson, Callahan, Van Sickle, & Hay (2005) found that students' ideas of groundwater storage structures had a wide range of scale and structure. For example, some students described scales of pore spaces and crack structures in rock on the order of houses and skyscrapers. Concepts of well depth showed a similar distortion, as students depicted typical depths of water wells to exceed 10,000 feet. Additionally, many students used language to describe storage of groundwater as rocks absorbing water similar to a sponge. This is not surprising given the fact that surface water is observable and tangible, whereas groundwater is an abstract concept and most students never have the opportunities to witness infiltration and interaction with porosity and permeability of geologic material.

Given the out-of-sight nature of groundwater, students have difficulty identifying groundwater as part of the water cycle. In a sample of 1000 junior high students, Ben-zvi-Assarf & Orion (2005) found that 70% of students did not identify groundwater as a component of the water cycle, even when the students were familiar with the associated terminology. Shepardson, Wee, Priddy, Schellenberger & Harbor, (2007) claim that the cyclic nature of watershed processes provides an excellent opportunity to promote the natural world from a systems-based perspective rather than in isolated segments. However, these authors found in a cross-age sample of 915 students from the Midwest of the United States that most of the students' ideas of watershed hydrology were restricted to surface processes of precipitation, evaporation, and condensation and that these poorly developed conceptions about watershed hydrology were retained from elementary

through high school. A later study similar in design by the same authors (2009) found that students often portrayed the water cycle in the context of mountain or coastal landscapes even though the students lived in the Midwest. Shepardson et.al., (2009) argue that these findings are a reflection of the misrepresentation of the water cycle in curriculum materials and the implications are such that science education is contributing little to the development of a knowledgeable public about watershed hydrology. Since ideas of groundwater are so susceptible to misconceptions, addressing methods to help promote conceptual change is necessary to improve groundwater education.

Conceptual change

Facilitating conceptual change

Changing students' ideas about natural scientific processes is complex and based on a wide range of factors. The National Research Council (1997) identifies five types of misconceptions that can interfere with learning; preconceived notions, nonscientific beliefs, conceptual misunderstandings, vernacular misconceptions, and factual misconceptions. A goal in science education is to move students from their incorrect understandings of the world towards those that are more scientific. In order to do this, Strike and Posner (1992) explain that teachers should use a discrepant event or anomalous data to create dissatisfaction with students' initial conceptions. By doing this teachers are creating cognitive dissonance as defined by Piaget, a necessary step to assimilate new information into schema. Unfortunately, as Brunsell and Marcks (2007) explain, the introduction of a discrepant event alone does not lead to conceptual change. Students often react to these events by ignoring them or subconsciously changing their perception of the event. Moving students towards dissatisfaction with their initial ideas

can start the conceptual change process in motion. Posner, Strike, Hewson, & Gertzog, (1982) (as described in Brunsell & Marcks; Dickerson, et. al., 2005; Talib, Matthews, & Secombe, 2005; Zhou, 2010) identify three other conditions that are necessary for conceptual change to occur - students must understand the new idea; they must understand how it can be used to resolve the dissatisfaction; and they must understand how the new idea can be used in other situations.

The development of different types of curricular and pedagogical interventions to help facilitate conceptual change in students' mental models is well documented in the literature. Examples include analogies, digital instruction, and learning models that all attempt to address a central belief of constructivism; that learners construct new knowledge within the context of what they already know. Coll, France, & Taylor (2005) suggest that analogies help to relate new knowledge to old knowledge and that the learner is acting much the same way as scientists do when building upon the body of scientific knowledge. Chiu & Lin (2004) found using multiple analogies of natural systems helped fourth grade students develop a better understanding of electrical currents. Similarly, Calik, Ayas, & Coll (2008) found students' conceptual understanding of solution chemistry was enhanced with the use of an analogy activity involving travel on a public bus.

Computer animated instruction was shown by Talib, et. al., (2005) to be an effective intervention compared to traditional undergraduate chemistry lectures in promoting conceptual change in chemical concepts of oxidation-reduction. These authors argue that embedding animations in instruction can provide an environment of real situations and processes in step-by-step sequences. She & Liao (2010) found that

middle school students involved within an individualized digital learning environment increased their conceptual change and scientific reasoning ability in several physical science topics. Like Talib, et. al., these authors used animations in addition to simulated experiments and analogies.

Several curricular models have been used in the classroom to help promote conceptual change as well. Ceylan & Geban (2009) for example, explain how using the 5E learning cycle model in instruction is more effective than traditional instruction for raising students' understanding of solubility concepts in tenth grade chemistry. The 5E learning cycle model uses an inquiry-based approach to teaching science in a specific order of activities that include Engagement, Exploration, Explanation, Elaboration, and Evaluation. Tsaparlis & Papaphotis (2009) showed how cooperative learning activities promoted twelfth grade students' understanding of modern atomic structure. The mental-model building approach (after Taylor, Barker, & Jones, 2003) was shown to improve and refine undergraduate students' mental models of groundwater occurrence (Reinfried, 2006). The mental model approach as a teaching strategy uses a four phase pedagogical style that incorporates cooperative learning with formative questioning about model representations to move students into constructing a more accurate mental model of hidden scientific phenomena.

The understanding of scientific concepts involves the ability to construct correct mental models of the concept or process. As Hyonyong (2003) argues, it is not enough to just understand components of a system, students must also understand how the components interact and work together in a system. Systems-based instruction provides a

framework in which students can investigate the interactions and interdependence with and between components in a system and changes in these systems over time.

Cyclic and system thinking

The need for system thinking in science is well documented. The National Science Education Standards promotes the study of Earth systems as a totality, not a collection of isolated parts (NCR, 1996). The concept of systems in Earth science occurs in other science education reform documents as well (e.g. *Benchmarks for Science Literacy*, AAAS, 1993, Biological Science Curriculum Study, 2000, *Framework for Science Education; Concept and Connections,* NRC, 2011). Hyonyong (2003) describes how Earth Systems Education (ESE) has been a major effort to restructure science education in the United States since the early 1990s. The ESE reform efforts are supported by both scientists and science educators. ESE provides an excellent opportunity for students to engage in system thinking about environmental issues and system interactions. ESE can demonstrate to students the need to view earth components as pieces of an integrated real world that surrounds and affects their lives. Understanding that humans are a part of nature, and that we must act in harmony with its laws of cycling, is a concept illuminated by Orion & Ault (2007) and is at the core value of environmental science education.

Students' disconnect between water systems and human engineered systems as described by Covitt et.al. (2009) is another example of the need for system thinking skills in science education. These authors tested elementary, middle, and high school students (n=40 each) for their understanding of the connection between groundwater and human-engineered systems and found that as students move from earlier to later grades, their

ideas about what underground water may look like become more sophisticated.

However; most students (85%) still used their above ground images of water to describe

underground water. When asked for example, how a landfill could contaminate a

groundwater well, many students indicated an above ground process such as trash

blowing into the well to account for groundwater contamination. The findings by these

authors support the STH levels defined by Ben-Zvi-Assaraf & Orion where most students

can identify the components of a system (declarative knowledge) but struggle to explain

the implementation and interactions of the components within the system (procedural

knowledge).

Role of models in science education

Models play an important role in science and science education to help promote

understanding of natural phenomena that is difficult to observe directly. Leager (2007)

explains that students use models as a means for direct visual study and to verify and

challenge their understandings of the natural world. Models help to promote critical-

thinking skills, encourage collaboration between students, engage students in scientific

discourse, and provide opportunities for scientific thinking. Zhou, (2010) contents that

the ability for students to visually compare the consequence of their ideas, mental images,

and predictions with the realistic processes displayed in a model can be helpful in

creating cognitive conflict and facilitating conceptual change. Feigerber, Lavrik, &

Shunyakov, (2002) explain when children are tasked with understanding large distances

(e.g. light years) and scales (e.g. the Solar System) it is difficult to do so, not because of

insufficient knowledge but because students are out of their "actual activity zone." That

zone is defined, according to these authors, as that part of the surrounding reality with

which students interact directly or indirectly, both biologically and physically. Thus, the actual zone of activity is determined not only by the biological limitations of the human organism (e.g. can only see the visible light of the electromagnetic spectrum) but also by the area of one's activity. A phenomenon such as groundwater is out of students' sight (biological) and their area of activity with groundwater would be based only on their experiences with groundwater. A visit to or view of an underground limestone cavern with drip stone formations and crystal clear lakes may be the only representation to enter into students' actual activity zone.

Using models in science education can provide the visual sensory information for the major pathway to discovery, learning, and knowledge (Wesson, 2011). In addition, models can serve as additional external representations of natural phenomena. Ainsworth (1999) describes how multiple external representations (MERs) can be used to support cognitive processes in learning and problem solving. One function MERs serve is in a complementary role where a single representation would be insufficient to carry all the information about the phenomena. Models can help augment other instructional materials. Although many types of models are used in science instruction, including physical, conceptual, and mathematical; physical models are used most frequently in elementary and middle grade education (Leager, 2007).

Physical models and teaching groundwater

Various versions of physical models are used frequently in undergraduate geology and hydrology courses. These models make use of sediments (gravel, sand, clay) with different pore space sizes to mimic groundwater aquifers and non-aquifers (confining units). Using water and dye in glass, plastic, or Plexiglas tanks students are

able to view the flow of water through various geologic mediums. Several studies in undergraduate settings have indicated that using these sand tank physical models have been useful in enabling students to observe and measure hydrological processes. Parkinson & Reid (1987) found that when using colored dye injected into the groundwater model, undergraduate geology students were able to construct a more correct schematic of groundwater flow direction compared to students only exposed to standard lectures about groundwater flow-nets. Similarly, Gates, Landford, Hodgson, & Driscoll (1997) showed an increase in first year geology students' conception of flow, interpretations, and predictions of groundwater flow regimes using a similar sand tank model. Kamini & Steven (2011) used physical groundwater models in addition to numerical modeling in undergraduate hydrology courses and found students were able to better estimate rates of groundwater flow and contaminant transport by linking physical and numerical models together. These authors contend that the sand tank models provided a way for students to visualize subsurface flow and transport processes while the numerical model allowed them to see the mathematics associated with the system and build predictions. Similar types of physical models have been used in higher education laboratories to support learning in geophysics, environmental sciences, and geomorphology courses (see Lehr, 1963; Merritts & Shane, 1992).

Gaps in research

A plethora of empirical research addresses conceptual change in students' thinking through a variety of curricular and pedagogical approaches. Although much of this research is within science education, a large proportion focuses on concepts in the physical and chemical sciences. Many studies highlight the use of various types of

models (physical and computer simulations) to facilitate better understanding of groundwater processes in undergraduate introductory geology and hydrology courses. However, there is a lack of research in the use of physical models in K-12 science education and more specifically in groundwater education to facilitate students' understanding of processes of flow, scale, and storage of water in the ground as well as anthropogenic impacts on groundwater. Since water cycle instruction typically begins in the elementary grades and is found in science curriculum through the middle grades, there exists a need for addressing how models can play a role in promoting conceptual change in students' mental images.

The aim of this study was to address the nature and role of physical models in enhancing sixth grade students' mental models of groundwater and groundwater processes that help to promote system thinking about groundwater and the water cycle. Using a mixed-methods approach with a non-experimental descriptive and comparative design, this research addressed the idea that sixth grade students' mental models about groundwater will change towards more valid concepts if they are given the opportunity to interact with physical groundwater models.

CHAPTER III

METHODLGY

This chapter provides a description of the methods for this research. Participants'

demographic information is provided, as well as, sample selection and size information.

How the instruments were developed and the use of instruments is presented. The

chapter further presents a description of data analysis techniques used in the research.

Research Design

This study employed a non-experimental descriptive and comparative mixed-

methods approach to answer the following research questions:

- What role do groundwater physical models play in enhancing students'
  understanding of groundwater and groundwater processes?

- How do students interact with the groundwater physical models?

- Which components of physical models help students develop mental
  models of groundwater processes that are consistent with those of
  hydrogeologists?

The research was carried out at a K-12 independent school using two classes of sixth

grade students. Approval of the research and access to the student participants was

provided through the administration of the School. The researcher served as the

participants' science teacher. Permission for students to be a part of the research data

collected was obtained through a consent form sent to parents that outlined the study and

the type of information that would be collected (Appendix A). Approval of the research

protocol was received from the Old Dominion University Institutional Review Board application in early March 2012.

Participants

Two intact classes of sixth grade earth science students were chosen as a convenience sample for this study. The participants (n=30) consisted of 15 boy and 15 girls with an age range of 11-12 years. Ninety-seven percent of the students are Caucasian and 3 percent African American. Approximately 7 percent of the students (n=3) are enrolled in the Academic Center at the School which provides support services to help students with the rigors of a college preparatory curriculum. Students enrolled in the program attend the Academic Center in place of a study hall period during the school day. Parents pay a supplemental fee for these services in addition to the cost of tuition. The students in this sample are all from middle to upper class families, consistent with the socio-economic make-up of the School population and surrounding community. Approximately 20% of students at the School receive some type of financial aid granted by the School from an endowment fund.

The School is a pre-kindergarten through twelfth grade college preparatory independent school in the Southeastern United States. Students in the middle grades and upper grades attend separate classrooms for each of their academic courses. All science courses/sections in pre-kindergarten through twelfth grade are taught in the Science and Technology Center on the School campus. Students in the two classes chosen for this study are taught by the researcher and number approximately one half of the sixth grade students at the School.

The research was carried out in the students' regular science classroom in the Center during their regularly scheduled class time. Both earth science classes used in this study meet in the morning between 8:30 to 10:30 am four days a week. The content (groundwater) and timing of the study was on schedule with the course curriculum in early March of the school year.

Students' identity was protected throughout the study by assigning a number to each student and only identifying students by their number. In this manner, additional reviewers of pre- and post- tests, observations, and interview responses were not able to identify the individual student. Students interviewed were assigned a pseudonym name to further protect their identity.

Apparatus

Eight sand tank models were used in this study to simulate groundwater conditions. The models are owned by the University and were on-loan to the School for the purpose of this investigation. The *Groundwater Exploration Activity Model* #30-1075 retails at $599 per model before shipping and handling from *NeoSci*, Inc. The model is constructed to represent a small vertical slice (20 x 11 x 4.5 inches) of the earth containing a groundwater aquifer system with several layers of different geologic mediums (gravel, coarse sand, fine sand, and clay). Vertical tubes inserted into the aquifer system at different levels (depths) serve as monitoring or pumping wells. The model also contains an underground storage tank (or pond) and a lake. A small submersible electrical pump placed in the back reservoir is used to circulate water throughout the model. Food dyes are used to demonstrate how a pollution plume could

move through various layers of unconsolidated material similar to the stratigraphic make-up of Virginia's Coastal Plain.

Materials

Instructional materials and Groundwater model activities

Curricular materials and activities used for the classroom instruction portion of this study were designed to reflect reformed-based teaching of groundwater concepts in the course curriculum. These included student-centered discussions, hands-on activities, power point notes and images of groundwater systems, and diagrams students used to label or identify water cycle and groundwater features. Instructions and directions for three learning activities using the *Groundwater Exploration Activity Model* involved the investigation of groundwater flow direction, polluted well and movement of pollution plume, and pollution of adjacent wells for the interactive portion of this study. A copy of the inquiry-based lesson activities can be found in Appendix E.

Measures

The data collection was based on a series of modified quantitative and qualitative research tools obtained from the literature and specifically designed for this investigation. In order to examine students' prior knowledge, understanding, and change in understanding of groundwater processes a 'zoom-in' type of analysis was used similar to that of Ben-zvi-Assarf & Orion (2005) in their study of students' perceptions of the water cycle. Three research tools were used for triangulation of data. These measures were intended to investigate students' ideas and changes in ideas rather that to measure their achievement. A description of each follows.

Groundwater Survey

The Groundwater Survey (GS) was developed using questions modeled upon various studies by other geosciences educators found in the literature (Dickerson & Dawkins, 2004; Ben-zvi-Assarf & Orion, 2005; Corvitt, Gynckel, & Anderson, 2009; Shepardson, Wee, Priddy, Schellenberger, & Harbor, 2005; 2009). It was designed to identify students' previous knowledge and understanding of the dynamic nature of the groundwater system and its environmental relationship with anthropogenic activities (see Appendix B). A blueprint was used to develop the GS and to enhance the construct validity (Table 2). The readability statistics scored as 76.4 on the Flesch reading ease score and the Flesch-Kincade grade level score was 5.1. The GS was field tested on two additional sixth grade classes (not taught by the researcher) using test-retest to help establish reliability of the instrument. The Pearson correlation (r) between the test and retest scores on the GS was $r(29) = .56, p < .001$. To help ensure face and content validity, an expert in hydrology in the University's Oceans, Earth, and Atmospheric Sciences Department reviewed the GS questions and scoring rubric. After adjusting from the field test information and content expertise feedback, the GS was used in a pre-test for prior knowledge, post-classroom lesson formative assessment, and post-model interaction summative assessment for a quantitative comparative and descriptive analysis to address the first research question.

Table 2

Blue Print for Groundwater Survey

Aspects	Groundwater Movement/Storage/Scale	Groundwater Wells	Groundwater Pollution
Physical Aspects	#1, #4, #6, #7, #8 #10	#1, #5, #7	#5, #8, #9
System Thinking Aspects	#3, #4, #8	#5, #6, #8	#5, #8, #9
Anthropogenic Aspects	#7, #8, #9	#5, #7, #9	#2, #8, #9

The GS contained nine multiple choice questions relating content to three aspects of groundwater (physical, system, and anthropogenic influences) and one open-ended draw-and-explain question. The multiple choice question asked students to 'choose all that apply' and the responses were scored using a rubric similar to the rubric used by Dickerson & Dawkins (2004). The possible responses listed for each multiple choice question spanned a high level of system thinking (more scientifically correct) to a lower level of system thinking or even disconnect (scientifically incomplete or incorrect understanding), thus individual multiple choice items on the GS overlapped in their assignment to categories in the blueprint.

The last item on the GS was a draw-and-explain open-ended question fashioned after Shepardson, Wee, Priddy, Schellenberger, & Harbor, (2005); Dickerson & Dawkins, (2005); and Covitt, Gunckel, & Anderson, (2009) that used a written prompt to elicit student responses to emphasize their thinking. The question asked students to draw and label a detailed picture of how groundwater occurs and moves in a provided space on the GS measure (see Appendix B). The draw-and-explain question was analyzed using a coding framework similar to Ben-Zvi-Assaraf & Orion (2005a).

Classroom Observations

To address the second research question, classroom observations were used in the natural classroom setting. Both classes were observed and video recorded during their regularly scheduled class period while student groups of two or three interacted with the *Groundwater Exploration Activity Model.* To address content validity, an interactive activities blueprint was designed to mirror the GS content areas of groundwater movement, storage, and scale; groundwater wells; and groundwater pollution. Table 3 contains the blueprint used to develop the interactive model activities. Three activities were an appropriate number of activities to fit within the allotted fifty minute classroom time. The three activities assisted students in creating several groundwater scenarios to help understand both groundwater storage and groundwater movement. In the first activity, the general flow of water through different geologic mediums provided students with a visual of how water saturates and moves between pore spaces of sand and gravel, as well as the lack of movement through clay. The polluted well (activity #2) provided students with a visual of how a polluted well can contaminate the groundwater system. Students observed the movement of the pollution plume as well to identify its

relationship with the groundwater flow direction and potential for adjacent well

contamination. Finally, the pumping well activity was designed to illustrate how a well

can become polluted as it draws from a polluted groundwater system.

Table 3

Blueprint for Classroom Instructional Activities using the Groundwater Exploration

Activity Model

Groundwater Content	Model Components	Description of Student Activity
Movement/Storage/Scale	Various porosities of material that will or will not store and transmit water, connection between water table, well levels, and lake level	Students add 'blue' water to tank and observe groundwater flow through different geologic mediums
Wells	11 wells at different depths, ability to pump a well with syringe pump	Students to note water levels in well, lake, and storage tank; Students add 'red' pollution to one well and observe flow of pollution plume
Pollution	Different dyes added to wells or lake water, or underground storage tank	Students pump adjacent well using syringe and observe any change in pollution plume

The researcher served as the facilitator during the activities and a second science

educator trained in the classroom observation protocol was present to record classroom

observations and later help identify behavioral elements from the recorded videos. To

minimize disturbance and reactivity in the classroom and increase reliability of the

classroom observations, four *Kodak Zi8 HD video cameras* with table top tripod stands were strategically placed in the classroom aimed at student tables to capture students' behaviors and comments during their interaction with the *Groundwater Exploration Activity Models*. The models have a submersible electrical water pump to facilitate water movement throughout the tank. Retractable electrical outlets hang from the classroom ceiling and were positioned with the student table arrangement in order for student groups to have electrical connection and avoid having cords on the classroom floor. The arrangement of cameras and student tables are illustrated in Appendix C along with the classroom observation guidelines used to record notes during classroom observations and viewing recorded videos.

Prior to any classroom observation data collection, the observers discussed the student behavioral criterion after one round of pilot observations of another sixth grade class not involved in the study to enhance consistency regarding student behavioral elements during the physical model interactions. These behavioral elements are described in the Data Analysis section.

Semi-Structured Interviews

Based on the trend analysis of scores from the pre-, formative, and summative GS assessments, a purposeful sample of eight students was chosen for follow-up semi-structured interviews. The goal of the purposeful sample was to capture a representative sample of score trends across all three GS assessments. This type of qualitative data collection helped yield a more complete picture of how interaction with the groundwater physical models served to facilitate changes in students' understanding of groundwater environments. Though open-ended questioning, students were asked about their

drawings and or responses on certain GS questions and their experiences with using the model. The first question asked students to explain their drawings on each of the GS assessments with follow up cues to elicited further explanation. The second question asked students how the model helped them to learn about groundwater. Additional questions addressed their likes and dislikes of using the *Groundwater Exploration Activity Model* and the final question of the interview asked students how they would construct a groundwater model if given a chance to build one (Appendix D).

The interviews were conducted during the students' normal class period by an additional science educator from the University. Each interview lasted approximately 25 minutes and was video recorded. The interview transcripts were coded using an iterative process (Creswell, 2007; Miles & Huberman, 1994) to identify categories that emerged from the content analysis. An additional science educator was used as a second rater to code a portion of the interview transcripts to help ensure reliability.

Procedure

This section provides a detailed description of the research process for this study. Table 4 outlines the research procedures and materials/measures used.

Pre-test of prior knowledge

Prior to the unit on groundwater, students were given the GS as a pre-test to determine prior knowledge. The GS was administered during the students' regular earth science class period and students were given approximately 40 minutes of the class period to complete the survey. Students were told that the GS was not graded in terms of their course grade, but only for the teacher to see what they already knew about our next topic of study.

Inquiry-based classroom lesson

The format of the groundwater lesson implemented in class reflected reformed-based science teaching endorsed by the American Association for the Advancement of Science (AAAS, 1994) and the National Research Council (NRC, 1996). The groundwater inquiry based lesson was taught by the researcher as a modified 5E learning cycle as outlined in table 4. Initial classroom discussions allowed students to explore questions of how groundwater gets into the ground, how they thing it moves and is stored below ground. Students received explanations through power point presentations with images displayed on the screen showing various two-dimensional cross sectional diagrams of groundwater scenarios (water table, wells, flow direction, and recharge and discharge). The topic of groundwater was framed within the context of water as an important weathering agent in the rock cycle. The water cycle system which students were first introduced to in their study of water in the atmosphere several weeks prior to the groundwater inquiry-based lesson, was reviewed at the start of the lesson with more emphasis on water in the ground. Students explored the nature of porosity and permeability through a hands-on activity that allowed them to test the rate of water flow through columns of gravel, sand, and clay. Students further engaged in the lesson by labeling and coloring a blank diagram of a cross section of a groundwater environment. The School's sixth grade earth science course does not have a textbook and label-and-color diagrams are a part of the course curriculum. Two class periods were devoted to the groundwater inquiry-based lesson.

Formative assessment

The GS was administered again after the inquiry-based lesson in the students' regular earth science class period as a formative assessment to determine the role that the lesson and porosity/permeability models played in enhancing their understanding of groundwater. Students were given the same directions and told that the GS was being used to see how useful the lesson was in helping them to understand groundwater.

Preparation for Groundwater Exploration Activity Models

The next class period was devoted to introducing students to the *Groundwater Exploration Activity Model* and its components and to show students the materials they would be working with on the following day. The model was not filled with water or operating. The introduction period allowed more time the following day for students to interact with the groundwater models.

Interaction with Groundwater Exploration Activity Models

Upon their arrival to class the following day, two models were set up at each of the student tables and the instruction sheet (Appendix E), a pencil, and all materials (syringe, pipette, pollution canisters, and waste bucket) for completing the activities. The water in each model was purposely colored blue in order for students to see the water level in the wells, pond, and lake. Several wells were numbered to help guide students with the instructions. Labels of west and east on opposite ends of the tank assisted students with describing groundwater or pollution plume flow direction. A small amount of pollution in the form of red food coloring was provided in a small labeled film canister. A large plastic syringe served as the pump to pump wells and a small plastic

pipette was used to place pollution into the wells as instructed. The video cameras were turned on as soon as the students began working.

Summative assessment

The GS was administered again following the interaction with the *Groundwater Exploration Activity Model* as a summative assessment to determine if interaction with the models improved students' understanding of groundwater. The GS was administered in the same manner with the same instructions except that students' were told the survey was to help determine whether the *Groundwater Exploration Activity Model* helped them to understand more about groundwater processes. The GS pre-, formative, and summative assessments were scored and analyzed using descriptive and inferential statistics as described in the Data Analysis section below.

The qualitative methods, both classroom observations and semi-structured interviews, were rooted in a grounded theory study intended to uncover the role physical models play in developing students' mental models of groundwater processes (Creswell, 2007). The classroom observation data from video/audio recordings were analyzed for behavioral elements as described in the Data Analysis section. Eight students were chosen for the semi-structured interviews based on the trend of their scores across the GS assessments. Students were interviewed individually during their regularly schedule class time in a separate location. A second science educator from the University, well versed in interview techniques and groundwater content knowledge, was used to avoid reactivity by student interviewees and to enhance reliability of the interviews. The interview protocol and guiding questions established for this study were used for each interview (see Appendix D). The students interviewed were compensated for their time

with a five dollar gift card from *Wendy's*. Interview recordings were transcribed and

systematically analyzed as described in the Data Analysis section.

Table 4

Outline of Research Process

Task	Time Allotted	Purpose	Measures/Materials Used
Administered Groundwater Survey	Approx. 40 minutes	Determine prior knowledge	Groundwater Survey (Appendix B)
Groundwater Inquiry-based lesson	Two class periods	Facilitate the learning of groundwater processes	Modified 5E Learning Cycle Classroom Activities (Appendix E)
Administered Groundwater Survey	Approx. 40 minutes	Determine the effects of classroom lesson on students' mental models of groundwater	Groundwater Survey (Appendix B)
Preparation for *Groundwater Exploration Activity Model*	One class period	Prepare students for Model activities	Introduction to *Groundwater Exploration Activity Models* and components and activity instructions
Interaction with the *Groundwater Exploration Activity Model*	One class period	Students explore the Models completing content activities	*Groundwater Exploration Activity Models* Videoed classroom observations (Appendix C)
Administered Groundwater Survey	Approx. 40 minutes	Determine the effects of interaction with the *Groundwater Exploration Activity Models* on students' ideas about groundwater	Groundwater Survey (Appendix B)

Table 4 (continued) *Outline of research process*

Task	Time Allotted	Purpose	Materials/Measures Used
Preliminary Data Analysis	One week	Determine participants for semi-structure interviews	Scoring of pre- and posts-Groundwater Surveys
Semi-structured Interviews	(25 minutes each)	Gain an in-depth view of how interactions with models helped facilitated understanding of groundwater processes	Guiding questions (Appendix D)
Final Data Analysis	Two weeks	Determine results of study	Coding of interviews

Data Analysis

The analytic approach used for this study relied on descriptive and inferential

testing for the quantitative data collected from the GS and content analysis for the

qualitative data collected from classroom observations and semi-structured interviews.

The data analysis included descriptive statistics (means, frequencies, and standard

deviation) to analyze scores question items on the GS. In addition, two paired samples *t*-

tests were conducted on the GS scores from pre-test to formative assessment after

classroom inquiry lesson and from formative assessment to summative assessment after

the *Groundwater Exploration Activity Model* interaction for a trend analysis (Tsai, et. al.,

2012; Milner, Templin, & Czerniak, 2011). This analytic approach was appropriate

because the researcher had scores from the GS generated from repeated measures with an

intervention for each student in the study. Each *t*-test data file contained 30 cases, one

for each student, and two variables (before and after scores).

Qualitative data from classroom observation videos were analyzed on student

behavioral elements within the context of the groundwater content aligned with the GS

blueprint (movement/storage/scale, wells, and pollution). The use of guidelines in classroom observations provided an effective way to capture students' behaviors and experiences (Cotton, Stokes, & Cotton, 2010). Behavioral elements for observations specifically designed for this study included: 1) time on task for each activity; 2) groundwater vocabulary used; 3) difficulty with completing task; 4) what activities were repeated the during the interaction; and, 5) how often students tried something outside the provided activity instructions (see Appendix C for guidelines). A second science educator who assisted with classroom observations also observed the video recording to help capture the behavioral elements as well as establish reliability.

Qualitative data collected from the semi-structured interview transcripts were systematically analyzed through an iterative process (Creswell, 2007; Miles & Huberman, 1994). Initially data were categorized into the groundwater content areas (movement/storage/scale, wells, pollution) aligned with the GS blueprint. Secondly, properties or subcategories were identified through a reiteration process of the interview transcripts. Chapter IV reports the findings from each of the three measures used for data collection.

CHAPTER IV

RESULTS AND CONCLUSIONS

Introduction

This chapter describes the processes used to analyze data and the findings aligned

with the research questions. The chapter includes a description of quantitative results

from the scores on the Groundwater Survey followed by the qualitative findings from the

classroom observations and semi-structured interviews. Triangulation of data is

presented through subthemes and categories that emerged from the qualitative data and is

presented within the context of the quantitative data.

Research Questions

This study centered on three research questions related to the use of physical

models to help students understand groundwater processes:

1. What role do groundwater physical models play in enhancing students'

understanding of groundwater and groundwater processes?

2. How do students interact with groundwater models?

3. Which components of physical models help students develop mental models of

groundwater processes that are consistent with those of hydrogeologists?

Quantitative Findings from the Groundwater Survey

The Groundwater Survey was used to address the first research question that of

the role physical models may play in enhancing students' understanding of groundwater

processes. The GS was administered to all students before any groundwater instruction

began as a pre-test of prior knowledge, after the classroom inquiry-based lesson as a

formative assessment, and finally as a summative assessment after students interacted

with the *Groundwater Exploration Activity Model*. The GS consisted of nine multiple

choice questions that asked students to choose all responses that apply and one draw-and-

explain question. Each question was scored as 2, 1 or 0 using a scoring rubric (see

Appendix B). Table 5 shows the GS scores for all three assessments. The range of

scores and the mean scores were greatest in the formative assessment given after the

inquiry-based classroom lesson.

Table 5

Descriptive Statistics of GS scores

	N	Range	Minimum	Maximum	Mean	Std. Deviation
PreTest	30	9.00	5.00	14.00	8.77	2.39
Formative	30	12.00	3.00	15.00	8.97	2.68
Summative	30	11.00	3.00	14.00	8.70	2.42

Table 6 shows the mean scores on each GS assessment based on gender. Across all three

assessments, the mean scores for males were slightly higher than females.

Table 6

Mean GS scores based on gender

Gender		PreTest	Formative	Summative
	Mean	8.80	9.60	9.07
Male	N	15	15	15
	Std. Deviation	2.60	2.80	2.28
	Mean	8.73	8.33	8.33
female	N	15	15	15
	Std. Deviation	2.25	2.50	2.58

GS trend scores over the repeated measures testing showed a net positive gain by 50% of the students and a net negative gain of in scores by 47% of students. Only one student in the study (3%) remained consistent in their trend score across all three assessments. Table 7 shows the breakdown of scores. Of the 50% of students showing a positive gain in scores, 27% (n=4) showed an increase from pre- assessment to formative and formative to summative; 40 % (n=6) showed a decrease from pre-assessment to formative and an increase from formative to summative; and, 33% (n=5) showed an increase from pre-assessment to formative and remained the same from formative to summative.

Of the 47% of students showing an overall negative gain in GS trend scores, 43% (n=6) showed a decrease in their score from pre-assessment to formative and a decrease from formative to summative; 43% (n=6) showed an increase from pre-assessment to formative and a decrease from formative to summative; 7 % of students (n=1) remained the same from pre-assessment to formative and then a decrease from formative to

summative; and, 7% of students (n=1) showed a decrease from pre-assessment to

formative and remained the same from formative to summative.

Table 7

Comparison of Positive and Negative Gains on GS Scores across all three assessments

GS score trend and percent (n=30)	Trend between pre-, formative, and summative assessments	Percent within trend
	Increase from pre to formative to summative	27%
Net Positive Gain	Decrease from pre to formative and increase to summative	40%
50%	Increase from pre to formative and remained the same to summative	33%
(n=15)		
	Decrease from pre to formative and decrease from formative to summative	43%
Net Negative Gain	Increase from pre to formative and decrease from formative to summative	43%
47%		
	Same score from pre to formative with decrease to summative	7%
(n=14)		
	Decrease from pre to formative and remained the same to summative	7%
No gain or loss	No increase or decrease from pre to formative to summative	100%
3% (n=1)		

Two paired sample *t*-tests were conducted to statistically evaluate the means and determine the effect size on the GS assessments. Table 8 contains the results of the paired *t*-tests. The paired *t*-test between the pre- and formative assessments was conducted to evaluate whether there was a gain in understanding of groundwater processes after the classroom inquiry-based lesson. The results showed an increase in the mean scores of 0.020 from the pre-assessment (M = 8.77, SD = 2.39) to the formative assessment after the classroom lesson (M = 8.97, SD = 2.69), $t(29) = -.416, p < .01$. The standardized effect size *d,* was shown to be small at .076.

The paired *t*-test between the formative and summative assessments, conducted to evaluate whether there was a gain in understanding of groundwater processes after the students had the opportunity to interact with the *Groundwater Exploration Activity Model*, showed a decrease in mean scores of 0.27. The mean score of the summative assessment after the physical model interaction (M = 8.70, SD = 2.42) was lower than the mean score for the formative assessment after the classroom lesson (M = 8.97, SD = 2.69), $t(29) = .713, p < .01$. The standardized effect size *d*, was shown to be slightly larger, yet still considered to be a small effect size at 0.130.

Table 8

Paired sample statistics

		Mean	N	Std. Deviation	*t*	*d*
Pair 1	Pre-test	8.80	30	2.34		
	Formative	8.99	30	2.68	-.416	.076
Pair 2	Formative	8.99	30	2.68		
	Summative	8.70	30	2.42	.713	.130

Summary of quantitative findings

The quantitative findings show a weak positive gain and small effect size for the use of physical models in helping students understand groundwater processes. Essentially 50% of students showed a positive gain in GS trend scores, while 47% showed a negative gain in GS trend scores. The mean scores between the formative assessment after the inquiry-based lesson and the summative assessment after the interaction with the *Groundwater Exploration Activity Models* showed a small decrease in mean scores. This begs the questions as to what factors contributed to the slight decrease in scores between the formative and summative assessments.

The goal of the Groundwater Survey was to quantitatively measure changes in students' understanding of groundwater process in the form of numbers and statistics. However, this measure alone, as in all quantitative methods applied in the social sciences, can lack contextual detail. The quantitative method was mixed with qualitative methods for just this purpose, to uncover those details and themes that are often undetectable in quantitative measures alone. In the following sections, the qualitative data from the classroom observations and the follow-up interviews are presented and discussed with respect to the quantitative findings.

Classroom Observations

To address the second research question of how students interact with the *Groundwater Exploration Activity Model* student behaviors in the classroom were observed and recorded while interacting with these models. This qualitative data collection and analysis are described in this section. The data are discussed within the context of the quantitative data generated from the Groundwater Survey measure.

Students worked in groups of two or three to interact with the *Groundwater Exploration Activity Models* using a student activity sheet with instructions and guiding questions (see Appendix E). Students worked through three activities presented on the sheet; the first two were more structured and addressed groundwater storage, movement, the water table, wells, and pollution. The third activity was more open-ended and less structured allowing students to try out different scenarios and make predictions while pumping wells.

The observations took place in both classes during the regular scheduled classroom time and were recorded using four video cameras strategically placed and aimed at student groups of two or three. Each of the eight video recordings were observed by the researcher and an additional science educator to note behavioral elements such as time on task, vocabulary used, difficulty with task, number of times trying an activity again, and how often students tried new activities different from instructions (see Appendix C). Four of the videos were of two groups of two students each group with their own model. Two of the eight videos were of student groups of three and two videos were of one group of two students. Four individual students were absent on the model activity day and made up the activity a day later but were not videoed or counted in the classroom observation data.

During the observations behaviors of students as they interacted with the *Groundwater Exploration Activity Models* were noted and recorded. The data were first categorized into groundwater content areas as presented in Table 9. The behavioral elements and their frequency of occurrence are categorized into the groundwater content areas (movement/storage/scale, wells, and pollution) to correlate to the GS blueprint.

Secondly, several behavioral subthemes arose from the classroom observations and these are described within the context of the quantitative findings.

Table 9

Behavioral elements and frequency from classroom observations

Behavior	Frequency
Groundwater movement, storage, scale	
Difficulty identifying water level in the wells, lake and pond as the water table	4
Identifies relationship between lake, pond, and wells as water table	4
Difficulty identifying pollution plume movement and groundwater flow direction as the same	4
Identifies the pollution plume movement direction is same as the groundwater movement	4
Difficulty identifying confining unit separates two aquifers	3
Identifies confining unit as separating two aquifers	4
Refers to confining unit as 'clay layer'	5
Claims the water moves faster in gravel layer	2
Groundwater Wells	
Difficulty using syringe to pump wells; pulls apart syringe spilling water	6
Uses syringe to pump air into well and push water or pollution down into well	5
Attempts to pump water out of lake or pond using syringe	7
Draws clean water from reservoir using syringe to flush out well	5
Identifies variation in well depths	4
Pumps deeper wells and identifies separated groundwater layer below confining unit	3
Identifies wells tapped in confining unit are more difficult to pump for water	2
Pumps wells up-flow of pollution and identifies clean water	4

Table 9 (continued) *Behavioral elements and frequency from classroom observations*

Groundwater Pollution	
Difficulty waiting for pollution to get into the groundwater system from well; describes pollution is 'just going down'	4
Repeatedly pollutes other wells	6
Difficulty identifying why deeper wells are not polluted from original pollution plume in upper aquifer	4
Pollutes lower aquifer by polluting deeper wells	3
Asks for more pollution	6
Uses waste water for more pollution	5
Identifies source of pollution when pumping other wells	6
Uses syringe to pump pollution out of well	4
Refers to pollution as 'the red'	4
Pollutes pond and lake	4
Dumps pollution on surface	2

Behavioral subthemes

Several subthemes arose in the student behaviors that help shed some light on the GS trend scores from formative to summative assessments. These subthemes included group structure, need for teacher guidance, difficulty using the models, creativity with the models, and developing misconceptions. Each subtheme is discussed with respect to the quantitative findings below.

Group structure

Groups of two students worked much more effectively as far as remaining on task compared to students who worked in groups of three. In groups of three, one student would inevitably have nothing to keep them engaged such as recording observations on the student handout or manipulating the model, and would often fall off task. Arguing for a turn erupted more in groups of three than in groups of two. In addition, groups of

three students were more likely to leave their work station and wander to another table to observe another group.

Tables that had two groups of two students would use the other group to discuss and compare their observations. Tables with only one group of two remained engaged with their model, but did not have another group and model within close proximity to compare their observations. Overall each student group completed their activity sheet within the class period and had ample time left to explore other aspects of the models if they chose to do so. It was noted in two separate groups of two students working at a table of four, after completing the student activity sheet, one member turned to studying for a test that was occurring in a different subject later in the day while the other member continued to interact with the model for the remaining 10 minutes left in the class period.

Comparison of group structures to GS trend scores for individual students showed that 10 out of 16 students working at tables with two groups of two had an increase in GS scores (n=7) or remained the same in their scores (n=3) from formative to summative. Students working in groups of three (n=6) showed a mixture of individual trend scores; two out six students with an increase in trend scores, one out six remained the same, and three out of six had a decrease in scores. The students working at tables with only one group of two showed a decrease in scores (n=4 out of 4). It appears that group structure during interaction with the *Groundwater Exploration Activity Models* may have had a small affect on GS trend scores. The group structure of four students at a table working in pairs with their own model produced more students with increase in trend scores. The advantage of this group structure may be that it provided students with an additional

model for comparison and to observe the actions of others within close proximity at the same table.

Need for teacher guidance

Teacher guidance to varying degrees was needed at some point during the class period by each of the student groups. On the student handout, the first activity asked students to define the relationship between the water level in the wells, lake, and pond. Half of the student groups did not describe the relationship using the phrase 'water table,' although the phrase was used in the inquiry-based classroom lesson. These students indicated the relationship on their activity sheets as 'the same' but did not identify it using the correct vocabulary until after the teacher intervened with probing questions referring back to the inquiry-based classroom lesson.

In the second structured activity, students were asked to pollute well #5 and identify the direction of plume movement. Several groups did not wait for the pollution to travel to the bottom of the well and get into the groundwater system and simply described the movement of pollution as 'going down' as they watched the movement in the well. The teacher had to reiterate instructions several times so that students would wait before they answered the question on their activity sheet.

Most of the groups identified the pollution plume movement as the same direction of the groundwater movement. In addition, a few groups mentioned the water moves faster in the gravel layer after they observed pollution movement in the gravel. However, two groups had to ask for help from the teacher. One group of three could only make the connection between the plume movement and the groundwater movement after

several probing questions from the teacher which included explaining the electric pump and water movement in and out of the tank.

The tanks contained a brown colored confining unit that separated the groundwater into two different aquifers. Some of the wells were deeper and tapped into the lower aquifer. Each group recognized that the wells varied in depth and some students related that to a deeper and separate aquifer while others had difficulty making that connection without guidance from the teacher. Several groups verbalized that the 'clay layer' won't let the pollution get into the bottom layer or that the clay layer doesn't let water go through it. No groups were observed using the term confining unit nor did the term appear in responses on the student activity sheets even though the term was defined in the classroom lesson. Some students needed help recognizing why the lower aquifer did not become polluted. The teacher suggested they pollute a deeper well and describe what happens. Only then did they acknowledge the two areas were separated by the brown layer.

The amount of teacher guidance given to student groups showed no particular association with decreasing or increasing GS trend scores for individual students. As the classroom teacher, this researcher can recognize that the student groups needing the most guidance, which included additional probing questions and recommendations to try specific activities, were composed mostly of academically weaker students. Groups that had a mixture of academic abilities or composed of students with higher academic abilities required less teacher guidance. In addition, those students that required more teacher guidance also showed the least creativity in their interactions with the models and had less elaboration of answers recorded on their student activity sheet. The need for

teacher guidance seems to be more of a reflection of individual academic ability or ability to work independently and perhaps tied to issues of motivation.

Difficulty using the model

Using the syringe to pump the wells presented difficulty to some students. Several students had physical difficulty trying to pump wells and draw water from the well. Upon the second or third attempt several gave it their full strength and actually pulled the syringe apart spilling water onto the table. Many groups tried to pump water from the lake or pond and discovered the syringe was too large to fit into these areas. At that point some students played with the pipette to draw water from those sources but discovered the pipette was too small to be an effective pumping device. It is worth noting that the groups that had difficulty using the syringe and pulled it apart were mostly boys (4 out of 6 groups). No relationship existed between observed difficulty pumping wells or using the syringe and individual GS trend scores.

Creativity in using the model

The syringe was also used in a creative manner by students as they pushed air into the wells to move the pollution down faster or used the syringe to draw water from the reservoir (the back of the tank) and used it to flush a well with water. Pollution activities were by far the favored activity by all groups. Only a small amount of pollution was given to each student group to avoid students from polluting all eleven wells at once. Students were instructed to discard clean water back into the reservoir and to discard polluted water into a waste container. Many students wanted to pollute additional wells but had used up their allotted red dye in their canister. Some students used the waste water while others withdrew pollution from one well and transferred the pollution to

another well. Some students chose to pollute the lake and pond in addition to the other wells. Only two student groups dumped pollution directly on the surface of sediments and watched pollution movement percolate down through the surface sediments.

Individual students showing the most creativity (n=11) were also observed in the videos as remaining more engaged with the model. These students were more prone to try out additional ideas with the model and make predictions about their ideas. Their answers on the student activity sheet showed more elaboration as well. Of these students, eight out of eleven had an increase in their GS trend scores. However, many of these students are also higher academic achievers and tend to show a higher degree of self-motivation in less structured discovery learning settings.

Developing misconceptions

Most of the student groups had no difficulty identifying the pollution source when they were asked to pump well #8 down-flow of the pollution plume from well #5 in the second student activity. However, as students continued to withdraw pollution from a well, comments such as "I cleaned the pollution" or "I de-polluted the well" were common. In addition, the pollution plume began to dissipate as the water cycled through the tank and several students commented that the "pollution was gone."

The strongest connection between classroom observation data to that of individual GS trend scores is seen in the development of misconceptions about groundwater pollution persistence. For example, of the 47% of students (n=14) with negative gain in their GS trend scores, 43% (n=6) lost points specifically on question #9 on the GS that addressed groundwater pollution persistence. Furthermore, students within the negative gain in GS trend scores that had increased on the formative assessment but decreased in

the summative assessment (n=4) all lost points specifically from their responses in question #9 on the GS. The question asked if groundwater becomes polluted what can happen to wells and lakes or ponds in the area. One of the correct choices states that pollution could stay in the groundwater for a long time. These students had chosen the response on their formative assessment but did not on their summative assessment. In addition, another choice on the same question claims pollution will mix with the groundwater and not be harmful anymore. These students did not chose the answer in the formative but did so in summative. These incorrect ideas about groundwater pollution can be seen as directly attributed to the model interaction. As the class period progressed and the tanks continued to run, the red pollution plume was dispersed and eventually disappeared giving some students the impression that groundwater pollution will always go away on its own.

Summary of classroom observations data

To address the second research question of how students interact with the *Groundwater Exploration Activity Model*, classroom observations of student behaviors were used. The classroom observation data were first categorized using groundwater content areas aligned to the GS blueprint for better clarity between groundwater model components and student interactions. Secondly, subthemes that emerged from student behaviors were described and reported within the context of individual GS trend scores. Overall, the trend in GS scores from the quantitative data showed almost a 50-50 split between students showing a net positive gain to those showing a net negative gain across all three assessment scores. In an attempt to understand the negative gain scores more thoroughly, the subthemes were analyzed in terms of individual GS trend scores.

The subthemes that showed a connection to individual GS trend scores included group structure, creativity, and development of misconceptions. The most significant link between classroom observations and GS trend scores was found to be the development of misconceptions about groundwater pollution persistence generated from using the model. The need for teacher guidance appears to be more related to students' academic strengths, including the ability to work independently. In addition, as students interacted with the groundwater models, motivational issues played a role as well in a less structured classroom setting. The more motivated students remained engaged longer with the models and were more likely to explore other aspects of the model and make and test predictions. However, no distinctive pattern was found between these students and their GS trend scores.

Semi-Structure Interviews

To address the third research question of how physical models help students develop mental images of groundwater processes consistent with those of hydrogeologists, eight students were chosen as a purposeful sample for one-on-one follow-up interviews based on their GS trend scores across pre-, formative, and summative assessments. The interviews were conducted by an additional science educator from the University. Each interview was videoed and a *Groundwater Exploration Activity Model* tank filled with water but not running was available for students to use to help explain their ideas. Guiding questions (Appendix D) were used during each of the interviews. The first question asked students to explain their drawings on each of the GS assessments with follow up cues to elicited further explanation. The second question asked students how the model helped them to learn about groundwater.

Additional questions addressed their likes and dislikes of using the *Groundwater Exploration Activity Model* and the final question of the interview asked students how they would construct a groundwater model if given a chance to build one. Several probing questions were used by the interviewer to elicit more elaboration from students.

Each interview lasted approximately 25 minutes and was transcribed for qualitative data analysis. Student responses were first categorized into groundwater content areas aligned with the GS blueprint. Secondly, subcategories emerged in each of the groundwater content areas through an iteration process of coding. Once these categories and subcategories were established, a second science educator who also helped with the classroom observation data coded two of the eight interview transcripts to help establish reliability. The inter-rater reliability value of .87 showed a strong level of agreement and reflected that criteria used to code and organize the interview data were lucid. Categories and subcategories are listed in Table 10 and are discussed with respect to representative student responses from the interviews and any significant connections to GS trend scores and/or specific items on the GS.

Table 10

Groundwater content categories and subcategories used to analyze interview data

---

Groundwater Movement/Storage/Scale:

                        Groundwater occurrence
                        Porosity and water movement
                        Direction of water movement
                        Connection of surface water to groundwater

Groundwater Wells:

                        Image and design
                        Pumping and water movement

Groundwater Pollution:

                        Plume movement
                        Source of pollution
                        Pollution persistence and clean up

The eight students chosen for the follow up interviews reflected a representative sample of GS trend scores. Each interview case was denoted as a rich, medium, or weak case based on students' individual responses, elaboration of answers, groundwater vocabulary used, and connections made to larger systems such as the water cycle. An interview was identified as a rich case if students elaborated with very little probing and used groundwater vocabulary frequently in their explanations that referenced connections of groundwater to a larger system. A medium case was identified if students needed a small amount of probing to elaborate on their answers and used explanations with some form of connections to larger systems, and finally a poor case was identified if students lacked elaboration even after the use of probing questions and did not use any

groundwater vocabulary or understand any connections to other components of the system. The list of students interviewed, their GS score trends, gender, and case richness is listed in Table 11. Pseudonyms were assigned to each student to protect their identity.

Table 11

List of interview participants in purposeful sample, GS score trends, and case richness

Student (pseudonym)	Gender	GS trend score	Case richness
1- John	M	decrease-decrease	medium
2- Don	M	increase-increase	weak
3-Diane	F	increase-increase	medium
4-Patrick	M	decrease-decrease	weak
5- Barbara	F	increase-decrease	rich
6- Charles	M	decrease-increase	medium
7-Andy	M	increase-decrease	rich
8- Jane	F	decrease-increase	medium

Groundwater movement/storage/scale

Groundwater occurrence

The first question in the interview asked students to explain their drawings across the pre, formative, and summative assessments from the open-ended draw and explain question (#10) on the Groundwater Survey. Of the entire student sample 70% (n= 21 out

of 30) and six out of eight students interviewed depicted groundwater in a type of solid

water storage of pipes, conduits, streams, pools, or lakes in their pre-GS assessment

drawing. Figure 1 is an example of a typical drawing.

10. In the space provided below, draw a detailed picture of how
    groundwater occurs and moves. Be sure to label your features and
    write any explanation you feel is necessary for me to understand your
    ideas about groundwater.
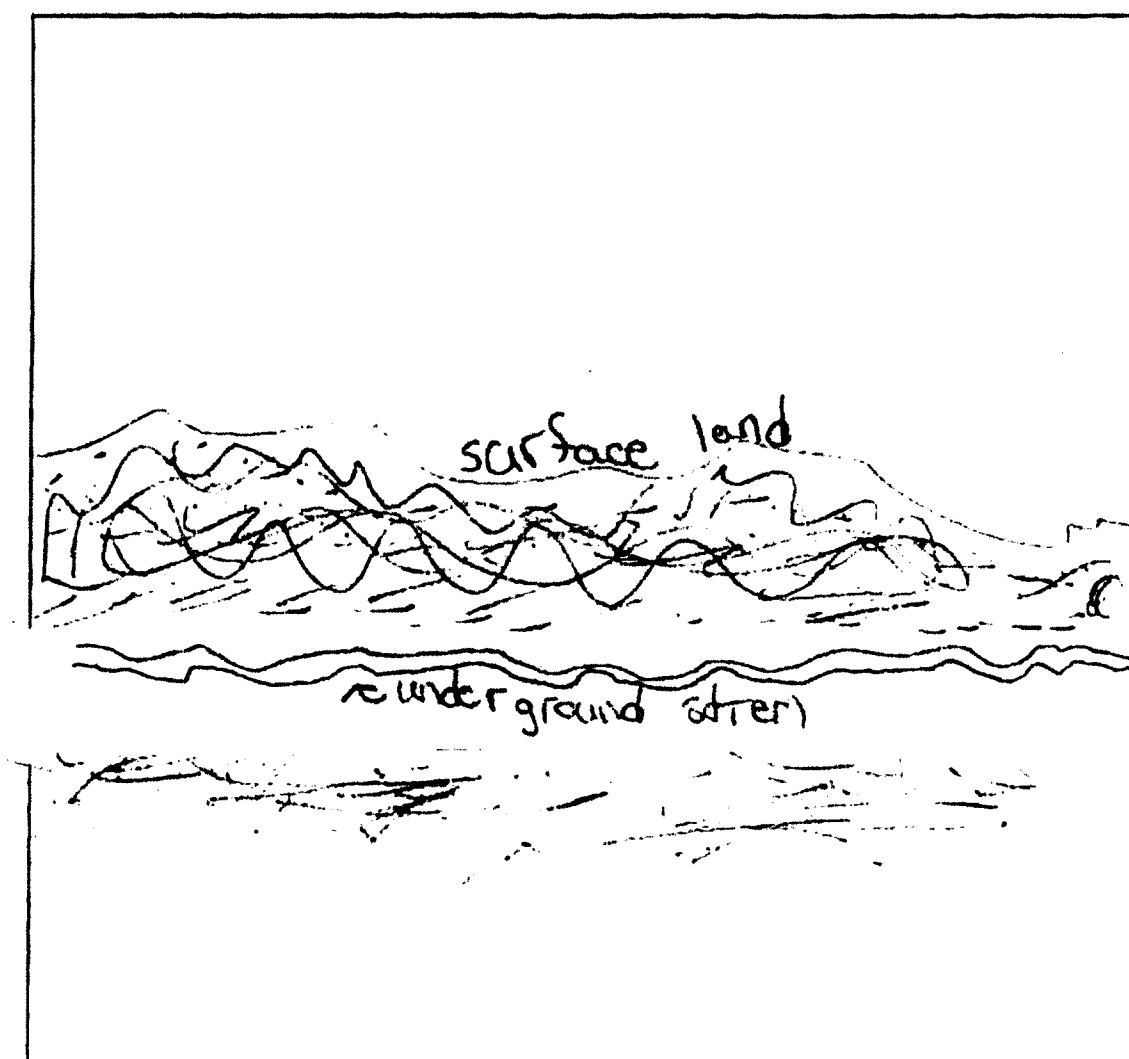
Figure 1: Typical student drawing on the GS pre-assessment showing solid underground
water storage in the form of an underground stream.

The 70% of students in the overall sample that had drawn an incorrect occurrence

of groundwater in their pre-assessment, changed their formative drawings to show strata

of sand, gravel, and clay often with a lake present, well, and well house. Six of the eight

students interviewed had changed their drawings and when asked why they had done so,

each student claimed it was because of what they had seen on the student handout with

homework questions given to them during the inquiry-based classroom lesson (see

student handout in Appendix E). Figure 2 depicts a typical student drawing on the

formative assessment that closely resembles the student handout used in the groundwater

inquiry-based lesson in the classroom.
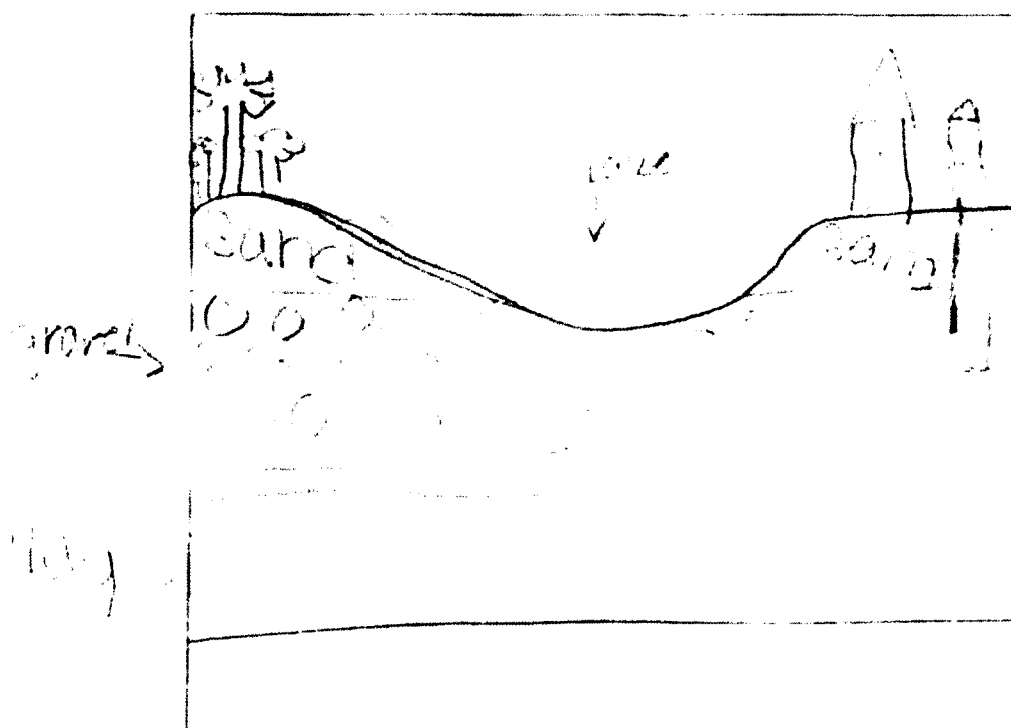
Figure 2: Student drawing on GS formative assessment. Note the layers of sediment, lake, house, and well tapped into gravel layer mimics the student handout from classroom lesson.

In the summative drawings, three students in the overall sample included multiple wells with strata that mimicked the appearance of the *Groundwater Exploration Activity Model*. It is interesting to note that Patrick, a weak case, was the only student in the interviews who had not changed his drawings across all three assessments to reflect any more detail in the subsurface groundwater environment. Only one other student in the sample had done the same. When Patrick was asked about his drawings he claimed "he didn't really care about any of these, I just drew something." Patrick's GS trend scores showed a decrease across all three assessments. In addition, Patrick was one of the students who needed more teacher guidance during the model interaction to help answer the questions on the student handout. Although Patrick's case is not representative of the entire sample, it does demonstrate that student motivational issues could have played a role in GS trend scores.

While a large percentage of students changed their drawings to reflect less surface feature representation of groundwater, responses on GS question #1 showed that students continued to choose surface water features as a source of groundwater. The question asked if a person drilled a well into the ground to get groundwater, from where would the water come. Seventy-nine percent (n=11 out of 14) of students with negative gains in their GS trend scores chose underground streams as a choice and 57% (n=8 out of 14) chose an underground lake as a choice on their summative assessment. In contrast, fewer incorrect responses were chosen by students who had positive gains in their GS trend scores. Their summative responses showed that 60% (n=9 out of 15) picked underground streams and 40 % (n=6 out of 15) picked an underground lake. Overall the incorrect choice of underground streams appeared more in both GS trend score categories than that

of an underground lake. The fact that the water was circulating in the model could have

prompted students to choose underground stream more so than a static lake. However, as

described in next section from interview responses, students did not express underground

streams or lakes or any solid water in their ideas about groundwater storage.

Porosity and water movement

Six students interviewed made reference to the classroom activity using the open

ended tubes filled with gravel, sand, or clay to measure the rate of water movement

through them. John's response was typical of what each of the students described, "I

learned about the sediment, the sand, the clay, and the gravel, and which one would make

it [water] flow the fastest. It [water] won't go through clay as much." Four students

described the activity with the sediment tubes and gave the results of their findings such

as Don claiming, "We even tested it, and the sand was like 8 seconds, and gravel like 3

seconds, and the clay was 5 hours and 30 minutes." The students who did not make

reference to the classroom activity did, however describe water moving through gravel

faster than clay at some point in their interview.

To elicit more elaboration, a few students were asked what the water would look

like in the ground from a bug or worm's view and many students claimed it would not be

solid water but would be more mixed with dirt. Charles, a medium case, claimed water

in the ground would "move through different layers like waves kind of, like when you see

a rock and water dripping off it...like if you have ever seen a very thin stream of water

going over a rock." Diane, also a medium case, described groundwater as "moving down

and spreading out and moving around the sediment."

All students interviewed made reference to different layers of sediments and that the movement of water through different types of sediments varied depending if it was gravel, sand, or clay. Most students stated that flow of water through gravel was the fastest because gravel was the biggest and a few claimed that is why gravel would make the best aquifer. Jane, a medium case, described pore spaces between gravel sediments would be the size of "a couple of centimeters or an inch." She also drew very large boulders in her diagrams and named it gravel. Andy, a rich case, claimed that "gravel has very high porosity with lots of pores and the water can seep though and stay in there and that would make a good aquifer."

Three of the eight students interviewed had difficulty identifying where the water may exist in the finer sized sediments within the model. Patrick claimed water was not present in the sand because he did not see any. Jane described water as being in the gravel portions of the model and the wells because she "could see the blue" but like Patrick she claimed water was not present in the sand because she could not see it. Furthermore, Patrick claimed water was present in the lower gravel layers of the models and that water source came from the deeper wells in that gravel layer; "the well all the way down here [points to gravel layer at bottom]… the water would probably flow out." On the other hand, Patrick claimed there was no water present in the adjacent sand layer (at the same depth in the model) because "it is squished down and the water does not flow into it." Diane, a medium case, claimed water existed in the upper fine sand layer above the model water table because she could "see it was blue" which was only food color staining from blue colored water that had been poured onto the surface in previous student use of the tank.

The other five students interviewed however, did recognize that water in the model existed everywhere below the model water table in the pores of the sand and gravel. Diane explained she knew water was in the sand because when her group pumped the shallow well #11 located above the water table in the model, water came out, "...it [the well] was completely empty and then we pumped it and water came out, we were completely surprised." Don, a weak case, claimed water was all over the model as he waved his hand across the sand areas except for in the clay. Clay was only described as 'impermeable' by Barbara. Other descriptions of clay included 'too thick' and 'more dense.' Most students interviewed made some kind of reference to the clay as blocking or stopping the water and/or pollution from moving through. On the other hand, Diane could not explain why the pollution did not go through the clay layer. She identified the pollution moving east and not down and made reference to other groups, "....and with everyone's it did the same thing," but she could not explain why even though she had explained the slow movement of water through the clay tube in the classroom activity earlier in the interview.

Five out of the eight students interviewed and 11 out of 30 students in the total sample had not included the correct response on GS question #4 that stated groundwater can move through the pore spaces of sediments on their pre-assessment; but did however, include it as a correct response in their formative and summative assessments.

From student interview responses and answers chosen on question #4 in the Groundwater Survey, it would appear most students gained an understanding of porosity and water movement and storage in pore spaces. Students did not describe storage of groundwater in terms of open solid water, but instead as mixed with sediment or moving

around or through sediment. The ability to physically see or not see water in pore spaces in the models had an impact on students' responses of groundwater storage in sediments.

Direction of water movement

In the total sample 11 out of 30 students with a mixture of GS trend scores showed groundwater moving across their formative and summative diagrams from left to right. Four out of eight students interviewed did the same and when asked why the water was moving to the right in their diagram these students claimed it was moving that way because it was heading towards a lake or pumping well that appeared in their drawing. Five students were asked which way the water was moving in the model, and all responded 'to the east' in relation to the labels that had been placed on the models, but these students could not explain why the water was moving to the east in the model. With a bit of probing Barbara and Andy, both rich cases, explained the circular motion of the water traveling in the model and related it to a force in the model system but did not articulate the electric pump as being the force that caused the water to circulate.

The impermeable brown layer in the model is slanted creating a sloping appearance to the east across the front of the model. Two students explained the water was 'moving down hill' and three explained the movement had something to do with the clay layer in the models. Diane claimed groundwater would move in the sloping direction because "there was extra space or something." Most students claimed water in the model could move upwards if it was being drawn into a pumping well. Only Barbara mentioned that the water "moves down hill under the influence of gravity." Barbara was one of two students observed in the classroom model interactions that had polluted the top sediment layers and noted the movement of pollution moving down through the upper

layers of sediment before joining the groundwater flow in the model. Providing students with a better understanding of the mechanics of the model (e.g. electrical pump and outlets for water flow) could help facilitate better understanding of groundwater movement in the model.

Connection of surface water to groundwater

In the total sample, approximately 50% (n=16 out of 30) of students included a lake or a pond in their formative and summative drawings and seven students interviewed claimed they had seen a lake in the student handout and also mentioned the lake in the model. When asked the connection between the groundwater and lake or pond water, answers varied tremendously. Barbara explained groundwater movement into the lake within the context of the water cycle and that the water could continue in the cycle from being "evaporated from the lake." Andy claimed the "water in a lake can't possibly stay in the lake if the lake bottom is sand or gravel. I'm sure it seeps into the groundwater." He went on to apply this idea to the model by describing how his group tried to fill the lake to overflow and the water would "seep out through the holes around the lake." On the other hand, Patrick claimed his group also overflowed the lake, yet Patrick could not understand where the water in the lake would go. "We tried to overflow the lake and every time it would get high, it [the water] would just go back down." When asked why it would do that, Patrick claimed there may be "something behind the sand that the water could go to" and points to the sand under the lake in the model. When asked if there was water in the sand just below the lake (half filled with water) he claimed there was not any water there.

Three students described rainwater as the source of water for the lake. Diane explained the lake water and groundwater would "kind of have to share the water." Jane explained that groundwater would only go into the lake if there was a 'really bad rainstorm, it [the water table] could get high enough it could intersect and leak." John claimed the rainwater would" leave the lake because gravity would drain the lake." Charles was the only student to mention a lake could get groundwater if it was "spring-fed." Interestingly, Don explained the exchange of groundwater and lake water was a result of pumping. "The groundwater would come into the lake if you pumped it or the water in the lake would go into a well that is being pumped." The syringe that was used in the activities for the purpose of pumping the wells was too large for students to fit it into the lake and draw water. This was one of the dislikes of the model that many students mentioned in both the interviews and in the classroom observations. The disadvantage of not being able to pump water from the lake seemed to hinder students understanding of the connection between the lake and the groundwater to some degree. On the other hand, overfilling the lake and watching it drain back down helped students to see that the lake water is connected to the groundwater system.

On the summative assessment, 16 out of 30 students in the total sample and four out of eight students interviewed gained points on the assessment by including the response in GS question #4 that claimed groundwater could move into a lake or nearby stream as one of the correct choices. In addition, question #3 on the GS showed 9 out of 30 students gaining points on their summative scores by including the response that groundwater was a source of water for lake water. All of these students showed an overall gain in their GS trend scores. On the other hand, 11 out of 30 students lost points

on their GS scores by claiming a hose or sprinkler or a well was a source of water for

lake water in responses on question #3. These 11 students all showed a decrease in their

GS trend scores. The ability to fill the syringe with water from the reservoir or a well and

then squirt it into the lake coupled with any mental images of hoses filling swimming

pools, for example, could have lead students to choose those incorrect responses on GS

question #3.

Groundwater wells

Well design

Images of wells appeared in 53% of pre-assessment drawings (n=16 out of 30).

The images overwhelmingly showed well houses that sat above ground with some type of

pipe or conduit in the ground that lead to the bottom of the well for a water source.

Groundwater wells that appeared in student drawings in both the formative and

summative GS assessments mostly appeared below ground with a well house on the

surface. This image mimicked the image in the student handout (see student handout in

Appendix E). Many of the images of the old fashioned well houses also had buckets and

stone facing on the above ground portion of the well. When asked if they had ever seen a

well like this before most students interviewed indicated they had seen it on the student

handout given in class; however the handout given in class showed a well house without

stone facing and without a bucket. Two students, Barbara and Andy described their

personal experience with seeing a well on their family farm and at the family cabin in the

woods in Connecticut, respectively. A few described seeing an old fashioned well in a

book or a movie. Diane claimed she had seen the image "in our Latin book they show

the ancient well." The image of the well became thinner from formative to summative

drawings and some students drew an indication of the well being pumped. In the overall sample of students 16% of students (n=5 out of 30) drew multiple wells at various depths in their summative drawings that mimicked multiple wells in the *Groundwater Exploration Activity Model.*

Pumping wells and water movement

Thirteen out of 30 students in the total sample drew wells extending below the ground into a gravel layer in their summative drawings. Eight of these students showed a decrease in their GS trend scores. Five out of eight students interviewed illustrated wells drawn in the same manner on their summative drawing. A well tapped into a gravel layer was illustrated in the student handout given during the classroom lesson and thus was easy for students to mimic. However, in the interviews, Barbara described that she drew her diagram that way because the gravel would make the best aquifer. Diane illustrated her well as tapped into a sand layer, but stated that "gravel would give you more water."

Most students interviewed described that groundwater would move towards a well that was being pumped. Andy was the only student interviewed that described the water table configuration as the result of pumping a well; "…it lowers the water table around the well because the water is being sucked up and you would have to drill the well deeper to get more water or drill another well." He did not indicate seeing this from the model; however, a picture was projected on the board during the classroom lesson that showed a deep pumping well creating a cone of depression causing the more shallow adjacent wells to go dry. The problems associated with over pumping a well were discussed during the classroom lesson.

Students indicated water was easier to pump out of the model wells that were tapped into gravel sediments. Jane and Andy indicated water was harder to pump from wells in the clay layer. Both Jane and Barbara indicated that the sediment would not come into the pumping well in the model because there were tiny holes at the bottom of the well that only water could get in. It is worth noting that a few models had well #8 tapped into the clay layer where as the others were tapped into sand above the clay layer. These differences can arise while filling the empty tanks originally with the various sediments provided by the manufacturer.

Question #5 on the GS asked when water is pumped from the ground, what can happen. The responses from the summative assessments showed students that had a negative gain in GS trend scores included more correct choices 50% (n=7 out of 14) than those students in the positive gain in GS trend scores 27% (n=4 out of 15). The correct responses in question #5 included that a pumping well will draw water from all directions, lower the water table, and can cause nearby wells to lose their water. Using the syringe to pump wells did not allow for continuous pumping to create any significant draw down of the water table in the model, therefore it was not the model that created a direct visualization of this concept. Students' responses for question #5 remained identical in 66% of the students from formative to summative. This suggests the classroom lesson may have had a stronger impact on students' ideas than the model activities. For those students who did not remain consistent in responses on the GS question #5 (31%) from formative to summative either gained points for including more correct answers between the two assessments, one of which was related to pollution, or lost points for including the only incorrect answer; that water would always be available

from a pumping well. This incorrect response could have been attributed to the fact that every well in the model always produced some amount of water when pumped.

Groundwater pollution

As noted in the classroom observation data, polluting the groundwater while using the models proved to be a popular activity that generated the most excitement among the students. In the interviews, all students spoke confidently about groundwater pollution they witnessed while using the model. For the pollution activities, students were instructed to use the small pipette and pollute well #5 with the pollution (red food coloring) provided in the film canister and describe the direction of pollution plume movement. Students were also directed to pump wells up and down flow of the pollution source and describe what they found.

Plume movement

In the interviews, each student correctly identified the plume movement to the east; however, as observed in the classroom observations, many students had difficulty identifying that the plume movement was the same direction as the groundwater movement. Each student that was asked about wells up flow of the pollution source (well #5) indicated that those wells did not get polluted because the pollution was moving to the east and not the west, but still could not explain why the pollution plume was moving to the east.

Source of pollution

Students were instructed to pump well #8 once the red pollution entered the groundwater. Most students recognized that pumping well #8 drew polluted water up into the well. Question #8 on the GS asked about wells in relation to pollution source.

Out of the total sample, only 17% (n=5 out of 30) chose the incorrect response on their summative assessment that wells up-flow of a polluted well could become polluted. Within the negative gains in GS trend scores, three out of 14 (21%) students chose the incorrect response and two out of 15 (13%) in the positive gain in GS scores

When asked if the pollution got to the deeper wells below the clay layer, most students said no because it was below the clay layer. John claimed "the pollution didn't really go to those wells because the clay would stop all the water, the pollution could not get pass this" (points to the clay unit). Both Diane and Patrick could not explain why the pollution would not go below the clay layer. Three students claimed they had polluted the deeper wells and were able to witness the pollution traveling in the lower aquifer in the model. These students identified that the pollution moved through the gravel much faster than through the sand.

From these responses, it is clear that the model provided a good visualization of groundwater pollution plume movement for most students to gain an understanding of potential pollution problems with pumping adjacent wells from a pollution source.

Pollution persistence and clean-up

Student ideas on groundwater pollution persistence and clean-up seemed to be directly related to their interaction with the *Groundwater Exploration Activity Model*. Students were given only a small amount of red food coloring in their canister. Several students claimed they did not have enough pollution so they recycled their pollution by pulling it out of polluted wells and using it to polluted different wells or the lake.

As noted in the subthemes in the classroom observation data, students' GS trend scores were affected by their incorrect responses chosen on GS question #9 which

addressed pollution persistence. The interview data showed a similar pattern. Four out

of eight students interviewed believed pollution could easily be eliminated if it were

pumped out of the wells. For example, John had changed his answers to the GS question

#9 not to include the response that groundwater pollution could stay in the ground for a

long time. When asked why he changed his answer between formative and summative

assessments, he claimed, "If you keep pumping all the pollution will come out, it doesn't

take all that long." Barbara was asked the same question why she had changed her

answers as well and she responded that" if you had a well it [the pollution] could be

drawn up and out of the system in a matter of a couple of hours and you could dispose of

the pollution properly." Both of these students gained useful insights from the model, but

which let them to conclusions that are not entirely accurate. Groundwater remediation

techniques used by hydrogeologists commonly include two procedures that can be

partially represented in the *Groundwater Exploration Activity Model* – effectively

diluting a relatively small quantity of pollution as it mixes with regional groundwater

flow, and pump-and-treat systems that contaminate groundwater extracted from pumping

wells (USGS, 2012). Thus the initial inferences by these students based on their

experiences with the model are not entirely incorrect. However, to effectively bring

polluted groundwater back to drinkability, both of these real-world procedures require

reducing the level of chemical contamination far lower that the students could simulated

by physically reducing the concentration and visibility of the food coloring in the model

aquifers. Thus although the pollution activities aided students in correctly identifying

plume movement with respect to pumping wells and potential contamination, the

constraints of the model gave an incomplete view of pollution persistence in the real world.

Models and student experiences

Questions about the model and students' experiences were also addressed during the interviews. All eight students interviewed had positive comments about the model. Most students claimed the model allowed them to see a side view of 'the layers and water' and how 'pollution moved in the ground.' The last question in the interview asked students how they would construct a model if they had the chance to do so. Barbara and Andy, both rich cases, expressed the most industrious and creative answers. They both described the type of materials they would use and where they would retrieve them as well as, how they would go about inserting wells and making the water flow through their model. It is worth noting that both of these students attributed their personal experiences with wells to family experiences. Conversely, Patrick, a weak case, immediately claimed he could not build a groundwater model when asked how he would go about doing it, "It would be impossible. I couldn't do it." All other students interviewed made reference to getting different types of sediments to 'make the different layers' but did not indicate much about wells or making the water move.

Connecting model aspects to real world

Several students were asked to compare movement of water in the model to that in the real world. Barbara recognized the distinction between movements of water in the model compared to real life by indicating a much longer time span. Barbara was also the student who explained her ideas within the context of the water cycle. She made the connection between pollution on the ground in her backyard affecting the marsh and

eventually into a larger body of water, "we live by the inlet and if it [pollution] moved into the inlet, it could go into the bay and a lot of other things could be affected." Patrick claimed the layers in the model would be similar to outside except it would be "a lot bigger and you wouldn't have clay, or sand, or gravel, you would have dirt." In addition, Patrick explained groundwater in the real world moved east like in the model and it was caused by "the Earth's tilt sometimes." Diane explained there are layers in the ground like shown in the model except those layers are "pretty deep" On the other hand, Jane described the layers of sediment as extending into the ground "maybe 50 or 20 feet to the bottom" and that is where the groundwater "can leak to the bottom and just stay there for a while until you pump it up." As mentioned earlier, many students explained groundwater in the real world as moving east like in the model but could not explain why or claimed it had something to do with a pumping well.

Summary of semi-structured interviews

To address the third research question of how physical models help students develop mental images of groundwater processes consistent with those of hydrogeologists, one-on-one follow up interviews were used to probe deeper into students ideas about groundwater processes. Eight students were chosen based on their GS trend scores across pre-, formative, and summative assessments as a purposeful sample. Student responses were first categorized into groundwater content areas aligned with the GS blueprint. Subcategories that emerged (Table 10) were analyzed with respect to student interview responses and GS trend scores of the entire sample.

Two categories emerged where students appeared to have gained the greatest understanding about groundwater processes; their ideas of porosity related to water

movement and movement of pollution plumes with respect to source of pollution and possible contamination of adjacent wells. As discovered in the classroom observations, misconceptions were apparent in the ideas of pollution persistence and ease of pollution clean-up.

Student illustrations of groundwater occurrence became more sophisticated from pre- to formative and summative assessments yet student interview responses indicated that their drawings had changed based on what they had seen on the student handout from the inquiry-based classroom lesson. Although students showed a significant change in their drawings to reflect less solid water storage of groundwater, the GS item #1 indicated those students with negative GS trend scores continued to chose incorrect answers about groundwater storage on the summative assessments more so than those students with a positive GS trend score. However, the interview responses indicated students' ideas of porosity and water movement showed less reliance on solid water surface features and more expression of water moving correctly through pore spaces in sediments. The direction of water movement in the model was correctly identified, yet student interview responses showed a lack of understanding of why water movement occurred in the direction that it did.

Concepts associated with the connection of groundwater to surface water had the most diverse responses. The interview responses from six students indicated that the groundwater and lake water were connected. Students with positive GS trend scores indicated groundwater could move into and out of a lake on the GS summative assessments. On the other hand, students in the category of negative GS trend scores, lost points on their GS scores by claiming a hose or sprinkler or a well was a source of

water for lake water. The ability to fill the syringe with water from the reservoir or a well and then squirt it into the lake coupled with any mental images of hoses filling swimming pools, for example, could lead students to choose those incorrect responses on those GS questions

Images of groundwater well design became more sophisticated in student drawings across the GS assessments. Students claimed they had gotten their design from books, movies, textbooks, and the student handout from the classroom lesson. Two students related their design to personal experiences from family trips.

Students' responses on particular GS items addressing the effects of pumping wells on the water table and adjacent wells showed a gain in understanding; however, this pattern did not appear in student interview responses as strongly. In addition, the limitations of the model did not allow students to visually see the effect of a pumping well on the water table configuration. It is suggested that the classroom lesson had more of an impact on students' ideas concerning this groundwater concept.

The model also facilitated in producing student misconceptions about groundwater persistence and clean-up. Because students were able to pump pollution out of the well with very little difficulty and watch the pollution plume dissipate as the water circulated, students came to an incomplete conclusion about this aspect of groundwater pollution. Student responses on GS assessments, classroom observations, and interview responses all illuminated this misconception.

Finally, interview responses and classroom observations overwhelmingly showed students had a positive experience interacting with the models. Interview responses

concerning connections between model aspects and the real world showed a variety of

ideas with some illustrating problems of scale and process.

CONCLUSIONS

This study investigated the experiences of sixth grade earth science students with groundwater physical models through an extended 5E learning cycle format. Specifically, this descriptive and comparative study sought to gather data about the use of groundwater physical models and the role they play in helping sixth grade students develop mental models of groundwater processes that are consistent with those of hydrogeologists. The students in this study consisted of two earth science classes in the sixth grade in the middle school of a K-12 independent school. The quantitative measure was mixed with qualitative methods for the purpose of uncovering details and themes that can be undetectable in quantitative measures alone. The conclusions drawn from both the quantitative and qualitative findings are discussed in the context of the three research questions.

1. What role do groundwater physical models play in enhancing students' understanding of groundwater and groundwater processes?

2. How do students interact with groundwater models?

3. Which components of physical models help students develop mental models of groundwater processes that are consistent with those of hydrogeologists?

The role of groundwater models to enhance understanding of groundwater processes

Movement, Storage and Scale

Overall the results suggest that using physical models in groundwater instruction provided both visual and haptic experiences for students to understand, to varying degrees, groundwater processes. Students' ideas about groundwater environments went from those of typical surface water features as illustrated in their GS pre-assessment to ideas showing different geologic mediums of different porosities as illustrated in their formative and summative drawings. Although the drawings mimicked the student handout given during the inquiry based classroom lesson, it became clear through interviews that using the simple model of sediment tubes helped students to develop the idea that porosity was associated with the size of sediments which influenced the rate of water movement through sediments. Using sediment tubes in conjunction with the *Groundwater Exploration Activity Model* tanks in an extended 5E learning cycle lesson, functioned in the role of multiple external representations (MERs). Both models yielded information on porosity and permeability and to some degree groundwater flow with some redundancy of information, yet each model had its own unique contribution of information. Ainsworth (1999) maintains that using MERs in this manner, to support complementary information, helps the learner construct deeper understanding. The ability to visualize pore spaces and water movement through sediments offered students a direct experience with groundwater movement with respect to porosity and permeability. In that sense, the models helped to take a phenomenon that was completely out of

students' actual activity zone (Feigerber, Lavrik, & Shunyakov, 2002) and bring it directly into their surrounding reality.

Students correctly described movement of water through various sediment sizes, but as seen in the classroom observations and the interview responses, many struggled to define movement of groundwater on a larger scale. Specifically, students had difficulty applying information from the model to the real world. They typically relied on their own direct experience or transferred model dynamics to a real world setting. For example, student responses indicating that there would be fewer sediment layers underground and more 'dirt' in a real world groundwater system is a perfect illustration of students relying on their direct experiences. Not many students have had the opportunity to see geologic strata displayed in a large outcrop view, yet experiences with dirt is a common occurrence in childhood outdoor play. Furthermore, the idea that groundwater may go through the layers and stop at the bottom and remain there until it is pumped up is a visual from the model incorrectly transferred to the real world. The inability to construct a mental model of correct scale and process of a real world system can be attributed to a lack of spatial reasoning ability as Black (2005) describes. Even though the models offer a below ground side-view of a groundwater environment, it is still within the realm of a two-dimensional representation with scale limitations. Thus, it remains difficult for this type of model to cultivate the spatial ability needed to interpret a larger three-dimensional groundwater system.

Groundwater Wells

Groundwater well design in students' drawings became more modern in appearance across the GS assessments. Books and movies were described by most students as the source for images of old fashioned well design with stone facings and buckets as seen in their pre-assessment drawings. Students' ideas about groundwater wells became more sophisticated after the groundwater classroom lesson and their interaction with the *Groundwater Exploration Activity Model.* In formative and summative drawings, wells appeared narrower and below ground extending into a specific sediment type; mostly that of gravel. The wells in the *Groundwater Exploration Activity Models* helped to provide a direct experience for students that would otherwise not be available to them. The idea that wells at different depths extended into different sediment types can yield different quantities and quality of groundwater was conveyed in some of the student interviews. These ideas of groundwater mechanics are a sophisticated concept directly attributed to the model use.

The ability to pump wells in the *Groundwater Exploration Activity Model* to draw water offered students a hands-on experience to witness the effect pumping wells can have on the groundwater system. Students were able to visualize where the water was coming from and recognize water is being pulled into a pumping well from different directions. However, because the wells are pumped using a large syringe, this does not allow continuous pumping of a well to create any significant drawdown. The concept of a pumping well creating a cone of depression to the water table configuration cannot be illustrated with the model using just the syringe. In addition students, were better able to gain information about the effects of pumping wells on groundwater flow by watching

the movement of pollution, represented by red colored water, in and around wells being

pumped

Groundwater Pollution

The *Groundwater Exploration Activity Model* notably supported the development

of students' ideas about groundwater pollution with respect to plume movement, source

of pollution and its effects on adjacent wells. Adding red colored water to create

pollution to the groundwater system generated a strong visual contrast in which students

could easily identify. Being able to manipulate the contamination of wells and pumping

wells down-flow or up-flow of a contaminated well provided tangible experiences with

pollution in groundwater systems. From responses on the GS items related to these

concepts, classroom observation data, and student interviews, it was evident that the

majority of students could identify sources of pollution and make predictions on how

wells being pumped down flow from a pollution source can become contaminated.

On the other hand, results from the GS assessments, classroom observation, and

the interviews indicated that the pollution activities using the *Groundwater Exploration*

Activity Model, created a source of student misconceptions concerning persistence of

pollution in a groundwater system. The misconceptions became clear from analysis of

students' responses on the GS multiple choice questions #9 as students added two

incorrect responses to their answers in the summative assessment.

As students explored pollution aspects using the model, many came to the

conclusion that groundwater pollution could simply be cleaned up by pumping out

pollution from wells and disposing of it. Although this method is practical solution to

many groundwater pollution problems in the real world, the temporal scale to which

students concluded from the model created an inaccurate idea of groundwater cleanup. In addition, the dilution of the red colored pollution in the tanks after a period of time reinforced the concept that pollution cleanup is an easy task or that pollution simply dissipates into the system in a short span of time. Dyche, McClurg, Stepans, & Veath(1993) argue that students often lack awareness of the boundary between physical models and the reality the model is representing. These authors recommend that students be encouraged to address the shared and unshared attributes between physical models and real world aspects the models are intended to represent.

These findings suggest that guidance during discovery learning is an essential component needed when using physical models in groundwater instruction. Kirschner, Sweller, & Clark (2006) argue that minimal guidance or absence of guidance during discovery learning can lead to misconceptions. These authors highlight evidence from numerous controlled experimental studies that suggest when students learn science in classrooms through pure-discovery means with minimal guidance and feedback; they often become confused and develop misconceptions. Further, those students with pure-discovery learning had difficulty transferring their learning to new contexts. The goal of using physical models in groundwater instruction would be to allow students to develop correct mental models about groundwater and transfer those ideas to a real world context. The implications of model misconceptions with respect to pedagogy are discussed further in the best practices section in Chapter V.

How students interact with groundwater physical models

In the groundwater inquiry-based classroom lesson, sediment tubes were a simple and inexpensive way to give students a direct hands-on experience with porosity and

permeability of different sediment sizes. Using these physical models to experience the rate of water movement through different porosities posed no problems for students to set up and execute the activity during the groundwater classroom lesson. Very little teacher guidance was needed for this type of model activity and students remained engaged by sharing their data with other groups and returned to the classroom later in the day to record the timing of water through the clay tube. The sediment tubes provided a basic understanding of porosity with respect to different sediment grain sizes and as a result, students were able to easily identify layers and pockets of different sediment types as they began their interaction with the *Groundwater Exploration Activity Model*. This larger and more complex physical model offered opportunities for students to creatively explore and investigate additional aspects of groundwater processes but also required more teacher assistance during the interaction. The results of the classroom observations showed that students were most intrigued with pumping and polluting the wells in the model. They became efficient with pumping wells through trial and error as they discovered the right amount of force and the angle needed to effectively pump water out of the wells. Students became creative with using the syringe to pump air through the wells to force water or pollution down through the well. Many quickly discovered they could recover pollution form one well and transfer it to another well. The model offered an opportunity for students to develop and test predictions as well. Classroom observation data showed several student groups claiming 'what if we tried this' as they explored other aspects of the model. Thus, this model allowed for ample exploration but as discussed in the best practices section in Chapter V, reflection and expression as a

formative assessment of student ideas should be an integral component of the learning process.

Findings from the interviews indicated students had very few dislikes or frustrations with using the *Groundwater Exploration Activity Model*. Many students expressed their disappointment in not being able to pump water out of the lake or pond in the model and several expressed the desire to have more time to work with the models. When students were asked how they would go about building their own groundwater model, only the students that were classified as rich cases (2 out of 8 cases) communicated sophisticated ideas about and methods of construction. Most of the students simply conveyed the idea of using sediment layers but nothing more about the workings of the model. A clear understanding of the mechanics of the model (e.g. electrical pump and outlets for water flow) could help facilitate better understanding of groundwater movement in the model and perhaps help avoid the misconceptions formed about pollution in the model. This in turn could help reduce any confusion gained from the model and transferred to real world groundwater systems.

Model components that help students develop mental models of groundwater consistent with those of hydrogeologists

Hydrogeologists, experts in groundwater systems, operate within the realm of the higher level system thinking about groundwater processes. Though extensive practice and training, hydrogeologists think in terms of surface water and groundwater interconnectedness with the ability to predict the consequences of human impacts on the system allowing them to make important environmental and economic decisions about groundwater resources. According to their System Thinking Hierarchical (STH) model

for earth systems (Table 1), Ben-Zvi-Assaraf & Orion (2005; 2010) identified the characteristics of higher level system thinking or the implementation stage to include the ability to make generalizations, to understand the hidden dimensions, and to think temporally (retrospection and prediction). The goal of the third research question was to identify those components of groundwater physical models that help students achieve higher levels of system thinking about groundwater and groundwater processes.

The majority of students achieved the ability to identify several components and processes of groundwater systems from working with the models; mainly that of porosity and permeability with respect to water flow. The identification of system components as defined by Ben-Zvi-Assaraf & Orion is the lowest level in the STH model. Although the sediment tubes gave students a direct experience with porosity and permeability, students rarely used the correct vocabulary; even though the correct vocabulary was introduced and used in the groundwater classroom lesson. The term porosity was often referred to as the bigger holes, spaces, or pores and the interconnection between pores with respect to water movement through the sediment was not mentioned by any of the students.

The findings suggest that not all students reached the ability to identify relationships among and within the components of groundwater systems or the ability to understand the cyclic nature of the system. These characteristics are defined as the synthesis of system components stage or the mid-level of STH model by Ben-Zvi-Assaraf & Orion. Only students in rich and medium cases in the interviews could express the idea of the connection between the lake and the groundwater system for example. In both the interviews and the classroom observation findings, it was clear many students had difficulty understanding the connection between the water table, lake, pond, and well

levels as being equivalent when the *Groundwater Exploration Activity Model* was not running. After plugging the model in to start the electrical pump, each student notes a change in water level, but still had difficulty identifying that level as the water table without guidance from the teacher.

The findings showed that the ability to pollute the groundwater system and observe the plume movement and its effects on wells down flow of the plume were the components of the model that best helped students achieve higher level system thinking about groundwater processes. Almost all students were able to make generalizations and predictions about the movement of pollution after interacting with the *Groundwater Exploration Activity Model*. These characteristics in the implementation stage of the STH model allow students to develop mental models of groundwater that are more consistent with those of hydrogeologists.

Overall, when students interviewed were asked how the *Groundwater Exploration Activity Model* helped them learn about groundwater, each articulated the idea that they were able to see how groundwater existed below the ground. The ability to understand the hidden dimensions of a system is a characteristic of the implementation stage at the highest level of the STH model as well. Better understanding of groundwater, that hidden portion of the water cycle that is out of most students' actual activity zone, allows students to move from declarative knowledge to more procedural knowledge of the water cycle and make those important connections between water on in the atmosphere, on the surface, and in the ground. The use of physical models in an extended 5E learning cycle lesson on groundwater played a important role in helping to achieve this. However, a pure discovery learning format while using models can lead to students developing

misconceptions. Best practices for using physical models in groundwater instruction are

discussed in Chapter V.

CHAPTER V

IMPLICATIONS AND BEST PRACTICIES

Introduction

The findings suggest that physical models played a significant role in helping students identify the components of porosity and permeability with respect to water flow in groundwater systems. Higher levels of system thinking were best demonstrated in the model components that allowed students to experience groundwater pollution activities and pumping groundwater wells. However, the results also indicated that not all students developed the understanding of the connection between surface water and groundwater. In addition, the potential exists for students to develop misconceptions about groundwater systems through the use of physical models, specifically more complex physical models as in the *Groundwater Exploration Activity Model*. A pure discovery learning format while using physical models without guidance or formative assessment probes can lead to misconceptions about groundwater processes as well as confusion between model attributes and real world groundwater systems.

This chapter discusses the implications of this study in the light of the new national science standards and best practices for using groundwater physical models to help promote higher order system thinking with groundwater and the water cycle. Emphasis on the importance of reflection/expression in a 5E learning cycle format used in groundwater instruction is also included. This chapter will close with a discussion of limitations of the present study and future research possibilities.

Implications

The implications of this study have a direct relationship to the change in national science standards to include the concept of groundwater. The 1996 National Science Education Standards had no mention of the term groundwater in the document. In the 2011 release of the new national science standards, *A Framework for K-12 Science Standards; Practices, Crosscutting Concepts, and Core Ideas* (NRC, 2011), groundwater is mentioned three times - as a component of the hydrosphere, as a component of the water cycle, and once in the context of a natural resource subject to human degradation. The new national standards, as in other educational reform efforts, will have the ability to affect curricular and instructional strategies in science education. Most state science standards are modeled after the national standards and given the increase in groundwater content in the new framework, it is likely that individual states will follow the lead and include more groundwater topics in their standards content.

The groundwater content as outlined in the new standards require students to understand groundwater not only as a component of a much larger system of the water cycle and the hydrosphere, but also how humans can impact the system. The need for system thinking about groundwater is critical for students to make the connections between surface water, groundwater, and anthropogenic influences. Groundwater physical models can play a key role in helping students make these connections when coupled with effective pedagogical approaches.

Best Practices

Use of multiple models and representations

The use of multiple representations of content material is beneficial to students in the learning process. Using more than one physical model to help promote understanding of groundwater processes allowed students to reach a deeper understanding of groundwater flow and storage; concepts that are otherwise hidden from students' direct experiences. Simple sediment tubes used in conjunction with the more complex *Groundwater Exploration Activity Model* helped to scaffold ideas about water movement through a micro-view of pore spaces to a more complex view of water movement in larger groundwater systems. Both visual and haptic representations integrated into a 5E learning cycle format that allows ample opportunities for expression of ideas is an effective pedagogical approach in groundwater instruction.

Need for expression and formative probes

The 5E learning cycle model is a reformed based practice used in science instruction that has been viewed as an effective instructional model for several decades (Goldston, Day, Sundberg, & Dantzlier, 2009). The 5E model uses five components – Engage, Explore, Explain, Elaborate, and Evaluate to promote inquiry based science instruction. The original strategy first sponsored by the Biological Sciences Curriculum Study (BSCS) has been constantly refined as new research emerges to support its effectiveness (Ceylan & Geban, 2009).

In this study, the 5E learning cycle model was modified with an extended Elaboration portion to include multiple physical models to facilitate better understanding of groundwater processes. Although the overall findings indicate that physical models

played a significant role in helping students understand groundwater processes, the results also indicated that students can develop misconceptions about real world systems the models are intended to represent. Groundwater instruction, like most inquiry based science instruction, should be integrated with appropriate guidance that includes opportunities for students to reflect and express their ideas. Through this formative assessment, teachers can gage student learning and adjust instruction appropriately.

Duran, Duran, Haney, & Scheuermann (2011) describe the importance of adding an Express phase to the 5E learning cycle model. Using formative assessment probes (Keeley & Eberle, 2008) to initiate the Express phase can force students to confront their own thinking and misconceptions along the course of learning. For example, adding a question that asks students why the red dye disappears in the groundwater tank while it is operating is necessary to help eliminate the misconception that pollution persistence in groundwater can be relatively short. A discussion of model temporal and spatial attributes with respect to real world scenarios needs to be an integral part of the instructional process. An Express phase (or multiple Express phases) can identify individual student understanding so that an appropriate Elaboration phase activity can be designed to match their understanding.

Group structure and cooperative learning

Classroom observations showed that student groups of two using the *Groundwater Exploration Activity Model* worked more effectively with students remaining more on task and less distracted than student groups of three. Further, tables consisting of two groups of two were able to interact together and essentially have access to two models in which to compare. In essence, this structure creates a setting of

cooperative learning and coupled with formative questioning and probes aligns with the pedagogical approach shown by Taylor et, al., 2003 and Reinfried, 2006 to help move students into constructing a more accurate understanding of large scale or hidden phenomena in science. Teachers and students should jointly critique physical models and what and how it represents real world phenomena. Taylor, et. al. suggest that teachers should probe and interpret students' views about what models are and compare these views with the way that scientists use models. Guidance and feedback should be considered a critical element in groundwater instruction while using physical models. It not only keeps students on task, but it can help students make the connections between physical models and the real world.

Limitations

This study was limited in scope due to its small sample size and thus statistical power becomes an issue in the quantitative data analysis. Using a mix-methods approach helped to capture a more complete picture of the role played in using physical models in groundwater instruction. Threats to internal validity also existed within the nature of repeated measures design with pre-, formative, and summative assessments potentially introducing a desensitizing effect on the GS scores. In addition, the fact that the GS did not count in students' course grade could have introduced student motivational issues. The triangulation of data sources helped to minimize these threats to internal validity. Using the qualitative measure of follow-up interviews on the purposeful sample of eight students allowed for richer data to emerge. Schwartz & Lederman (2008) describe this type of approach as essential to uncovering information not reflected through questionnaires or surveys. Without the classroom observations and follow up interviews,

any misconceptions and details on the level of sophistication of student ideas, would not have materialized.

The setting within an individual independent school can yield threats to external validity. Due to this threat, results from this study cannot be generalized to larger populations and other settings. The natural setting of a classroom alone can introduce more back-ground noise yielding a threat to ecological validity. As with any research design, there exists problems with attrition, as students may be absent on scheduled days of lessons and/or model activities. All students were able to complete the model activities and the GS assessments, but four students were absent during the classroom observation data collection and thus, were not counted in that data collection. In addition, researcher bias can be an issue as well. To minimize these threats, additional people, as mentioned in Chapters III and IV, were used in coding qualitative data to help establish reliability and reduce researcher bias.

Although these limitations exist, this study was able to yield valuable information to other practitioners as is the researcher. Uncovering information about how students develop their ideas about groundwater through use of physical models, including misconceptions that may arise, can help teachers tailor groundwater instruction to achieve higher levels of system thinking. Further, the cost of the more complex physical models are high and gaining information about their usefulness in helping students understand such phenomena is important in making curricular decisions.

Direction for Further Research

The use of physical groundwater models in the classroom setting would benefit

from additional research. The results of this study helped to highlight the role that

physical groundwater models can play in promoting student understanding of

groundwater processes and generated ideas of best practices for instruction. Along a

focus in STEM, future research might evaluate the impact of having students construct

their own groundwater model or modify an existing model (e.g. developing a continuous

pumping device to observe a cone of depression) might have on their understanding of

groundwater processes.

Potential exists for the expansion of this study. Future research could explore the

degree to which multiple Express phases in a 5E learning cycle can help eliminate

misconceptions generated by physical models. At a basic level, future research would

include larger sample sizes that incorporated more observations and interviews than the

current study. In addition, testing students in other age ranges, other school settings, and

geographic locations would add strength to the study by exploring student experiences

and how those experiences relate to their mental models of groundwater. It is worth

noting that the two rich cases in the student interviews were from students who had

strong family experiences with the outdoors. How this variable plays into students'

mental models about groundwater processes and system thinking is worth further

investigation.

Groundwater, like so many other geosciences phenomena, is a difficult concept to

teach and a difficult concept for students to understand. Students can memorize

groundwater diagrams and vocabulary and on the surface appear to understand but still

not formulate the correct mental model. In the classroom years ago, a student raised his hand and asked if he were to dig down to the saturated zone, could he swim through the blue water shown in the picture displayed on the screen. This type of question is the 'ah-ha' moment for teachers who realize words and pictures are not enough to understand something that cannot be seen.

REFEREENCES

American Association for the Advancement of Science (1994) Benchmarks for Science Literacyhttp://www.project2061.org/publications/bsl/default.htm

Ainsworth, S. (1999). The functions of multiple representations. *Computers & Education*, 33, 131-152.

Ben-zvi-Assarf, O. & Orion, N. (2010). Four case studies, six years later: developing system thinking skill in junior high school and sustaining them over time. *Journal of Research in Science Teaching, 47*(10), 1253-1280

Ben-zvi-Assarf, O., & Orion, N. (2005) A study of junior high students' perceptions of the water cycle. *Journal of Geoscience Education, 53*(4), 366-373.

Ben-zvi-Assarf, O., & Orion, N. (2005a) Development of system thinking skills in the context of earth system education. *Journal of Research in Science Teaching, 42*(5), 518-560.

Black, A. (2005). Spatial ability and Earth science conceptual understanding. *Journal of Geoscience Education, 53*(4), 402-414.

Brunsell, E. & Marcks, J. (2007). Teaching for conceptual change in space science. *Science Scope,* Summer, 20-23.

Calik, M., Ayas, A., & Coll, R., (2009). Investigating the effectiveness of an analogy activity in improving students' conceptual change for solution chemistry concepts. *International Journal of Science and Mathematics Education, 7.* 651-676.

Coll, R., France, B. & Taylor, I. (2005). The role of models and analogies in science education: implications from research. *International Journal of Science Education, 27*(2), 183-198.

Cotton, D. Stokes, A. & Cotton, P. (2010). Using ovsrvation methods to research the student experience. *Journal of Geography in Higher Education, 34*(3), 463-473.

Covitt, B., Gunckel, K, & Anderson, C. (2009). Students' developing understanding of water in environmental systems. *The Journal of Environmental Education, 40*(3). 37-51.

Ceylan, E. & Geban, O., (2009). Facilitating conceptual change in understanding state of matter and solubility concepts by using 5E learning cycle model. *H.U. Journal of Education, 36,* 41-50.

Chiu, M., & Lin, J., (2005). Promoting fourth graders' conceptual change of their understanding of electric currents via multiple analogies. *Journal of Research in Science Teaching, 42*(4), 429-464.

Creswekk, J.W. (2007). Qualitative Inquiry and Research Design: Choosing among five approaches. Thousand Oaks, California: Sage Publications.

Dickerson, D., J. Penick, K. Dawkins, & M. Van Sickle. (2007). Groundwater in science education. *Journal of Science Teacher Education.* 18, 45-61.

Dickerson, D. & Callahan, T. (2006). Groundwater is not an educational priority. *Ground Water, 44*(3): 323.

Dickerson, D., J. Penick, K. Dawkins. (2006). Eighth grade students' understanding of groundwater. *Journal of Geoscience Education. 52*(2), 178-181.

Dickerson, D., T. Callahan, M. Van Sickle, & G. Hay. (2005). Students' conceptions of scale regarding groundwater. *Journal of Geoscience Education, 53*(4): 374-380.

Dickerson, D. & Dawkins, K. (2004). Eighth grade students' understandings of groundwater. *Journal of Geoscience Education, 52*(2), 178-181.

Duffy, D., Dickerson, D., Whittecar, G., & Adcock, A. (2011) (unpublished manuscript). Groundwater in state science standards documents.

Duran, E., Duran, L., Haney, J. & Scheuermann, A. (2011, March). A learning cycle for all students; modifying the 5E instructional model to address the needs of all learners. *The Science Teacher.* 56-60.

Syche S., McClurg, P., Stephans, J. & Veath, M. (1993). Questions and conjectures concerning models, misconceptions, and spatial ability. *School Science and Mathematics, 93*(4), 191-197.

Feigenberg, J., Lavrik, L. & Shunyakov, V. (2002). Space scale: models in the history of science and students' mental models. Science & Education, *11,* 377-392.

Fortner, R. & Reyer, R. (2000). Discrepancies among teachers' priorities for and knowledge of freshwater topics. *The Journal of Environmental Education, 31*(4), 51-55.

Gates, A., Langford, R., Hodgson, R., & Driscoll, J. (1996). Groundwater simulation apparaturs for introductory and advance courses in environmental geology. *Journal of Geoscience Education. 44*(5), 559-564.

Goldston, J., Day, J., & Sundberg, C. (2010) Psychometric analysis of a 5E learning cycle lesson plan assessment instrument. *International Journal of Science and Mathematics Education, 8*(4) p633-648.

Gooding, J & Metz, B. (2011, Arpil/May). From misconceptions to conceptual change. *The Science Teacher.*pp. 34-37.

Groves, F., & Pugh, A. (2002, November). *Environmental science misconceptions: Resolution of an anomaly.* Paper presented at the annual meeting of the Mid-South Educational Research Association, Chattanooga, TN.

Hyonyong. L. (2003). *Teaching and learning about the Earth.* ERIC clearinghouse for Science Mathematics and Environmental Education, Columbus, OH. (ERIC Document Reproduction Service No. ED482726)

Jameson, R. (2001, April). *Combating misconceptions about groundwater using a wet tube model of the water table and capillary fringe.* Poster session presented at the annual meeting of the Southeast Section of the Geological Society of America.

Kamini, S. & Loheide, S. (2011). Linking physical and numerical modeling in hydrogeology using sand take experiments and COMSOL multiphysics. *International Journal of Science Education, 33*(4), 547-571.

Keely, P. & Eberle, F. (2008). Using standards and cognitive research to inform the design and use of formative assessment probes. In National Science Teachers Association, *Assessing Science Learning* (pp. 203-226).

Khalid, T. (2003). Pre-service high school teachers' perceptions of three environmental phenomena. Environmental Education Research, *9*(1), 35-50.

Kirschner, P., Sweller, J. & Clark, R. (2006). Why minimal guidance during instruction does not work: an analysis of the failure of constructivist, discover, problem-based, experiential, and inquiry-based teaching. *Educational Psychologist, 41*(2). 75-86.

Leager, C. (2007) Making models: more than child's play. *Science and Children, 44*(6), 50-52.

Lehr, J. (1963). Groundwater flow models simulating subsurface conditions. *Journal of Geological Education 11,* 124-132.

Matthews, M. (2007). Models in science and in science education: an introduction. *Science & Education, 16,* 647-652.

Merritts, D. & Shane, E. (1992). Effective use of hands-on activites, state-of-the-art technologies and computers in introductory environmental geology. *Journal of Geological Education,* 40, 273-278.

Meyer, W. (1987). Venacular American theories of earth science. *Journal of Geological Education, 35,* 193-196.

Miles, M. & Huberman, A. (1994). Qualitative Data Analysis: An expanded source book. Thousand Oaks, California: Sage Publications.

Milner, A., Templin, M., & Czerniak, C. (2011). Elementary science students; motivation and learning strategy use: constructivist classroom contextual factors in a life science laboratory and a traditional classroom. *Journal of Science Teacher Education, 22*(2). 151-170.

National Research Council. (2011). *A Framework for Science Education; Concepts and Connections.* National Academy of Sciences. 190 pp.

National Research Council. (1997). *Science Teaching Reconsidered.* National Academy of Sciences. 88 pp.

Parkinson, R. & Reid, I. (1987). A physical model for shallow groundwater studies and the simulation of land drain performance. *Journal of Geography in Higher Education, 11*(2), 125-132.

Reinfried, S. (2006). Conceptual change in physical geography and environmental

  sciences through mental model building: the example of groundwater.

  International Research in Geographical and Environmental Education, 15(1), 41-

  61.

Rice, J., & Neureither, B. (2006). An integrated physical, Earth, and life science course

  for pre-service K-8 teachers. *Journal of Geoscience Education, 54*(3): 255-261.

Rutherford, J., Ahlgren, A. (1994). Science for all Americans [Electronic version].

  American Association for the Advancement in Science, www.project2061.org.

She, H., & Liao, Y. (2010). Bridging scientific reasoning and conceptual change through

  adaptive web-based learning. *Journal of Research in Science Teaching, 47*(1),

  91-119.

Shepardson, D., B. Wee, M. Priddy, L. Schellenberger, & J. Harbor. (2007) What is a

  watershed? Implications of student conceptions for environmental science

  education and the National Science Education Standards. *Science Education.* DOI

  10.1002/sce.20206 Retrieved September 25, 2007 from Wiley InterScience

  database (www.interscience.wiley.com).

Shepardson, D., B. Wee, M. Priddy, L. Schellenberger, & J. Harbor. (2009) Water

  transformation and storage in the mountains and at the coast: Midwest students'

  disconnected conceptions of the hydrologic cycle. *International Journal of

  Science Education, 31*(11) 1447-1471.

Strike, K. & Posner, G. (1992). A revolutionist theory on conceptual change. *Science

  Education, 66*(2), 211-227.

Suvedi, M. Drueger, D. Shrestaha, A, & Bettinghouse, D. (2000). Michigan citizen'

  knowledge and perceptions about groundwater. *The Journal of Environmental

  Education, 31*(2),16-21.

Schwartz, R. & Lederman, N. (2008). What scientist say: scientists' view of natur of

  science and relation to science context. *International Journal of Science

  Education,* 30(6), 727-771.

Talib, O., Matthews, R. & Secombe, M. (2005). Computer-animated instruction and

  students' conceptual change in electrochemistry: preliminary qualitative analysis.

  International Education Journal, 5(5), 29-42.

Taylor, I, Barker, M. & Jones, A. (2003). Promoting mental model building in astronomy education. *International Journal of Science Education, 25*(10), 1205-1225.

Tsai, M., Hou, H., Lai, M., Liu, W., & Yang, F. (2012). Visual attention for solving multiple choice science problems: an eye tracking analysis. *Computer and Education, 58* (2), 375-385.

Tsaparlis, G., & Papaphotis, G. (2009). High-school students' conceptual difficulties and attempts at conceptual change: the case of basic quantum chemical concepts. *International Journal of Science Education, 7*(1), 895-930.

United States Geological Survey. Groundwater basics. http://water.usgs.gov/ogw/

United States Geological Survey. Using oxygen to clean up groundwater contamination. Toxic Substances Hydrology Program. http://toxics.usgs.gov/highlights/orc_test.html Feb. 2012.

Wesson, K. (2011). Minds, models, and maps. *Science and Children*, Summer, 14-15.

Windschitl, J.T. & Braaten, M. (2008). How novice science teachers appropriate epistemic discourses around model-based inquiry for use in classrooms. *Cognition and Instruction, 26*, 310-378.

Zhou, G. (2010). Conceptual change in science: a process of argumentation. *Eurasia Journal of Mathematics, Science & Technology Education, 6*(2) 101-110.

APPENDIX A

LETTER TO PARENTS

PARENTS ASSENT/CONSENT FORM

Dear Parents of 6th grade Earth Science students,

Since winter break, we have started our geology unit and are currently studying groundwater processes. Like many scientific concepts, groundwater is a hidden phenomenon that students struggle with to develop correct mental images of its processes.

During the groundwater unit of study, students will have the opportunity to interact with large Plexiglas sand tank physical models that are very similar to those used in university level hydrology courses. As mentioned in an earlier e-mail last semester, I am interested in how these particular models may facilitate conceptual change in sixth grade students' mental images of groundwater as part of my doctorial research.

There are no grades attached to the model activities or the information I gather; however I feel certain this information will help us plan better hands-on activities in our science classrooms in the future. Students will not be identified by name in any way in my dissertation or any future publications. Information that I gather will be in the form of surveys, classroom observations, and one-on-one follow up interviews. This data collection will take place in students' science class and will not impact the instruction or the curriculum.

All students in the 6th grade will have the opportunity to interact with these models in a fun and collaborative manner. You will probably be hearing a lot about them from your child. This will give you a good opportunity to have a conversation about water resources and the need to protect these natural resources.

Attached you will find the *Parents Assent/Consent* form that the university requires me to distribute to each parent. Please read over this letter and have your child return it to school with your signature or you may return a signed copy via email to me.

If you have any questions or concerns, please do not hesitate to contact me.

Sincerely,
Debra Duffy
Earth Science Teacher
debraduffy@capehenry.org
757-481-9478 ex 107

PARENTS INFORMED ASSENT/CONSENT DOCUMENT FOR CHILD'S PARTICIPATION
OLD DOMINION UNIVERSITY
<u>PROJECT TITLE:</u> THE NATURE AND ROLE OF PHYSICAL MODELS IN ENHANCING SIXTH GRADE STUDENTS' MENTAL MODELS OF GROUNDWATER AND GROUNDWATER PROCESSES

INTRODUCTION

The purposes of this form is to give you information that may affect your child's decision whether to say YES or NO to participation in this research study at your child's school entitled, THE NATURE AND ROLE OF PHYSICAL MODELS IN ENHANCING SIXTH GRADE STUDENTS' MENTAL MODELS OF GROUNDWATER AND GROUNDWATER PROCESSES, and to record the consent of those who say YES.

RESEARCHERS

Daniel Dickerson, PhD Responsible Project Investigator Associate Professor Darden College of Education Department of STEM Education and Professional Studies Old Dominion University	Debra Duffy Research Assistant Darden College of Education Department of Teaching and Learning Old Dominion University

DESCRIPTION OF RESEARCH STUDY

The purpose of this study is to gain an understanding how physical groundwater models help to facilitate students' ideas about groundwater processes.

If your child decides to participate and you agree, then he/she will join a study involving research about groundwater. As part of the study students will participate in a lesson about groundwater, take a pre and post test regarding what they learned, and possibly respond to interview questions about the lesson. Students will take a pre- and post-survey to help the researchers better understand their ideas about groundwater. Video cameras will be used during the classroom interactions with the groundwater models and digital recorders will be used in the interviews. The information will be transcribed and the transcriptions will be analyzed. After the data have been analyzed, the tapes and recordings will be destroyed. We will not disseminate any information, oral or written, that identifies your child or your child's participation with this study. If you agree YES, then your child's participation will last for one interview that will last for approximately 20-30 minutes (all other activities are part of normal classroom instruction). We are simply trying to find out how to better teach students about groundwater. There is potential for approximately 30 students to participate in this study.

RISKS AND BENEFITS

There are minimal risks associated with this study beyond what are normally experienced in typical classroom settings. No information that identifies your child or your child's participation with this study will be used without you and your child's permission. Your child's participation in this study is in NO way linked to his or her grade.
BENEFITS: There are no direct benefits for participation. Indirect benefits include helping to better teach students about groundwater, which may help enhance the quality of education all children receive.

NEW INFORMATION

If the researchers find new information during this study that would reasonably change your or your child's decision about participating, then they will give it to you and your child.

CONFIDENTIALITY

The researchers will take reasonable steps to keep all information confidential. Only the researchers will see the data and will keep all data in a locked filing cabinet prior to its processing. The results of this study may be used in reports, presentations, and publications; but the researcher will not identify your child. Of course, your child's records may be subpoenaed by court order or inspected by government bodies with oversight authority.

WITHDRAWAL PRIVILEGE
It is OK for you and your child to say NO. Even if you and your child say YES now, you and your child are free to say NO later, and walk away or withdraw from the study -- at any time. You and your child's decisions will not affect your child's relationship with Old Dominion University, or otherwise cause a loss of benefits to which your child might otherwise be entitled.

COMPENSATION FOR ILLNESS AND INJURY
If you say YES, then your participation does not waive any of your child's legal rights. However, in the event of injury arising from this study, neither Old Dominion University nor the researchers are able to give you or your child any money, insurance coverage, free medical care, or any other compensation for such injury. In the event that your child suffer injury as a result of participation in any research project, you may contact Daniel Dickerson, Responsible Project Investigator, at 757-683-4676 or Dr. George Maihafer, the current IRB chair, at 757-683-4520 at Old Dominion University, or the Office of Research at Old Dominion University at 757-683-3460.

VOLUNTARY CONSENT
By signing this form, you are saying several things. You are saying that you have read this form and that you are satisfied and understand this form, the research study, and its risks and benefits. The researchers should have answered any questions you may have about the research. If you have any questions later on, then the researchers should be able to answer them: Daniel Dickerson, Responsible Project Investigator, at 757-683-4676   If at any time your child feels pressured to participate or if you have any questions about your child's rights or this form, then you should call Dr. George Maihafer, the current IRB chair, at 757-683-4520, or the Old Dominion University Office of Research, at 757-683-3460.

And importantly, by signing below, you are telling the researcher YES, that your permission for your child to participate in this study. A copy of this form is included for your records.

	Date
Parent / Legally Authorized Representative's Printed Name & Signature	

INVESTIGATOR'S STATEMENT
I certify that I have explained to this subject the nature and purpose of this research, including benefits, risks, costs, and any experimental procedures. I have described the rights and protections afforded to human subjects and have done nothing to pressure, coerce, or falsely entice this subject into participating. I am aware of my obligations under state and federal laws, and promise compliance. I have answered the subject's questions and have encouraged him/her to ask additional questions at any time during the course of this study.

Investigator's Printed Name & Signature	**Date**

APPENDIX B

GROUNDWATER SURVEY AND SCORING RUBRIC

Groundwater Survey

The purpose of this survey is for me as your teacher to understand what you know about groundwater. This survey will only be used to help me plan activities for the next school year. The survey will be scored but DOES NOT count as part of your grade. You will be able to see your scores at a later date. You have 40 minutes to answer the survey questions. Please answer all questions to the best of your knowledge.

Circle your responses.

1. If a person drilled a well into the ground to get groundwater, from where would the water immediately come? (Choose all that apply)

    a. river
    b. sand layer
    c. underground lake
    d. water tower
    e. soil
    f. spigot or faucet
    g. solid/cracked rock
    h. underground stream
    i. lake

2. How could a groundwater well become polluted? (Choose all that apply)

    a. underground leaking fuel (gasoline) tanks
    b. landfill (garbage dump)
    c. you or your neighbor spilling chemicals (like bleach) on the ground
    d. trash blowing into the well
    e. a truck carrying gasoline overturns and spills its content on the ground
    f. animal waste from farms
    g. fertilizer or pesticides on agricultural (crops) fields
    h. a factory that releases pollution into a river

3. Where might water come from that is in a lake or pond? (Choose all that apply)

   a. rain water
   b. a hose or sprinkler
   c. groundwater
   d. a well
   e. snow/ice melting

4. Water in the ground will: (Choose all that apply)

   a. move through pore spaces in sediment
   b. remain still in the pore space or cracks in rock
   c. move slower than surface stream water
   d. move faster than surface water
   e. move into a nearby stream or lake
   f. move into a nearby well

5. When water is pumped from a well, what can happen? (Choose all that apply)

   a. Pumping will pull water up directly below the well.
   b. Pumping will pull water towards the well from all directions.
   c. Pumping causes the water table to be lowered near the well.
   d. Pumping could cause polluted water to move into the well.
   e. Pumping the well can cause nearby wells to lose their water to the well being pumped.
   f. Water will always be available from the pumping well.

6. Which of the following can be a source of groundwater? (Choose all that apply)

   a. rainwater
   b. snow/ice melting
   c. spigot or faucet
   d. wells
   e. surface streams
   f. surface lakes or ponds
   g. the ocean

7. How deep might a person drill a well to reach a source of groundwater? (Choose all that apply)

   a. 2 feet
   b. 25 feet
   c. 50 feet
   d. 200 feet
   e. 2000 feet
   f. 20,000 feet
   g. 200,000 feet

8. Mr. Jones' well is up hill of Mr. Smith's well. Mr. Jones had a spill of gasoline into his well. What could happen to Mr. Jones' and Mr. Smith's wells and to the groundwater system? (Choose all that apply)

   a. Both wells could become polluted
   b. Only Mr. Jones' well will be polluted
   c. Wells located uphill of Mr. Jones' well can be polluted
   d. Nothing will be polluted because gasoline floats on water
   e. Wells downhill of Mr. Jones' well can be polluted
   f. Lakes or streams downhill of Mr. Jones' well can be polluted

9. If groundwater becomes polluted what can happen to other wells and lakes or ponds in the area? (Choose all that apply)

   a. Water in other wells could become polluted.
   b. A nearby lake or pond could become polluted.
   c. The pollution in the groundwater could travel great distances to other wells and lakes or ponds.
   d. The pollution could stay in the groundwater for a long time.
   e. The pollution will mix with the groundwater and not be harmful anymore.
   f. The pollution will be gone in a day or two so as long as people don't use the water for that time, everyone will be safe.

10. In the space provided below, draw a detailed picture of how groundwater occurs and moves. Be sure to label your features and write any explanation you feel is necessary for me to understand your ideas about groundwater.
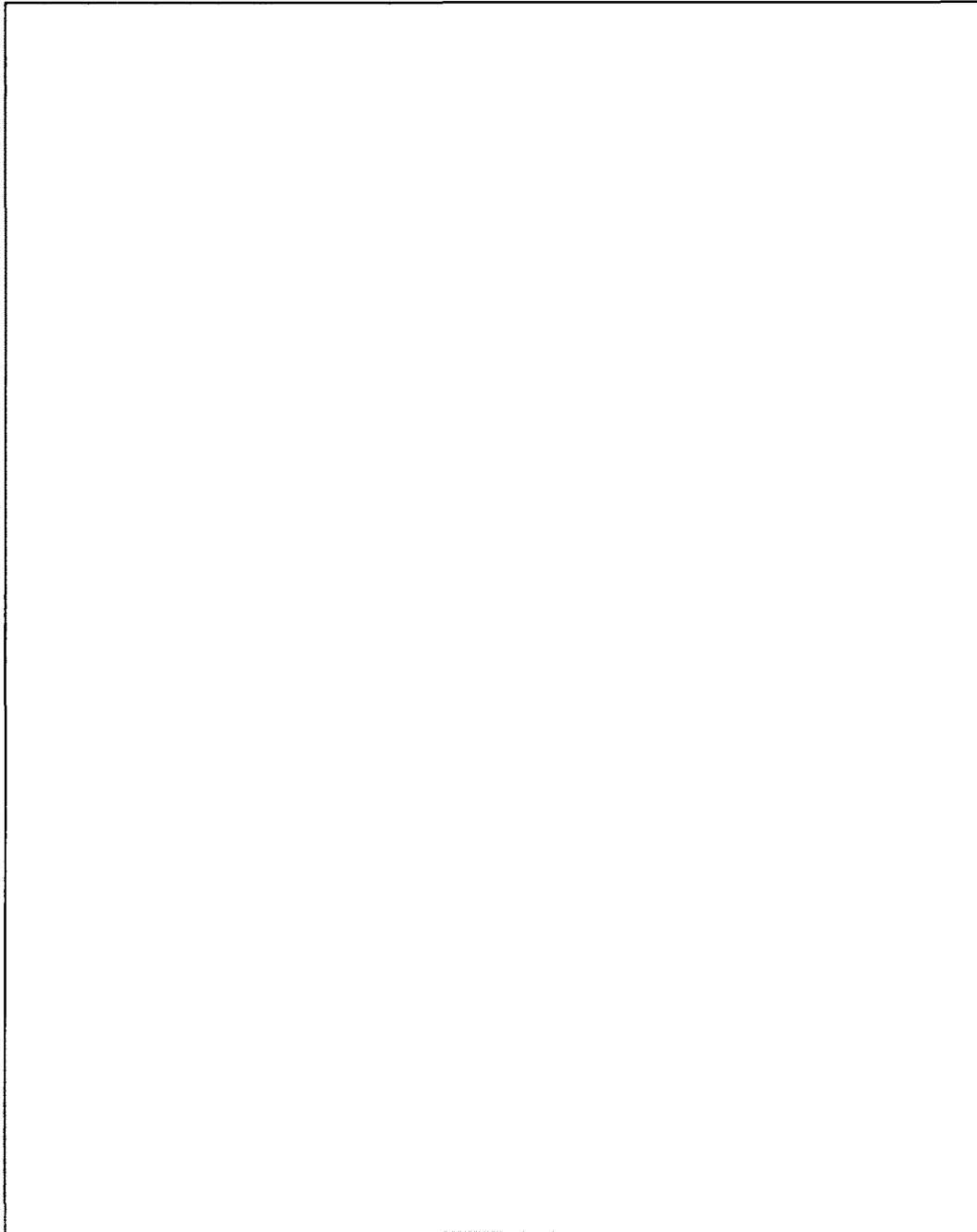
Scoring Rubric for Items in Groundwater Survey

Item	1. If a person drilled a well into the ground to get groundwater, from where would the water come? (Choose all that apply). a. river b. sand layer c. underground lake d. water tower e. soil f. spigot or faucet g. solid/cracked rock h. underground stream i. lake	
Score	**Definition of Level**	**Classification of Level**
2	Understands groundwater occurrence and how it functions	Answer includes one or more of the following: B, G, or E
1	Understands groundwater occurs beneath the surface of earth, but does not understand how groundwater functions	Answer may or may not include any of the following: B, G, E AND Must include one or both of the following: C, H
0	Does not understand that groundwater resides beneath the surface of the earth or in what medium	Answers include F, A, I or D with or without any other combination.

Item	2. How could a groundwater well become polluted? (Choose all that apply)
	
	    a. underground leaking fuel (gasoline) tanks
	    b. landfill (garbage dump)
	    c. people dumping chemicals on the ground
	    d. trash blowing into the well
	    e. a truck carrying gasoline overturns and spills its content on the ground
	    f. animal waste from farms
	    g. fertilizer or pesticides on agricultural (crops) fields
	    h. a factory that releases pollution into the river	

Score	Definition of Level	Classification of Level
2	Recognizes groundwater connection with surface and below ground sources	Answers include all EXCEPT for D.
1	Recognizes that surface OR underground sources affect groundwater but not both; or incomplete recognition of surface or below ground sources	Answers of A, B, C,E,F G or H; NOT D
0	Does not understand groundwater and surface connections	Answer is D with or without any of the other choices

Item	3. Where might water come from that is in a lake or pond? (Choose all that apply) a. rain water b. a hose or sprinkler c. groundwater d. a well e. snow/ice melting	
Score	**Definition of Level**	**Classification of Level**
2	Recognizes surface water and groundwater connection	Answers include A, E, AND C;
1	Recognizes only surface water connection or only recognizes groundwater input	Answers include A, C, OR E
0	Does not understand water source connections	Answers include B or D with or without any other choices.

Item	4. Water in the ground will: (Choose all that apply) a. move through pore spaces in sediment b. remain still in the pore space or cracks in rock c. move slower than surface stream water d. move faster than surface water e. move into a nearby stream or lake f. move into a nearby well	
Score	**Definition of Level**	**Classification of Level**
2	Understands mediums groundwater can move through AND understands movement is slower that surface water movement	Answers include A, C, E AND F
1	Recognizes how groundwater moves but not where groundwater moves to; OR Where groundwater can move to but not how groundwater moves	Answers include A,C. E OR F AND does NOT include B or D
0	Does not understand groundwater movement	Answers include B and/or D, with or without combinations listed above

Item	5. When water is pumped from a well, what can happen? (Choose all that apply) a. Pumping will pull water up directly below the well. b. Pumping will pull water towards the well from all directions. c. Pumping causes the water table to be lowered near the well. d. Pumping could cause polluted water to move into the well. e. Pumping the well can cause nearby wells to lose their water to the well being pumped. f. Water will always be available from the pumping well.	
Score	**Definition of Level**	**Classification of Level**
2	Understands how groundwater moves in response to a pumping well AND the connection b/t a pumping well and adjacent wells	Answers include B, C AND D, E With or without A
1	Understands how groundwater moves in response to a pumping well OR the connection between wells and pumping; OR partial understanding of both	Answers include B,C, D, OR E With or without A
0	Does not understand that pumping a well can affect groundwater flow and adjacent wells	Answer includes F only or A only or F and A only OR F with any other combination.

Item	6. Which of the following can be a source of groundwater? (Choose all that apply) a. rainwater b. snow/ice melting c. spigot or faucet d. wells e. surface streams f. surface lakes or ponds g. the ocean	
Score	**Definition of Level**	**Classification of Level**
2	Understands sources of recharge	Answers include A,B, E, AND F
1	Understands atmosphere OR ground sources of recharge	Answers A, B, E, OR F With or without D and G
0	Does not understand sources of groundwater recharge	Answers include C only OR D and G only With or without the above combinations

Item	7. How deep might a person drill a well to reach a source of groundwater? (Choose all that apply) a. 25 feet b. 50 feet c. 200 feet d. 2000 feet e. 20,000 feet f. 200,000 feet	
Score	**Definition of Level**	**Classification of Level**
2	Understands appropriate depth levels for obtaining groundwater	Answers include A, B, C, and D OR B, C, AND D
1	Partially understands appropriate depth levels for obtaining groundwater	Answers include A, B, C or D but not all of them together
0	Inappropriate understand of depth of groundwater occurrence	Answers include E or F with or without the above combinations OR A only

Item	8. Mr. Jones' well is up hill of Mr. Smith's well. Mr. Jones had a spill of gasoline into his well. What could happen to Mr. Jones' and Mr. Smith's wells and to the groundwater system? (Choose all that apply) a. Both wells could become polluted b. Only Mr. Jones' well will be polluted c. Wells located uphill of Mr. Jones' well can be polluted d. Nothing will be polluted because gasoline floats on water e. Wells downhill of Mr. Jones' well can be polluted f. Lakes or streams downhill of Mr. Jones' well can be polluted	
Score	**Definition of Level**	**Classification of Level**
2	Understands groundwater movement and movement from pollution source	Answers include A, E, and F AND can include B
1	Partial understanding of groundwater pollution	Answers lacking in one of the above AND may include B
0	Lacks understanding of groundwater movement and movement of pollution	Answers C or D with or without any combinations above

Item	9. If groundwater becomes polluted what can happen to other wells and lakes or ponds in the area? (Choose all that apply) a. Water in other wells could become polluted. b. A nearby lake or pond could become polluted. c. The pollution in the groundwater could travel great distances to other wells and lakes or ponds. d. The pollution could stay in the groundwater for a long time. e. The pollution will mix with the groundwater and not be harmful anymore. f. The pollution will be gone in a day or two so as long as people don't use the water for that time, everyone will be safe.	

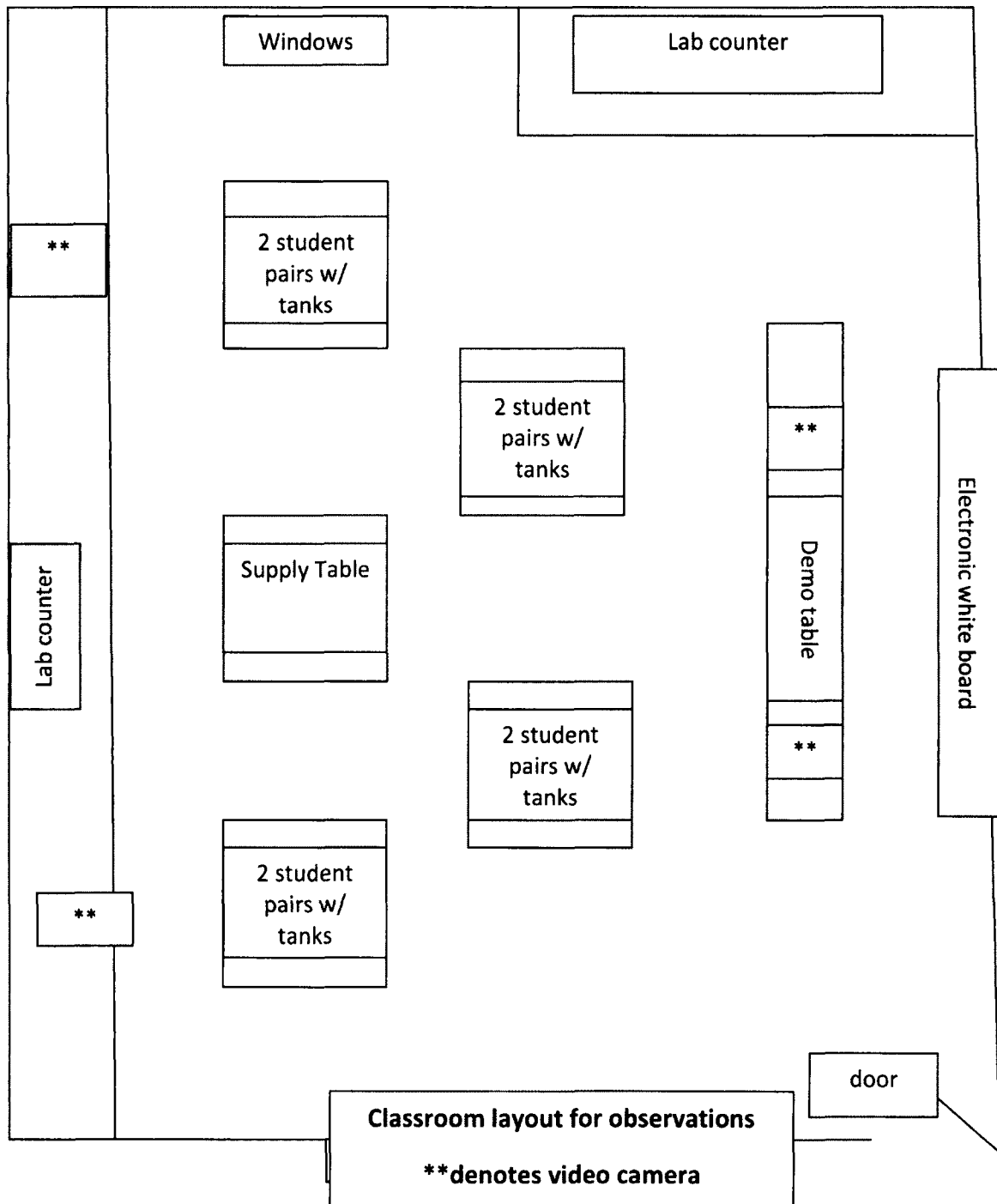| Score	Definition of Level	Classification of Level
2	Understands movement of pollution can contaminate other wells AND surface water features AND pollution source travels far AND persist in the groundwater system	Answers include A, B, C, AND D
1	Understands potential of pollution to contaminate other sources OR understands potential for pollution to travel far away and persist	Answers include A, B, C, OR D
0	Does not recognize potential contamination or movement	Answers include E or F or both with our without any combination above.

Item	#10 Draw a detailed picture of how groundwater occurs and moves	
Score	**Definition of Level**	**Classification of Level**
2	Draws correct depiction of groundwater occurrence below ground Shows correct depiction of groundwater movement Correct vocabulary used in labels	Groundwater occurs in pores or cracks in rocks Groundwater movement in downhill direction and movement is connected through diagram Shows discharge or recharge of groundwater correctly
1	Shows groundwater occurring below ground but in incorrect scale of storage Shows groundwater movement correctly Correct vocabulary used in labels	Groundwater mimics surface water features of lakes or rivers Groundwater moving in the correct direction OR movement is disconnected
0	Shows groundwater occurrence in context of human features Incorrect movement of groundwater (e.g. ejecting fountain) Incorrect vocabulary used in labels	Groundwater in pools, tanks, pipes, etc. Unreasonable movement such as ejecting fountain No water shown/labeled below ground surface

APPENDIX C

CLASSROOM OBSERVATION GUIDELINES

CLASSROOM LAYOUT

Classroom Observation Guidelines

Date_____ Time_____ Class_____

GROUNDWATER CONTENT ACTIVITY	STUDENT BEHAVIORS (time on task, vocabulary used, difficulty with task, repeating an activity, trying new activities different from instructions)
Movement/ Porosity and Permeability	
Wells	
Pollution	

Classroom Layout

Windows

Lab counter

**

2 student pairs w/ tanks

2 student pairs w/ tanks

**

Demo table

Electronic white board

Lab counter

Supply Table

2 student pairs w/ tanks

**

**

2 student pairs w/ tanks

door

Classroom layout for observations

****denotes video camera**

APPENDIX D

INTERVIEW PROTOCOL

Opening Script:

Thank you for taking the time to talk with me today. I am interviewing a few students to get their ideas and opinions about the groundwater models we used in class a few days ago. This information will be used to help prepare for next school year. Your name will not be revealed in the information I gather today. This is not a test and your grade in science is not affected by anything you say today. The interview should take about 20 to 25 minutes.

Guiding Questions for Student Interviews

1. I have your drawing here before us. Can you talk me though this drawing?

2. How did the model help you learn about groundwater?

3. What part of the model did you like best? Why?

4. What was the hardest or most frustrating part of the model?

5. If you could build your own groundwater model how would you go about doing it?

APPENDIX E

GROUNDWATER INQUIRY BASED LESSON

STUDENT HANDOUTS

Modified 5E Leaning Cycle Stages	Activity	Class Periods
Pre-test of prior groundwater knowledge	Groundwater Survey administered to class	1
Engage students with inquiry questioning of water movement and weathering	Review of water cycle and why water is important in the weathering process Activity: Color the water cycle diagram and answer questions using the diagram (class work/homework) Inquiry questioning about groundwater	1
Explore porosity and permeability	Porosity and Permeability Activity: Students work in groups of three using open ended clear tubes filled with gravel, sand, or clay, one pie pan, and colored water (see activity sheet), students time the flow of water through the tubes using stop watches.	2
Explanation of porosity and permeability and groundwater movement	Review class data; inquiry questioning; Power point notes with pictures explaining porosity and permeability; aquifers, wells, water table and pumping wells.	2
Elaboration of groundwater units	Groundwater diagram and prediction questions. Students color water areas and answer questions (class work/homework)	3
Formative Evaluation of inquiry classroom lesson	Groundwater Survey administered to class	4
Extended Elaboration	Introduce groundwater physical model components and directions.	4
Extended Elaboration	Groundwater Physical Model Interaction. Students work in pairs and complete activities using the model.	5
Summative Evaluation after interaction with physical model	Groundwater Survey administered to class	6

Student Sheet
Water Cycle Questions

Use the water cycle diagram provided to answer the following questions.

1. What is the 'power source' that drives the water cycle?

2. What force helps out this power source?

3. How does water fall to the surface of the earth?

4. Name two ways water returns to the atmosphere.

a.

b.

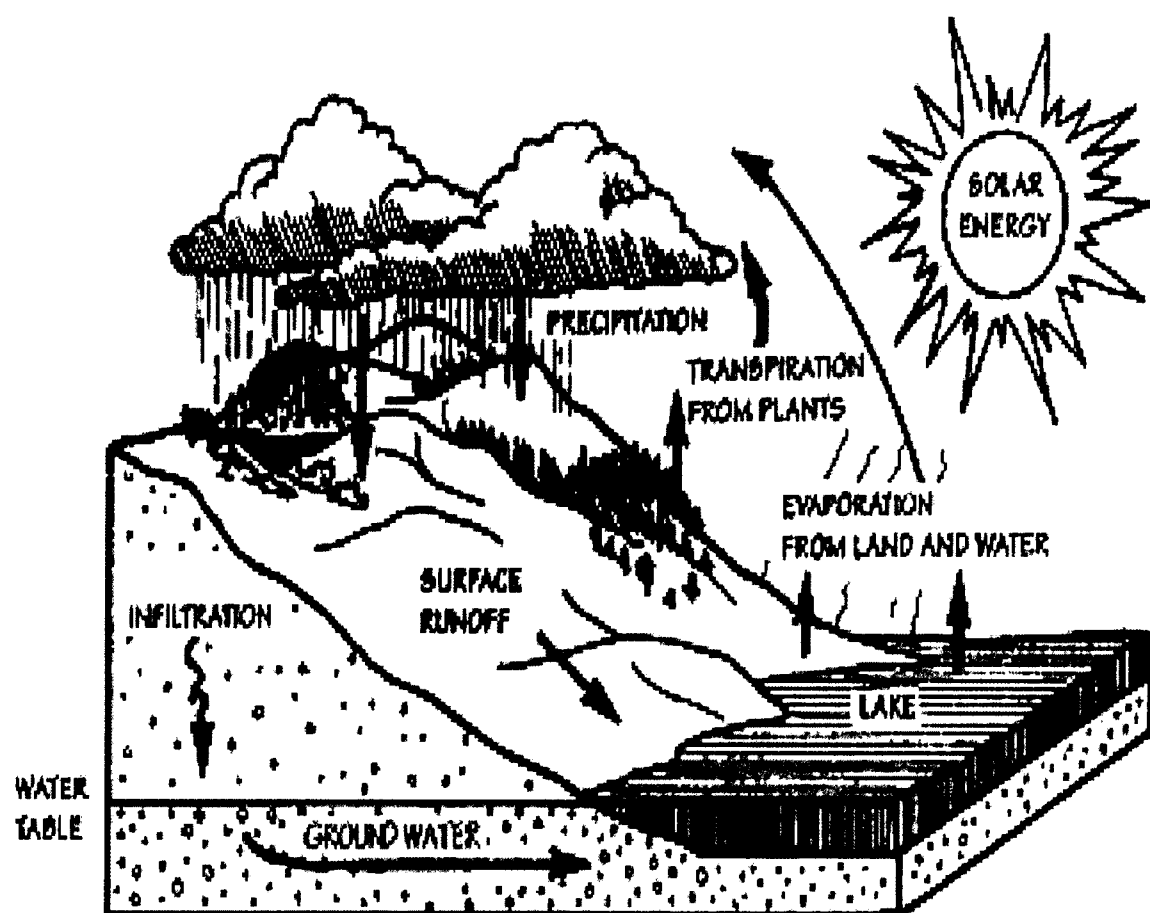5. What are two paths what water can take after it hits the ground?

a.

b.

6. How does water move inside the ground?

Student Sheet
Water Cycle Diagram

Water Cycle

Student Sheet
Investigating Groundwater Movement

Materials:
3 plastic open ended tubes
1 pie pan
Beaker
Blue food coloring
Stirrer
Stop watch

Procedure:
1. Hold tube in pie pan and fill half full with the designated sediment size your group is given.
2. Measure out 100 mL water from sink in beaker.
3. Mix 4 drops of blue food coloring and stir until mixed thoroughly.
4. While holding the tube in the pie pan securely, pour the water into the tube and start the stop watch.
5. Stop the time when water seeps out of the bottom of the tube and into the pie pan.
6. Record you results on the board to share with the class.

Data Table:

Sediment Category	Time
Gravel	
Sand	
Clay	

Analyze and Conclude:
1. Which tube had the fastest time?

2. Which tube had the slowest time?

3. Why is there a difference between the speed of the water flow and the sediment size?

4. In your own words define porosity.

5. In your own words define permeability.

Student Sheet
Groundwater Questions

Use the groundwater diagram provided to answer the questions below.

1. In which layer is the well tapped into?

2. Is the groundwater able to flow in this layer? Why or why not?

3. Which layer would have water moving the slowest? The fastest? Why?

4. What is the relationship between the late and the water table (WT)?

5. Which layer would make the best aquifer? Why?

Student Sheet
Groundwater Diagram

Groundwater Diagram
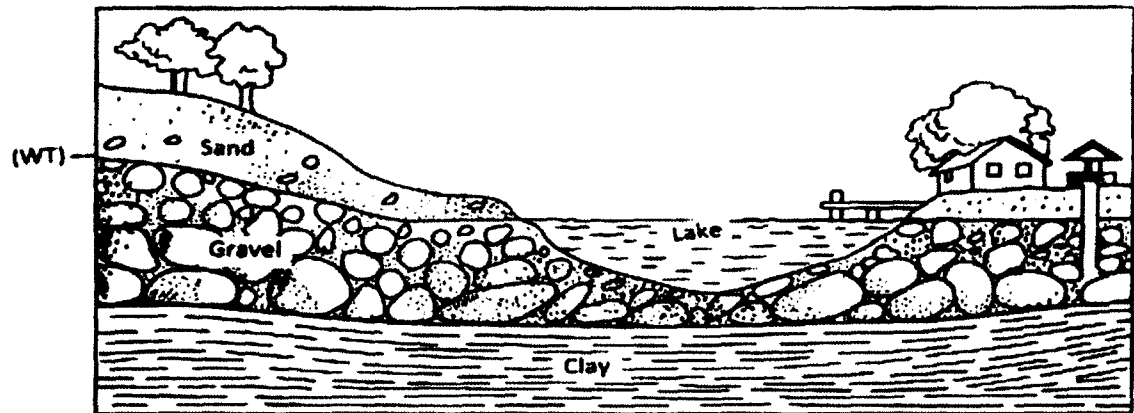
STUDENT SHEET
GROUNDWATER PHYSICAL MODEL ACTIVITIES

Name of Group Members: _____

_____

Follow the directions below and work through each activity.

1. Water table and well levels:
a. Before the pump is turned on, what is the relationship between the water level, well level, and lake/pond level?

b. What is this called?

c. Plug in the pump and describe what happens:

Activity #2. Well pollution:

Using the small pipette fill it with pollution from the black canister. Pollute well #5 ONLY and wait for the pollution to get into the groundwater. Watch the movement of the red pollution plume.

a. In which direction is the pollution plume moving east or west?

b. What is the relationship between the red pollution plume movement and the groundwater movement?

c. Pump well # 8 using the large syringe. Does the well become polluted? What is the source of the pollution?

d. Pump well #10. Does pollution get into the well? Why or why not?

Activity #3. Pumping other wells:

Try pumping other wells and describe what happens in the table below:

Well number	What happened

Which wells did not become polluted? Why?

VITA

Debra L.F. Duffy
1627 Keswick Drive
Norfolk, VA 23518
757-857-6859

Education:

PhD. Education Curriculum and Instruction – August, 2012
Old Dominion University
Dissertation topic: The nature role of physical models in facilitating 6th grade student's mental images of groundwater and groundwater processes

Secondary Education Certification June, 1998
Virginia Wesleyan College, Virginia Beach, Virginia
Virginia License in Earth and Space Science #02-32589
Recertification granted by Virginia Department of Education in 2005, 2008

M.S. in Geology – December, 1991
Old Dominion University, Norfolk, Virginia
Thesis: Geomorphology of Quaternary alluvial fans and terraces, Augusta County, Virginia

B.S. in Geology, minor oceanography – May, 1985
Old Dominion University, Norfolk, Virginia

Experience:

Cape Henry Collegiate School August 1998 to present
Virginia Beach, Virginia
Upper and Middle School Faculty/Middle School Science Department Chair

NASA Global Climate Change Education Program May 2009-present
Langley, Va.
Grant reviewer (electronic and panel reviewer)

Tidewater Community College April 1988 – present)
Chesapeake and Va. Beach Campus
Assistant Professor (Adjunct) – Geology and Oceanography

Old Dominion University August 1997- May 1998
Norfolk, Virginia
Adjunct Faculty

Applied Marine Research Laboratory
Old Dominion University Research Foundation September 1990-August 1997
Norfolk, Virginia
Wetland Studies Supervisor – project coordinator of wetland delineation and mitigation

Publications and Presentations:

Dickerson, D., Horne, P. Duffy, D. (in press). Developing and implementing Internet-2 based interactive programs in a museum setting. *Curator.*

Dickerson, D. and Duffy, D.F. (2008). Tablet PCs in the earth science classroom. abs. Geological Society of America, National Association of Geoscience Teachers Southeast Section Meeting, Charlotte NC.

Duffy, Debra. (2006). Overseas travel offer both students and teachers worthwhile experiences. Virginia Journal of Science Education, vol. 1 no.1

Whittecar, G.R. and Duffy, D.F. 2000. Geomorphology and stratigraphy of Late Cenozoic alluvial fans, western Virginia, U.S.A. Southeastern Geology, vol. 39, pp. 259-280.

Whittecar, G.R. and Debra F. Duffy, 1998. Geomorphology and stratigraphy of Late Cenozoic alluvial fans, Augusta County, Virginia *in* The Appalachian Highlands Beyond the Wisconsinan Glacial Border, Geological Society of America Special Paper.

Duffy, Debra, 1996. The shedding of the Blue Ridge, where does it all go? *in* Virginia's Natural History Weekend Retreat Program Guide, September, 1996, presented as a joint effort of the Virginia Museum of Natural History and Wintergreen Resort, 10 pp.

Duffy, D., Lawrence, J., and R. Heffener, 1996. The impact of public policy on wetland delineations; a case study in the Dismal Swamp of Virginia. abs. Virginia Academy of Sciences, Fredricksburg, Virginia.

Duffy, Debra, 1995. Alluvial fan deposits in the Stuarts Draft vicinity, Central Virginia, *in* The Geology Summer Field School Spring Edition, Afton Mountain Field Trip Guide, Radford University, Dept. of Geology and Institute of Engineering Geoscientists, 15 pp.

Duffy, Debra. 1994. Landslides, boulder fields and other surface geology of the Virginia Blue Ridge *in* Virginia Natural History Retreat Program Guide, September, 1994, presented as a joint effort of the Virginia Museum of Natural History and Wintergreen Resort, 35 pp.

Carlson, R.J., D.L.F. Duffy, and S.L. McKay, 1994. Creative writing: A teaching and learning tool in Introductory Geology. abs. Virginia Academy of Sciences, Harrisonburg, Virginia.

Whittecar, G. Richard and Debra L. Duffy, 1992. Geomorphology and stratigraphy of Late Cenozoic alluvial fans, Augusta County, Virginia, *in* Alluvial Fans and Boulder Streams of the Blue Ridge Mountains, West-Central Virginia, G.R. Whittecar, ed., Southeastern Friends of the Pleistocene 1992 Field Trip Guide Book, 127 pp.

Whittecar, G.R. and D.L.F. Duffy, 1992. Terrain models graphically illustrate landscapes and geologic structures. abs. Geological Society of America, Northeast section meeting, National Association of Geology Teachers special session, Harrisburg, Pennsylvania.

Duffy, D.L.F., and G. Richard Whittecar, 1991. Geomorphic development of segmented alluvial fans in the Shenandoah Valley, Stuarts Draft, Virginia. abs. Geological Society of America, Northeast-Southeast sections meeting, Baltimore, Virginia.

Duffy, D.L.F. and G. Richard Whittecar, 1990. Geomorphic implication of segmented alluvial fans, Stuarts Draft, Virginia. abs. Virginia Academy of Sciences, Fairfax, Virginia.

Whittecar, G.R., D. Ryder, and D.L.F. Duffy, 1989. Geomorphology of debris fans and alluvial fans in Central Virginia. abs. Appalachian Geomorphology Symposia: Binghamtom Conference, Carlisle, Pennsylvania.

Whittecar, G.R. and D.L.F. Duffy, 1988. Soil stratigraphy and weathering characteristics on alluvial fans, Blue Ridge Mountains, Central Virginia. abs. Geological Society of America national meeting, Boulder, Colorado.